Radiation Shielding Calculations for MuCool Test Area at Fermilab

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Objectives

1. **Dose level around the MuCool Test Area (MTA)**

   at normal operation and at beam accidents.

2. **Proper classification to satisfy radiation safety requirements.**

- **3D geometry model: target hall**
  berm
  access pit
  service building (cryo & compressor rooms)
  parking lot

- **Beam and target**

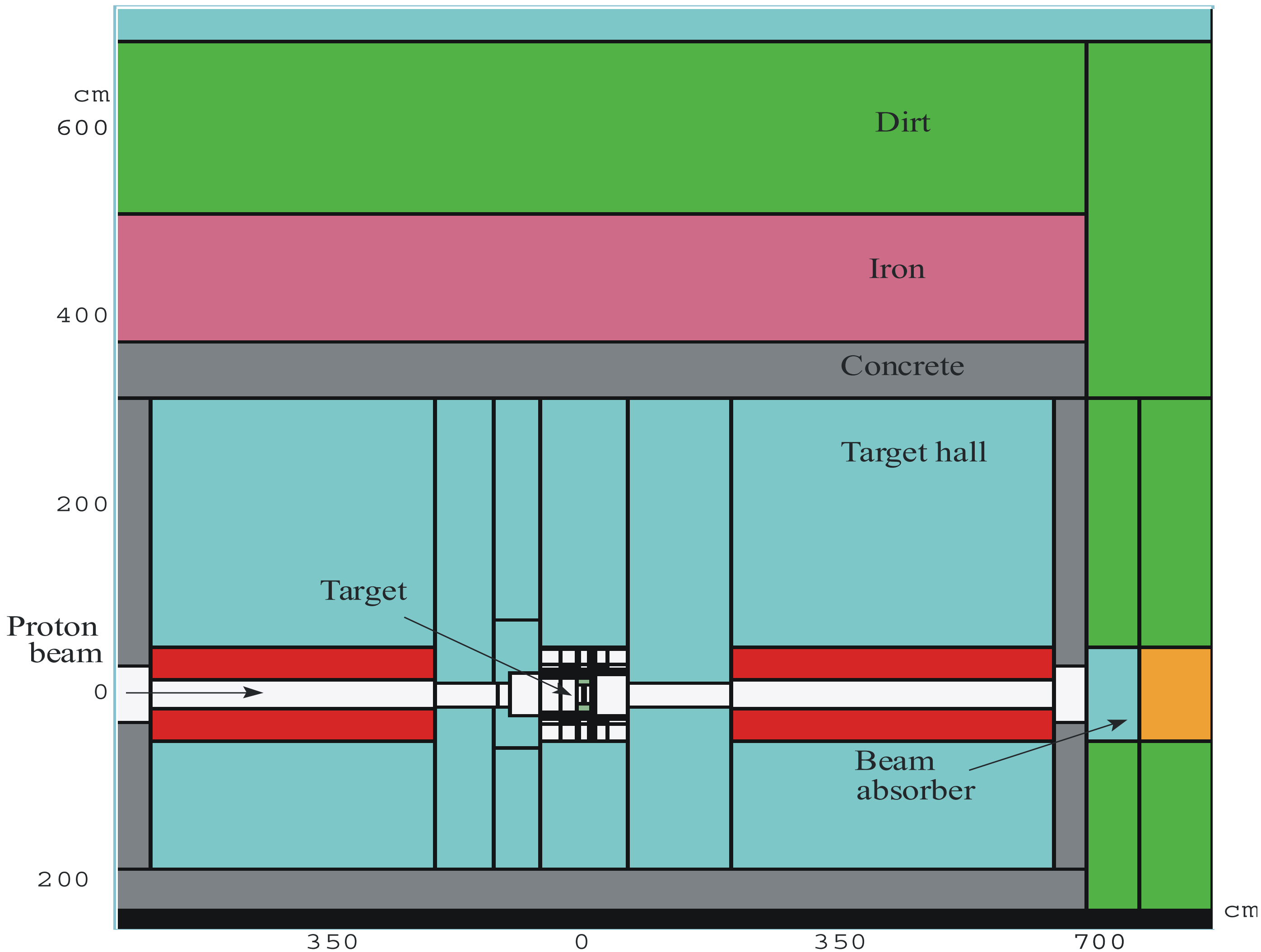
- **Results of MARS Monte Carlo calculations & classification**

Why MARS?

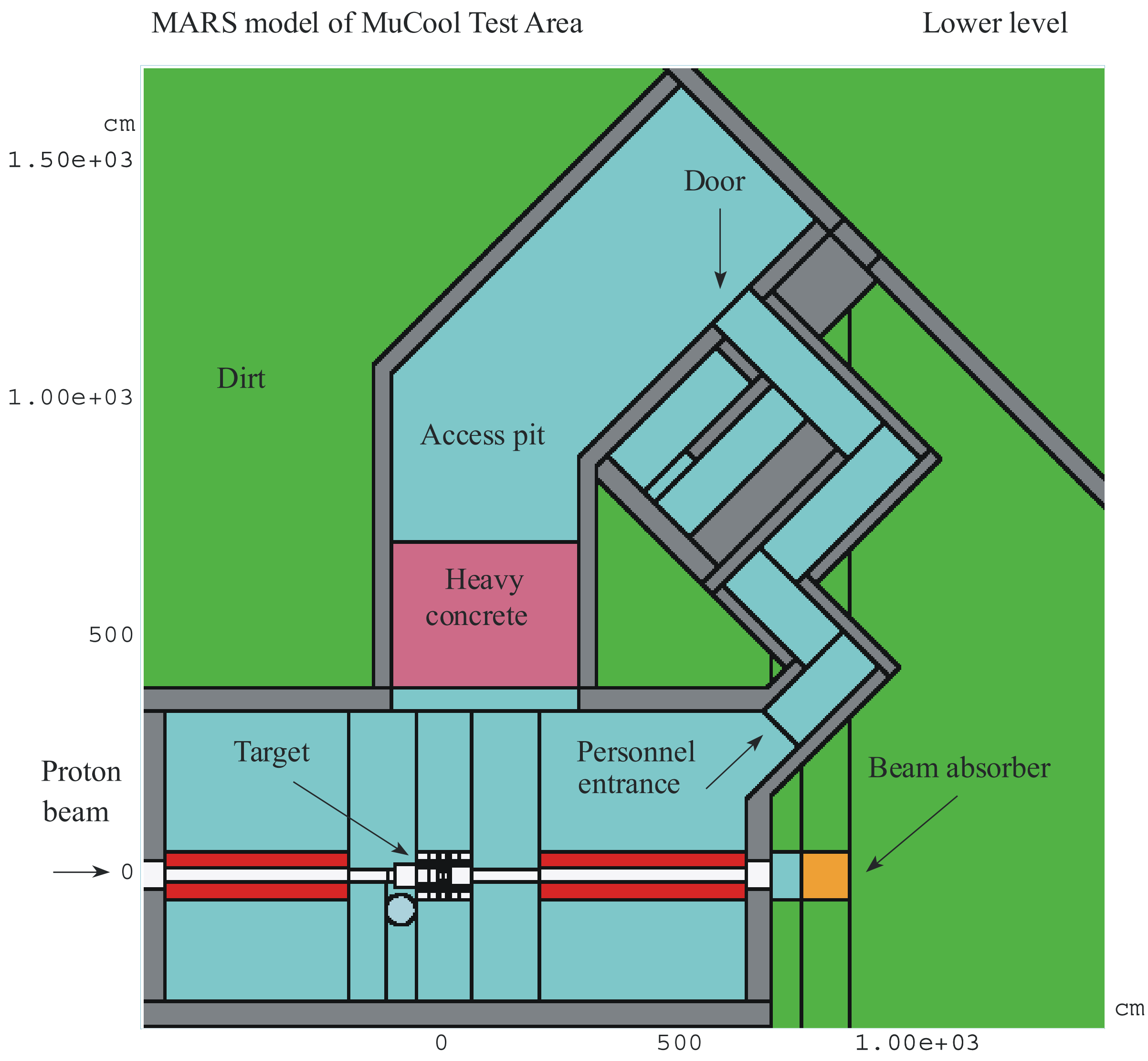
- **Low-energy neutrons (below 20 MeV) in MARS are transported with the ENDF/B-VI data by invoking the MCNP code.**
  Currently it is a standard in the 'neutron world'.

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

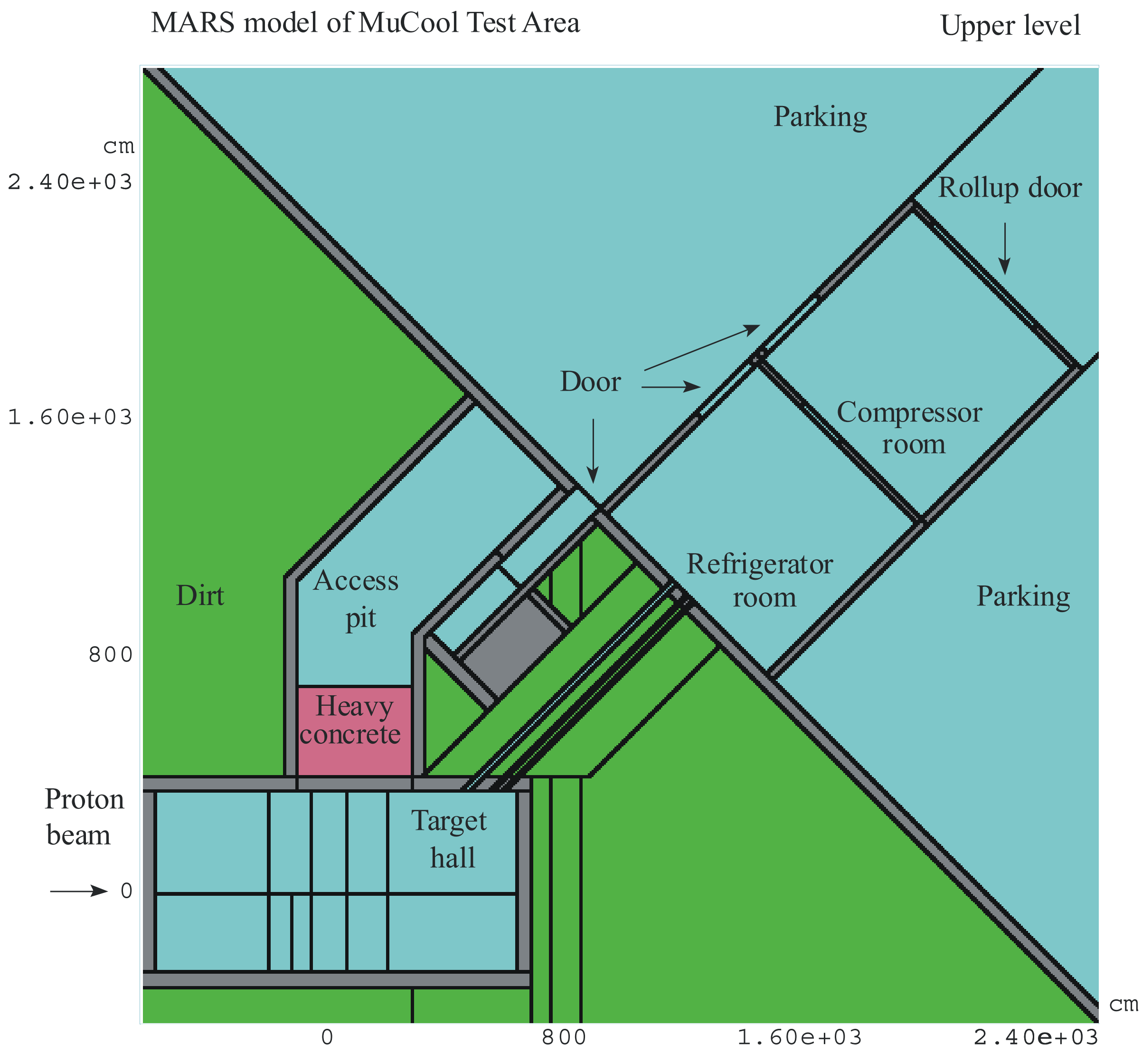
Elevation View of the MARS Model of the MTA



Plan View


MARS model of MuCool Test Area
Lower level
cm
1.50e+03
1.00e+03
500
0
Door
Dirt
Access pit
Heavy concrete
Target
Personnel entrance
Proton beam
Beam absorber
0
500
1.00e+03
cm

Plan View


MARS model of MuCool Test Area
Upper level
cm
2.40e+03
1.60e+03
800
0
Proton beam
Parking
Rollup door
Door
Compressor room
Refrigerator room
Parking
Dirt
Access pit
Heavy concrete
Target hall
cm
0
800
1.60e+03
2.40e+03

Beam & Target

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

$2x10^{14}$ p/s or $1.3x10^{13}$ 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

Spallation neutron studies → full absorption (≈100%) targets of heavy & dense materials (Pb, U^{nat}) 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.

A Credible Accident Scenario

- **The misbehaved proton beam (400 MeV) hits the beamline at Z = -280 cm.**
- **Deflection angle is 50 mrad upward.**
- **Duration of the accident is one second.**

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- **At Fermilab booster (8 GeV) the deflection angle of about 1 mrad is usually considered.**
- **Repetition rate 15 Hz.**

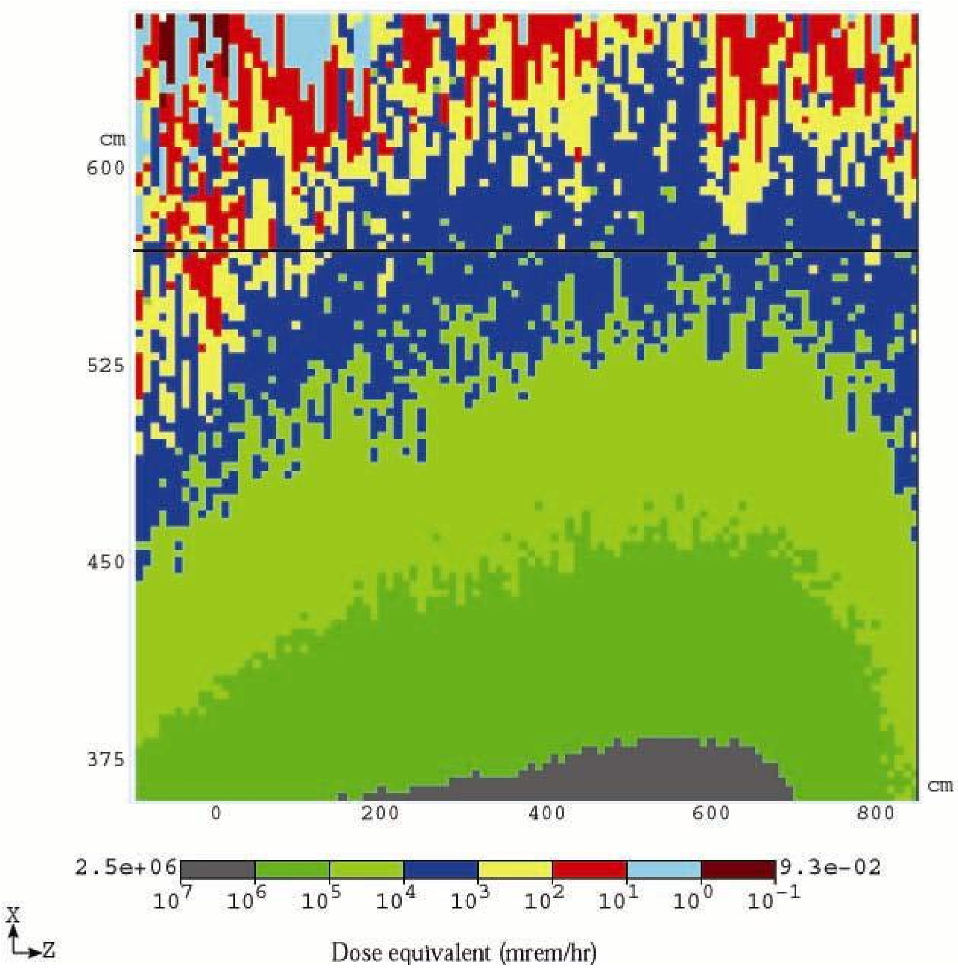
An 11-feet dirt shielding => 0.02 mrem/s.

Fermilab Radiological Control Manual (FRCM) => No precautions are needed under accident conditions at dose ≤ 1 mrem in 1 hour.

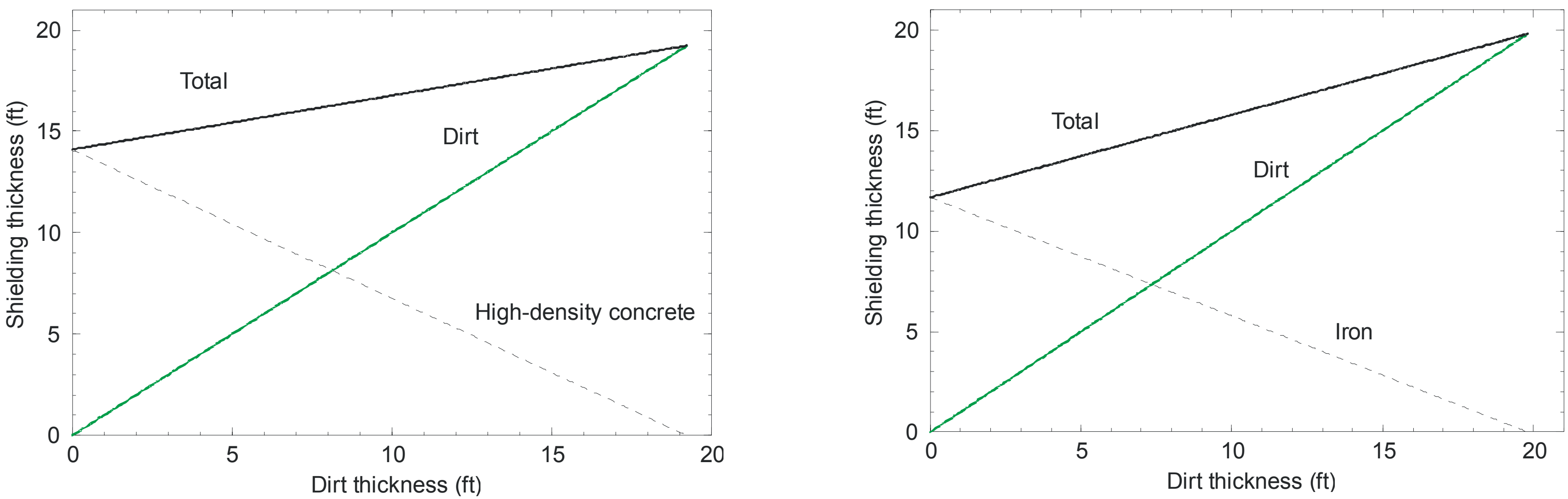
Dose Equivalent above the Berm (normal operation)

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

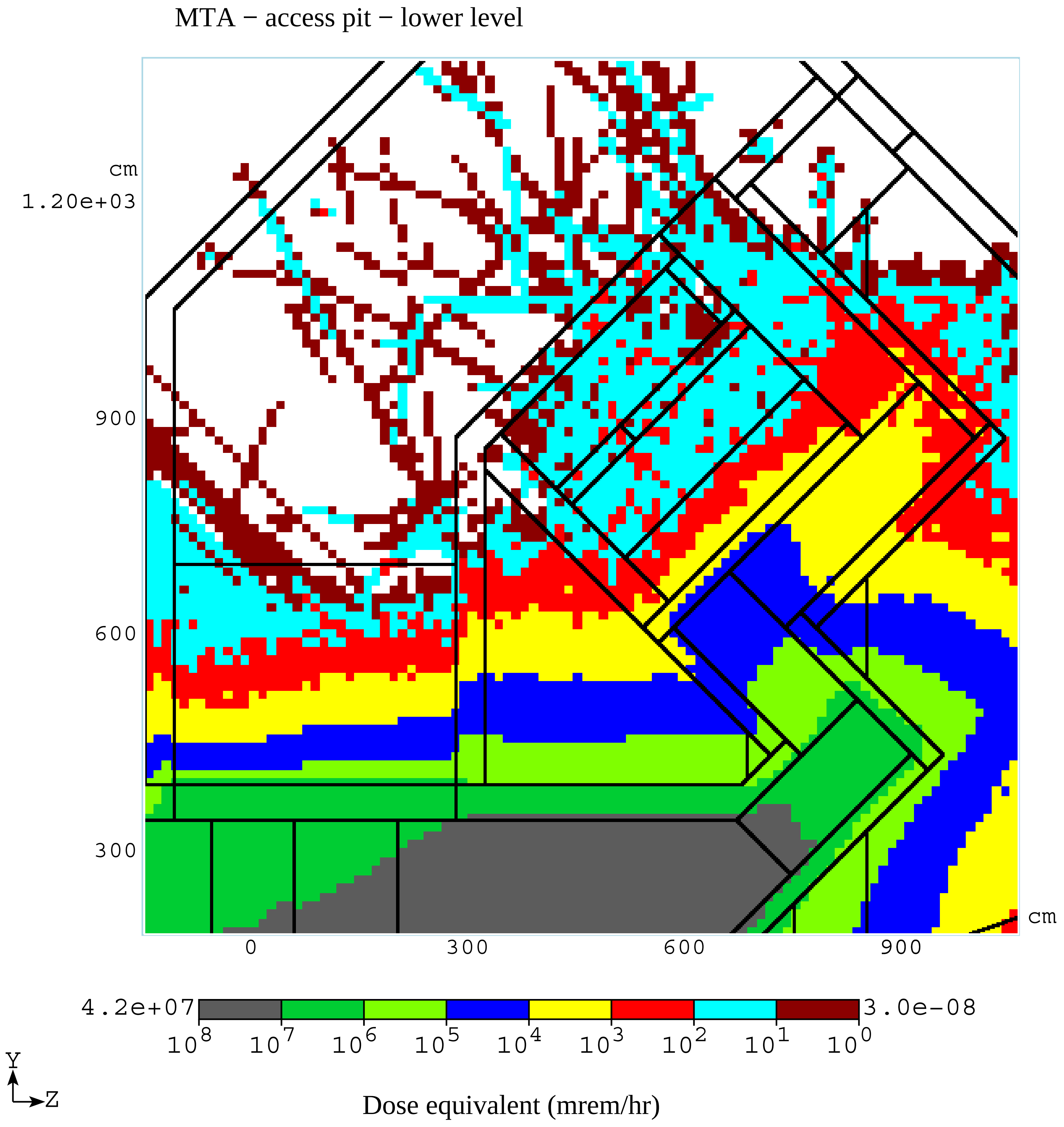
Material (density, g/cm^3)	Attenuation length, α (cm)
Compacted soil (2.24)	39
High-density concrete (3.64)	28
Iron (7.87)	23



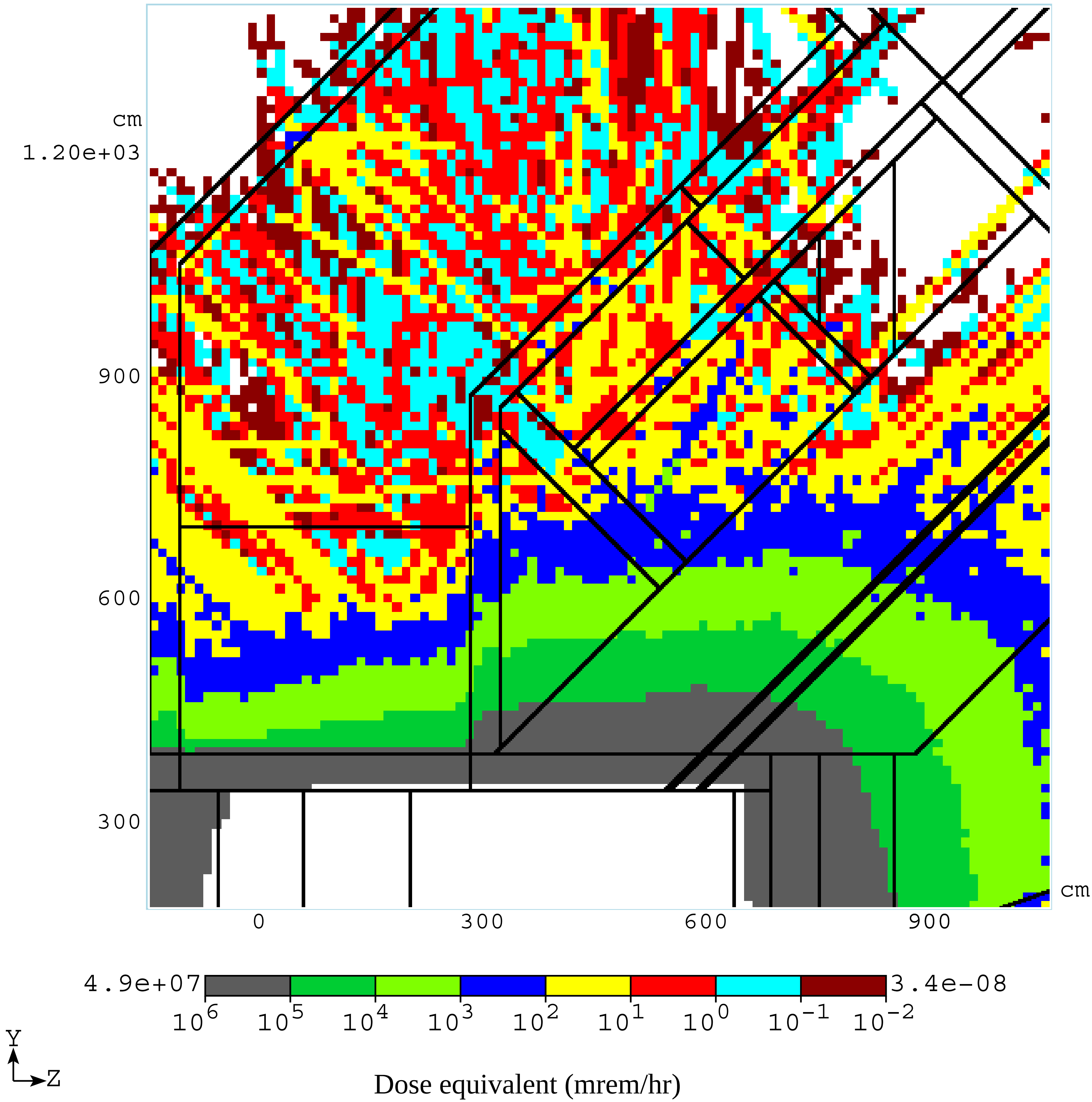
Dose Equivalent above the Berm (normal operation)



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


MTA − access pit − lower level
cm
1.20e+03
900
600
300
0
300
600
900
cm
4.2e+07
3.0e-08
10^8 10^7 10^6 10^5 10^4 10^3 10^2 10^1 10^0
Y
Z
Dose equivalent (mrem/hr)

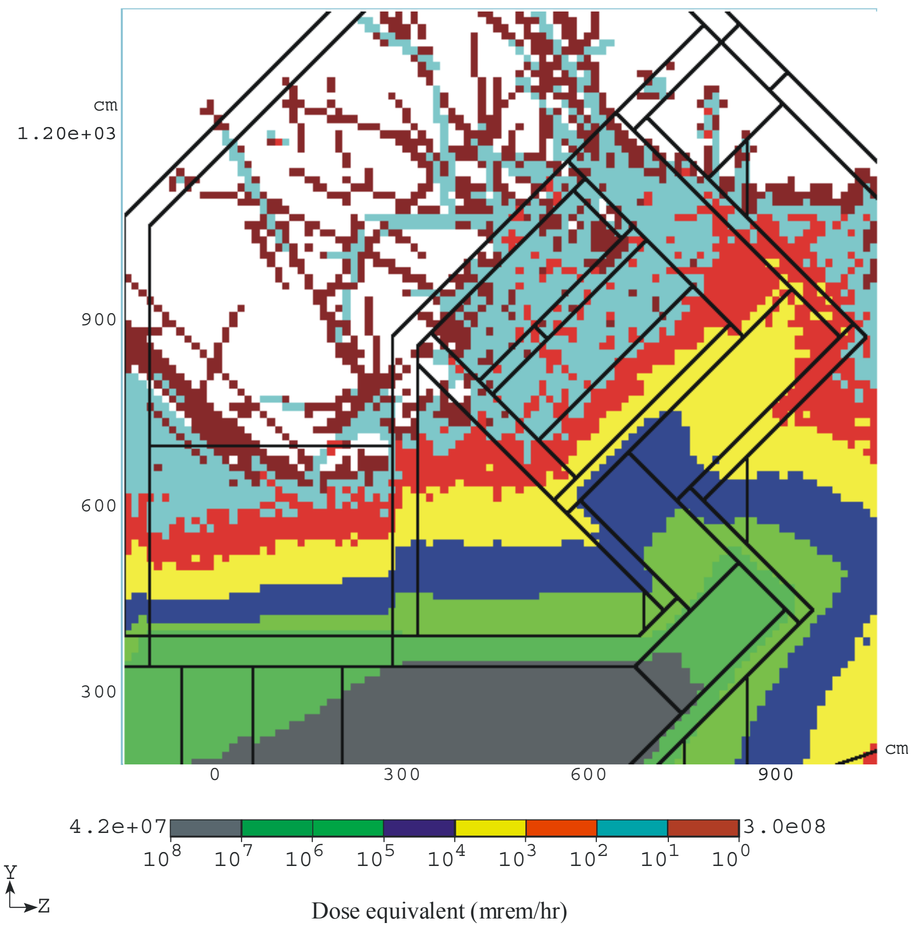
MTA − access pit − upper level



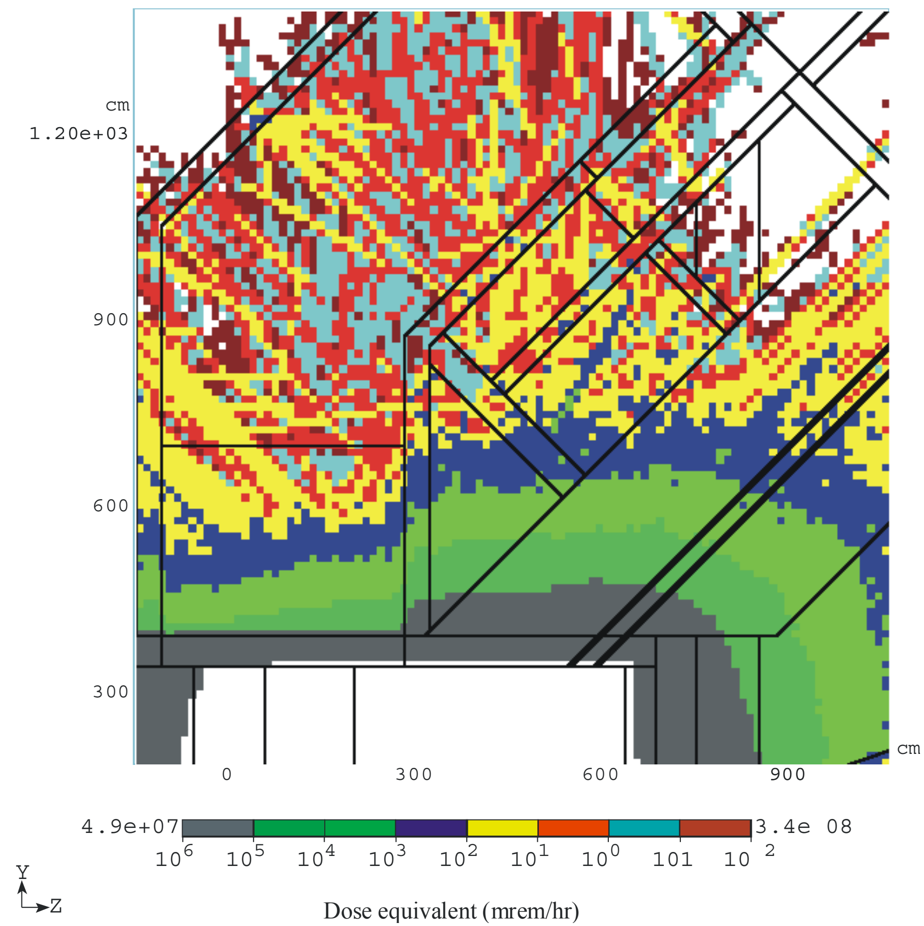
Dose equivalent (mrem/hr)

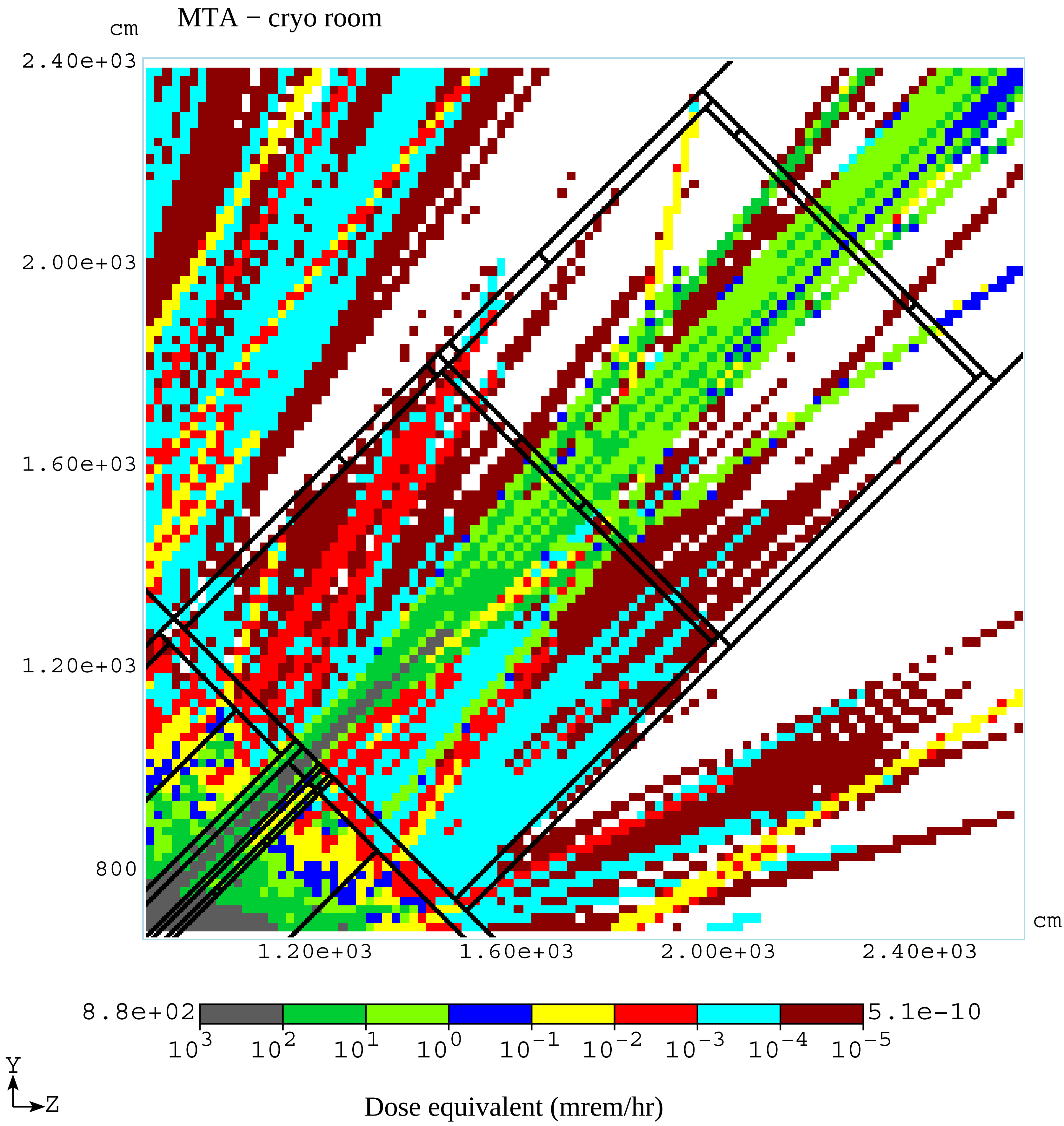
Dose Equivalent in the Access Pit (normal operation)

Lower Level



Upper Level

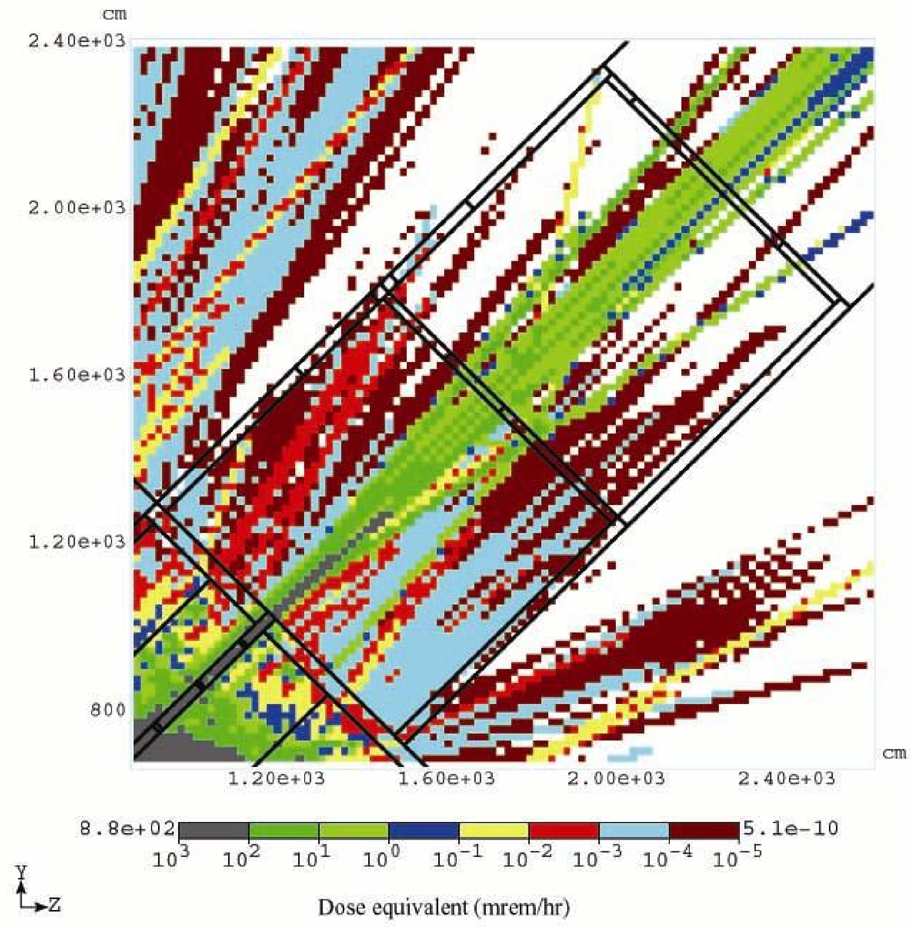




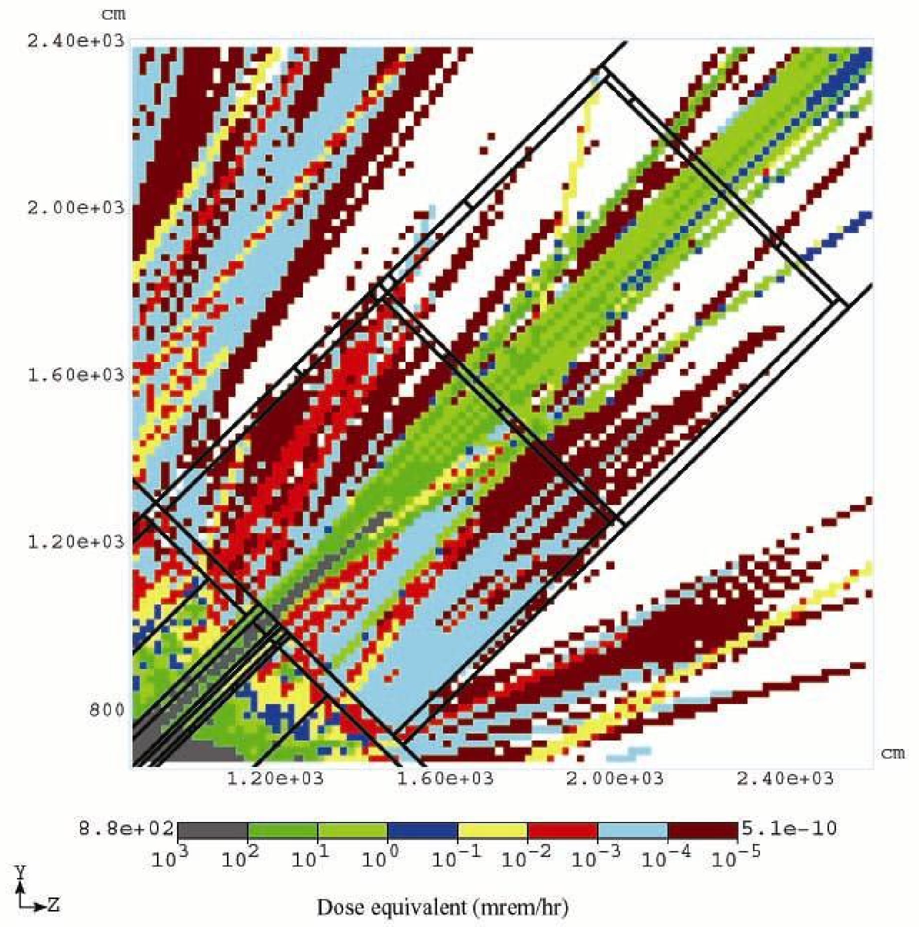
MTA − cryo room
cm
2.40e+03
2.00e+03
1.60e+03
1.20e+03
800
1.20e+03
1.60e+03
2.00e+03
2.40e+03
cm
8.8e+02
5.1e-10
10^3 10^2 10^1 10^0 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5}
Y
Z
Dose equivalent (mrem/hr)

Dose Equivalent in the Cryo Room (normal operation)

10" penetration

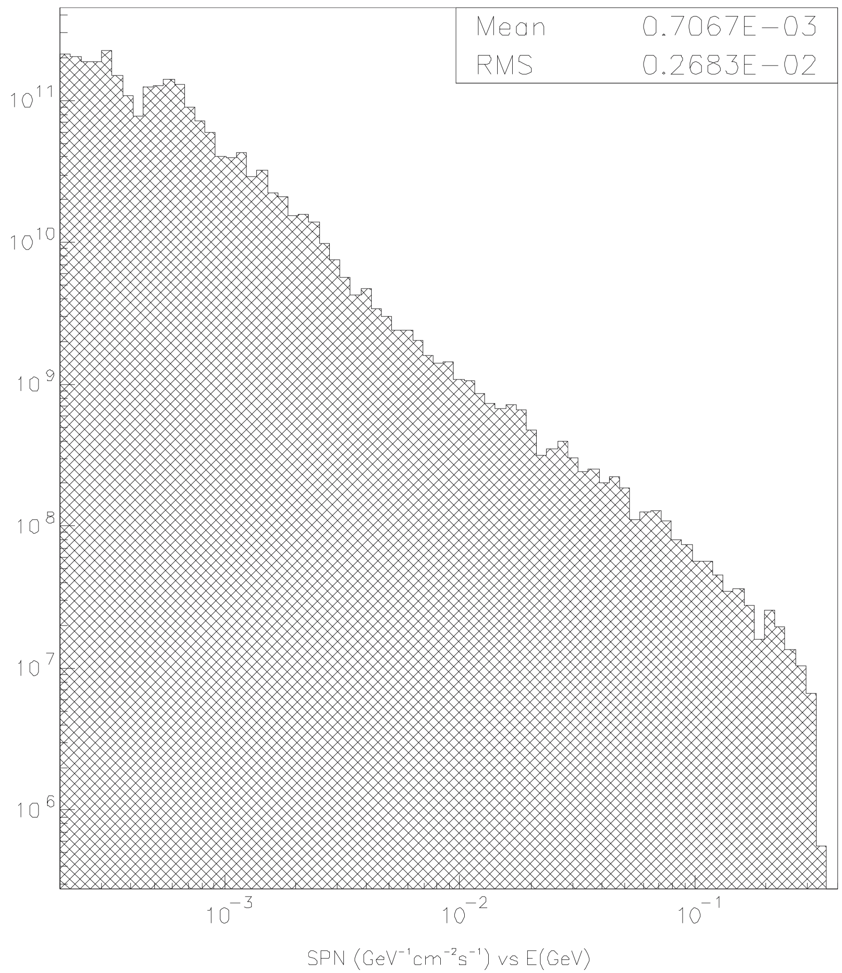


4" and 8" penetrations

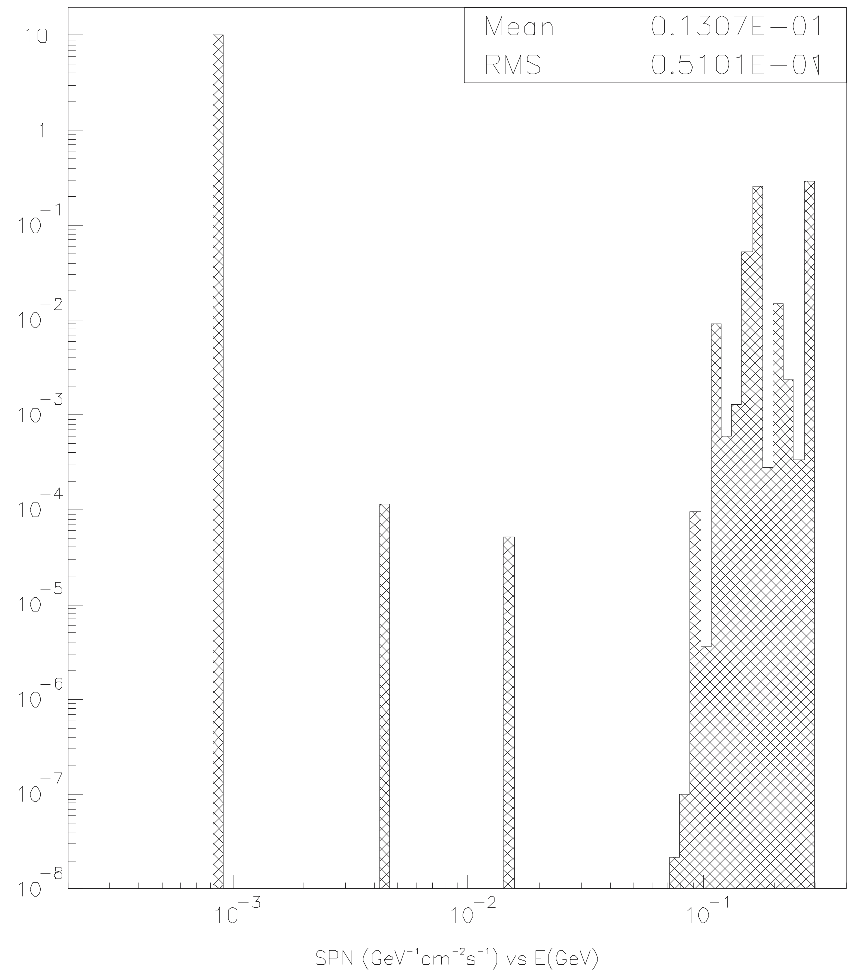


Neutron Energy Spectra in the 10" Penetration

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.**

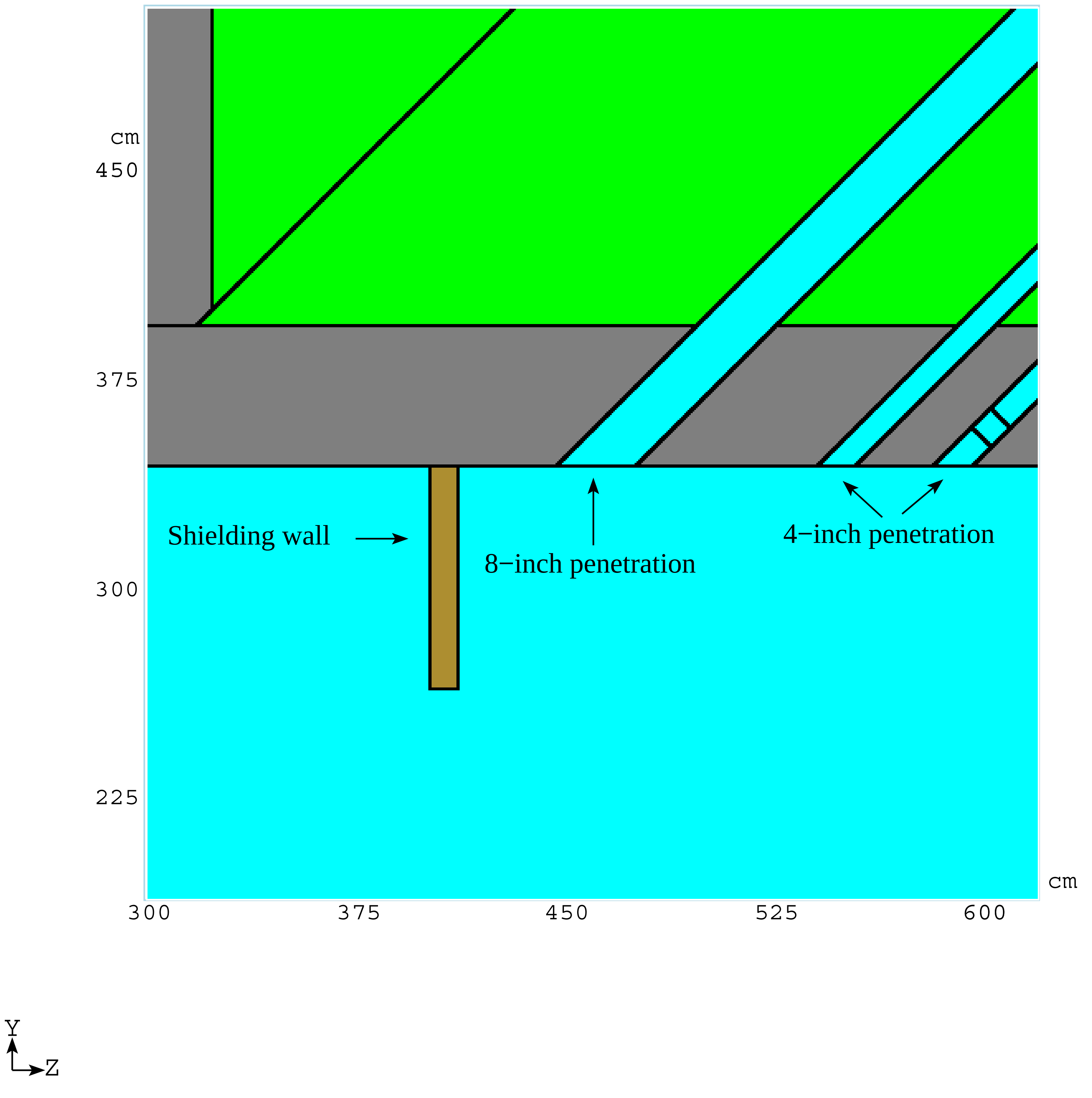
   H x W x T = 220 cm x 190 cm x 20 cm

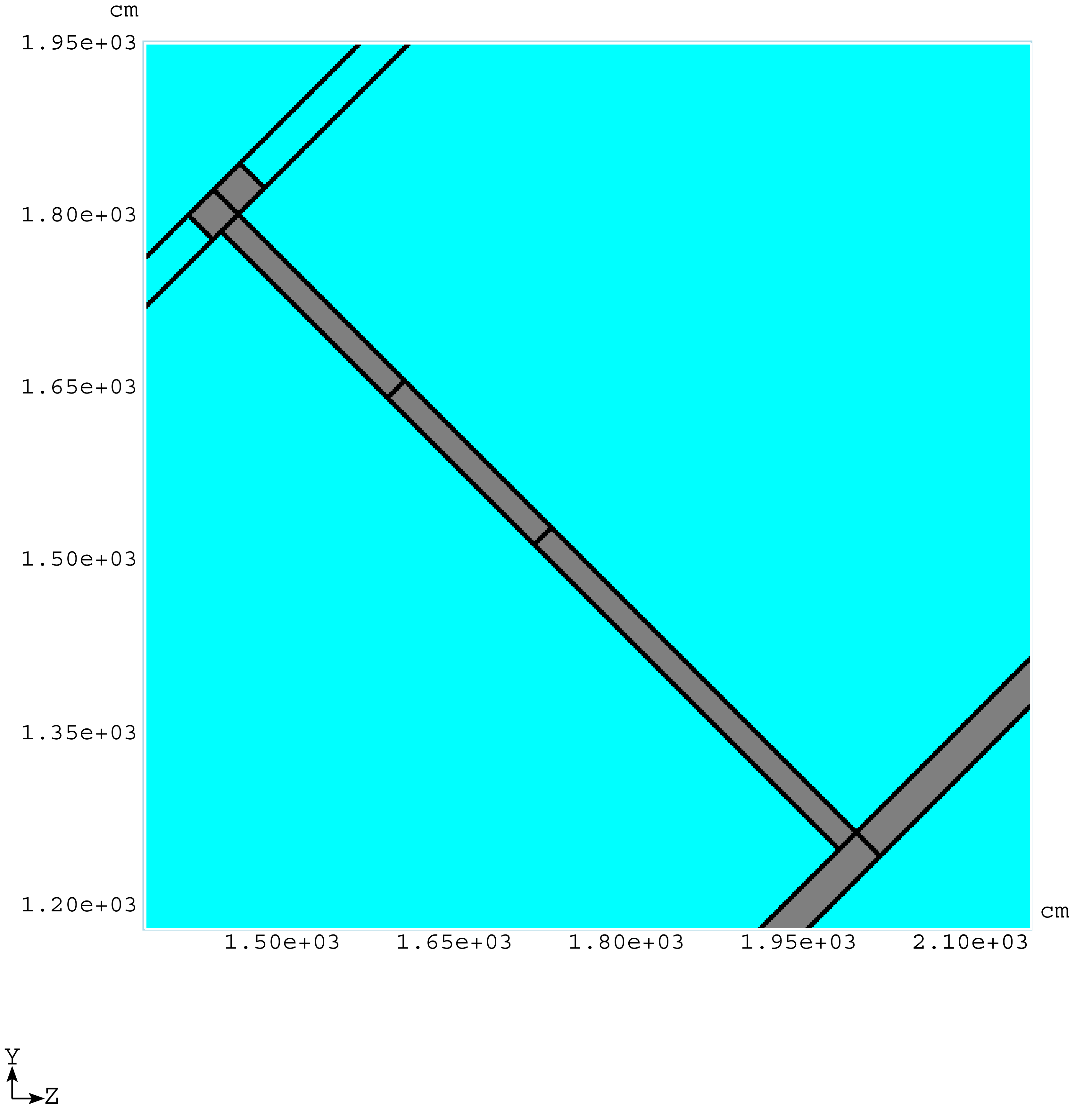
   Regular concrete ≈ 2000 kg.

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

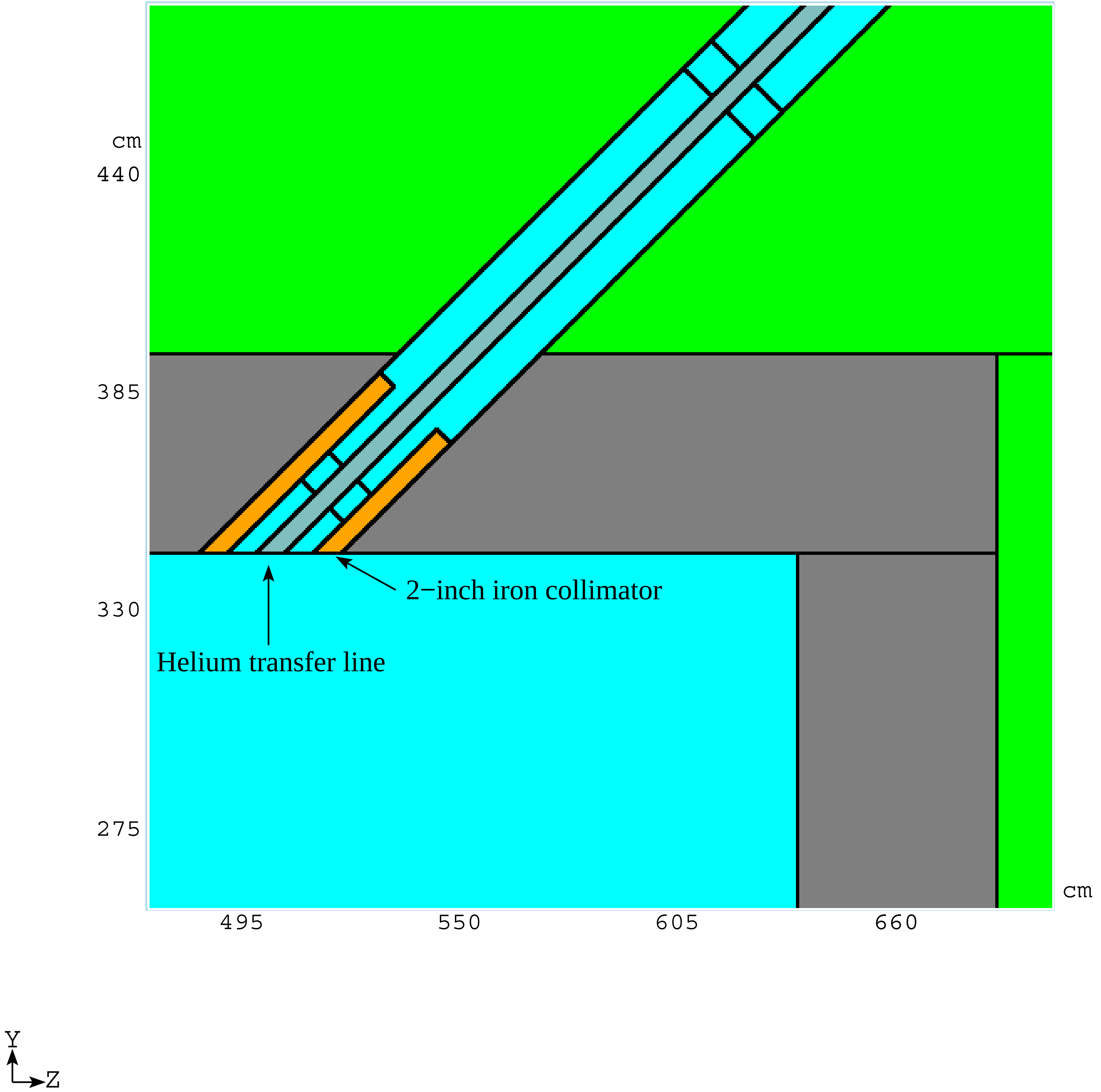
   Two 1″ iron collimators, 20″ in length, inside the 8″ penetration.

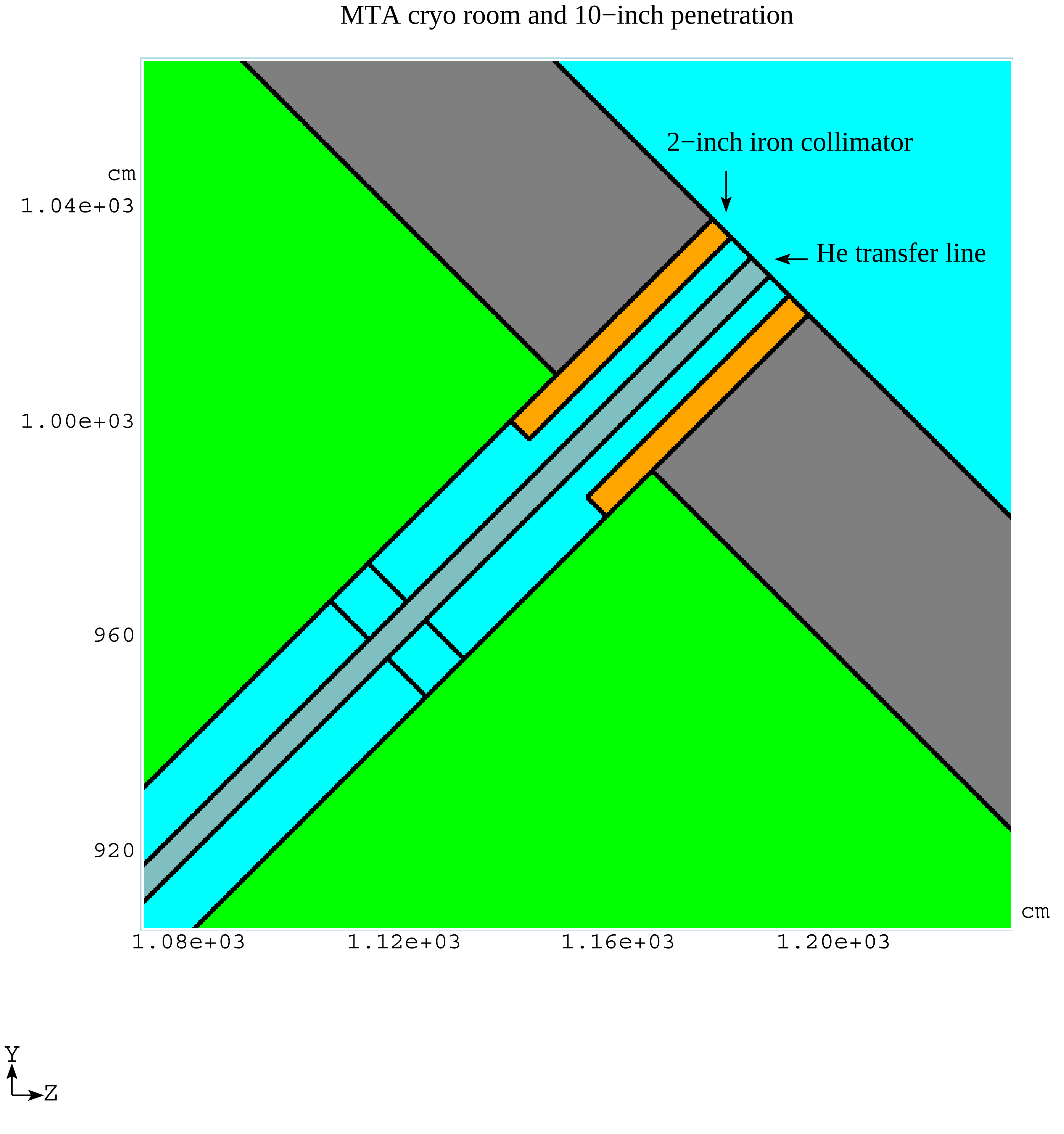
MTA target hall and shielding wall in front of penetrations



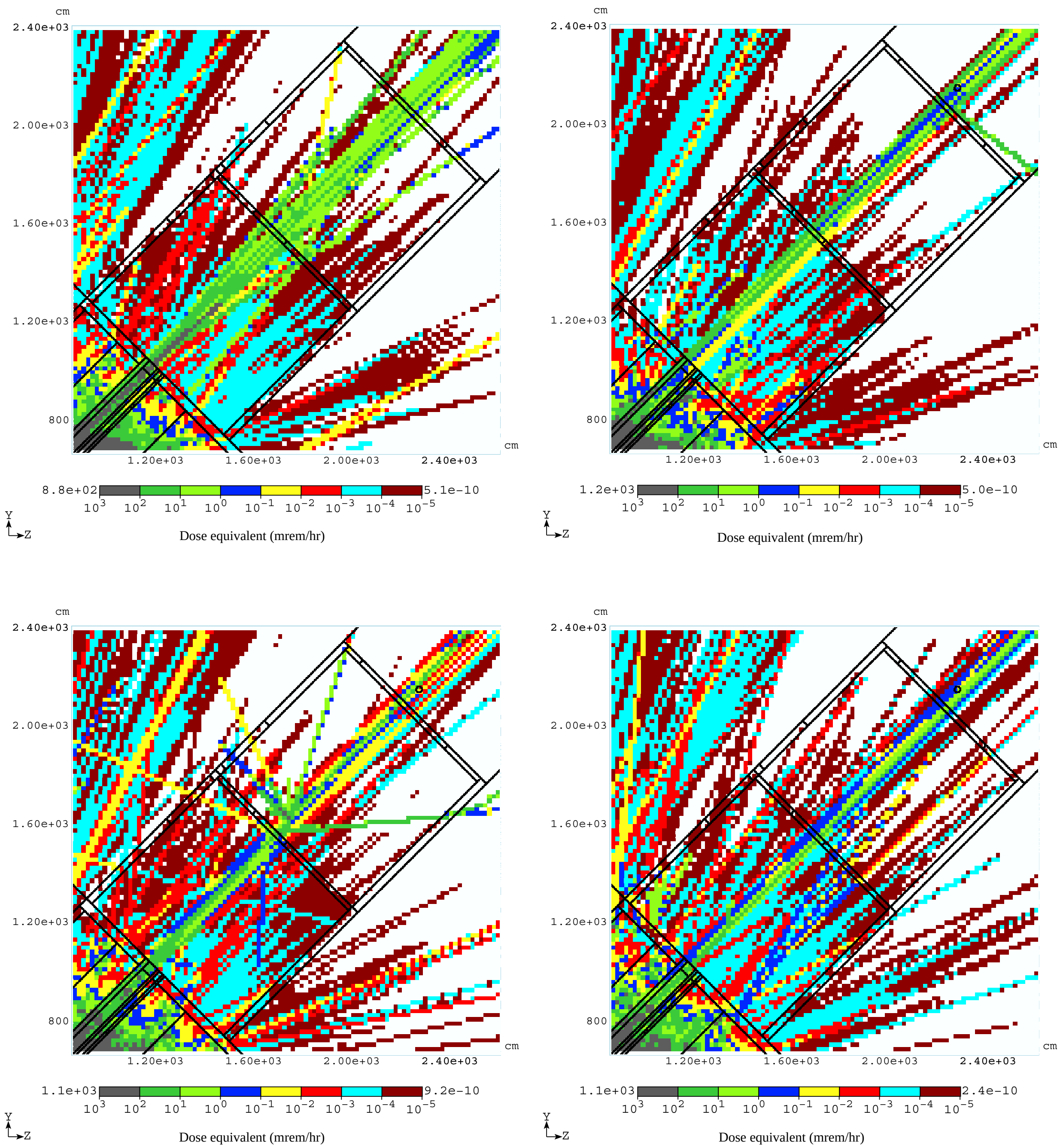

cm
1.95e+03
1.80e+03
1.65e+03
1.50e+03
1.35e+03
1.20e+03
cm
1.50e+03
1.65e+03
1.80e+03
1.95e+03
2.10e+03
Y
Z

MTA target hall and 10−inch penetration





MTA cryo room and 10−inch penetration
2−inch iron collimator
He transfer line
cm
1.04e+03
1.00e+03
960
920
cm
1.08e+03
1.12e+03
1.16e+03
1.20e+03
Y
Z

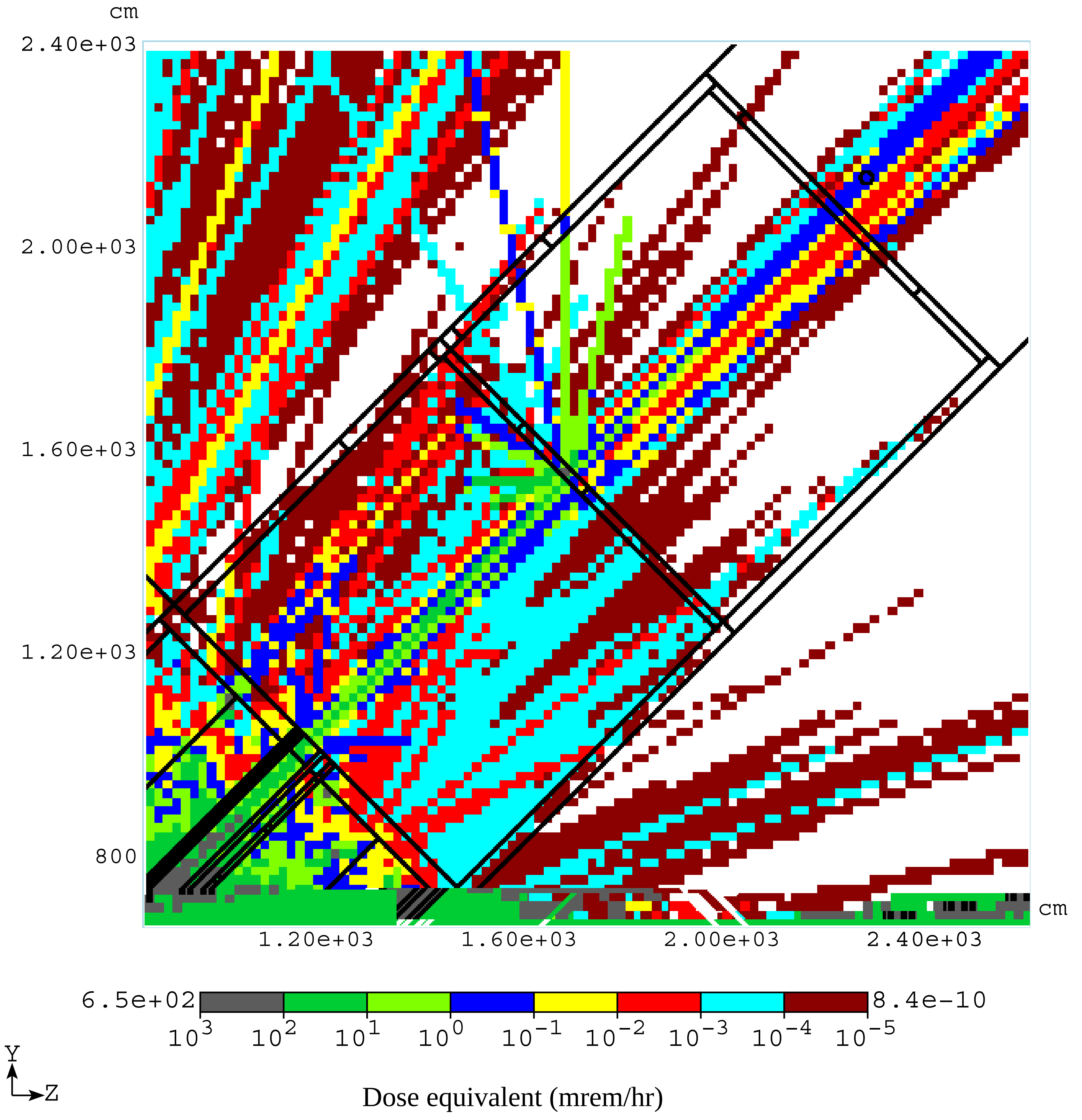


Calculated dose distributions in the refrigerator and compressor rooms as well as at parking lot for the following shielding options: (i) unshielded penetrations (top, left); (ii) a shielding wall in the target hall in front of the penetrations (top, right); (iii) a 20-cm thick concrete wall instead of the door between the refrigerator and compressor room (bottom, left); (iv) 5-cm thick and 50-cm long iron collimators at both ends of the 25-cm penetration (bottom, right).

Combination of 2nd and 3rd additional shielding options

The wall instead of the inner door in the service building and

iron collimators in the 8" and 10" penetrations.



cm
2.40e+03
2.00e+03
1.60e+03
1.20e+03
800
cm
1.20e+03
1.60e+03
2.00e+03
2.40e+03
6.5e+02
8.4e-10
10^3 10^2 10^1 10^0 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5}
Y
Z
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 30-cm iron block => the predicted dose at parking lot ≤ 0.05 mrem/hr at normal operation.

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 (not controlled) area (dose rate below 0.05 mrem/hr).**