M4 Beam Line Drop Hatch Near the Diagnostic Absorber

MARS Shielding Simulation

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A drop hatch is required in the M4 line upstream of the M4 shield wall near the diagnostic absorber. A MARS simulation is required to show that the design and placement of the drop hatch meets all requirements of the Fermilab Radiological Controls Manual.

Introduction

A drop hatch is required in the M4 line to permit moving magnets into the M4 enclosure during operation of muon g-2 and subsequently during nominal mu2e operation. A design for a 17.5' long by 5'4" wide drop hatch placed just upstream of the M4 line shield wall labyrinth is shown in Figure 10. A MARS [2] simulation has been made to show the impact of the drop hatch design on the efficacy of the M4 line enclosure shielding.

There are three principal concerns:

1. The drop hatch design must provide the nominal 16' shield required for the M4 line for 8 kW beam delivery to the mu2e experiment.
2. The2' wide notch in the enclosure wall required to accommodate loads lowered into the tunnel must not compromise the efficacy of the M4 line shield wall labyrinth, specifically, during the construction phase of the PS, TS, and DS. 8 GeV beam is to be delivered to the Diagnostic Absorber during this phase and beam power is limited to 170 watts.
3. Similarly, the 2' notch must not compromise the efficacy of the M4 line shield wall labyrinth, specifically, during the construction phase of the PS, TS, and DS during any beam accident condition while beam is delivered to the diagnostic absorber.

The Diagnostic Absorber and M4 shield wall are designed to permit unlimited personnel access during construction of the PS/TS/DS. During the construction phase of the PS/DS/TS, personnel access in the M4 line will be excluded in the region beginning downstream of the M4 line shield wall and ending at the entrance to the PS room. Once nominal operation of 8 kW beam to the experiment is established, only the first concern will apply since personnel access in the PS room will be virtually eliminated by the anticipated high residual activity there.

Concern 1

A plan view of the MARS model at the beam line elevation is shown in Figure 1. All details of this model have been examined in depth [1] except for the drop hatch. A transverse, elevation view of the M4 beam line including the drop hatch is shown in Figure 2. The shielding thickness in the vicinity of the drop hatch meets or exceeds the 16' minimum required for the M4 line; no further consideration of the drop hatch for Concern 1 is required.

Concern 2

A MARS simulation is required to show whether the notch in the enclosure wall for the drop hatch has any impact on the radiation leakage through the M4 shield wall labyrinth when the beam line is operated for commissioning fast and slow resonant extraction with up to 170 watts of beam at 8 GeV to the Diagnostic Absorber. Figure 3 is a histogram taken from reference 1 showing the total hadron flux resulting from this condition; the drop hatch notch was not present in that simulation. The result of a similar MARS simulation, this time including the drop hatch notch, is shown in Figure 4. A side-by-side comparison of Figure 3 and Figure 4 indicates that the notch does not change the flux pattern through the labyrinth. Consequently, the radiation effective dose calculation made in reference 1 for the end of the M4 line does not need to be repeated and Concern 2 is addressed. Figure 5, Figure 6, and Figure 7 show flux distributions in various transverse elevation sections of the drop hatch and are included for future reference.

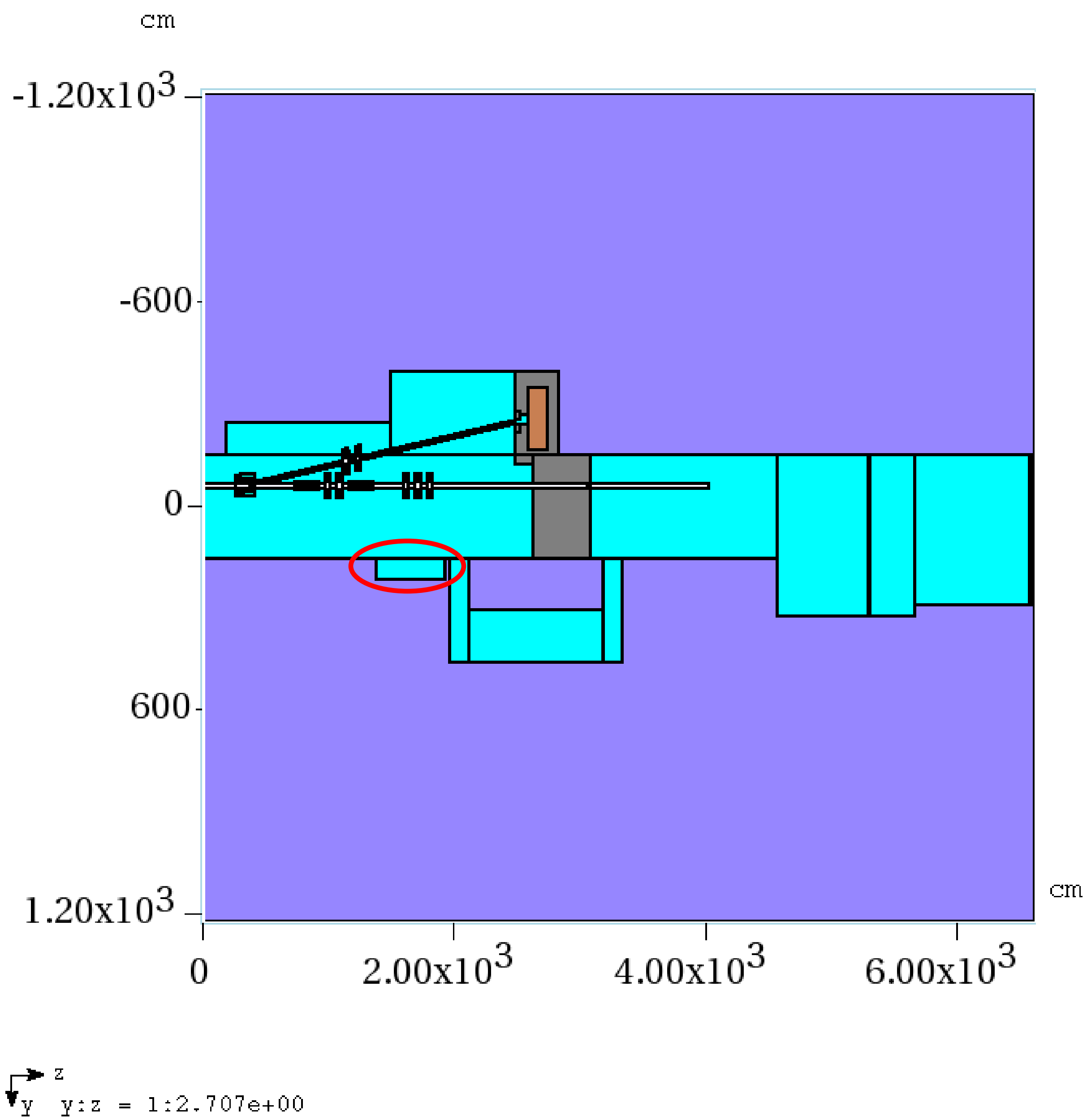

Figure 1: Plan view of M4 line at diagnostic absorber showing the bypass around the shield wall and the new drop hatch location located within the red ellipse.

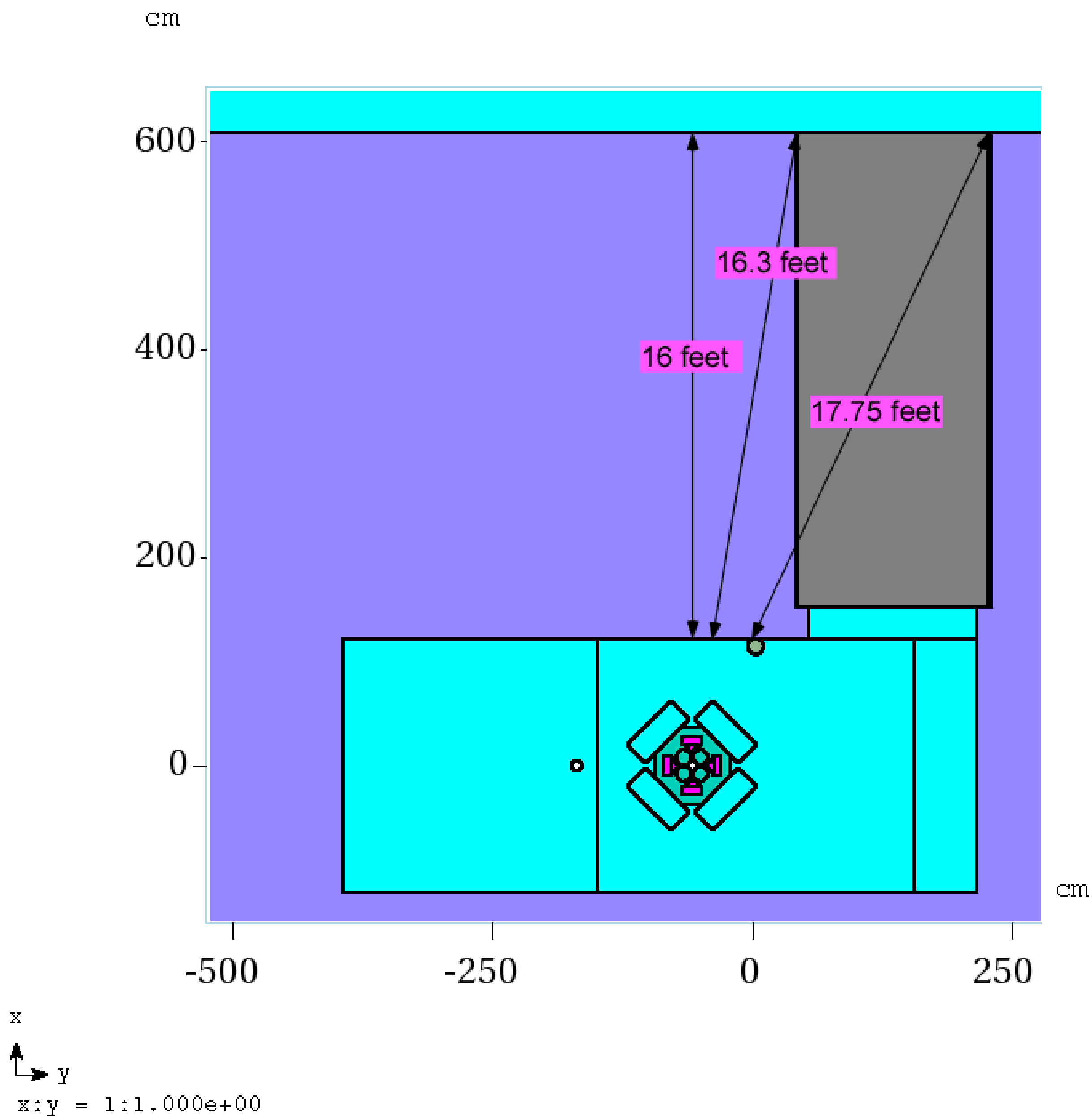

Figure 2: Transverse elevation view of the M4 line at last quadrupole before the M4 line shield wall. A drop hatch containing 15 feet of shielding is sufficient to meet the 16 foot shielding requirement as indicated by the annotated rays. The cyan box at left is the bump out in the enclosure to accommodate the diagnostic absorber. The center cyan box represents the nominal 10' wide x 8' high tunnel enclosure. The cyan box at right is a 2' wide bump out beneath the drop hatch. The grey box designate a 15' thick stack of C blocks 3' x 3' x 6'. The cyan box just below the shielding blocks represents the hole in the ceiling which is 5'4" wide by 17.5' long.

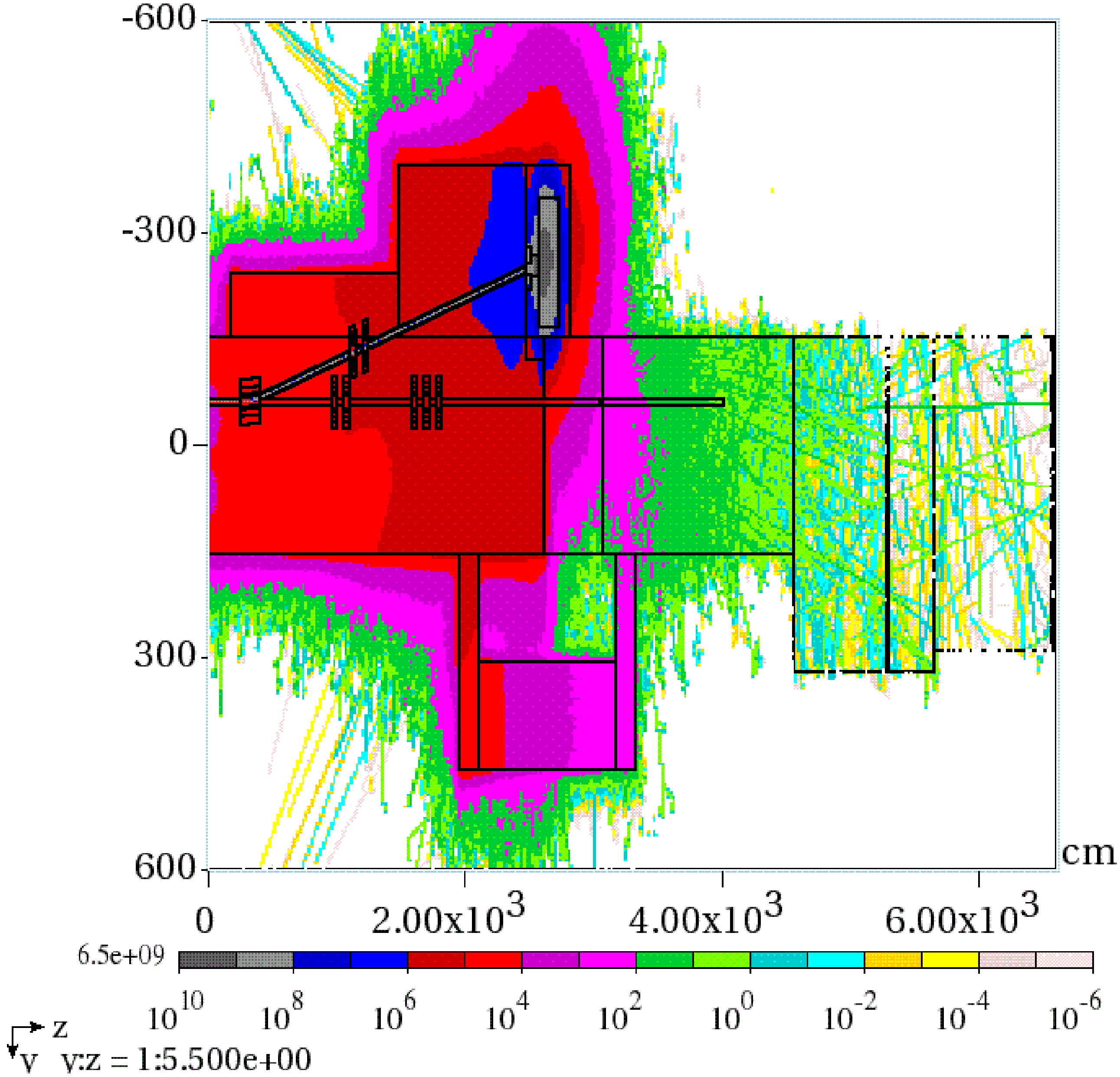

Figure 3: This is a histogram of flux in the plan view due to normal 170 watt beam directed to the diagnostic absorber. This simulation was run before the drop hatch was added to the MARS model. The flux distribution can be compared with that shown in Figure 4. There is no significant difference between the flux distributions downstream of the M4 shield wall between the 2 cases.

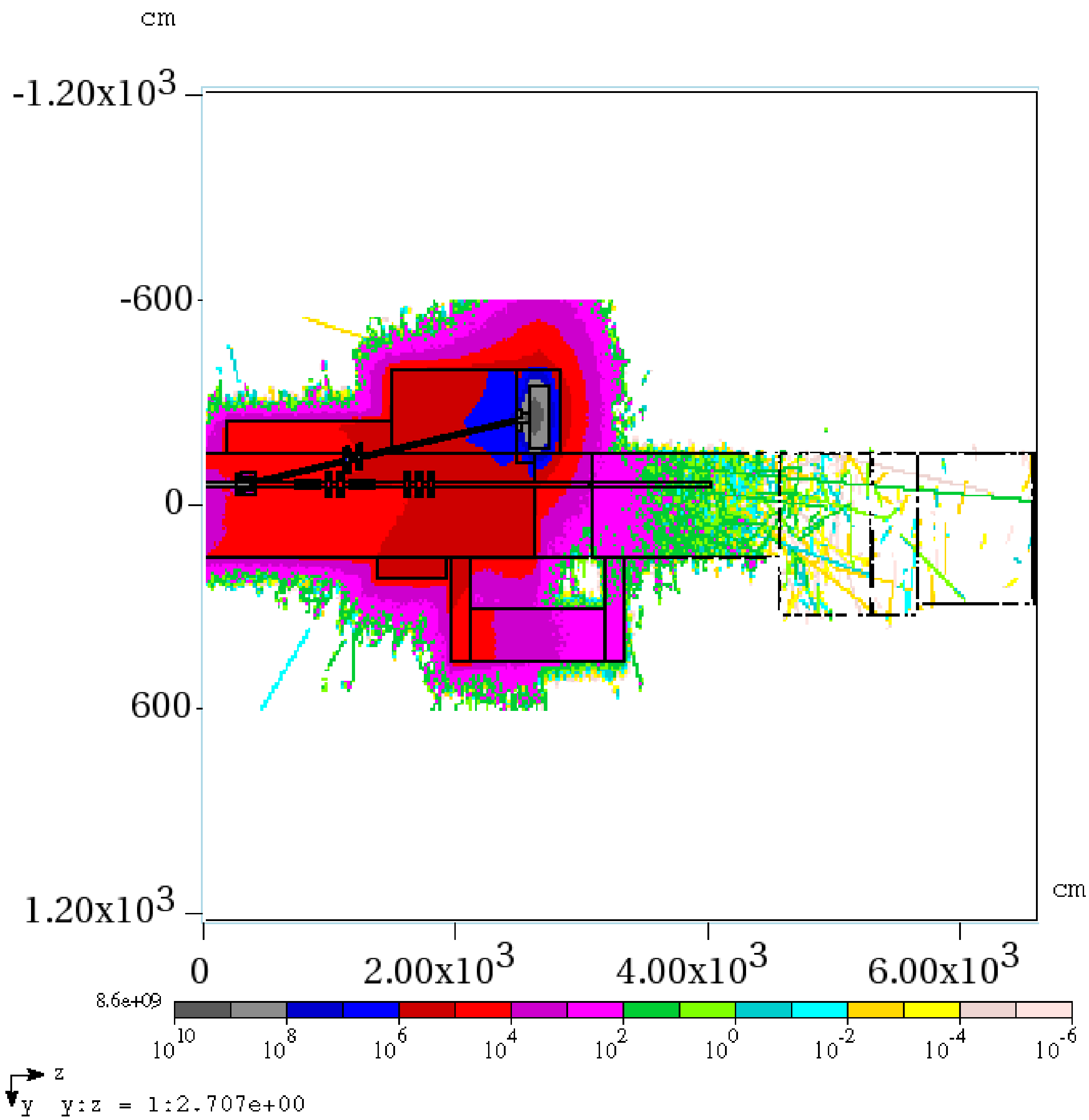

Figure 4: This is a histogram of flux in the plan view due to normal 170 watt beam directed to the diagnostic absorber. This simulation includes a drop hatch just upstream of the shield wall bypass labyrinth. The flux distribution can be compared with that shown in Figure 3. There is no significant difference between the flux distributions downstream of the M4 shield wall between the 2 cases.

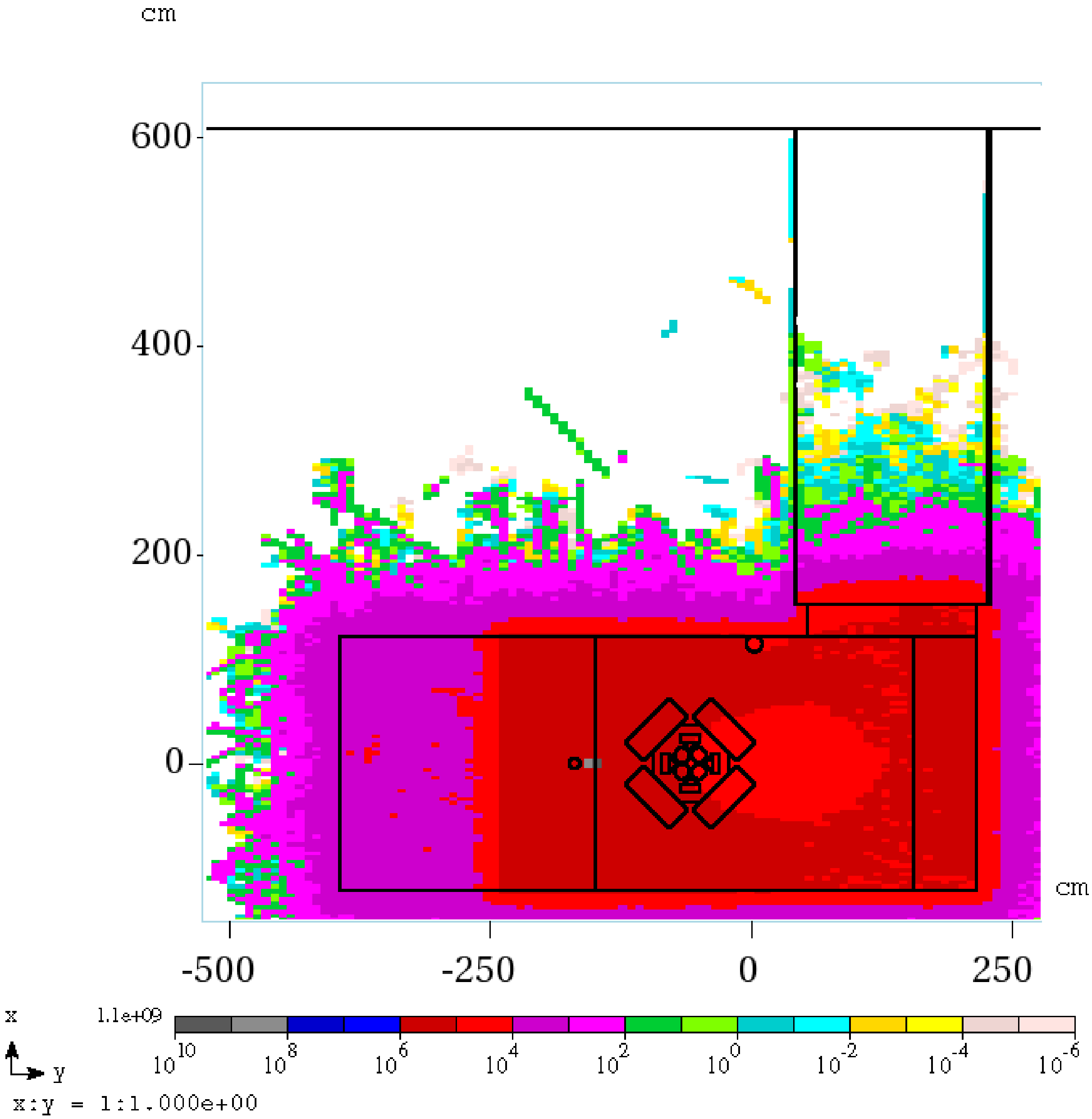

Figure 5: Histogram of the flux distribution in a transverse elevation view of the M4 beam line due to normal 170 watt operation to the diagnostic absorber. The flux distribution is averaged over a 2 foot longitudinal section at the upstream end of the drop hatch.

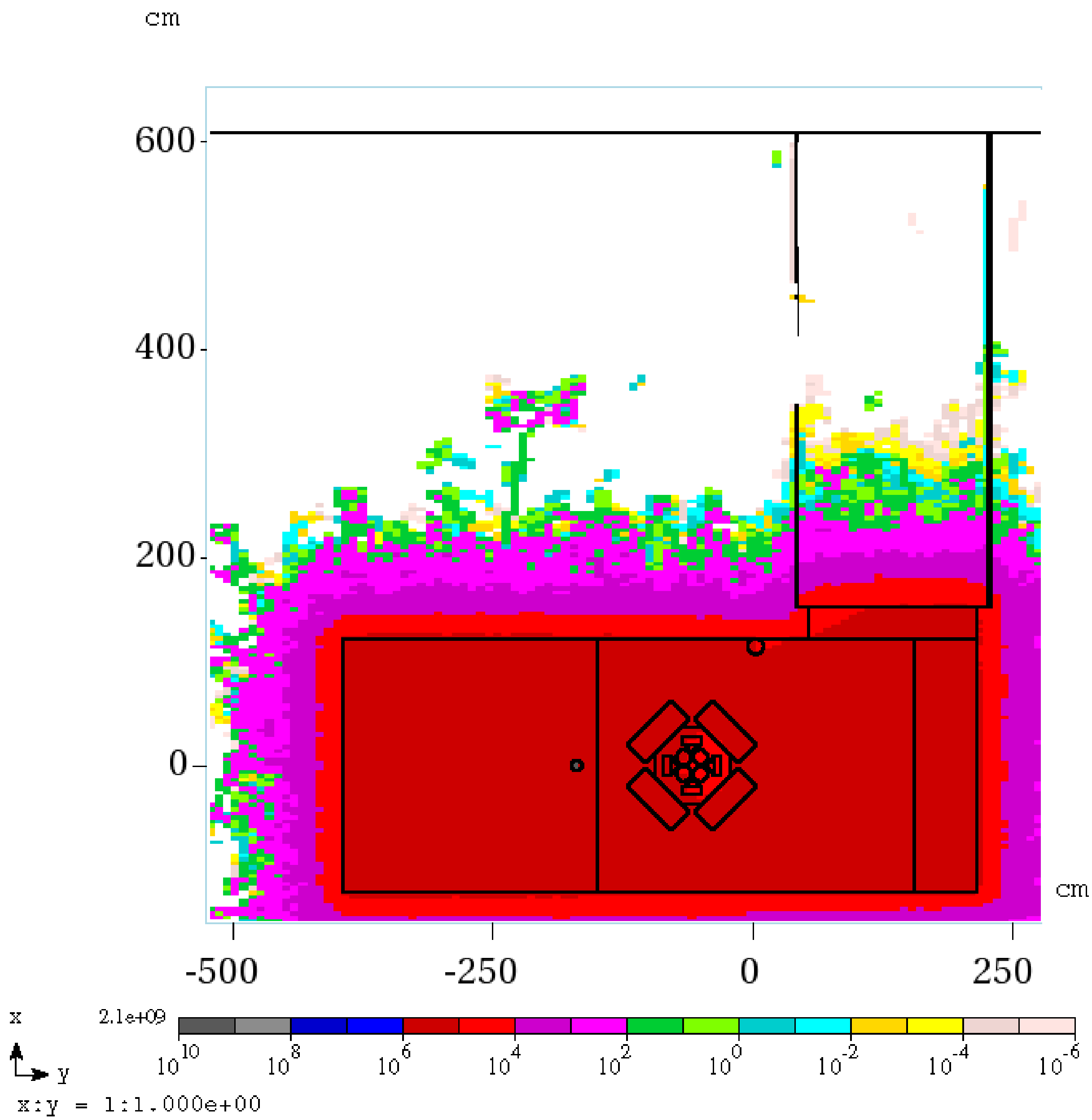

Figure 6: Histogram of the flux distribution in a transverse elevation view of the M4 beam line due to normal 170 watt operation to the diagnostic absorber. The flux distribution is averaged over a 2 foot longitudinal section at the midpoint of the drop hatch.

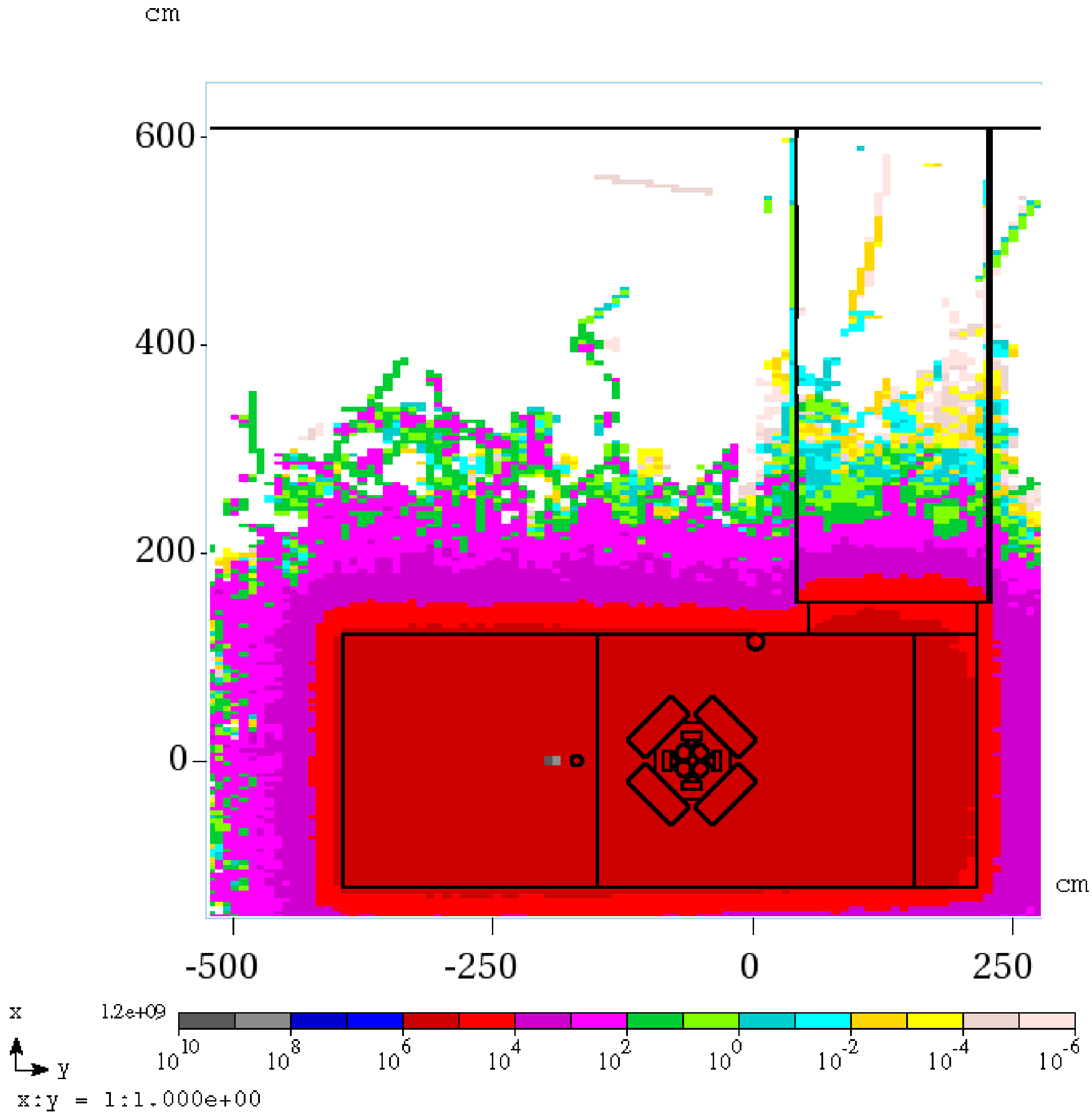

Figure 7: Histogram of the flux distribution in a transverse elevation view of the M4 beam line due to normal 170 watt operation to the diagnostic absorber. The flux distribution is averaged over a 2 foot longitudinal section at the downstream end of the drop hatch.

Concern 3

An accident condition was considered in reference 1 in which the entire 170 watt proton beam is lost on the MDC switch magnet. Results of two MARS simulations required for the problem are shown in Figure 8 and Figure 9.

In Figure 8, the total flux is depicted from the primary beam loss. The predominant flux for this accident condition is directed to beam left side of the beam enclosure because the MDC magnet is a critical device which must be energized in order to deliver beam to the Diagnostic Absorber. The MDC magnetic field tends to shape the shower resulting from mis-steered beam.

 A surface located at the plane of the upstream surface of the M4 line shield wall was created to collect the resulting shower particles. The surface extended to the limits of the model in the x and y direction so the source particles in the labyrinth contribute to the flux shown in Figure 9. The particle collection from this surface was used as a source term for the second run shown in Figure 9.

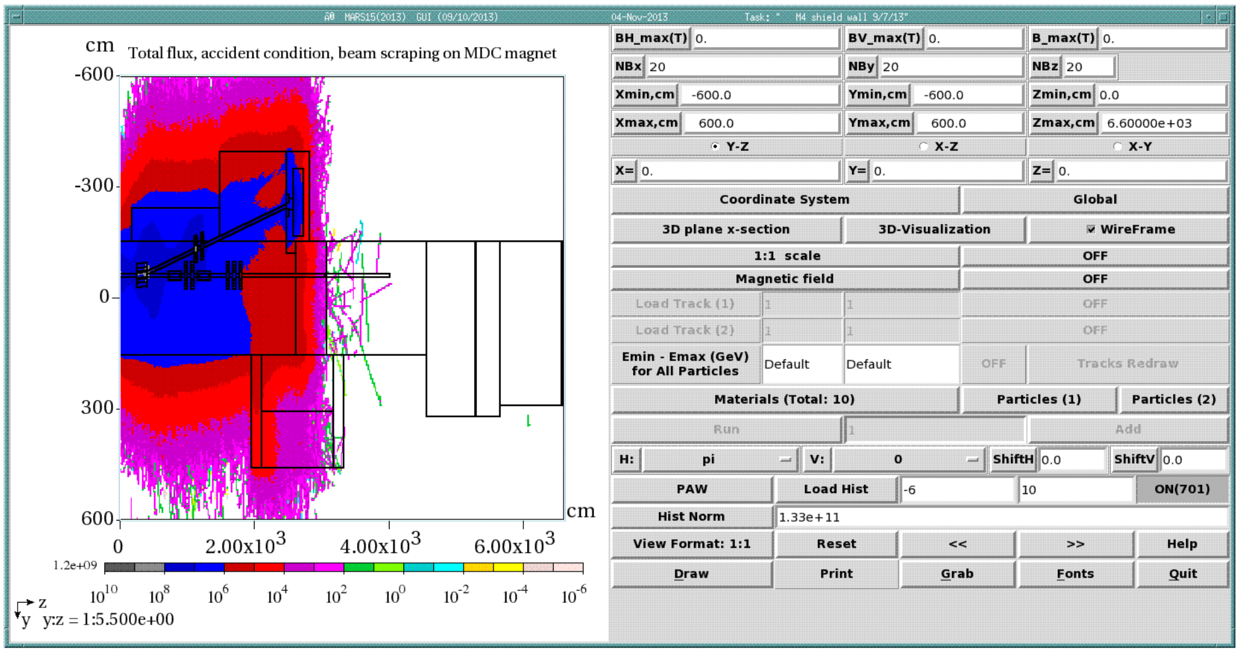

Figure 8: This figure is taken from Reference 1: Stage 1 run, total flux in M4 line enclosure upstream of the shield wall resulting from a 170 watt beam loss on the MDC switching magnet.

It is clear from an examination of Figure 9 that the predominant flux occurs on the left side of the beam enclosure downstream of the M4 shield wall and would be the major contributor to prompt effective dose rate at the end of the M4 line. Also, from examination of Figure 8 and Figure 9, any increase in flux through the labyrinth due to the presence of the drop hatch notch would be very small compared with that originating from the downstream surface of the M4 shield wall.

An interlocked radiation detector system, the TLM, will be employed throughout the M4 beam line enclosure. The TLM will be connected to the Radiation Safety System and will cause beam delivery to the M4 line to be interrupted in the event the trip level, preliminarily established in Reference 1, is reached.

To ensure FRCM requirements [3] are met, it will be prudent to compare TLM response upstream of the M4 shield wall with a measurement of prompt effective dose rate at the end of the M4 beam line enclosure during initial beam line commissioning. The trip level can be checked and/or adjusted as necessary at that time.

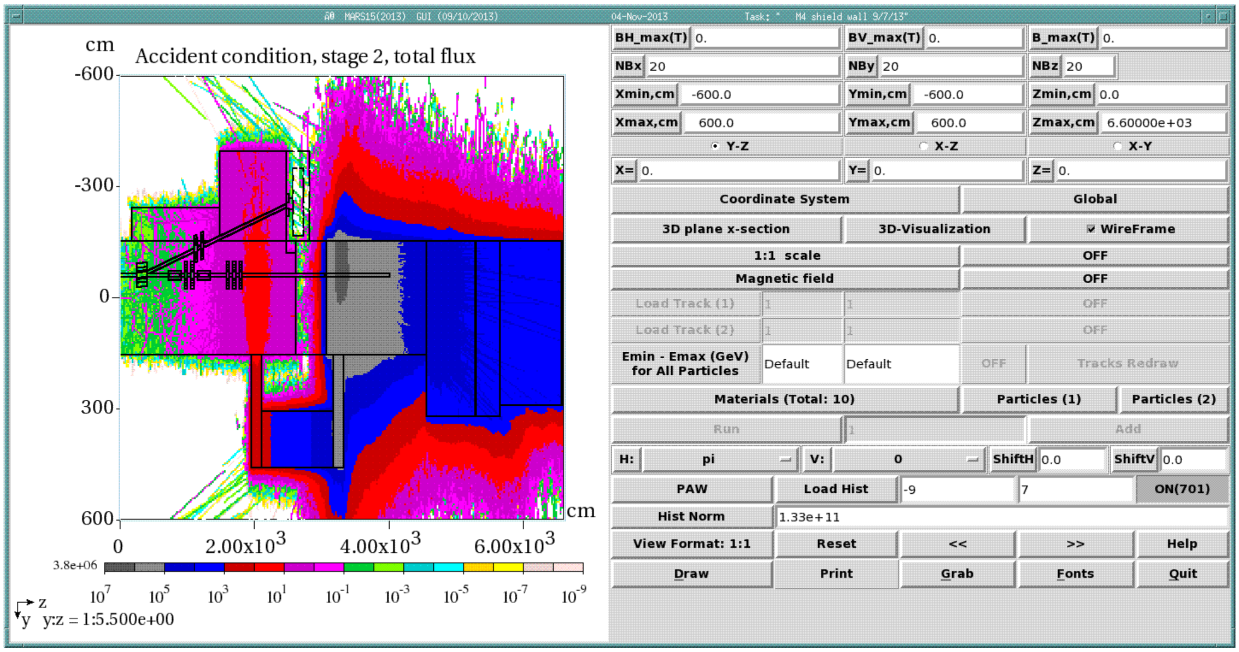

Figure 9: This figure is taken from Reference 1: Stage 2 run, total flux in M4 line enclosure downstream of the shield wall resulting from a 170 watt beam loss on the MDC switching magnet. A particle file generated in the stage 1 at the surface of the upstream shield wall run illustrated in Figure 8 is the source term for the stage 2 run. It is clear that the predominant source which would reach the downstream end of the M4 line enclosure comes through the shield wall. Back scatter through the upstream leg of the labyrinth can also be seen in this figure.

References

1. A.F. Leveling, Diagnostic absorber design and MARS Simulations, Mu2e Document 3308-v3, November 7, 2013
2. N.V. Mokhov, "The Mars Code System User's Guide", Fermilab-FN-628 (1995); N.V. Mokhov, S.I. Striganov, "MARS15 Overview", Fermilab-Conf-07/008-AD (2007); in Proc. of Hadronic Shower Simulation Workshop, Fermilab, September 2006, AIP Conf. Proc. 896, pp. 50-60 (2007); http://www-ap.fnal.gov/MARS/.
3. Fermilab Radiological Controls Manual, http://esh.fnal.gov/xms/ESHQ-Manuals/FRCM

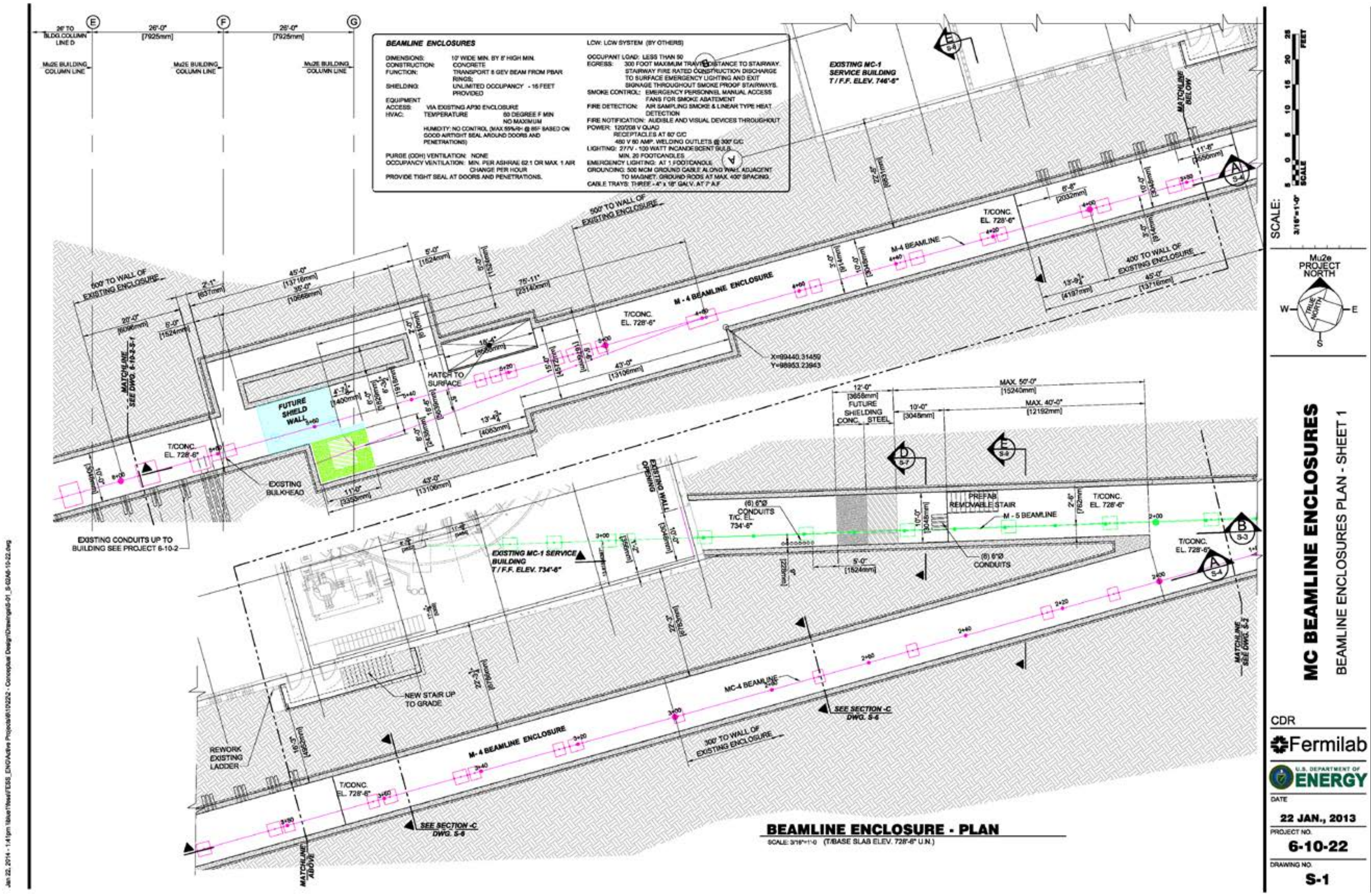

Figure 10: FESS drawing showing the location of the M4 line drop hatch