Radiation Shielding Studies for the MuCool Test Area at Fermilab

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Outline

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- **3D Geometry Model of the MuCool Test Area (MTA)**
- **Proton Beam & Target**
- **Calculated Dose Distributions & Neutron Energy Spectra**
- **Classification**

Introduction

The MuCool Test Area (MTA) is an intense primary beam facility derived directly from the Fermilab Linac to test heat deposition and other technical concerns associated with the liquid hydrogen targets being developed for cooling intense muon beams.

In this study the results of Monte Carlo radiation shielding calculations performed using MARS14 code are presented and discussed.

The areas taken into account:

- Downstream portion of the target hall and berm around it
- Access pit
- Service building
- Parking lot

Final classification is given for these areas at normal operating conditions according to the Fermilab Radiological Control Manual.

Introduction - Why MARS?

- Low-energy neutrons (below 20 MeV) in MARS are transported with the ENDF/B-VI data by invoking the MCNP code. Currently it is a standard in the 'neutron world'.

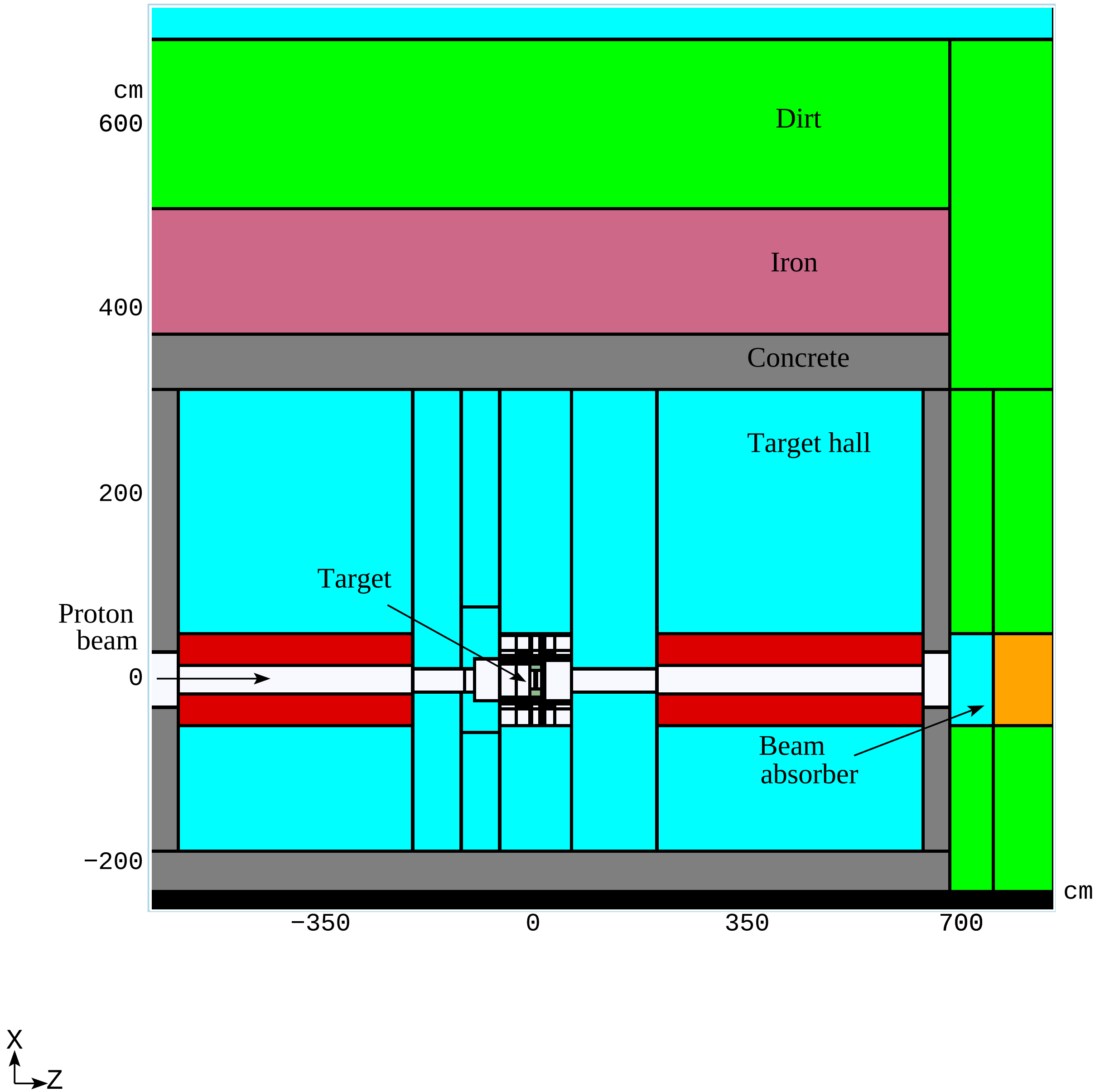
  When working with the MARS-MCNP duet, there are two options:

  (i) Invoking MCNP collision physics within MARS;

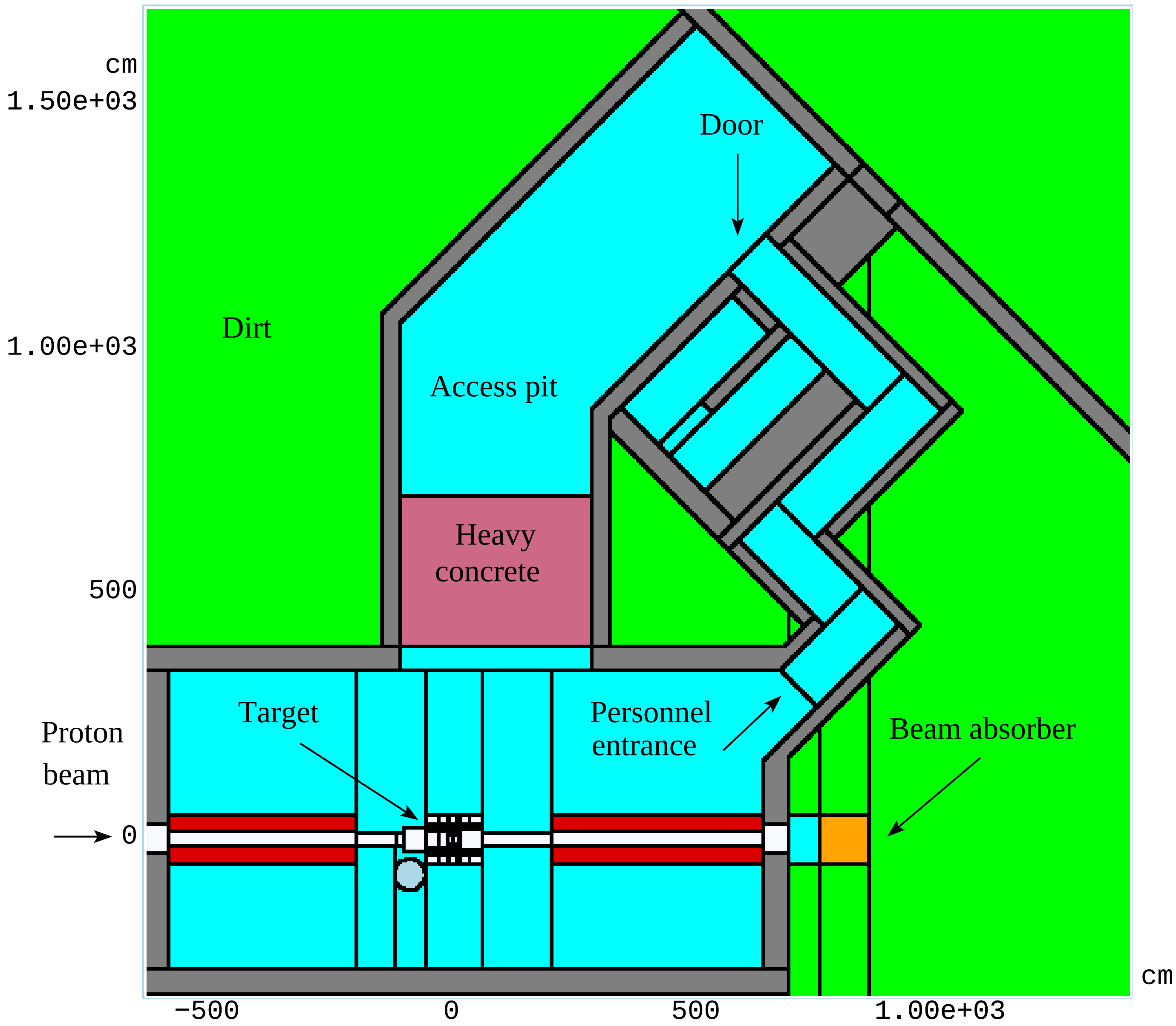
  (ii) Generating a source of low-energy neutrons for subsequent MCNP standalone modeling.

- Such deep-penetration problems require using an efficient variance reduction technique like mathematical expectation method implemented in MARS.

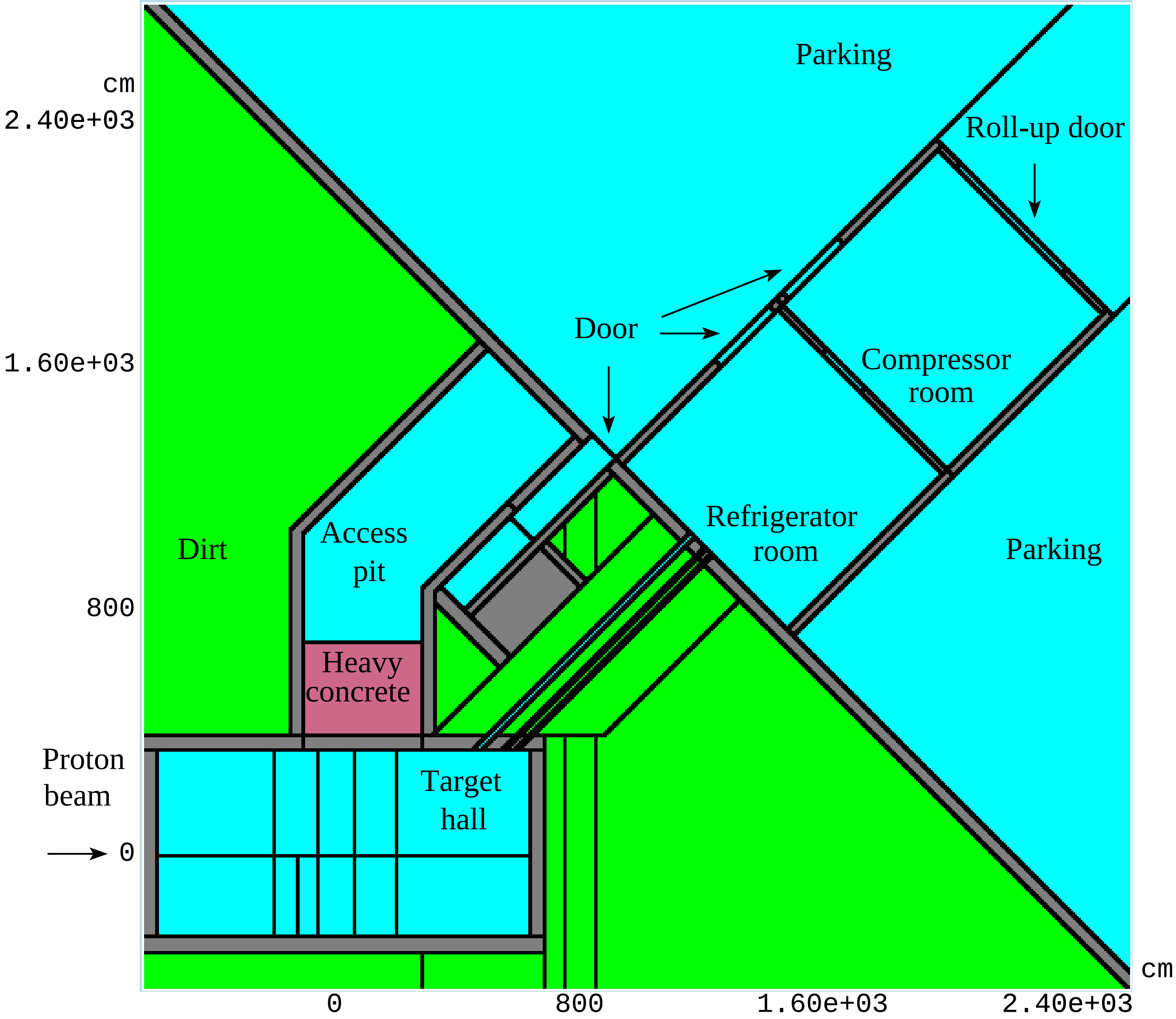
Geometry Model – Elevation View (Target Hall)



Geometry Model – Plan View (Lower Level)



Geometry Model – Plan View (Upper Level)



Proton Beam & Target

Beam: 400-MeV protons; $\sigma_r = 1$cm

2×10^{14} p/s or 1.3×10^{13} p/pulse at 15 Hz repetition rate

Proton interaction lengths, λ (cm)

	LH_2	Al	Cu
λ_{tot}	910	29	10
λ_{inel}	1110	41	16

Targets

Target	L (cm)	R (cm)	% of λ_{tot}
LH_2	21	10.5	2
Cu	1	10	10

Proton Beam & Target (2)

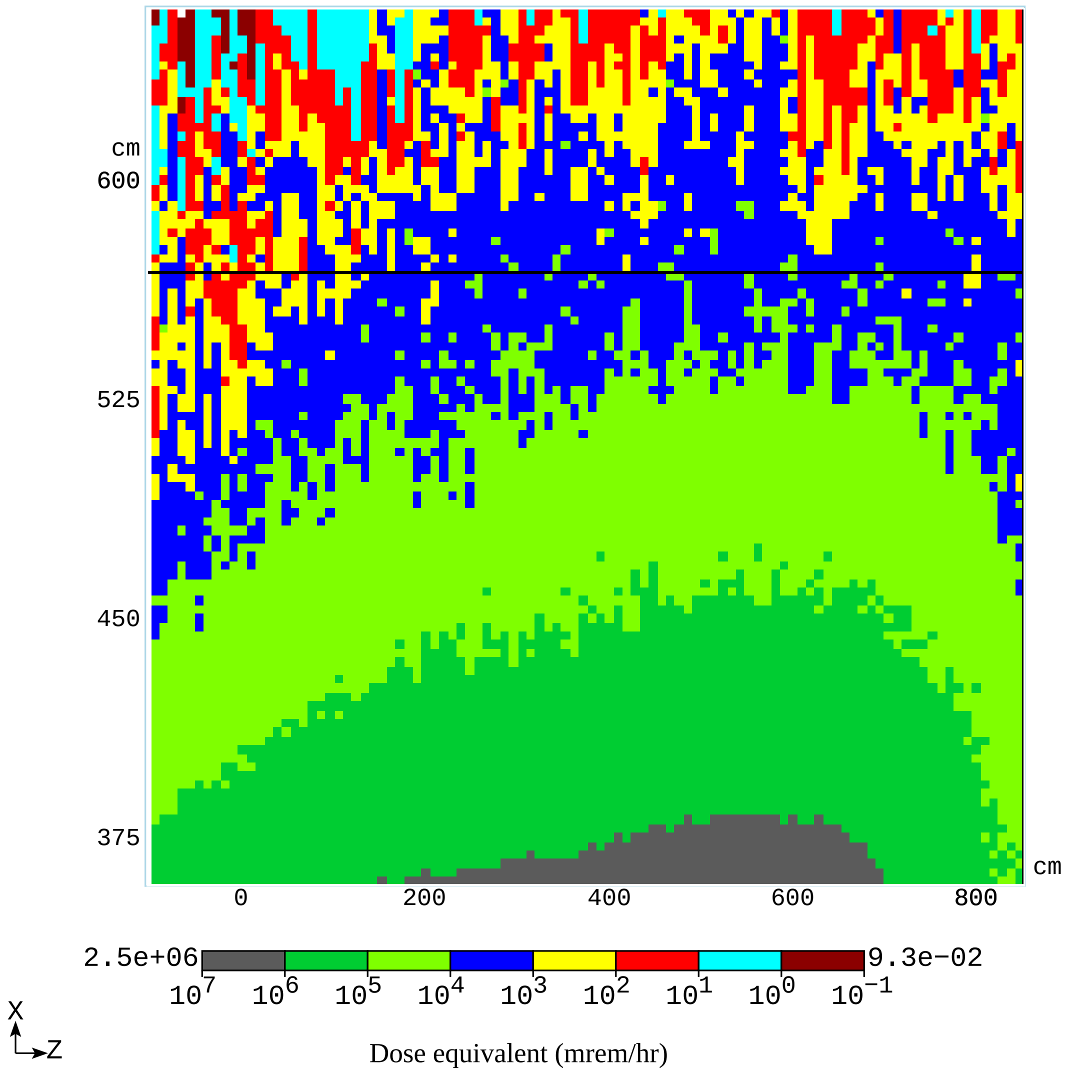
Spallation neutron studies → full absorption (≈100%) targets of heavy & dense materials (Pb, Unat) are used.

- It is claimed that the facility can serve as a multi-purpose one for future operations.
- The 1-cm thick copper target (10% of interaction length) is considered as a generic (modest "averaged") target.

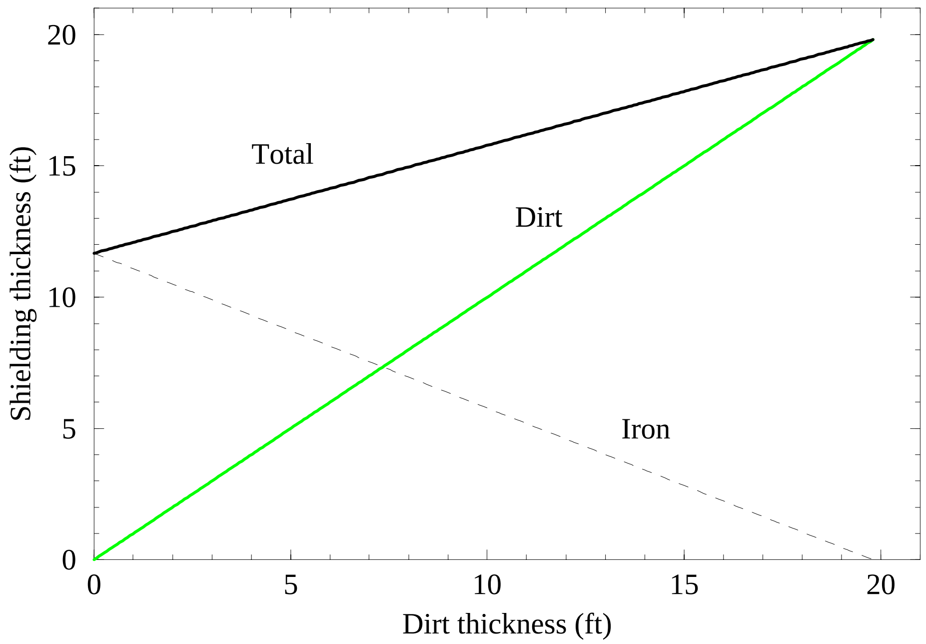
Calculated Dose Distributions above the Berm (normal operation)

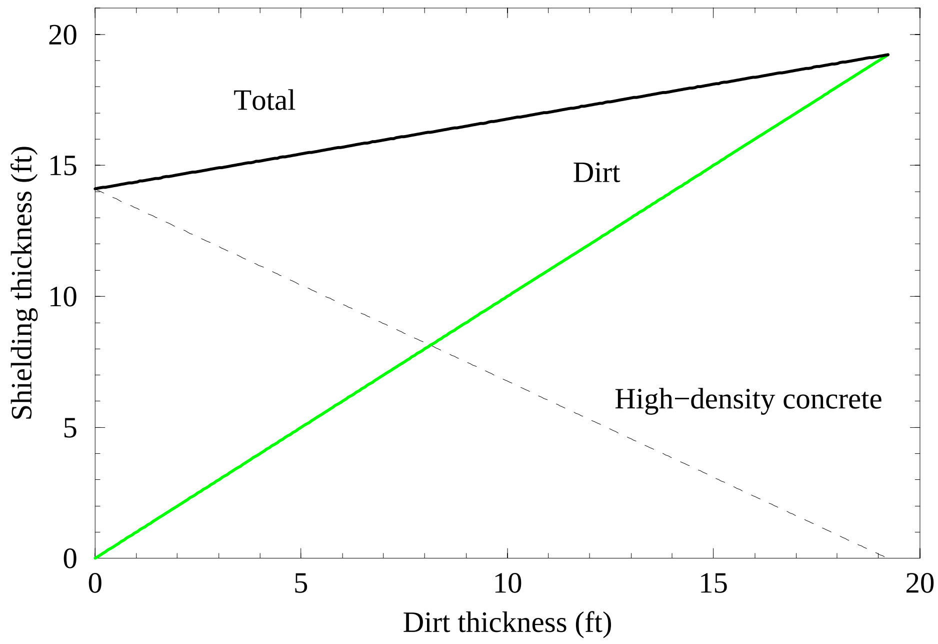
$$Attenuation = \exp(-x_1/\alpha_1 - x_2/\alpha_2)$$

Material (density, g/cm^3)	Attenuation length, α (cm)
Compacted soil (2.24)	39
High-density concrete (3.64)	28
Iron (7.87)	23



Dose Equivalent above the Berm (normal operation)

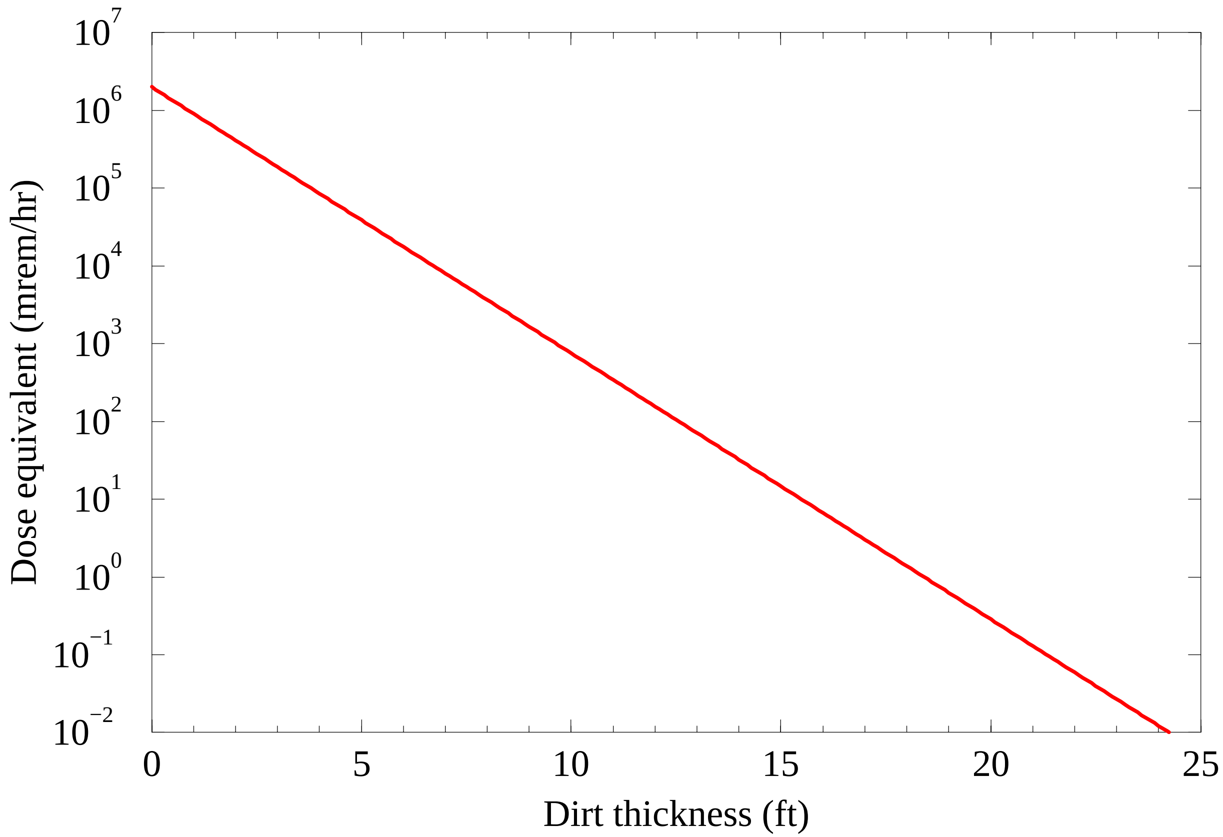




Calculated shielding compositions which provide the dose level of 0.5 mrem/hr on the top of the MTA shielding.

10.5' of high-density concrete + 2' of dirt (**total is 12.5'**) provide 5 mrem/hr on the top Controlled Area of minimal occupancy (0.25 – 5 mrem/hr, just signs).

Dose Equivalent above the Berm (normal operation) (2)



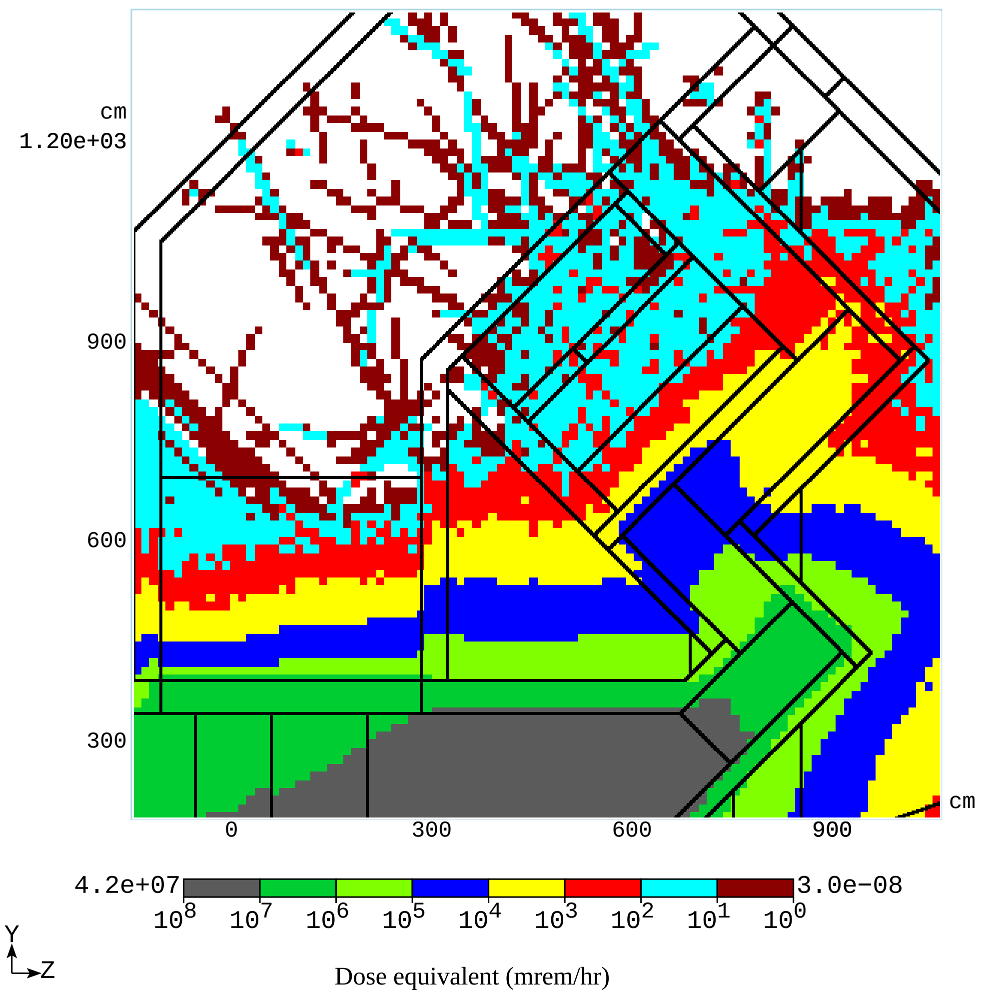
At present we have 11' of dirt → 330 mrem/hr (10% target).

For a 21-cm LH2 (2% target) it means 66 mrem/hr.

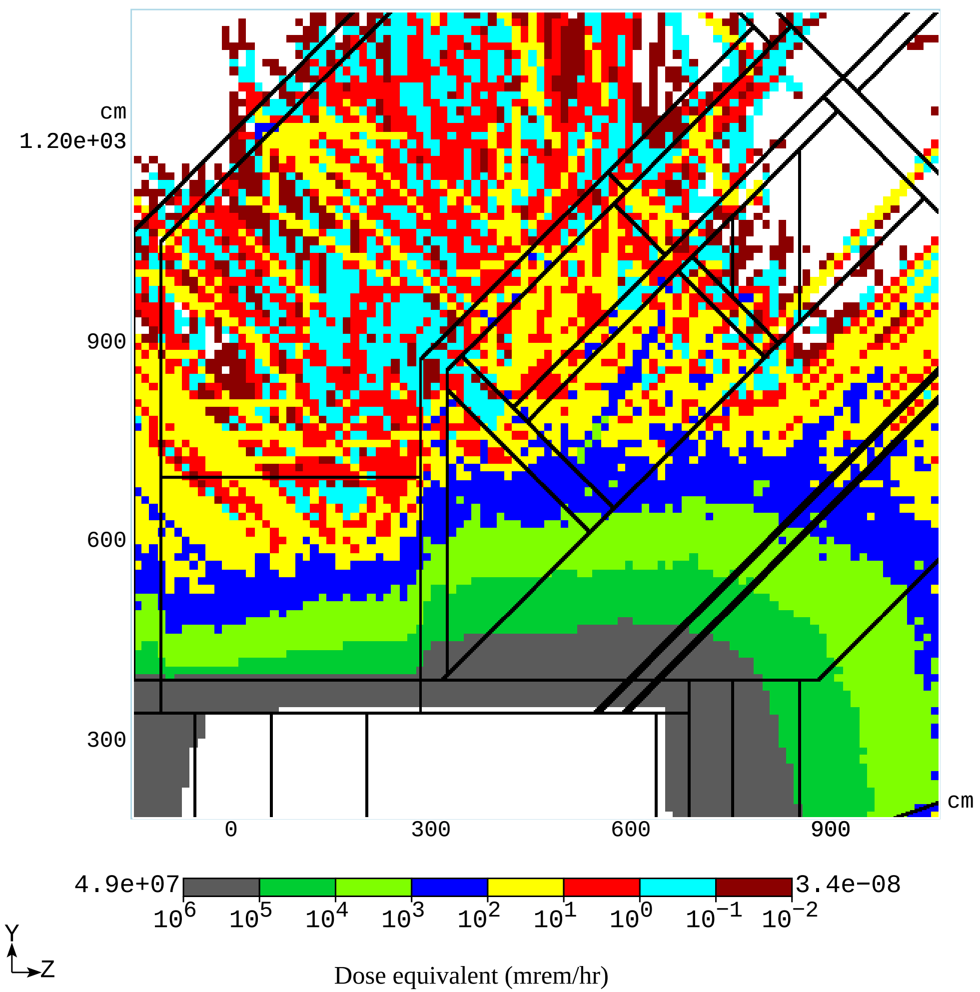
Radiation Area → dose rate from 5 up to 100 mrem/hr (Fermi RCM).

Calculated Dose Distributions in the Access Pit (normal operation)

Lower Level

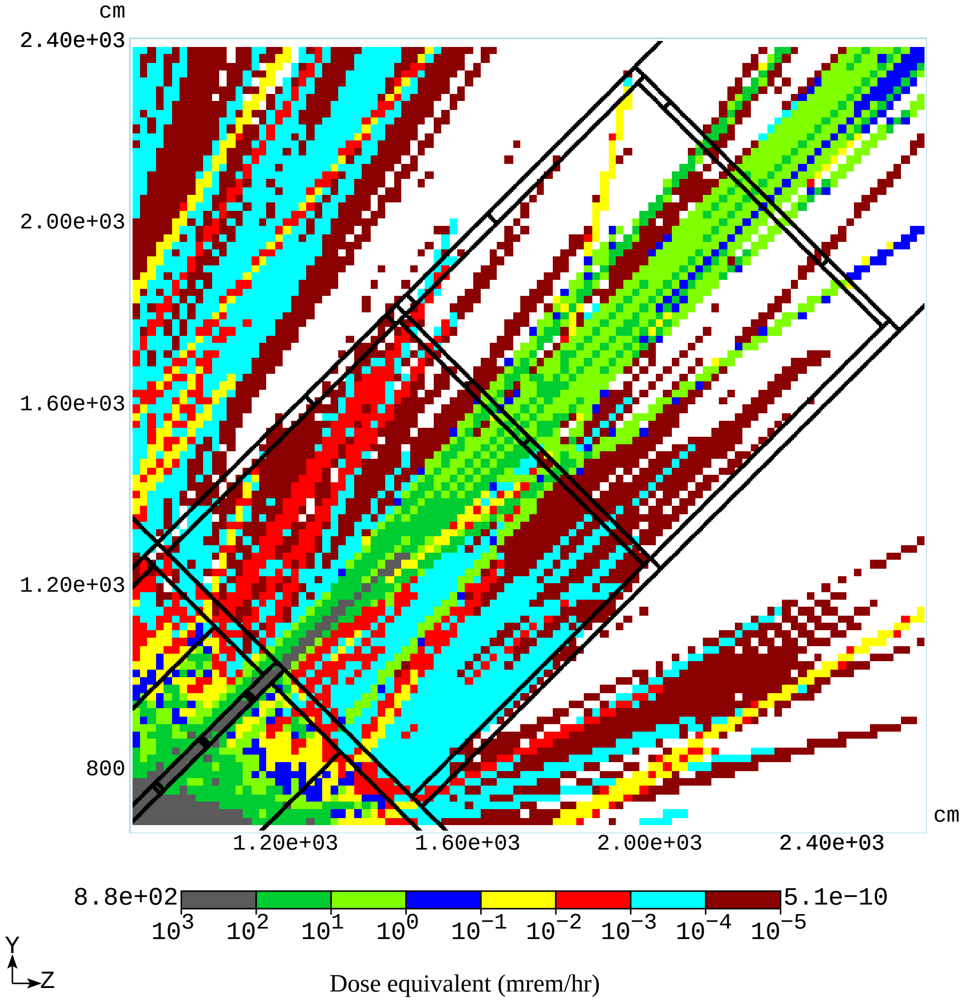


Upper Level



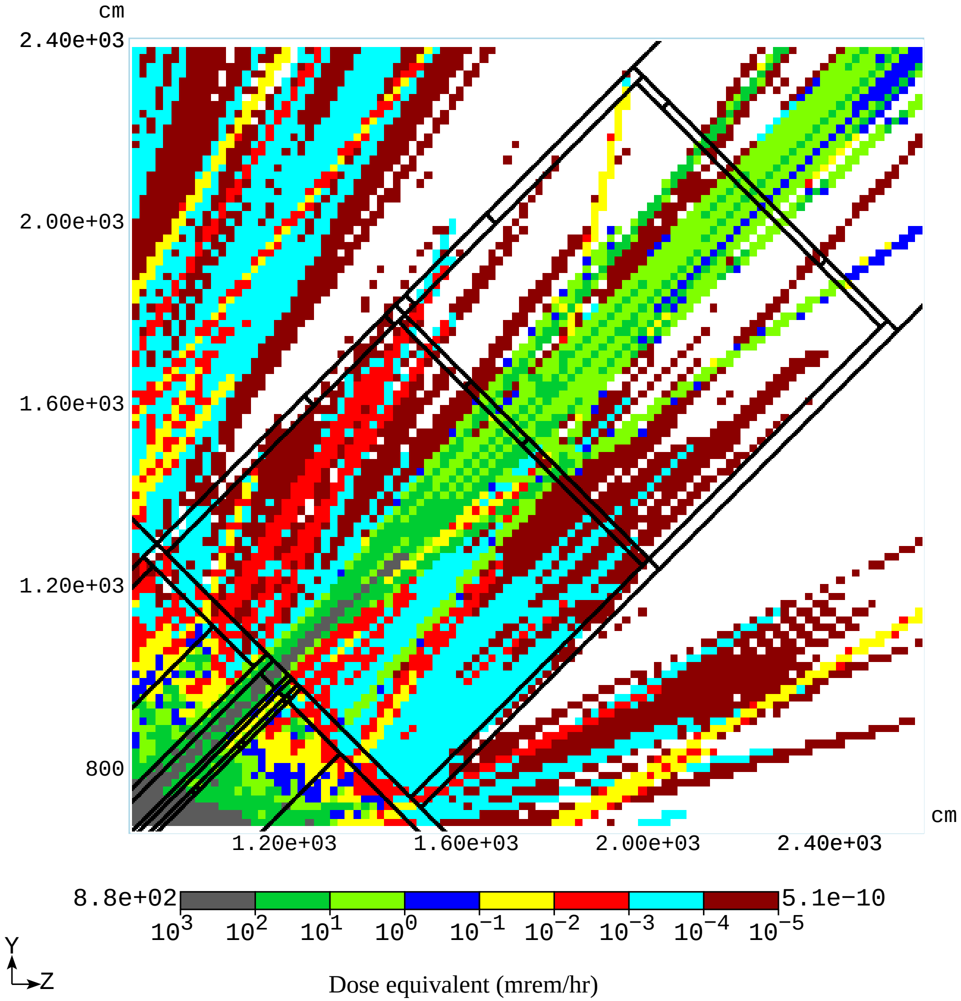
Dose Equivalent in the Cryo Room (normal operation)

10" penetration



Dose equivalent (mrem/hr)

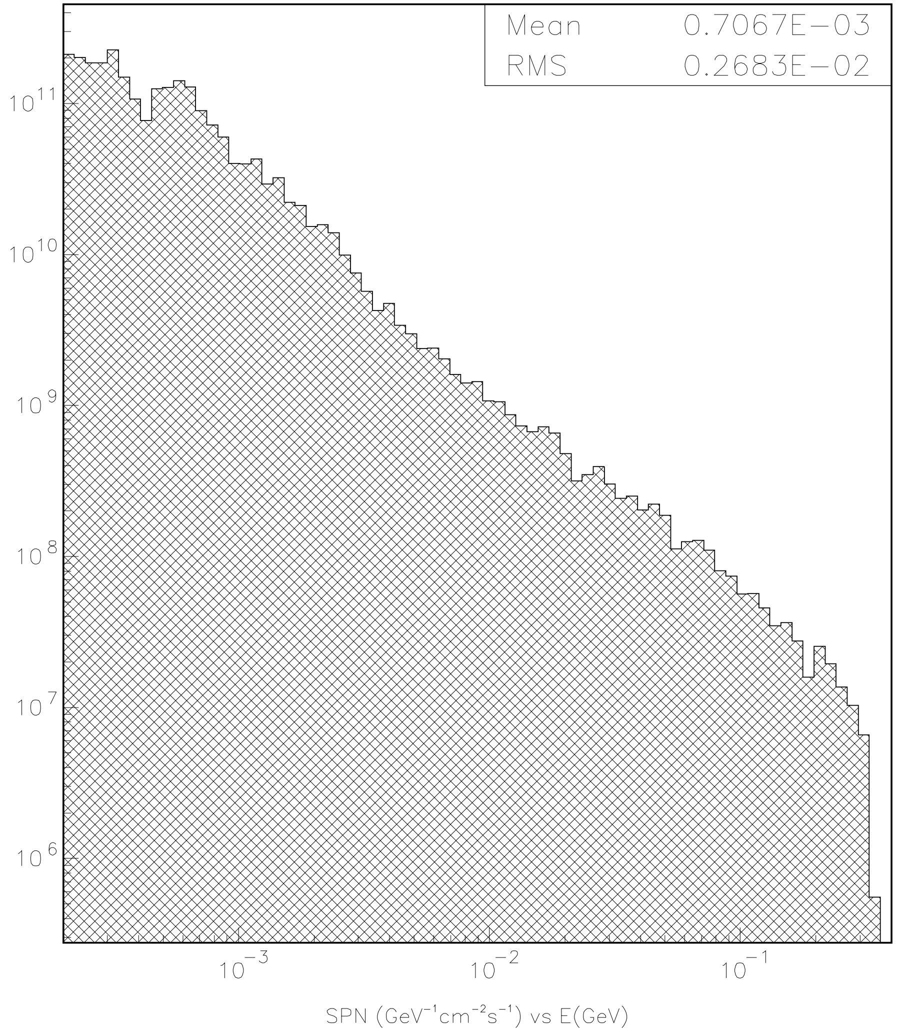
4" and 8" penetrations



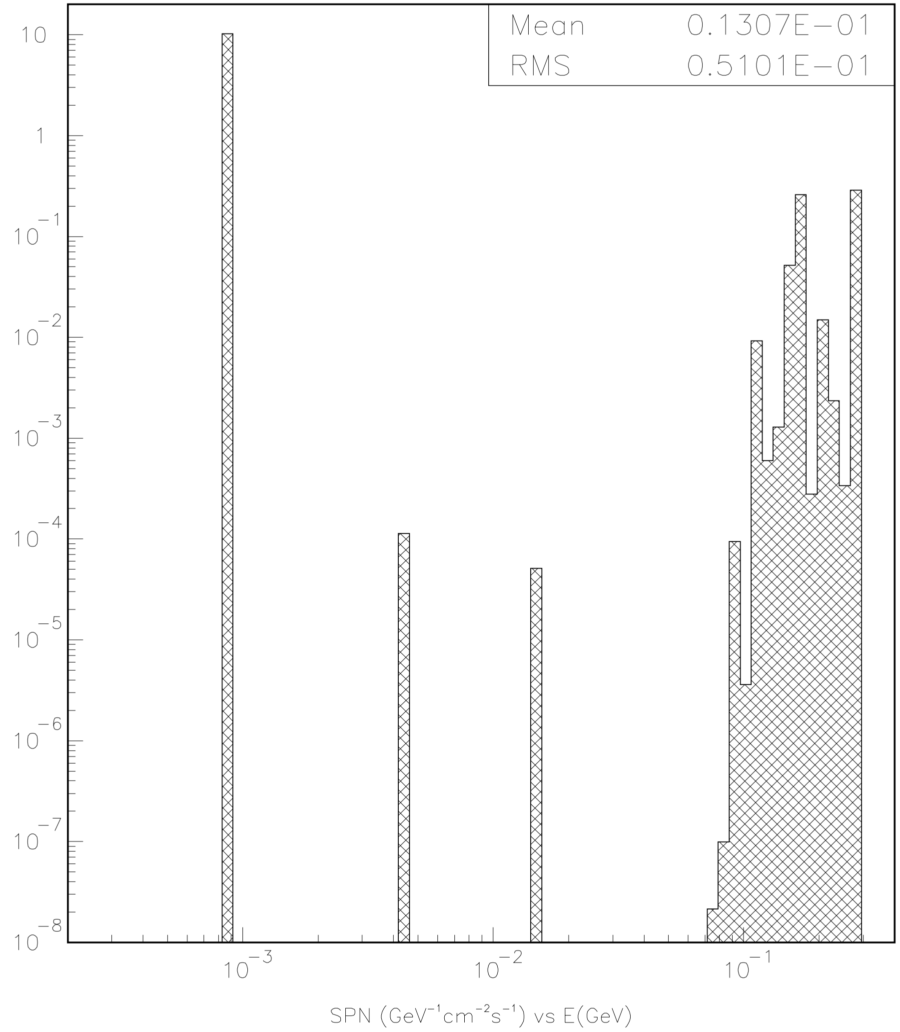
Dose equivalent (mrem/hr)

Neutron Energy Spectra in the 10" Penetration (normal operation)

Near target hall



Near cryo room



Three options for additional shielding

1. **A wall in target hall in front of penetrations.**

H x W x T = (200 + 95) cm x 80 cm x 10 cm

↓ ↓

BMCN ***Tungsten***

↓ ↓

600 kg **1500 kg**

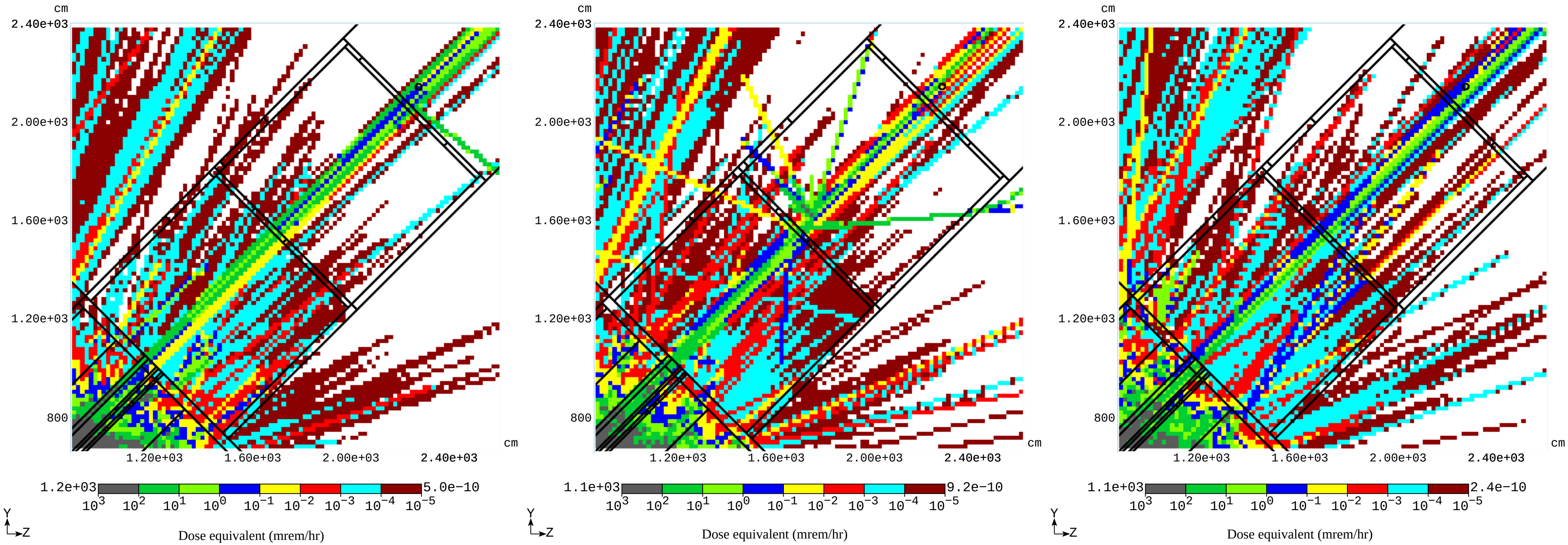
2. **A wall instead of the door between cryo room & compressor room.**

H x W x T = 220 cm x 190 cm x 20 cm **Regular concrete ≈ 2000 kg.**

3. **Two 2″ iron collimators, 20″ in length, inside the 10″ penetration.**

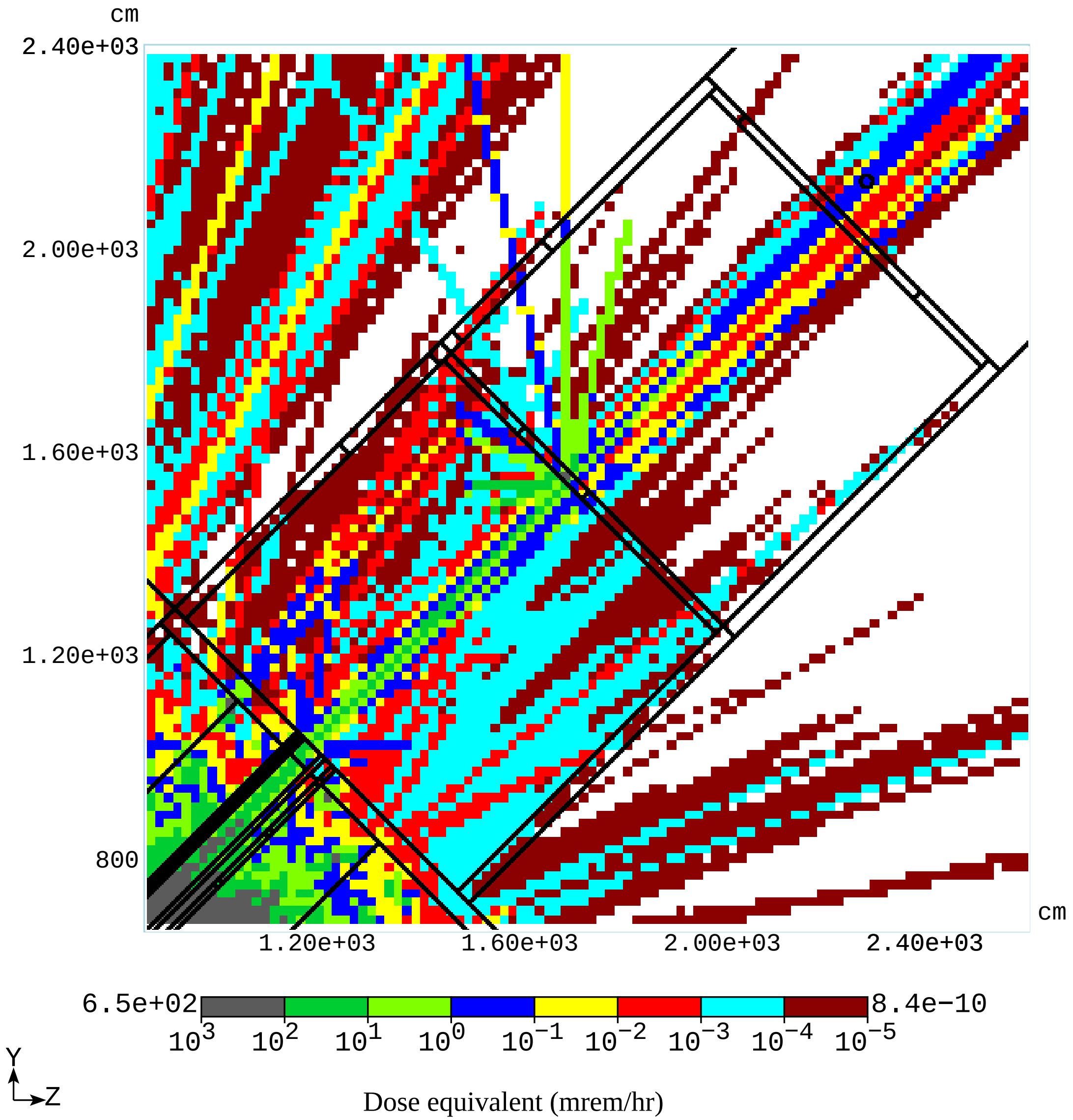
Two 1″ iron collimators, 20″ in length, inside the 8″ penetration.

Dose Distribution in the Service Building for the 3 shielding options



To reduce dose at the parking lot, both 2nd and 3rd option are more efficient when compared to the 1st one.

Dose Distribution in the Service Building (options 2 and 3 together)



Dose equivalent (mrem/hr)

To reduce further the dose at parking lot, additional local shielding is required

near the internal wall in the refrigerator room.

A 50-cm iron block => the predicted dose at parking lot $\leq$ 0.05 mrem/hr

at normal operation at 10^{14} p/s.

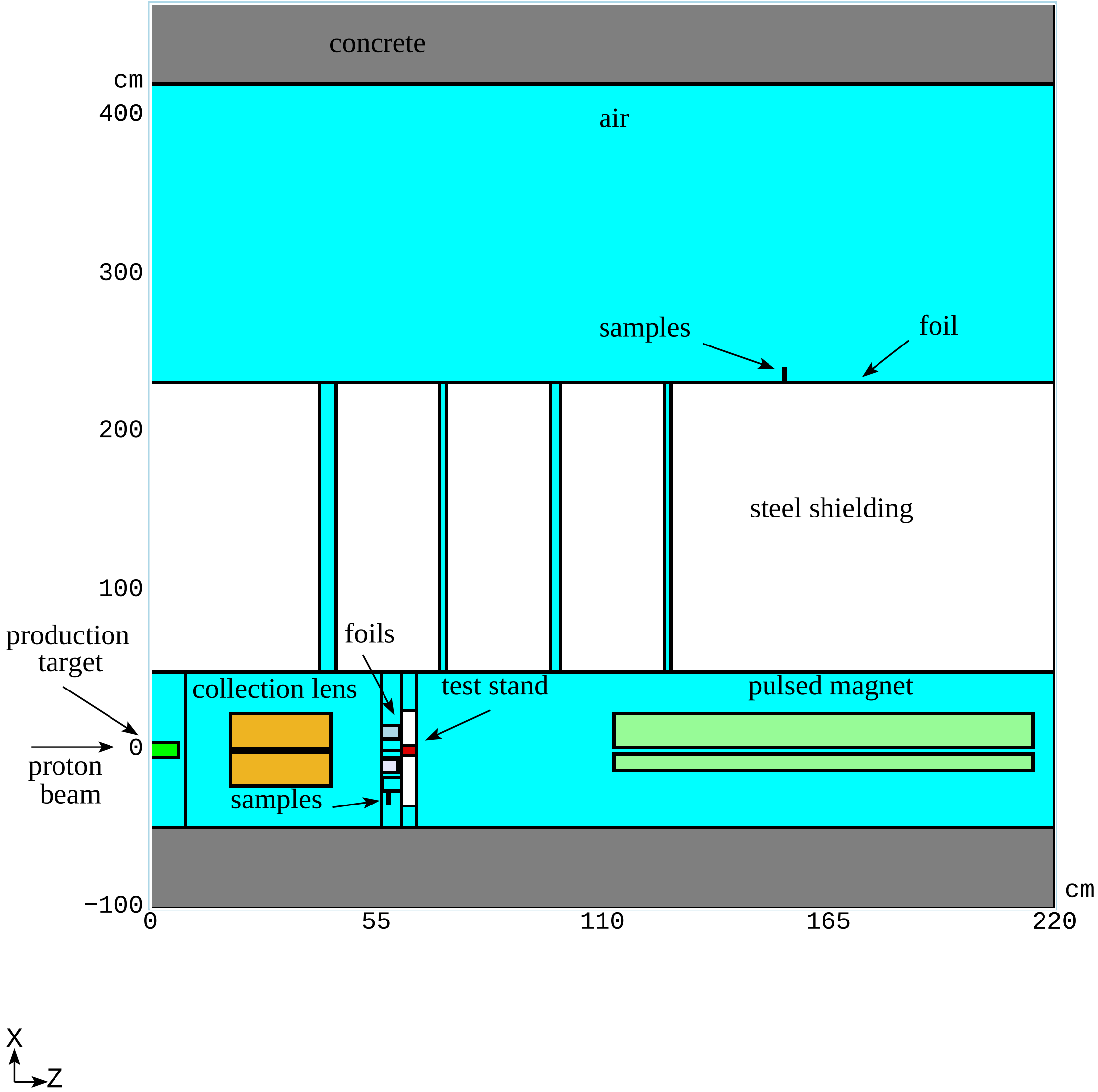
Conclusions

1. A credible beam accident at MTA is less severe than normal operation.

2. At normal operation the following classification is suggested (Fermi RCM):

- Berm above target hall – Controlled Area of minimal occupancy (0.25 – 5 mrem/hr);
- Access pit – Radiation Area with rigid barriers/locked gates (5 – 100 mrem/hr);
- Cryo room - Radiation Area with rigid barriers/locked gates (5 – 100 mrem/hr);
- Compressor room - Controlled Area of minimal occupancy (0.25 – 5 mrem/hr);
- Parking lot – Normal area of unlimited occupancy (dose rate ≤ 0.05 mrem/hr).

Quality of the calculations – NuMI Activation Experiment (2000-2001)



AP0 Enclosure at Fermilab

Quality of the calculations – NuMI Activation Experiment (2000-2001)