LBNF Hadron Absorber Final Design Review – Risks and Quality Assurance

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LBNF Hadron Absorber

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Relevant Documents

- DUNE-doc-32426
  - Engineering Risk Assessment
  - Risk Prevention Through Design Assessment
- DUNE-doc-30781: Installation documentation
  - Weld plans and analyses
  - Stability calcs
  - Installation plan
- DUNE-doc-32085
  - Quality Assurance and Control Plan

Risk Prevention Through Design

- DUNE-doc-32426
- Outstanding risks not mitigated through design choices – require alternative mitigation
- Example of a remaining risk with mitigations:
  - Measure all parts and integrate into assembly model and choose ideal parts to mitigate risk of loose-tolerances causing interference
    - Can set methodology for mitigation, but this does not physically stop parts like Blue Blocks from being procured under/over the “ideal” size
    - In case of Blue Blocks, can select better blocks for use in important stacks

Risk Prevention Through Design

- Several risks have “catastrophic” consequences if realized (ex. >1 death possible), which is an automatic “moderate” hazard that requires mitigation/signoff at minimum.
- Example of a mitigated risk: 9.11” steel fails structurally during install
  - Lift/load proof tests of 9.11 steel prove that the threads can take required load, and weld tests on acceptance prove it can be welded reliably
    - The consequence of one failing during a lift is not addressed by that
  - Crane safety practices (standing clear of loads) reduces likelihood of injury *and* the severity of the hazard itself (keeping multiple people away from the load means fewer possible injuries)
  - Keeping parts on the crane while stability welds are made highly reduces the likelihood of parts tipping
  - Collectively, the likelihood of incidents is reduced on several fronts, as is severity.
- Final residual risk assessed as “Minor”
  - This does not mean the situation is now trivial – procedures need to be followed

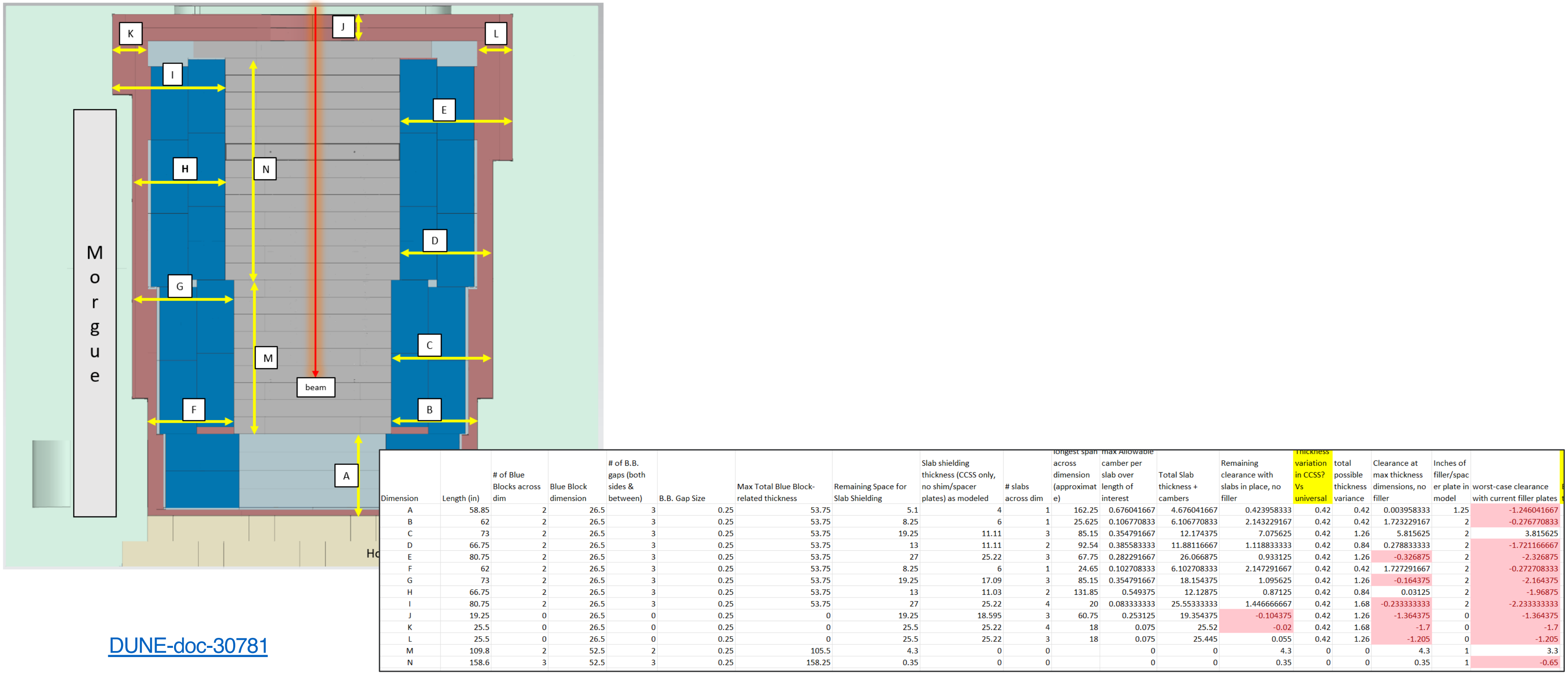
Engineering Risks for Absorber

- Execution Risks
  - Tolerance Stack-up
  - Fabrication
  - ES&H
- Operational
  - Radiological/ES&H
  - Component failure
  - Machine protection

Execution Risks

- Personnel risks
  - Hazards associated with moving heavy parts and stability of the stack
  - Environmental hazards – weld smoke, egress from spaces, fall risk due to heights
- Blue Block installation
  - Steel is mildly radioactive
- Tolerance risks
  - Oversize/undersize parts, variable Blue blocks

Critical Bunker/Module Chase Dimensions

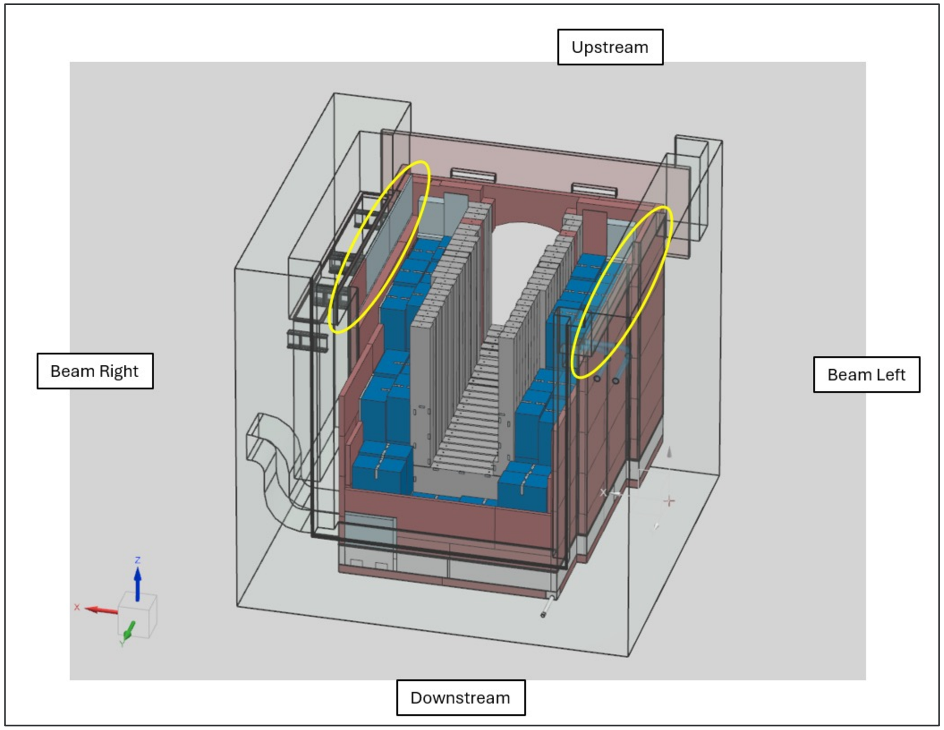


Dimension	Length (in)	# of Blue Blocks across dim	Blue Block dimension	# of B.B. gaps (both sides & between)	B.B. Gap Size	Max Total Blue Block-related thickness	Remaining Space for Slab Shielding	Slab shielding thickness (CCSS only, no shim/spacer plates) as modeled	# slabs across dim	longest span across dimension (approximate)	max Allowable camber per slab over length of interest	Total Slab thickness + cambers	Remaining clearance with slabs in place, no filler	Thickness variation in CCSS? Vs universal	total possible thickness variance	Clearance at max thickness dimensions, no filler	Inches of filler/spacer plate in model	worst-case clearance with current filler plates
A	58.85	2	26.5	3	0.25	53.75	5.1	4	1	162.25	0.676041667	4.676041667	0.423958333	0.42	0.42	0.003958333	1.25	-1.246041667
B	62	2	26.5	3	0.25	53.75	8.25	6	1	25.625	0.106770833	6.106770833	2.143229167	0.42	0.42	1.723229167	2	-0.276770833
C	73	2	26.5	3	0.25	53.75	19.25	11.11	3	85.15	0.354791667	12.174375	7.075625	0.42	1.26	5.815625	2	3.815625
D	66.75	2	26.5	3	0.25	53.75	13	11.11	2	92.54	0.385583333	11.88116667	1.118833333	0.42	0.84	0.278833333	2	-1.721166667
E	80.75	2	26.5	3	0.25	53.75	27	25.22	3	67.75	0.282291667	26.066875	0.933125	0.42	1.26	-0.326875	2	-2.326875
F	62	2	26.5	3	0.25	53.75	8.25	6	1	24.65	0.102708333	6.102708333	2.147291667	0.42	0.42	1.727291667	2	-0.272708333
G	73	2	26.5	3	0.25	53.75	19.25	17.09	3	85.15	0.354791667	18.154375	1.095625	0.42	1.26	-0.164375	2	-2.164375
H	66.75	2	26.5	3	0.25	53.75	13	11.03	2	131.85	0.549375	12.12875	0.87125	0.42	0.84	0.03125	2	-1.96875
I	80.75	2	26.5	3	0.25	53.75	27	25.22	4	20	0.083333333	25.55333333	1.446666667	0.42	1.68	-0.233333333	2	-2.233333333
J	19.25	0	26.5	0	0.25	0	19.25	18.595	3	60.75	0.253125	19.354375	-0.104375	0.42	1.26	-1.364375	0	-1.364375
K	25.5	0	26.5	0	0.25	0	25.5	25.22	4	18	0.075	25.52	-0.02	0.42	1.68	-1.7	0	-1.7
L	25.5	0	26.5	0	0.25	0	25.5	25.22	3	18	0.075	25.445	0.055	0.42	1.26	-1.205	0	-1.205
M	109.8	2	52.5	2	0.25	105.5	4.3	0	0		0	0	4.3	0	0	4.3	1	3.3
N	158.6	3	52.5	3	0.25	158.25	0.35	0	0		0	0	0.35	0	0	0.35	1	-0.65

DUNE-doc-30781

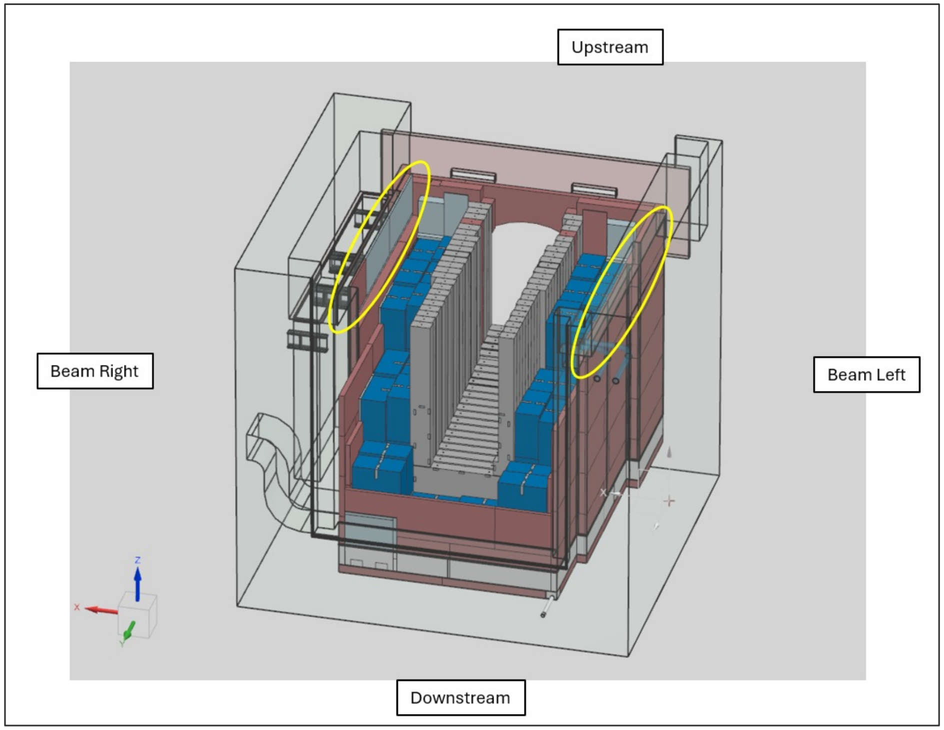
Execution Risk Mitigations

- Stability Analyses (see DUNE-doc-30781)
- Weld Plan/Install Plan that follow a "staircase" install pattern to minimize exposed high ledges
  - See installation plan (same doc)
  - Worker training and experienced personnel (contract ironworkers)
- Avoid chipping Blue Block paint or welding, wear dosimetry
- Ventilation through Bunker
- Add life safety tieoff points as needed during assembly
  - Drop-in concrete anchors can be placed in bunker walls



Execution Risk Mitigations

- Ventilation through Bunker
- Add life safety tieoff points as needed during assembly
  - Drop-in concrete anchors can be placed in bunker walls
- Tolerancing
  - Cataloging and QC dimensional inspections, plus assembly model, to make sure all parts will fit
  - Flexibility in design for over/undersize parts
    - Filler pieces, leveling shims, grout underlay, leveling screws
    - Insert shims to lock in module positions after install



Drop-in Anchors for Fall Protection – Wilson Hall Tunnel Hatch

Operational Risks – Radiological/ES&H

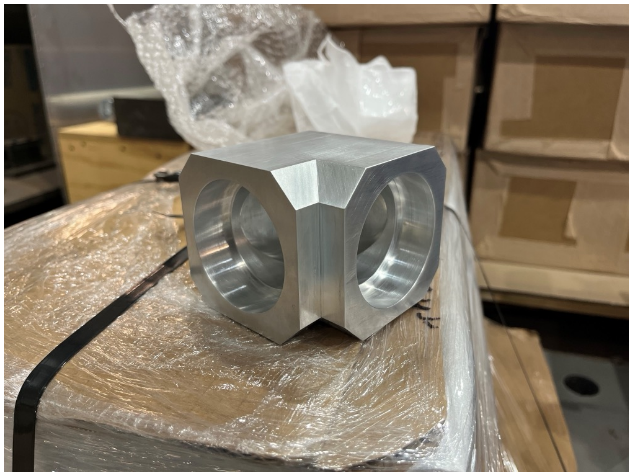
- Prompt and residual doses
  - Radiation Safety interlock system to prevent exposure to beam-on radiation
  - Maintenance scenarios – detailed residual dose models inform access locations and temporary shielding positions
- Remote handling operations capability to minimize worker dose
  - Will be addressed during operations if needed, with specific procedures and new equipment (not Project scope)
  - For now, provisions made to accommodate remote handling (pick points, morgue space, etc.)
- Access controls to top of Bunker near ledge
  - Temporary barriers

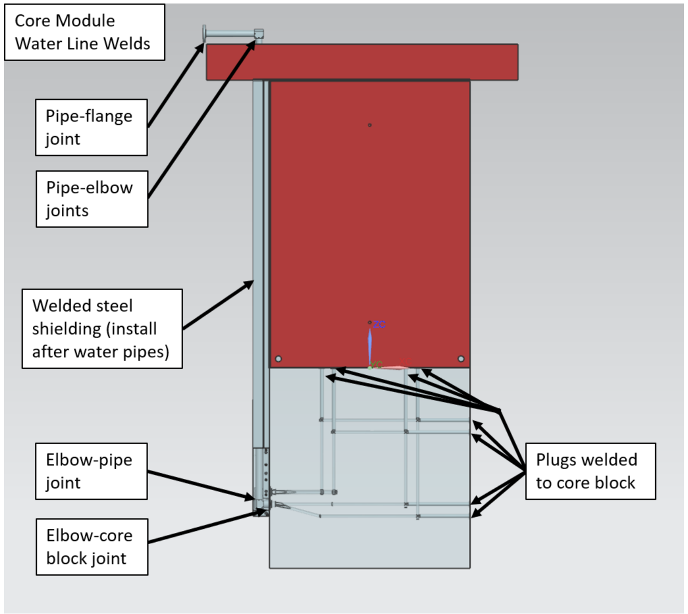
Operational Risks - Component Failure

- Core Block Weld Failure
  - Welds on water lines are critical to functioning of the Absorber – failure delays experiment
  - Resulting water spill could damage Absorber
  - Aluminum can be difficult to weld with repeatable high quality
    - NuMI and LBNF horns reliably make inner conductor welds to NAS Class I specification
- Mitigation: test and practice welds
  - Previous testing (see DUNE-doc-32354) made test welds on representative core block plugs
    - 5 of 6 reached NAS Class 1
    - New tests planned (see next slide)
  - RAW Pan to catch and divert major leaks to spill tanks

Aluminum Weld Tests

- Follow-on testing planned: core block to elbow joint, elbow to pipe joints, and flange joint
  - Ongoing prep work. Welding may be complete by time of FDR
  - Additional pipe-to-pipe weld tests for more info on process
  - X-ray and destructive inspections planned to verify weld quality
  - Match results to penetrant and visual in-process examinations





Core Module Water Line Welds

Pipe-flange joint

Pipe-elbow joints

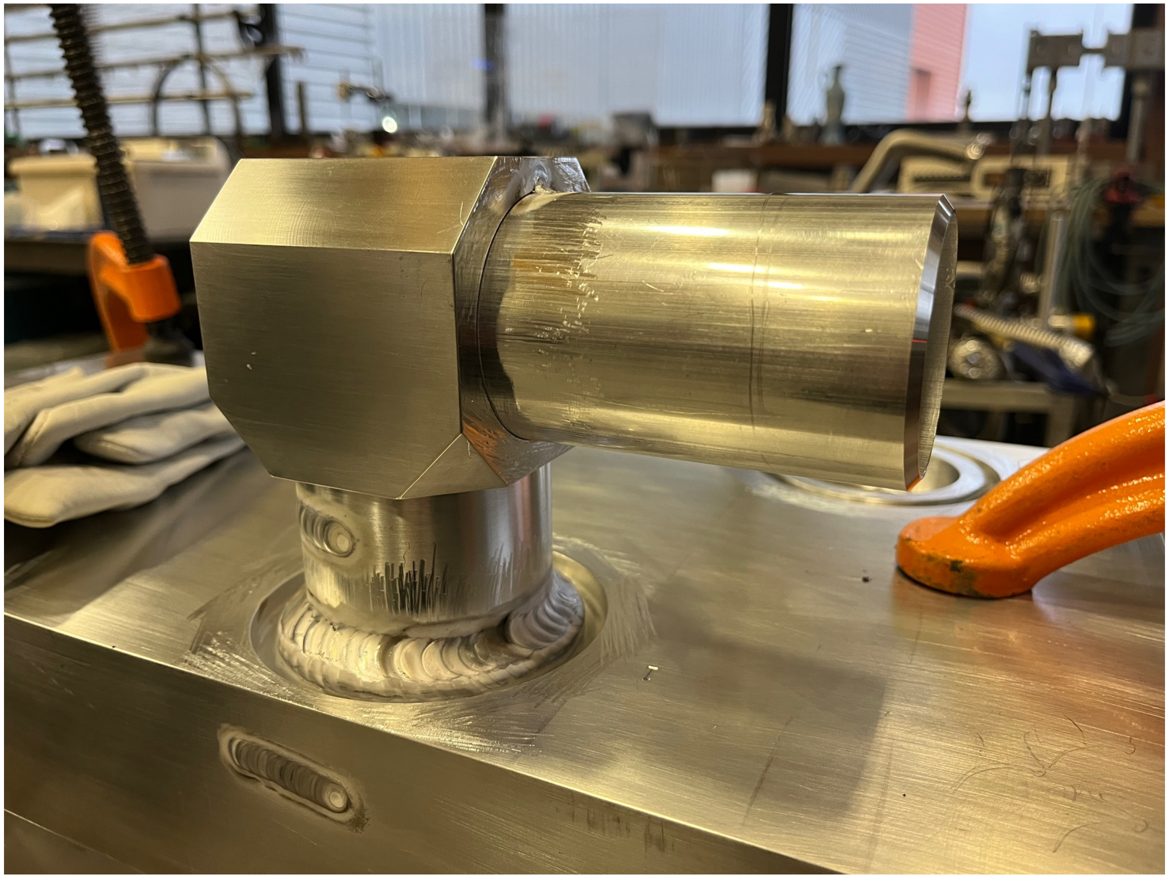
Welded steel shielding (install after water pipes)

Elbow-pipe joint

Elbow-core block joint

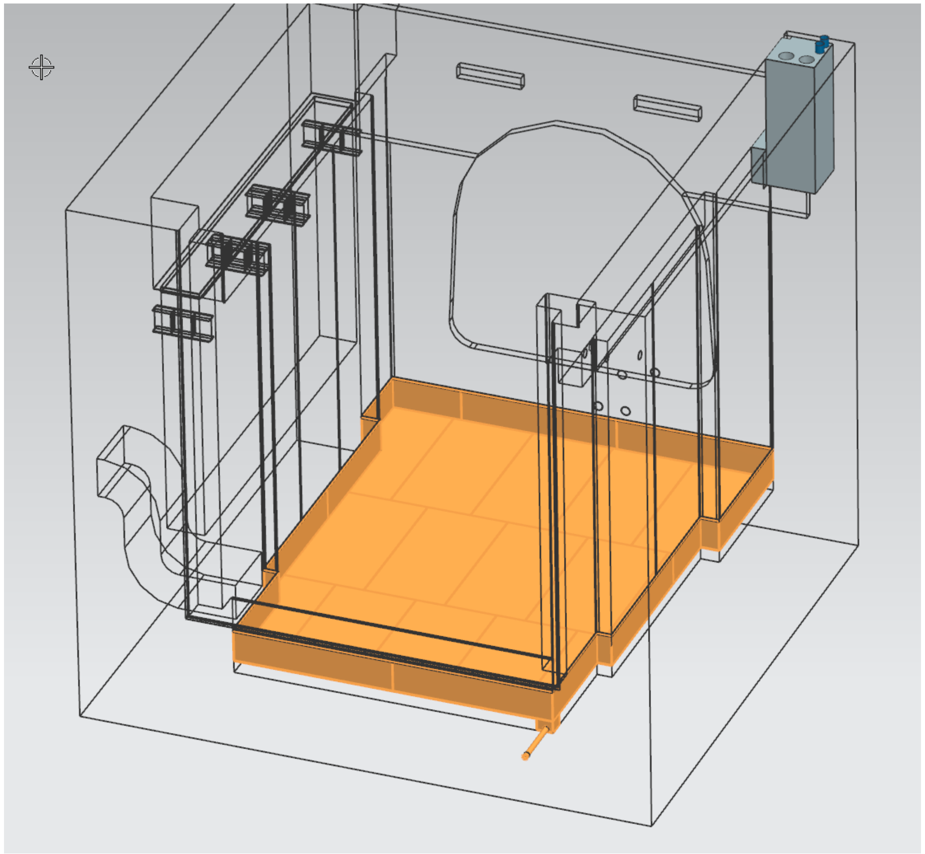
Plugs welded to core block

Aluminum Weld Test Updates



Operational Risk – Water Leak Containment

- RAW Pan
  - Stainless steel sheets welded into leak-tight bathtub
  - Drains to spill tanks on lower level of Absorber Hall (Sump Room)

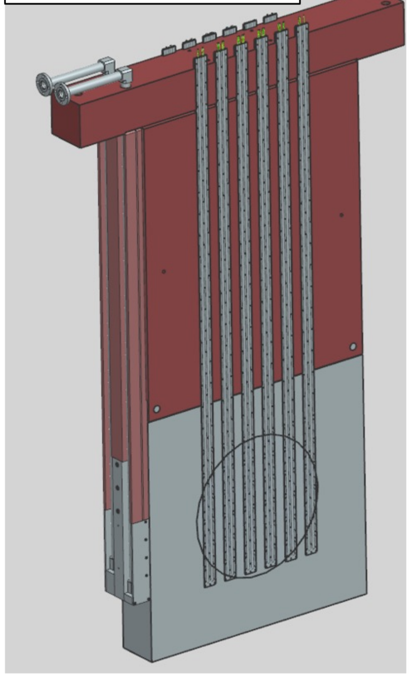


Operational Risks - Machine Protection

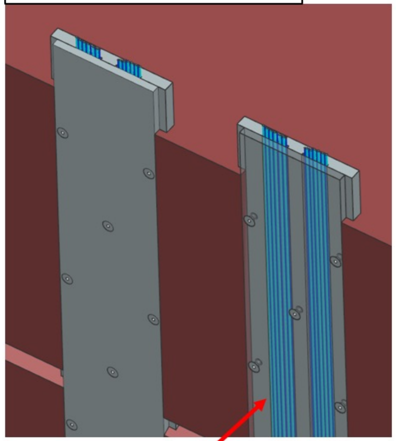
- Risk of damaging absorber with accident pulses
  - Analyze accident cases to determine survivability of accident pulses
  - Limit accident pulses to 2 with detection and permit system
- Due to severity of consequence of many accident pulses (damage to Absorber), have 3 independent systems that can withdraw permit
  - Thermocouple (TC) array embedded in Core
    - Monitors absolute temperature and pulse-to-pulse variation by monitoring temperature
  - MuMS muon counts (not Absorber scope, but feeds to same Abort Concentrator)
  - Upstream pre-target BPMs (also not in Absorber scope)
- TC bars are replaceable without removing core module
  - Can operate with some failed TCs – beam shower is wide
  - NuMI Absorber TC's operating since 2005 without failures

Thermocouple Core Block

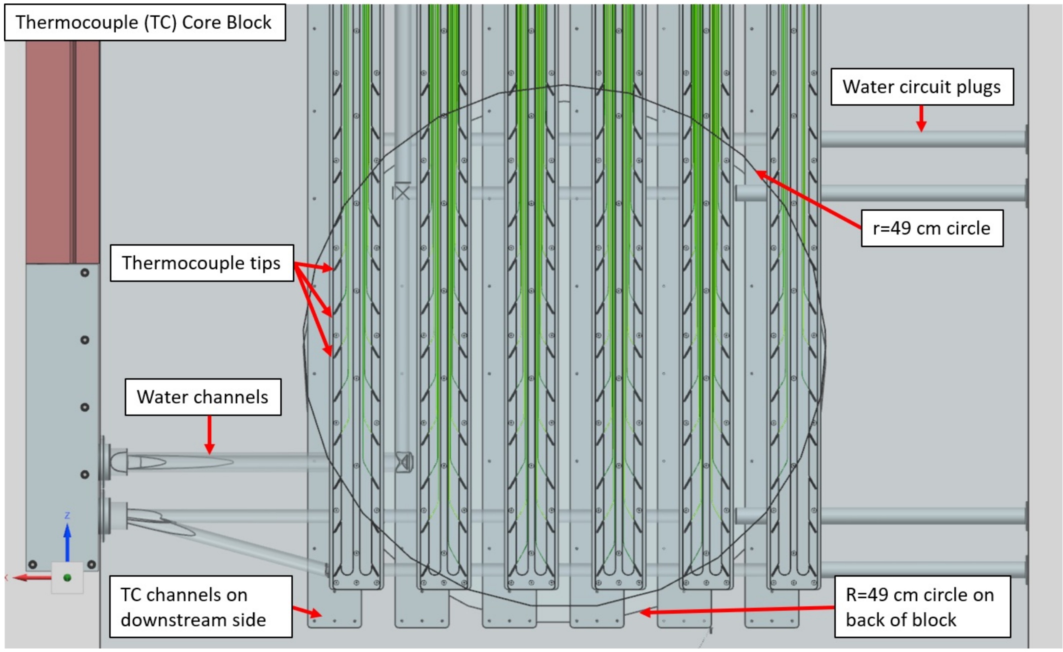
Thermocouple Core Module



Detail of Thermocouple Bars



Thermocouples sandwiched between 2 plates in channels



Thermocouple (TC) Core Block

Water circuit plugs

r=49 cm circle

Thermocouple tips

Water channels

TC channels on downstream side

R=49 cm circle on back of block

Thermocouple Beam Test

- Have requested beam time for a thermocouple test
  - Linac beam (400 MeV protons) to the ITA test area in the MTA beamline
  - Tune pulses to deposit comparable energy in thermocouples compared to Absorber
    - Similar temperature rise
- Test full readout and processing chain for thermocouples to test response time of integrated system
  - Multiple readout schemes under consideration
    - Industrial control modules (slower, cheaper)
    - Thermocouple readout cards for PLC (faster, expensive)
  - Test PLC checking a single channel to estimate performance with all channels

Quality Assurance and Control

QA/QC Plan

- DUNE-doc-32085
- Cover procurement/acceptance, fabrication, and installation of the Absorber and its components
- Details:
  - Core block weldments fabrication (and testing), core module fabrication, water pipe weldment fabrication
  - Absorber Bunker dimensions, steel support weldment alignment, RAW Pan leak-tightness, core module installation, and steel shielding base layer leveling
  - As-received part inspections on 9.11” steel, other components, and integration into Assembly Model for tolerancing control
  - General in-process installation inspections to verify assembly is proceeding according to print
- This is not a final plan
  - Project QA has been involved in development to date

Inspections

- Dimensional inspections of parts before install
  - Integrate into Assembly Model - CAD and analytical tolerance model
    - Parts are received before assembly begins, leave time to catalog
    - Verify that parts will fit into the Bunker in major X-Y-Z dimensions
- Parts at limits of tolerances (Blue Blocks and 9.11” steel) could result in interferences
  - This will allow modification ahead of assembly to avoid interferences entirely (ex., move a Blue block elsewhere, or flame-cut a slab in half to cut down camber)
- Leak tests of RAW Pan, core modules, and piping
  - Visual, penetrant, fluid, helium depending on parts in question
- In-process dimensional inspections
  - Measure against assembly prints (yet to be drawn) for each step
  - Alignment will make initial survey of Bunker (also feeds into Assembly Model)

Risks and QA/QC: Questions?

Backup

Programmatic Risks – Procurement & Contracting

- Vendor performance is highly variable
  - Cost
  - Schedule
  - Highly likely there will be issues
- Long-lead parts are planned to be procured earlier in the purchasing process to allow time for delays – otherwise, likely to inflict needless project delays
- E.g., assembly fixtures for core modules are relatively simple weldments required for install
  - Recent experience with the LBNF horn test stand illustrates issues
    - Delays in delivery, install, and alignment
    - Cost was higher than expected for a straightforward frame

Thermocouple Core Block

- Example accident scenarios:
  - Baffle or bafflette strikes
    - Less beam reaches absorber
  - Target failure or beam misses the target
    - More beam reaches the Absorber
  - System designed to limit accident pulses to 2, i.e. prevent a third accident pulse
  - Upstream BPMs can detect a mis-steered beam, TCs provide more data about profile and upstream conditions.
  - An abnormal pulse will have a detectable temperature change at the TC array

Collaborations / Partnerships / Members

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