Fermilab

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Final design review for Accelerator Radiation Safety Improvements Level 3

Overview presentation for review panel

A. Leveling

10/20/15

Outline

- Purpose of the Final Design Review (FDR)
- Charge questions
- Notes on Preliminary Shielding Assessments (PSAs)
- Muon Campus modes
- Input for charge questions
  - PSAs
    - Changes since PSAs were approved
  - Total Loss Monitor System
  - Radiation Safety and Electrical Safety Interlocks
  - ODH monitoring
  - Friskers, Wallflowers, and Air Monitors
  - In tunnel shielding
  - MARS simulations

Purpose of FDR (from Mu2e doc.db 5061-v2)

- FDRs take place prior to the CD-3c review by DOE
- "Final Design Reviews will be held when designs and drawings are 80-90% complete. The design is mature enough to be reviewed but it is still possible to make adjustments based on feedback. A Final Design Review provides assurance that the completed design will meet all functional and performance specifications as well as interface agreements."
- Review committees are required to include experts from outside of Mu2e

Charge questions

1. Is the scope of the Radiation Safety Improvements subproject adequate to meet the requirements of the Fermilab Radiological Controls Manual (FRCM)?
2. Is the design, fabrication, and implementation of the TLM systems for the AP1 to Delivery Ring, Delivery Ring, and M4 beam line technically sound and mature enough to be considered a final design? Are there any remaining issues that require attention prior to the fabrication and installation of TLM systems?
3. Is the design of the Electrical and Radiation Safety Systems for the Delivery Ring, M4 beam line, Production Solenoid Room, Transport Solenoid Room, and Detector Solenoid Room technically sound and mature enough to be considered a final design? Are there any remaining issues that require attention prior to the fabrication and installation of these systems?
4. Is the design of the ODH systems for the Production Solenoid, Transport Solenoid, and Detector Solenoid rooms technically sound and mature enough to be considered a final design?
5. Is the plan to deploy Friskers, Wallflowers, and Air Monitors technically sound and mature enough to be considered a final design?
6. Has the design of in-tunnel shielding systems been adequately reviewed? Can these designs be considered final designs?
7. MARS simulations have recently been completed for the Production Solenoid room shielding berm. Supplemental concrete and steel shielding masses have been included as a result of the latest simulations. Is the final simulation result compliant with the requirements of the FRCM? Was the final simulation completed using acceptable modeling techniques?

These charge questions were derived from the Mu2e Design Review Plan, which is posted on the review Indico site.

Regarding the Preliminary Shielding Assessments . . .

- The Muon Campus PSA (Beams-doc-4513-v7) includes items that are not a part of the Mu2e project, and thus not within the scope of this review. For example:
  - Delivery Ring Cleanup Abort: Delivery Ring AIP
  - Diagnostic Absorber in M4 line: Beam line tunnel GPP
  - M5 shield wall: Muon g-2 Project
  - M4 Beam Line Penetrations to MC-1: Beam line tunnel GPP

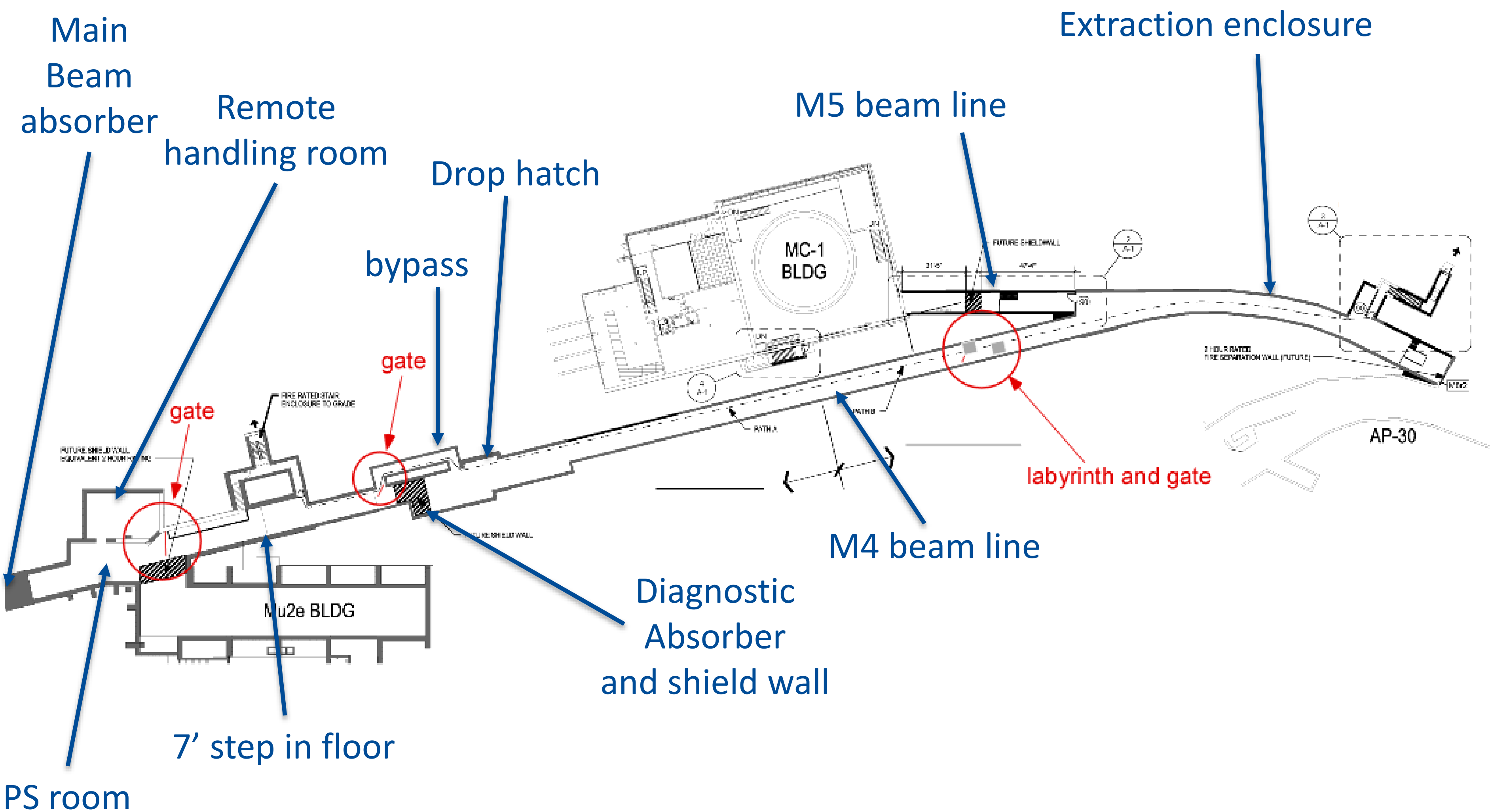
- These elements have been reviewed elsewhere, specifically in the muon campus PSA

Regarding the Preliminary Shielding Assessments . . .

- Some significant changes have been made to the Mu2e target station after construction start
- Technically, review of the changes could be put off until the Final Shielding Assessment process
- These changes are the subject of recent MARS simulation updates and are the subject of charge question 7
  - Mu2e Target Station Shielding
  - Mu2e Target Station Surface water activation
  - Mu2e Target Station Air Activation
  - North wall shield

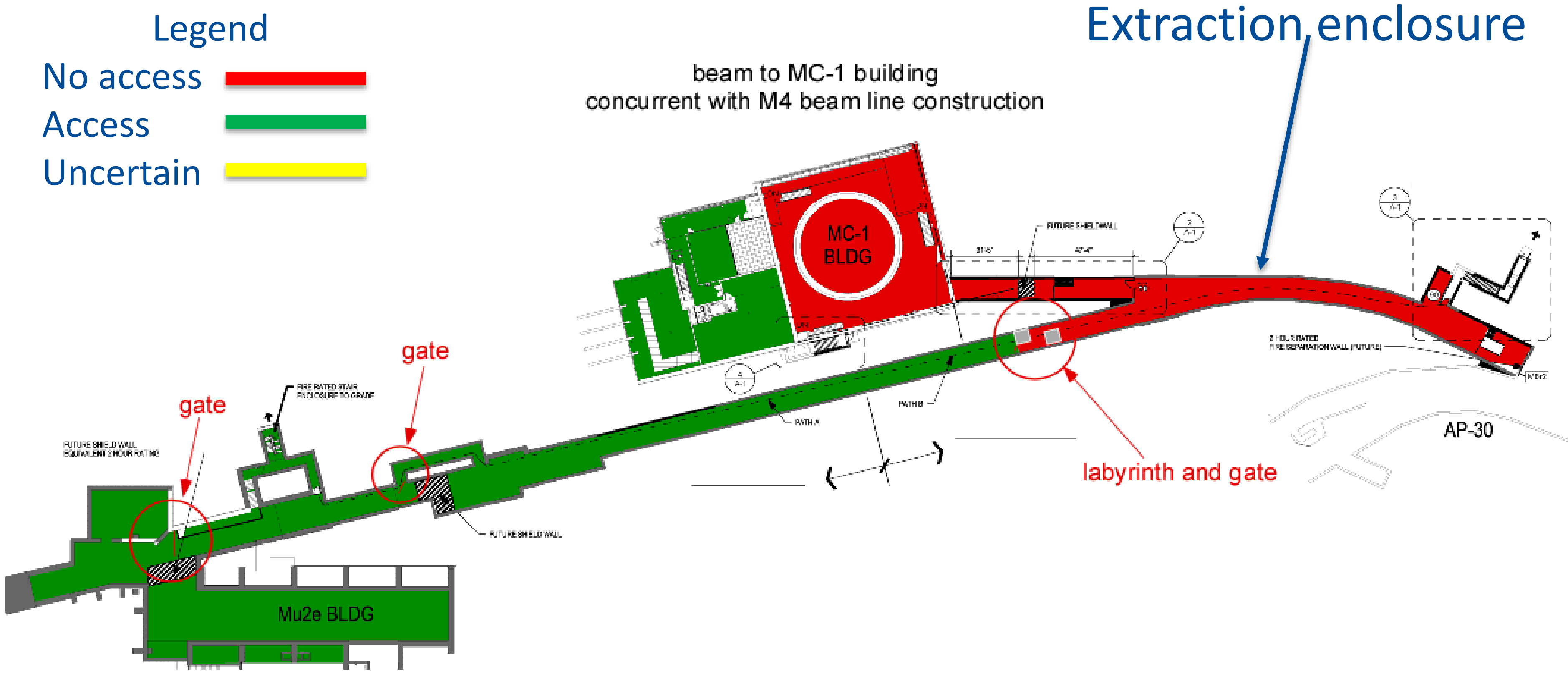
Muon campus modes

Muon Campus schematic - partial



Beam to MC-1 with temporary labyrinth

- Muon g-2 experiment run starts with M4 upstream labyrinth in position and interlocked gate forming the boundary of the extraction enclosure
- M4 beam line is built in the section between the upstream labyrinth and the diagnostic absorber



Fermilab

Beam to MC-1 building after labyrinth removal

- Activate both M4 beam line ESS and RSS
- Move M4 upstream labyrinth concrete to diagnostic absorber
- With upstream M4 line RSS and ESS made up, continue to run muon g-2

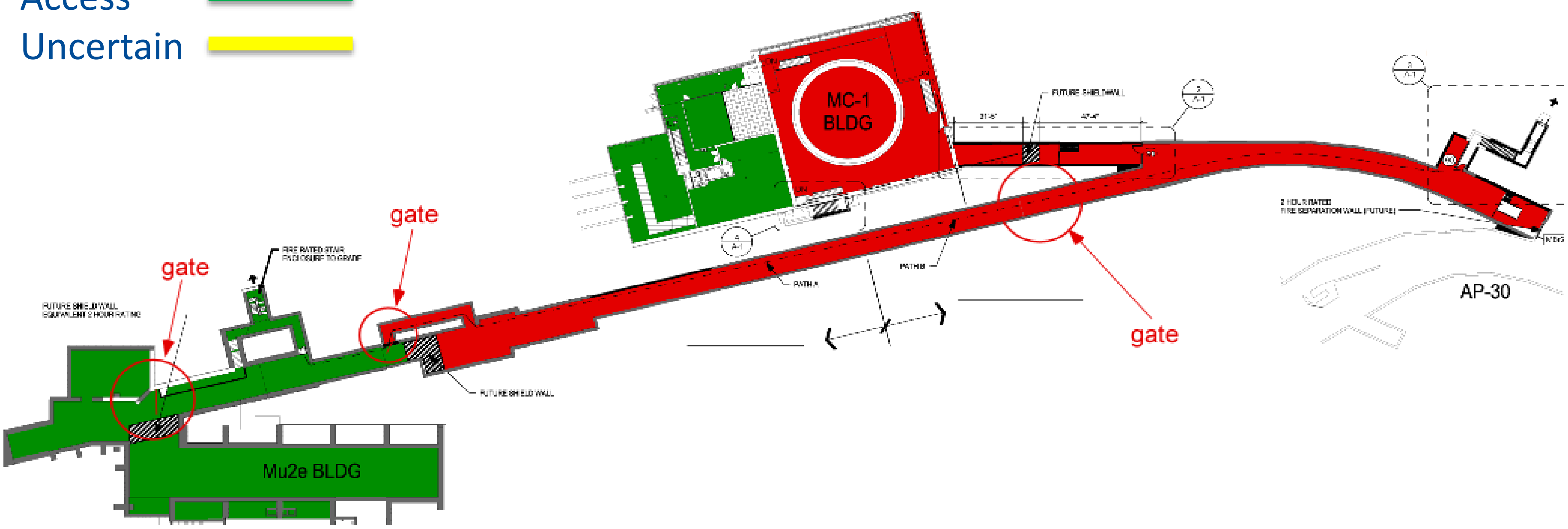
Legend

No access

Access

Uncertain

beam to MC-1 building
concurrent with downstream M4 beam line construction

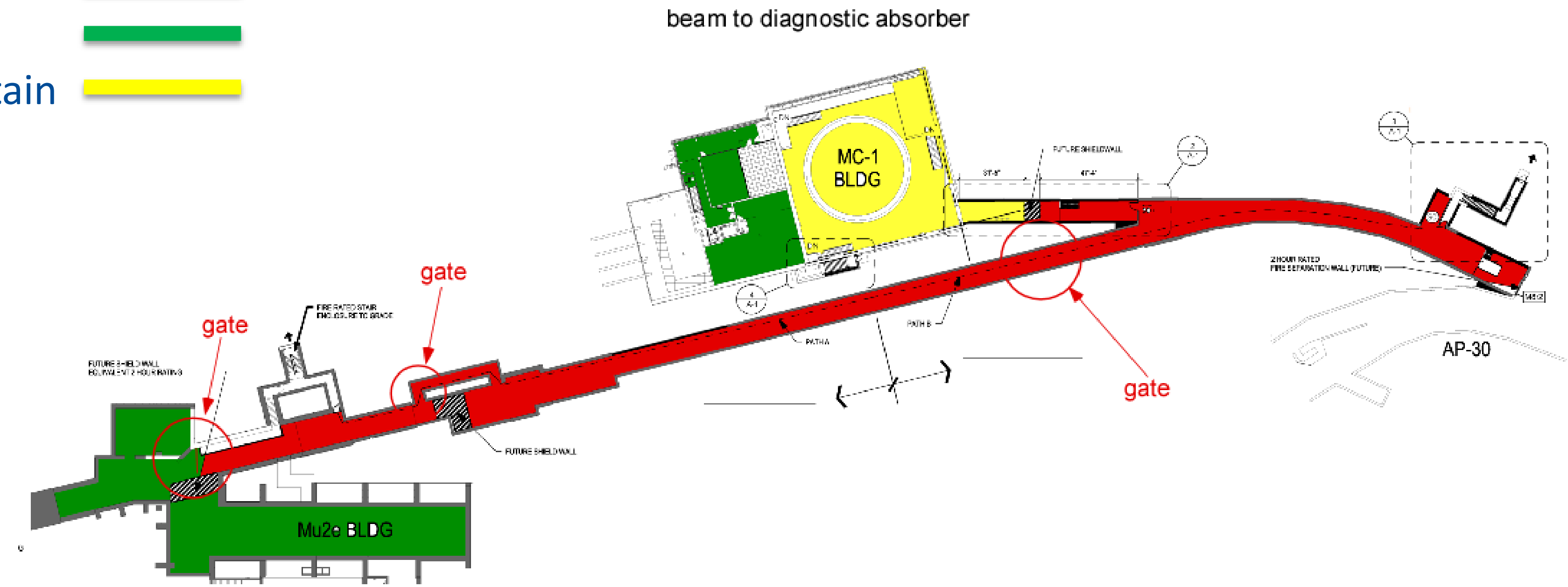


Fermilab

Beam to Diagnostic Absorber

- With downstream M4 line ESS and RSS made up, occasionally take beam to diagnostic absorber during muon g-2 down periods.
- Solenoid Room work continues without interruption

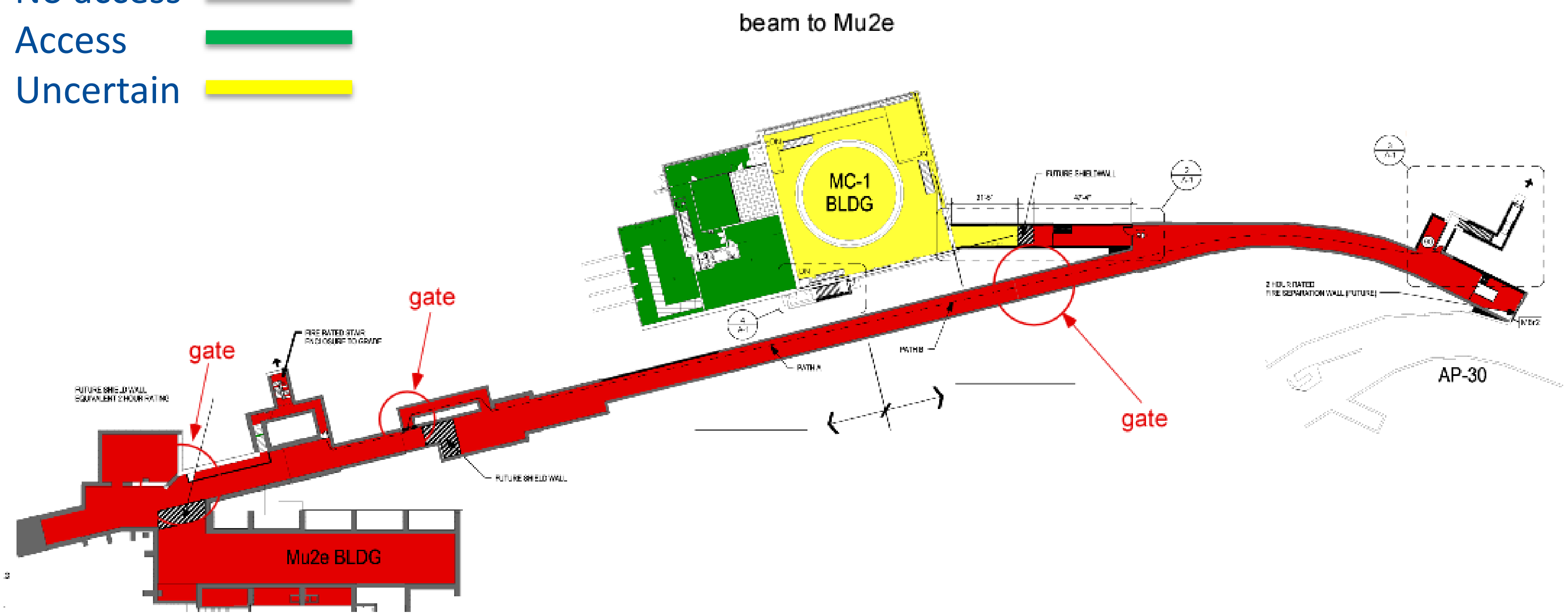
Legend
No access
Access
Uncertain



Beam to Mu2e

Legend

No access
Access
Uncertain



Input for Charge question 1

- Preliminary Shielding Assessments are required by FRCM prior to going out for bids for construction on new accelerator/beam line projects
- Two construction phases
  - Muon campus - PSA is at Beams doc.db 4513-v7
    - Reviewed and approved by Accelerator RSO & staff
      - Documented at Mu2e doc.db 4313-v1
  - Mu2e Experimental Area - PSA is at Beams doc.db 4611-v2
    - Reviewed and approved by Accelerator RSO & staff
      - Documented at Mu2e doc.db 4313-v1
- In early shielding assessment work, it became clear that interlocked radiation detectors would be necessary for the muon campus
  - Directorate approval required to use interlocked detectors in lieu of passive shielding
    - Approval was obtained - Mu2e Document 3823-v1

Input for Charge question 1

- Some additional evaluations not included in the PSAs
  - MC1 to M4 beam line penetration calculations
    - Mu2e doc 3831-v1
  - Radiation Shielding Evaluation of the M4 Beam Line Drop Hatch
    - Mu2e doc 3806-v1
  - Dose attenuation calculation for M4 beam line cable penetrations to Mu2e Detector Hall
    - Mu2e doc 2571-v2
- Recent MARS simulations (discussed below) provide revised/expanded coverage of some PSA topics

Input for Charge question 2

- TLMs
  - Level 3 scope includes:
    - AP1 to Delivery Ring
    - Delivery Ring
    - M4 beam line
  - Final approval of TLM systems was granted by ESH&Q Section June 5, 2015 (Mu2e doc.db 4132-v2)
  - A full implementation of 8 permanent systems has been installed in the Booster
  - Data collection for normal operations and for over 200 accident scenarios has been collected at the Booster (Beams doc.db 4914-v1)
  - A Booster shielding assessment remains to be completed
  - We have realized the full design, construction, and implementation of TLM systems in an off-project venue
  - The implementation of TLM systems is described in the muon campus PSA

Input for Charge question 3

- Interlock systems
  - FDR scope includes:
    - M4 beam line
    - Mu2e Production Solenoid Room (aka target hall)
    - Mu2e Transport Solenoid Room
    - Mu2e Detector Solenoid Room
    - Extinction Room
    - Detector Hall
- Work remaining to complete interlock systems final design:
  - Interlock plan is based upon earlier conception drawings
  - We will meet with the integration team leader to review various safety system boundaries using current construction drawings
  - A new subdivision of the M4 beam line will be created to permit Muon g-2 operation while accessing the remote handling room
    - Requires additional ESS RMMS module
  - Team center drawings will be updated to indicate these changes
  - Change request for this additional scope will be initiated

Input for Charge question 3

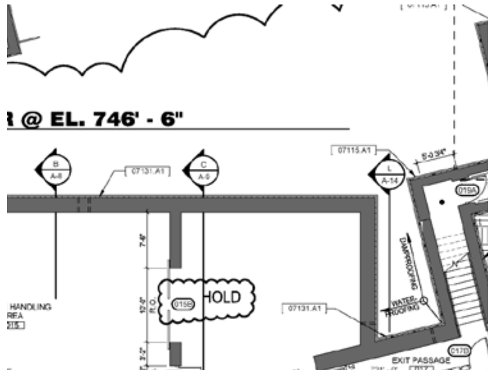
- Some post CD-3c AD Operations/AD ES&H decisions may remain:
  - Will the PS Room be controlled
    - with interlock key access, or
    - by RSO lock and key access ala pbar target vault, beam enclosure drop hatches, NuMI target vault, NO1 target train, etc.?
    - Search and secure of the PS room by operations will be impractical after beam operation begins
  - Search and secure procedures for all areas
    - to be developed after the final equipment and shield configurations are established
- The resolution of these issues is not required to complete the final design

Input for Charge question 4

- ODH monitoring systems
  - The ODH systems cost estimate is based upon ODH monitoring systems for similar room sizes
  - There is no technical design analysis for ODH systems at this time
  - Recently, we learned Particle Physics Division has been working independently on ODH monitoring systems for the Transport Solenoid and Detector Solenoid areas
  - The delineation of responsibility for ODH monitoring systems across the 3 rooms remains to be clearly defined
  - The role of ODH monitoring systems requires integration with ODH fan and control systems
  - A dialog between AD and PPD ODH monitoring system experts has started

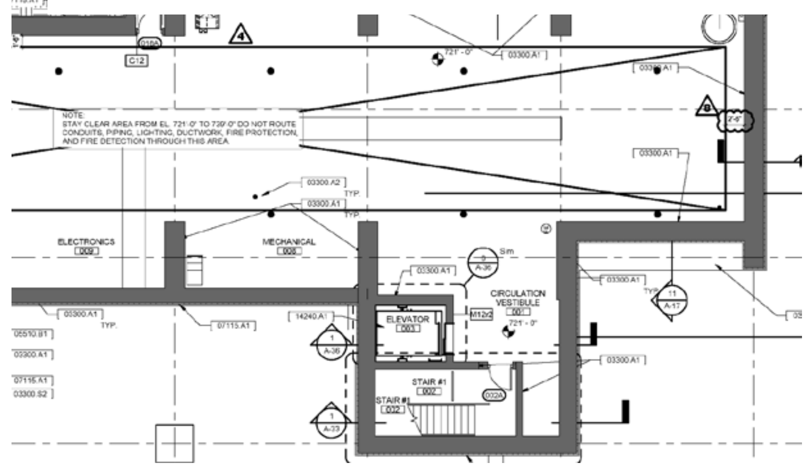
Input for Charge question 4

ODH Sources
1. Production Solenoid
2. Transport Solenoid
3. Detector Solenoid
4. Cryo vacuum pumps
5. Others?



ODH Scenarios
1. Construction
2. Installation
3. Cooldown
4. Field mapping
5. HRS installation
6. Detector shielding installation
7. Final installation
8. Operation

ODH issues
1. Determination of ODH classification
2. PPE for personnel access
3. ODH exhaust fan enabling/disabling and transition between beam on/beam off
4. Location, lifetime, and type of ODH monitors wrt beam shower
5. Is the ODH fan permanently disabled once access to the PS room is no longer possible?



Fermilab

Input for Charge question 5 – Friskers, Wallflowers, Air Monitors

- Friskers, Wallflowers, and an Air Monitor deployment and Exit Stairway Locations
- We have planned for electric power to be installed at indicated monitor locations
- See Mu2e doc.db 3730-v6 for details

exit stairway locations	Frisker	Wallflower
Delivery Ring Extraction Enclosure Emergency Exit	0	0
M4 line exit (near drop hatch)	1	1
Extinction Enclosure Exit	0	0
Exit Stariway near Transport Solenoid	0	0
Detector Hall Exit Stairway	1	1

Air monitor locations	Air Monitor
Extraction Enclosure Air Exhaust Stack	1

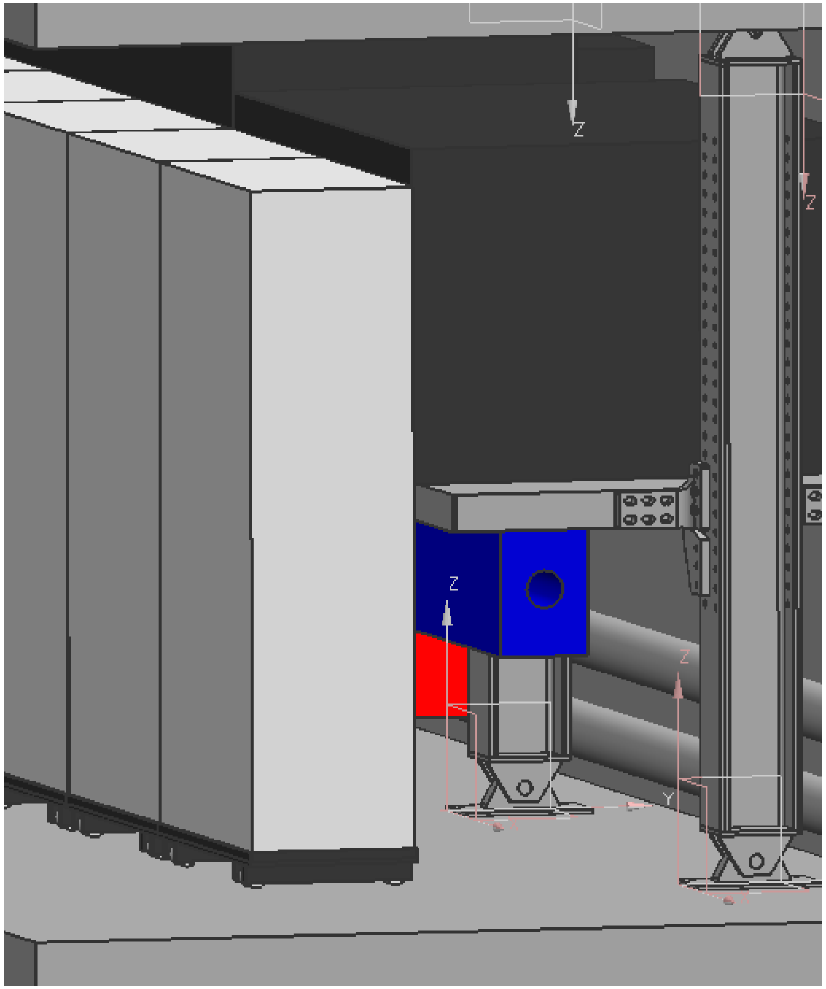
Input for Charge question 6

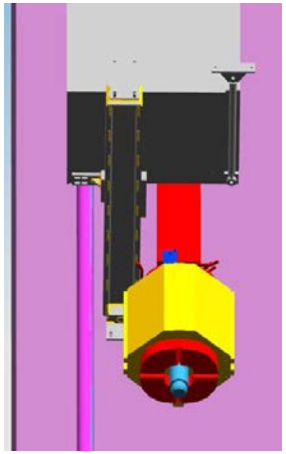
- In tunnel shielding at 3 locations:
  - AP30 extraction region
    - Supplemental shielding required at the slow resonant extraction region during Mu2e operation
      - Reduces effective dose rate in the AP30 service building
      - Minimizes effective dose rate due to skyshine
  - M4 line upstream shield wall
  - Temporary shield wall to be installed near the upstream end of the M4 beam line enclosure during the first Muon g-2 run
    - Permits construction of the M4 beam line during Muon g-2 operation
  - M4 line shield wall at Diagnostic Absorber
    - The M4 line upstream labyrinth concrete is to be relocated to the vicinity of the diagnostic absorber
    - Permits 6 W single turn and 170 W resonantly extracted beam to diagnostic absorber during PS, TS, DS construction activities

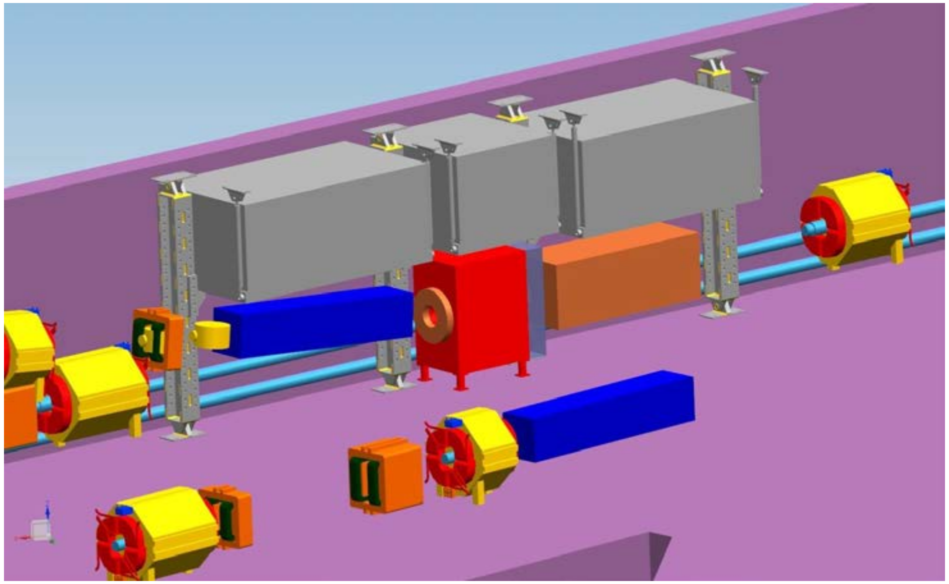
Input for Charge question 6 - AP30 extraction region

- MARS simulation described in Mu2e doc 3719-v2 and 3719-v3
- Simulation results reported in the Muon Campus PSA
  - Beams doc.db 4513-v7
- Muon Campus PSA was reviewed and approved
  - Mu2e doc.db 4313-v1
- Material for the mechanical design and review of AP30 in tunnel shield are found at Mu2e doc6152-v1:
  - Final Design & Proposed Installation Plan.pdf
    - Reviewed by AD MSD:
      - MSD Engineering Review Closeout Letter.pdf
    - Reviewed by FESS:
      - ADMSD14-001 FESS Review.pdf

Input for Charge question 6 - AP30 extraction region





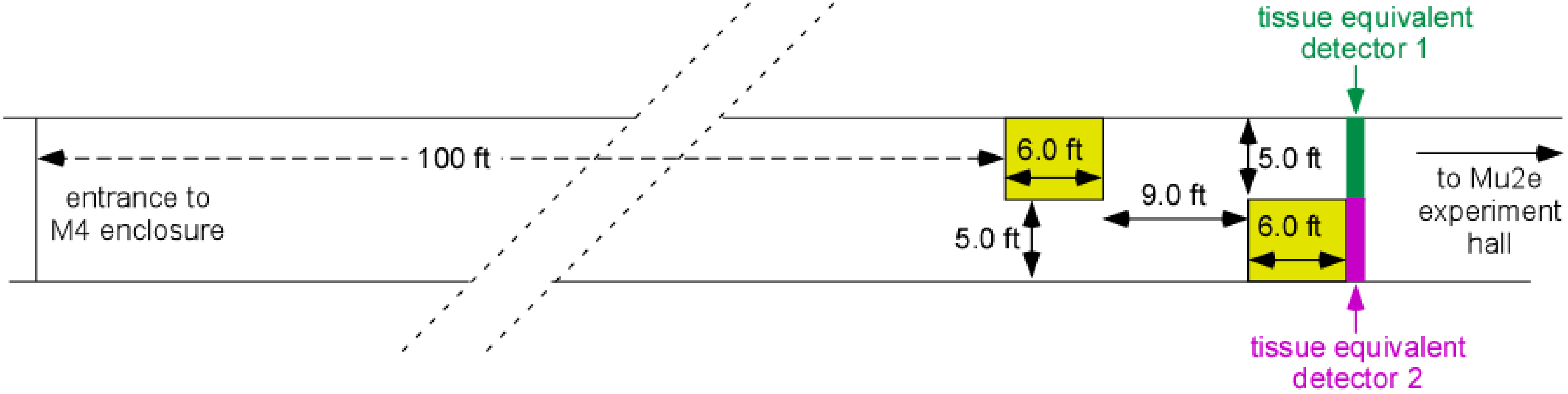


Input for Charge question 6 - AP30 extraction region

- One caveat on the MARS simulation:
  - The MARS simulation was done for an earlier inside-out extraction scheme
  - The extraction system design has changed to outside-in
  - The extraction septa (2) lengths have changed
  - C magnet, quad, and Lambertson magnet designs have changed
- We will repeat the simulation when the extraction design is finalized
- We expect no significant change in performance of this shield
- The new simulation result would be reported in the Final SA

Input for Charge question 6 - M4 line shield wall

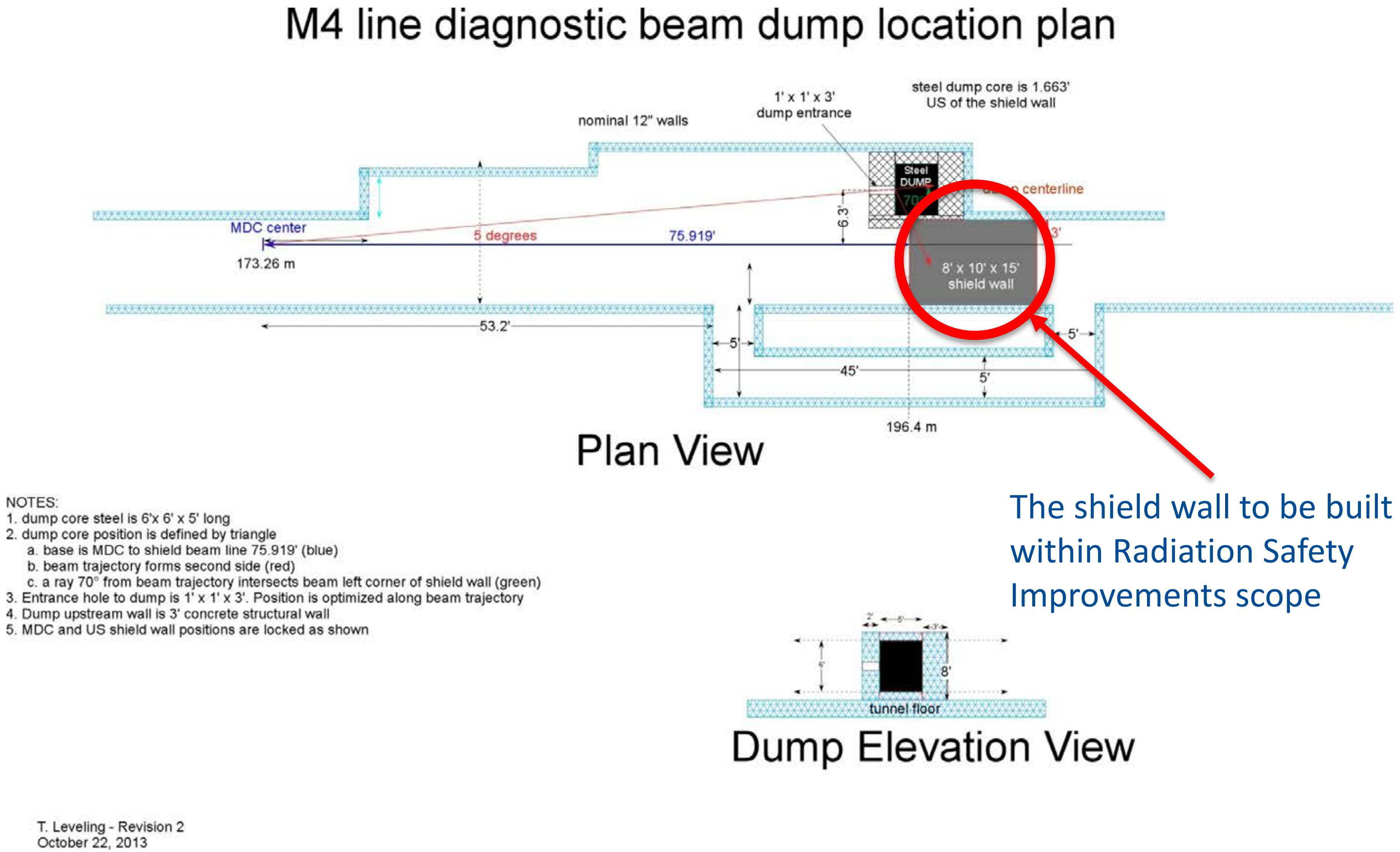
- M4 line upstream shield wall is considered in:
  - The Muon g-2 PSA (GM2 doc 403-v2)
  - MARS simulation was reported in GM2-doc 624-v2
  - Muon g-2 PSA was reviewed and approved by AD ES&H (GM2 doc 403-v2)



Input for Charge question 6 - M4 line shield wall at Diagnostic Absorber

- M4 line shield wall at Diagnostic Absorber
  - MARS simulation is described in detail in Mu2e doc 3308-v3
- Simulation results reported in the Muon Campus PSA
  - Beams doc.db 4513-v7
- Muon Campus PSA was reviewed and approved
  - Mu2e doc.db 4313-v1

Input for Charge question 6 - M4 line shield wall at Diagnostic Absorber



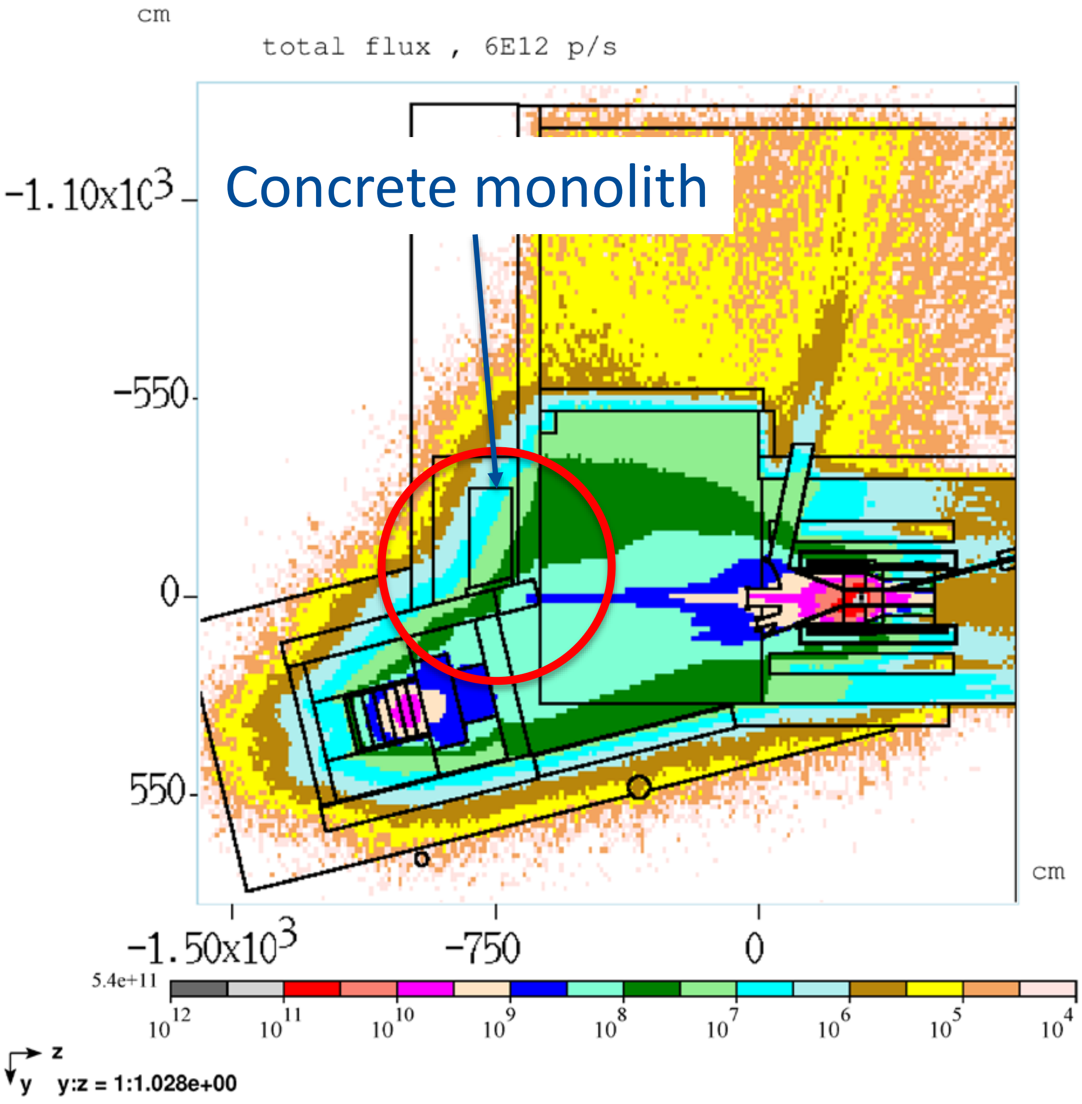
The shield wall to be built within Radiation Safety Improvements scope

MARS Simulations

- A set of MARS simulations was conducted in CY 2015 to answer questions related to target handling and associated radiological issues (Mu2e doc 5746-v3)
  - Several of the simulation results and subsequent analysis triggered additional simulations and corrective actions on these topics:
    - Surface water activation downstream of the Production Solenoid
    - Prompt effective dose rate at north wall
    - Prompt effective dose rate on shielding berm
    - Air activation in the target hall due to beam operation

MARS Simulations - Surface water activation downstream of the Production Solenoid

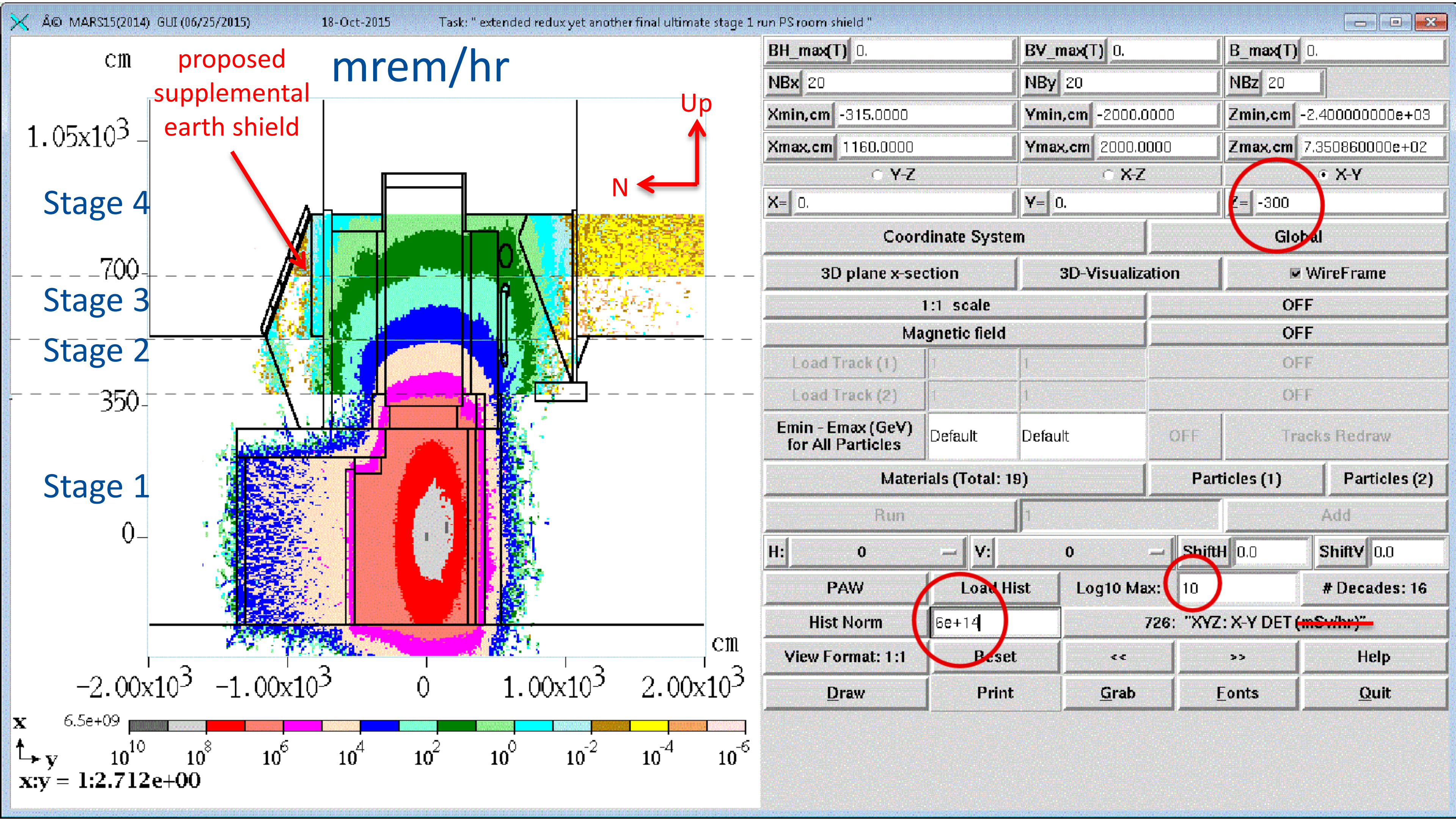
- Indicated secondary flux appeared to contribute to prompt effective dose rate on berm surface (discussed below)
- Surface water and groundwater activation were then scrutinized
  - Independent simulations indicated groundwater was OK but surface water activation was significant
  - A concrete monolith was designed and constructed to prevent surface bound water movement through the activating flux in the region of concern



Fermilab

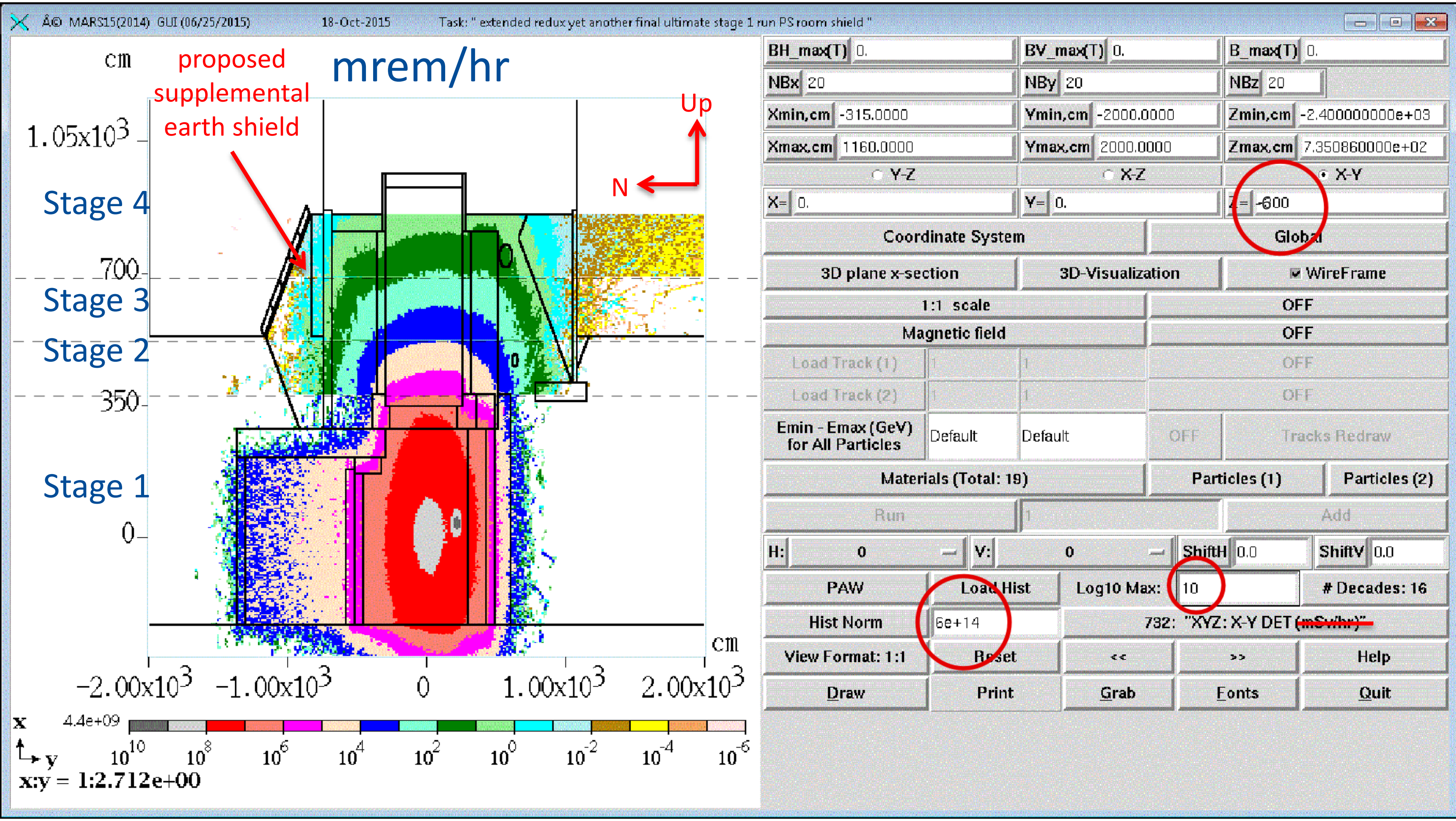
MARS Simulations - Surface water activation downstream of the Production Solenoid

MARS Simulations – North Wall Prompt Rates, z=-300cm



Fermilab

MARS Simulations – North Wall Prompt Rates, z=-600cm



Fermilab

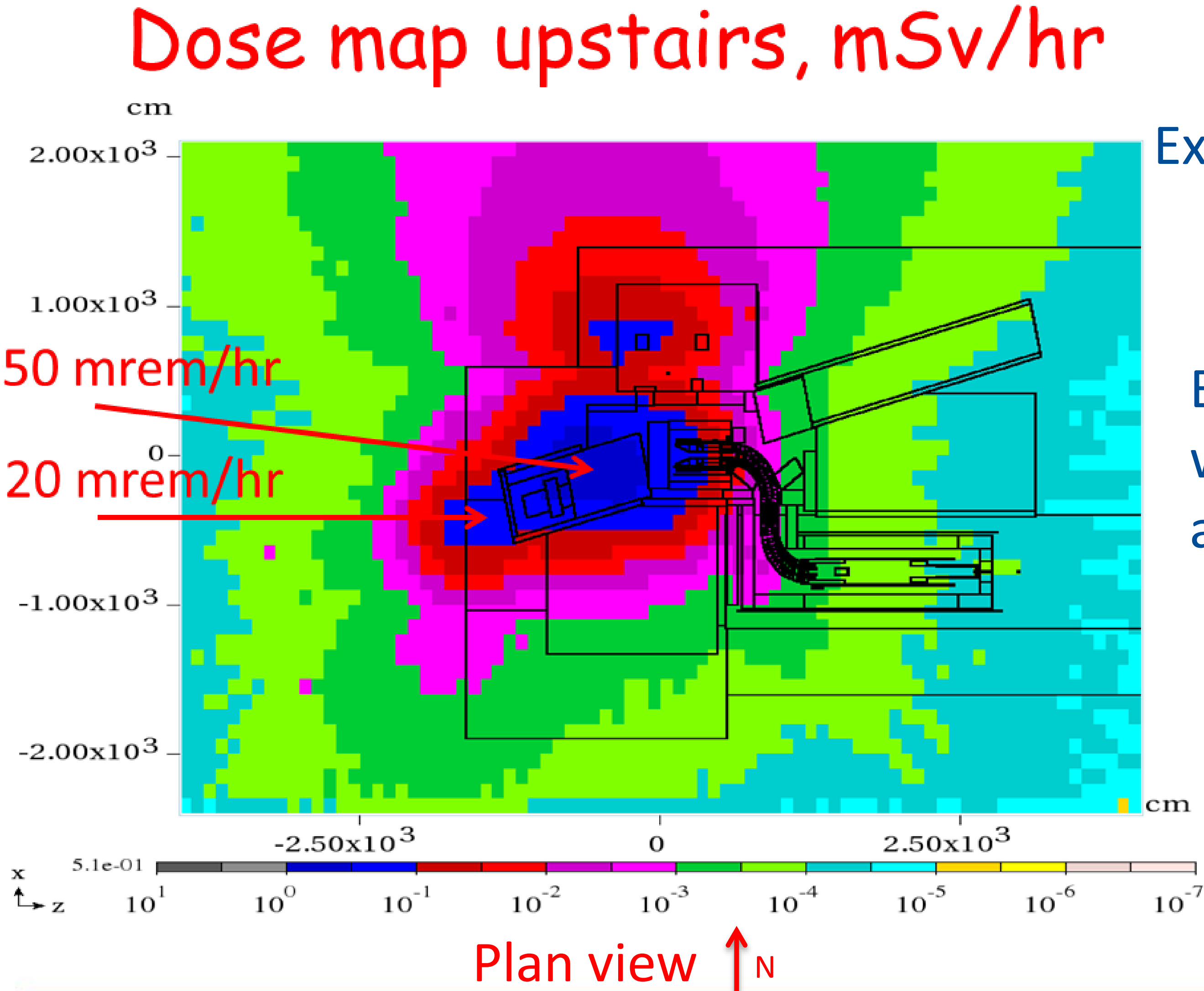
MARS Simulations – North Wall Prompt Rates

- Prompt effective dose rate at the north wall appear in the range of 1 to 4 mrem/hr
- FESS has suggested a shielding berm could be added
- The berm could be installed after mobile crane footprint area is no longer required
- This would be added after project completion

MARS Simulations – Shielding Berm Prompt Rates

- Prompt dose rates were reported in the Mu2e Experimental Area PSA at 50 mrem/hr
- Since the Mu2e Experimental Area PSA was written, numerous changes to the facility were made, e.g.,
  - RHR enlarged
  - Shielding steel was added over the beam absorber
- Also, considered backfill density in MARS simulations is greater than actual backfill used for backfilling around tunnel structures
  - This would lead to under estimation of prompt rates by factor of 2
- We noted the FRCM design criteria for new facilities is < 5 mrem/hr
- Some effort was made to understand the source term leading to higher than desired prompt effective dose rates and to make a correction
- Shielding steel is ultimately being placed in the excavation to supplement earth berm shielding

MARS Simulations – Shielding Berm Prompt Rates (As reported in the PSA)



From Mu2e Experimental Area PSA
- V. Pronskikh
- Y. Eidelman

Backfill in this model was a mixture of soil and concrete

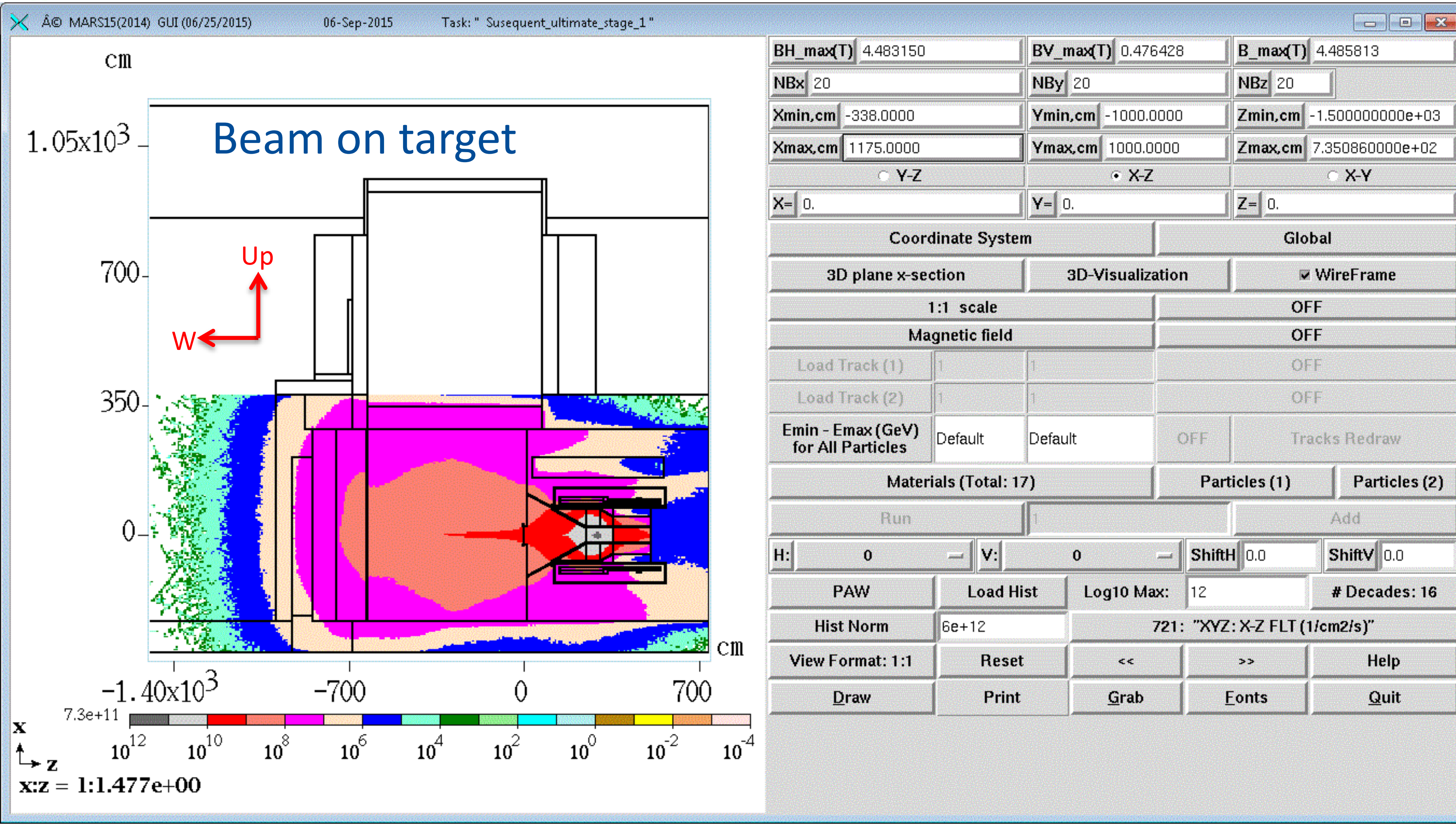
Shielding has been improved since PSA submittal. Dose rates are presently approximately an order of magnitude lower.

MARS Simulations – field measurement of backfill density

- Nominal density of soil backfill in MARS simulations is 1.9 g/cc
- We determined density of CA7 backfill is 1.64 g/cc
- Latest MARS simulations consider approximate backfill volumes using CA7
- Factor of 2x increase in prompt rates at berm surface as a result of this consideration

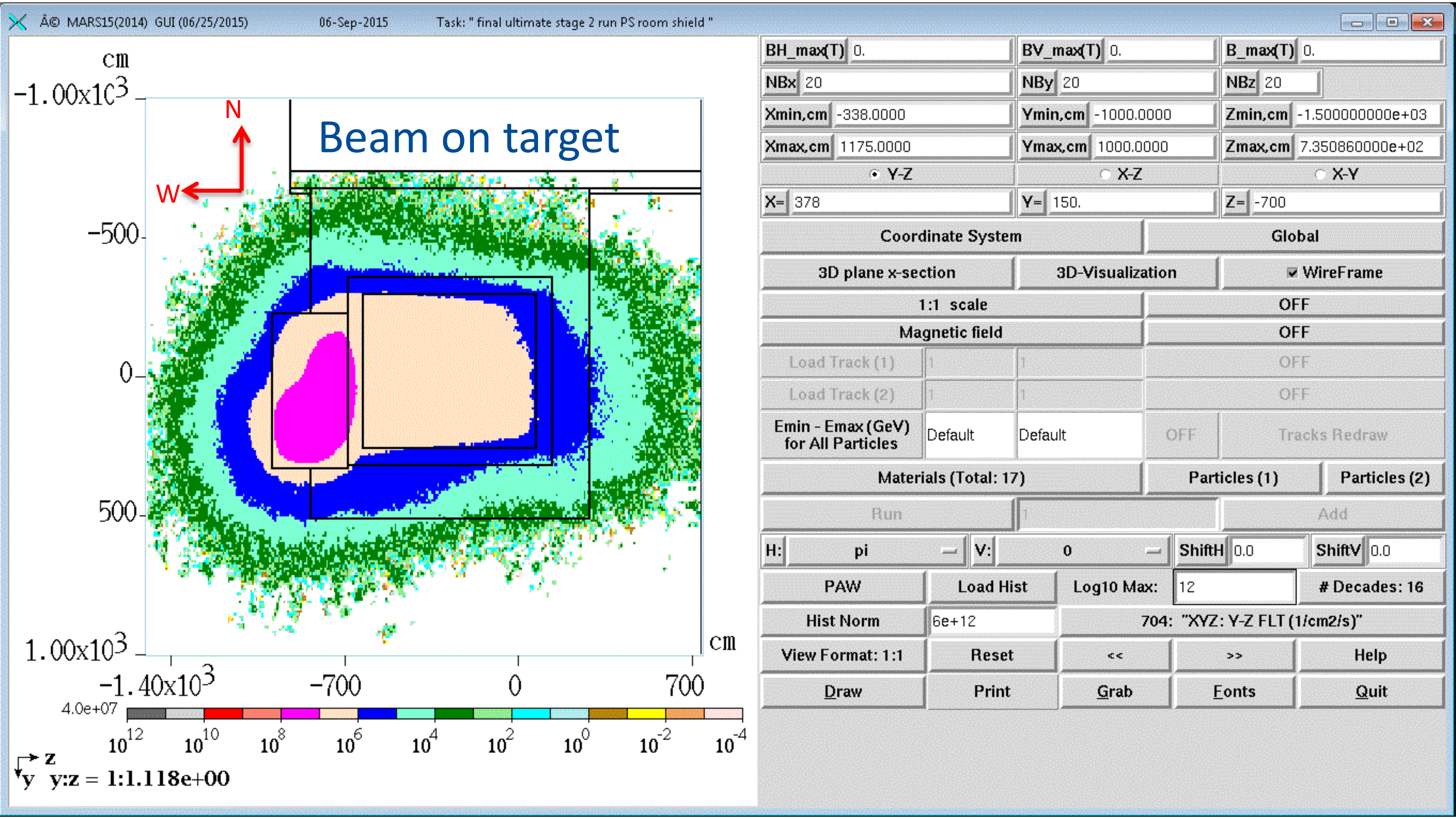
5 gallon pail of	gross lb	net lb	gm	volume cm^3	density
empty pail - tare	2.2	0	0.0		-
ca6 - compacted	75.3	73.1	33227.3		1.94
ca7 - compacted	63.7	61.5	27954.5		1.64
ca7 - compacted with water	80.8	78.6	35727.3		-
pail of water	39.8	37.6	17090.9	17090.9	1.0

Elevation view – total flux at y = 0 cm



Fermilab

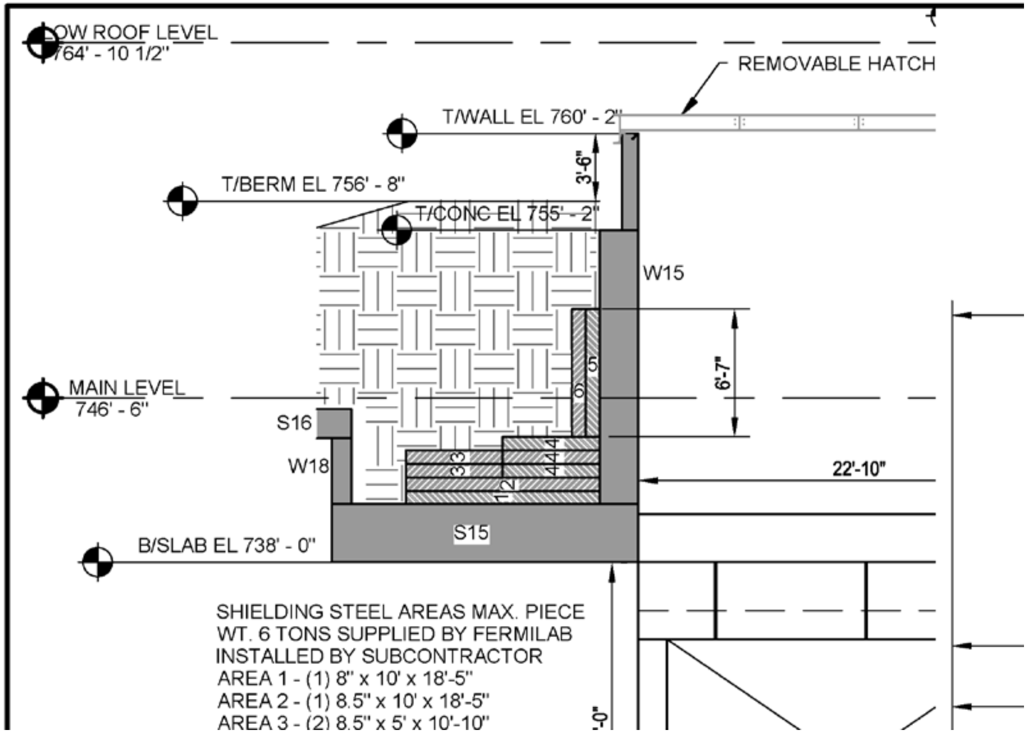
Plan view top of PS ceiling concrete – total flux at 378 cm



Fermilab

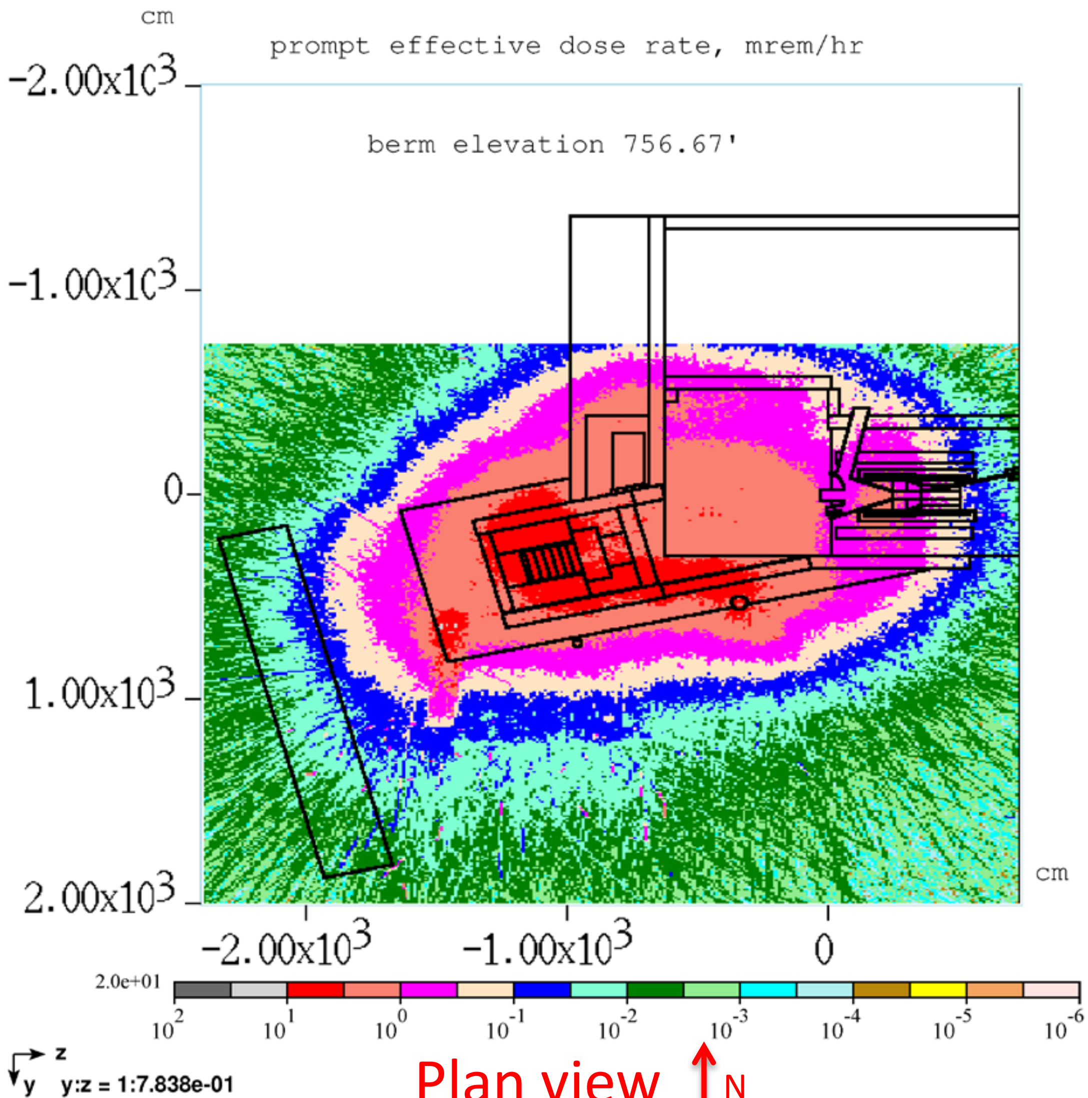
Supplemental steel shielding

- This shielding steel has been located and is being prepared for installation
  - 2/3 of plates have been cut
  - Drilling and tapping holes for lifting fixtures
  - Painting



MARS Simulations – Shielding Berm Prompt Rates

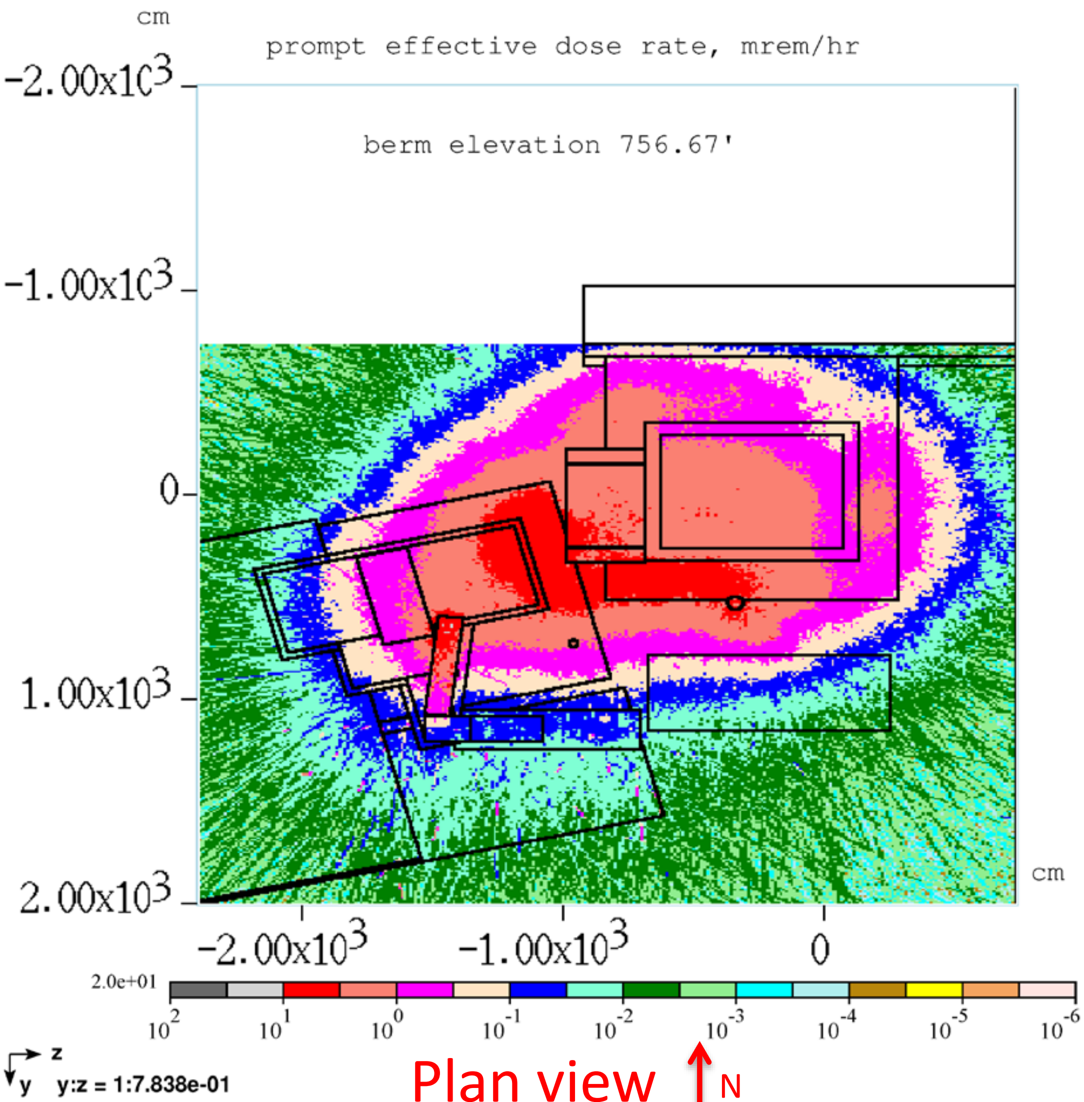
Wireframe is shown at PS centerline



Plan view
N

MARS Simulations – Shielding Berm Prompt Rates

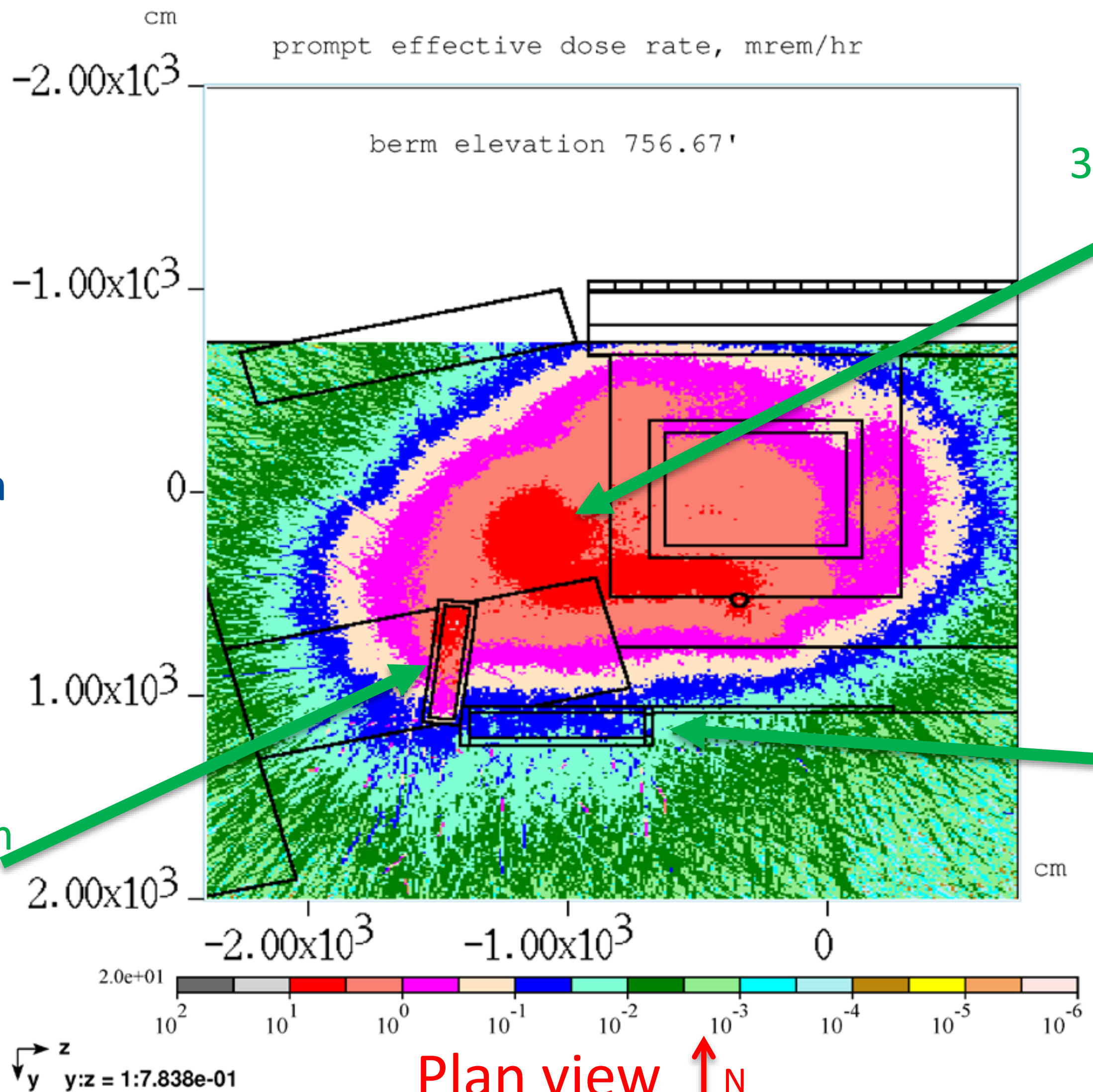
Wireframe is shown at 4 m above PS centerline



Plan view ↑ N

MARS Simulations – Shielding Berm Prompt Rates

Wireframe is shown at 7 m above PS centerline



Berm surface
3 to 5 mrem/hr

Exit stairway
0.14 mrem/hr

Extinction room drop hatch
7 mrem/hr

Plan view ↑N

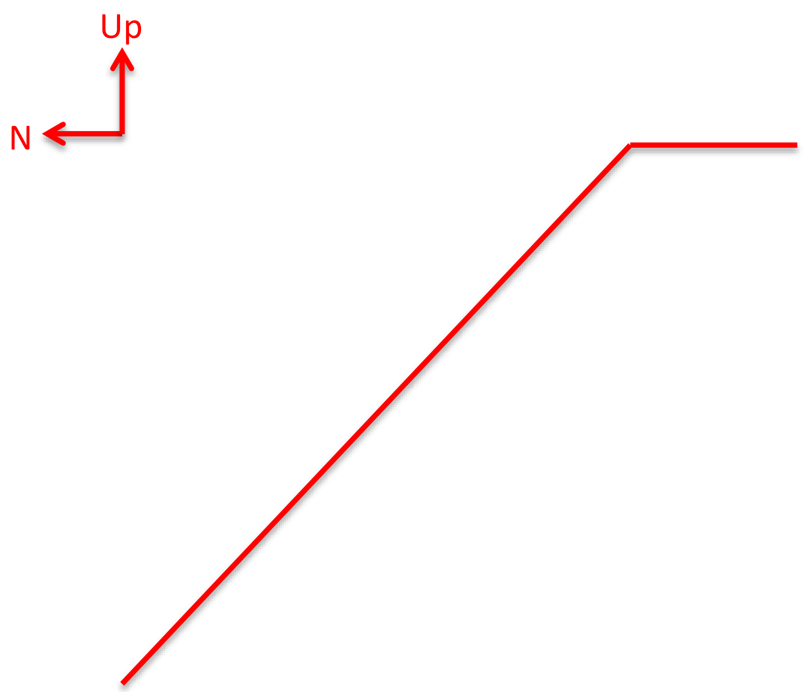
MARS Simulations – Shielding Berm Prompt Rates

- PS drop hatch loading was evaluated by Middough and was determined to hold up to 19’ of concrete blocks
- Extinction room drop hatch effective dose rate could be reduced further with additional concrete

MARS Simulations - Radiation Skyshine

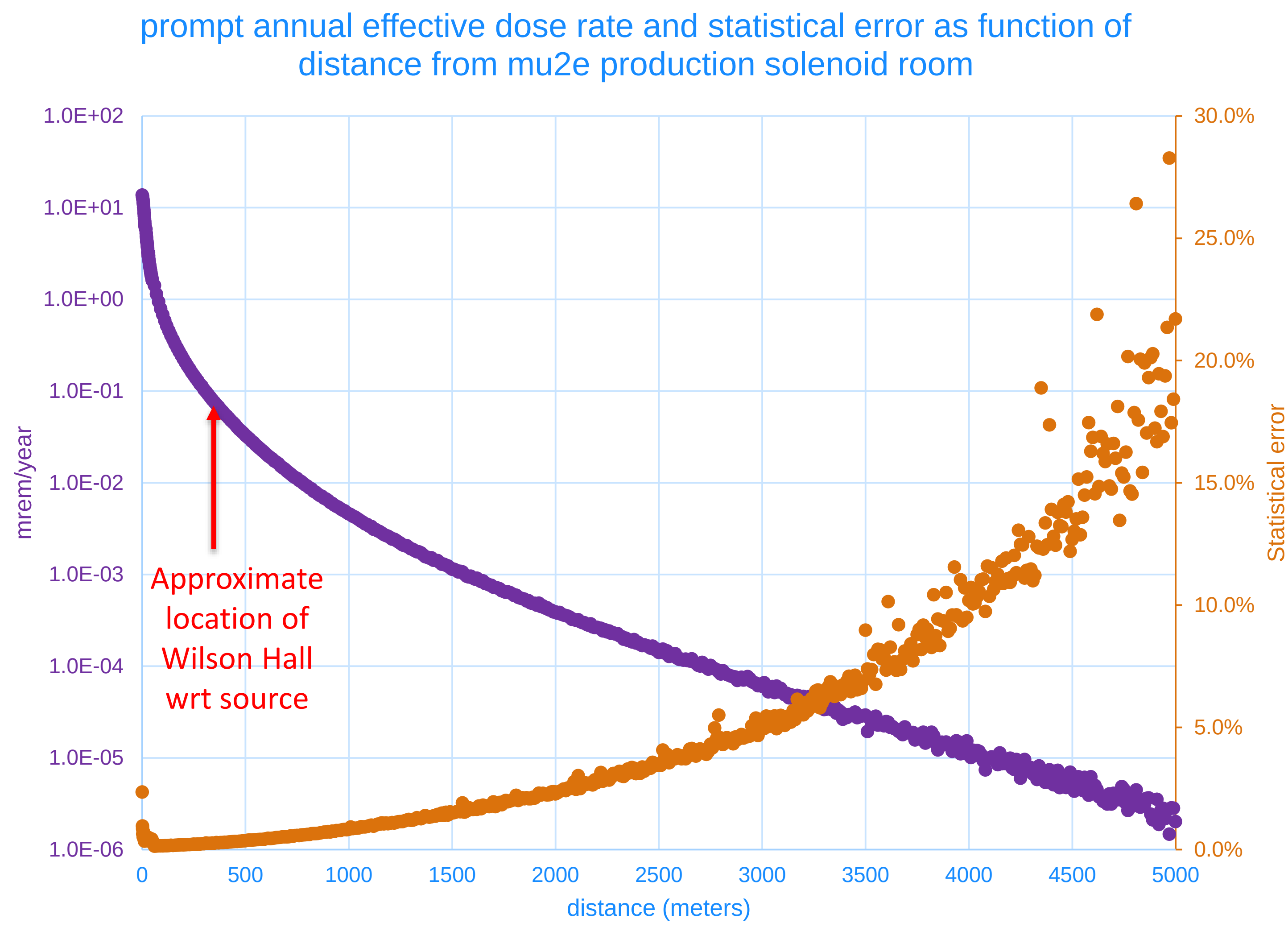
Radiation Skyshine is calculated from a particle source crossing planes indicated by the red lines.
The shield includes the north wall supplemental earth shield and 19’ of concrete in the PS drop hatch

Temporary proton source was used to check efficacy of crossing surface



Fermilab

MARS Simulations - Radiation Skyshine



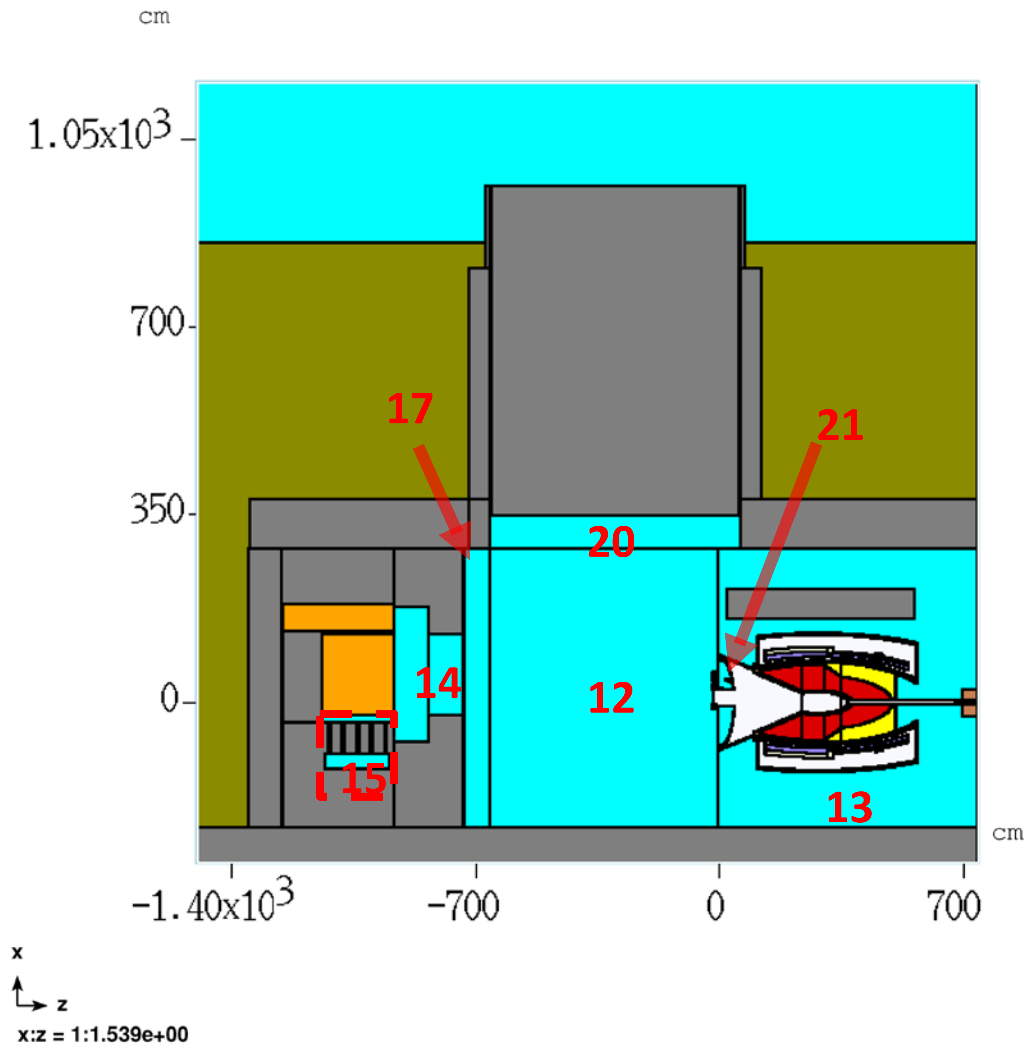
Fermilab

MARS simulations – Air Activation

- Air activation calculated in a MARS simulation and reported at Mu2e doc.db 5569-v4
  - Production of isotopes was simulated by three methods
    - Involved but straight-forward calculations
  - Calculation of transit time for radioactive decay is also straight-forward when working with a finite list of known parameters (tunnel cross sections, lengths, fan speeds)
- Minimizing the annual release of radioactivity requires
  - Making the stack exhaust fan flow rate ALARA
  - Stack exhaust fan flow rate must be sufficiently high to remove
    - Exhaust air volume from dump cooling system (165 to 250 cfm)
    - All other sources of inward air leakage along the air decay path, essentially, but not limited to, the M4 line

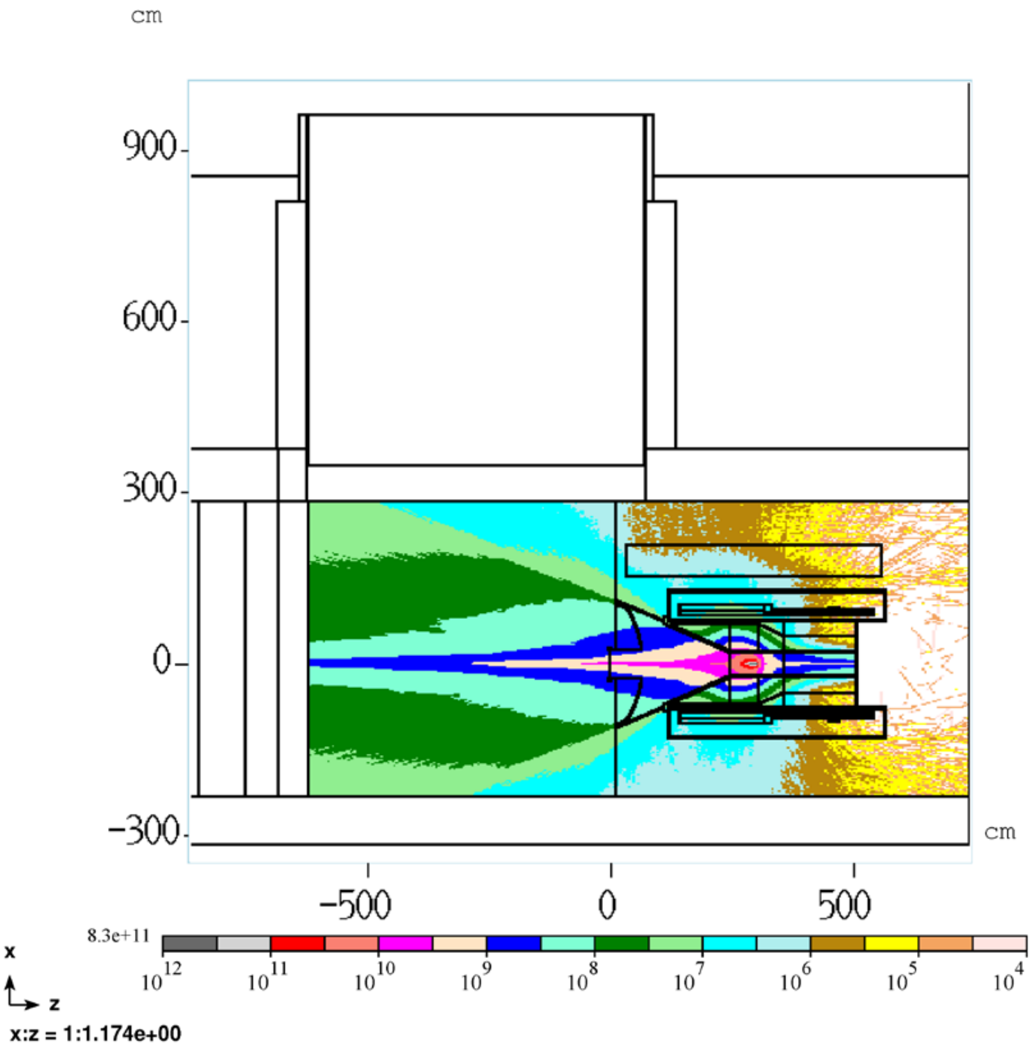
MARS simulations – Air Activation

- Air volume regions and IM numbers
  - 20 – air volume beneath PS hatch
  - 14 – dump entrance
  - 17 – irregular region at dump entrance
  - 12 – main PS room volume
  - 13 – concrete yoke air and US region
  - 21 – end cap



MARS simulations – Air Activation

- Elevation view
- Hadron flux >30 MeV

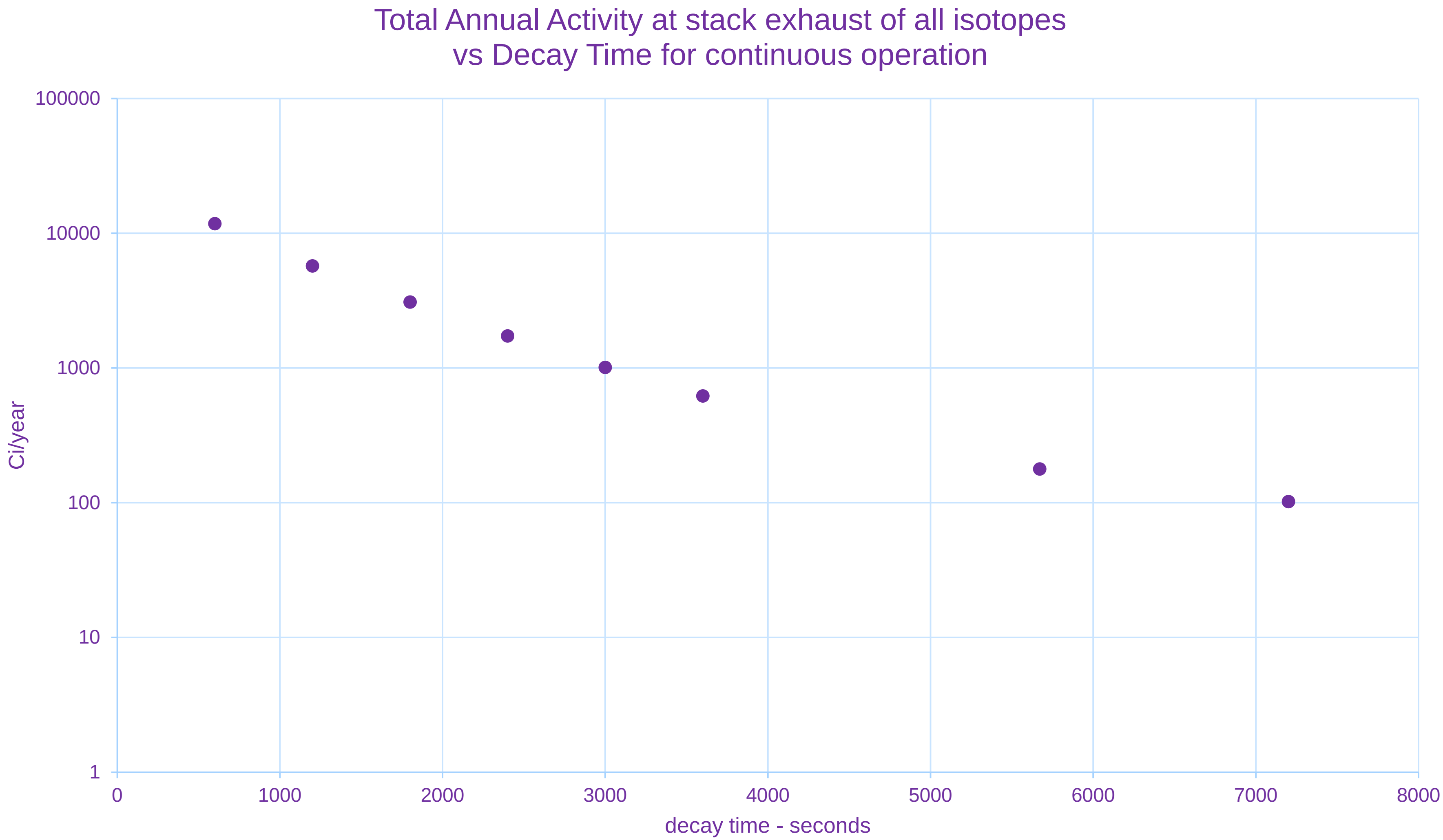


MARS simulations – Air Activation, relative abundances

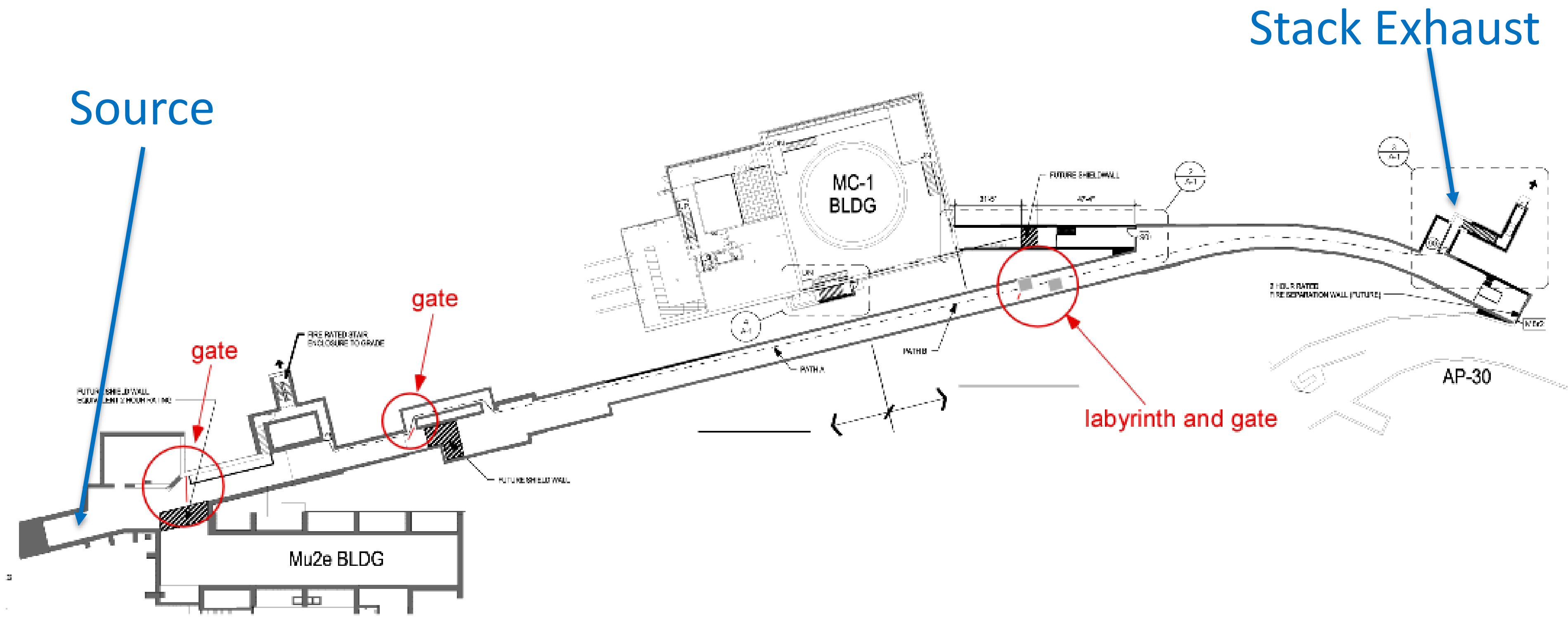
IM	Name	Description	Volume (cc)	Be7 Bq/sec/volume subdivided run	Be7 Bq/sec combined volume run
12	PS room main volume	Box volume between PS and west wall	2.5E+08	725	
13	Yoke air	Box volume surrounding PS, yoke, and upstream of PS	1.77E+08	9	
14	Dump entrance	Reentrant volume	8.59E+06	114	
15	Dump cooling air ducts	Duct work beneath dump	2.33E+04	0	
16	Dump cooling air channels	Layer of air outside of dump steel	2.37E+06	143	
17	Dump/PS air	Irregular volume between 12 & 14	3.51E+07	127	
18	RHR air	Air volume of RHR	4.96E+08	1	
20	PS drop hatch void	Air volume under PS hatch	2.05E+07	3	
21	Dish air	Air volume in end cap	1.07E+06	31	
Total			9.85E+08	1155	941

Fermilab

MARS simulations – Air Activation



MARS simulations – Air Activation



Fermilab

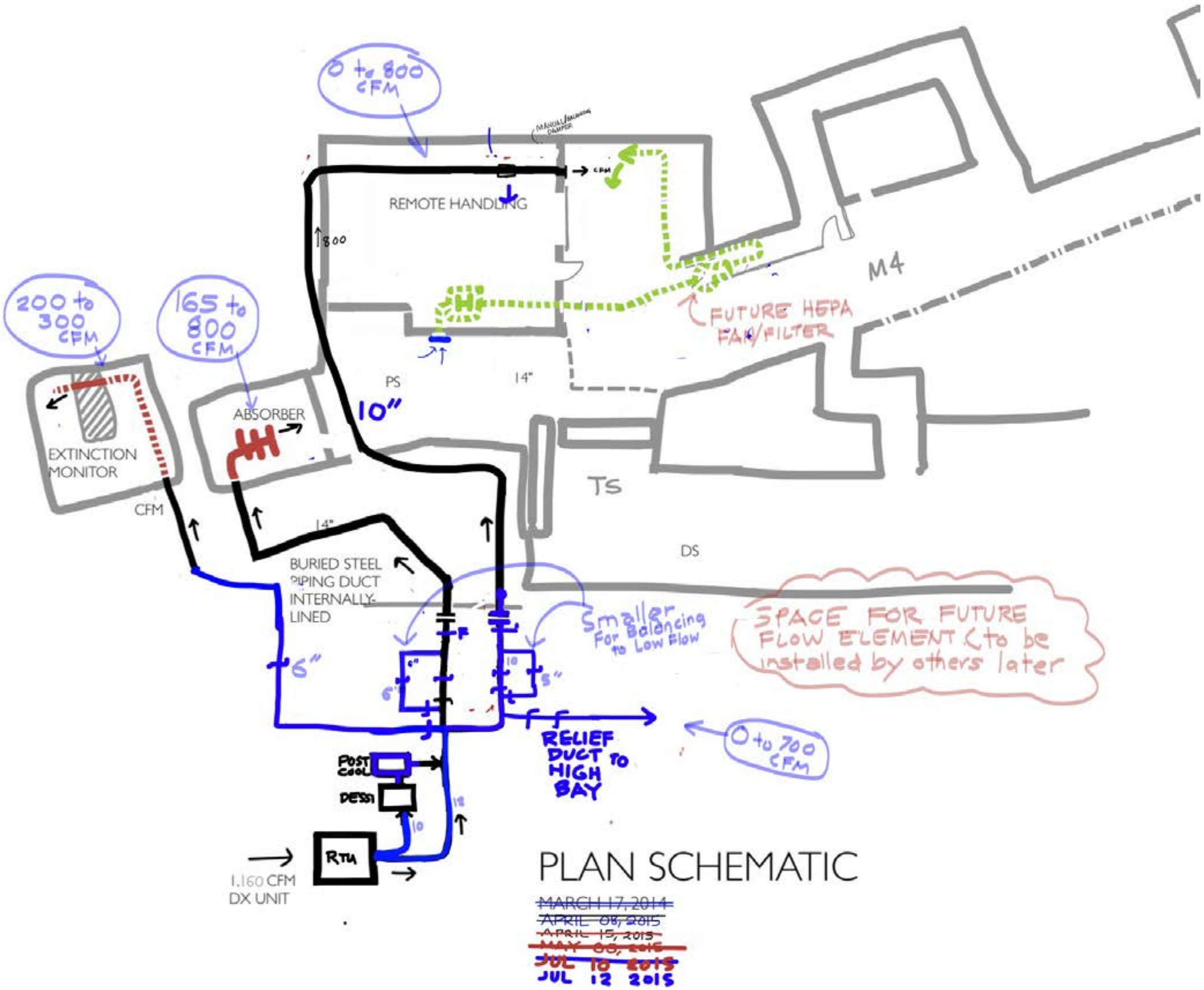
MARS simulations – Air Activation

- Sources of inward air leakage:
  - Electrical conduits
  - Doorways
  - enclosure underdrain pipes at sump locations
  - drop hatches (3)
  - detector room boundary leaks
  - M5 line sources (limited by M5 line air barrier)
  - Delivery Ring sources (limited by extraction enclosure air barrier)
  - Others?

MARS simulations – Air Activation

- What are we doing?
  - We have an air handling working group formed after the target handling review conducted in early March 2015
    - A summary of the effort is documented in Mu2e doc.db 5768-v1
    - We have a list of penetrations
      - New candidates are being added as they are discovered
  - We are working to define boundaries of the PS room for air containment
    - A number of possibilities are under consideration
  - We also consider the possibility of substituting air volume of the largest source (volume 12) with helium or a contained air volume

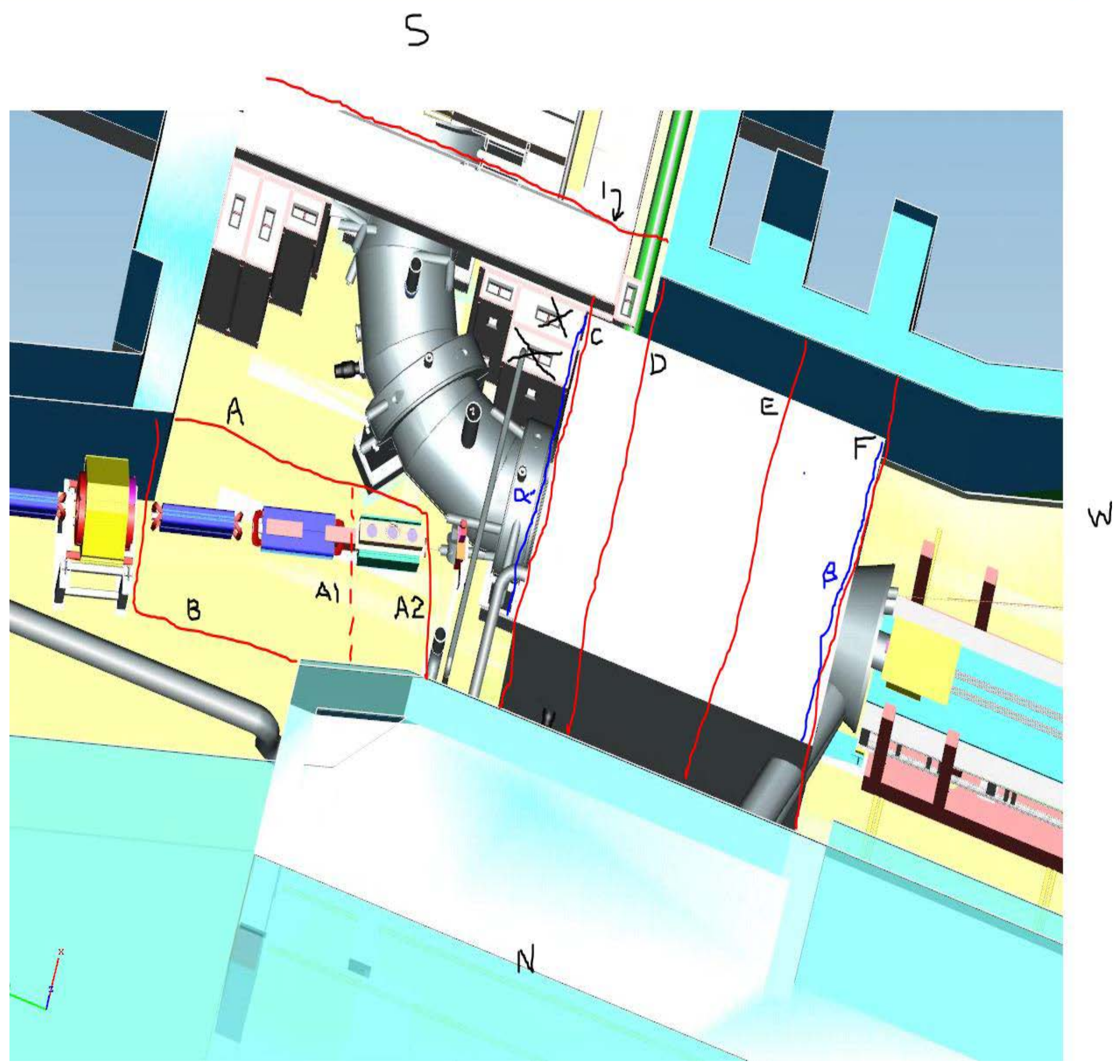
MARS simulations – Air Activation



MARS simulations – Air Activation

- Possible air barrier locations under consideration at the PS room and Detector Room

- We are exploring these possible solutions



MARS simulations – Air Activation

- An ANYSYS analysis of the beam dump cooling air flow rate requirement has been revisited
  - Documented in Mu2e doc.db 5855-v4
  - The range of acceptable flow is now 165 to 250 cfm (was 800 cfm)
- Ultimately, the effort to seal up sources of inward air leakage cannot be completed until facility construction is complete and all equipment, shielding, and air barriers have been installed
- This activity will remain after completion of the Mu2e Project

- End of Materials for Review Panel