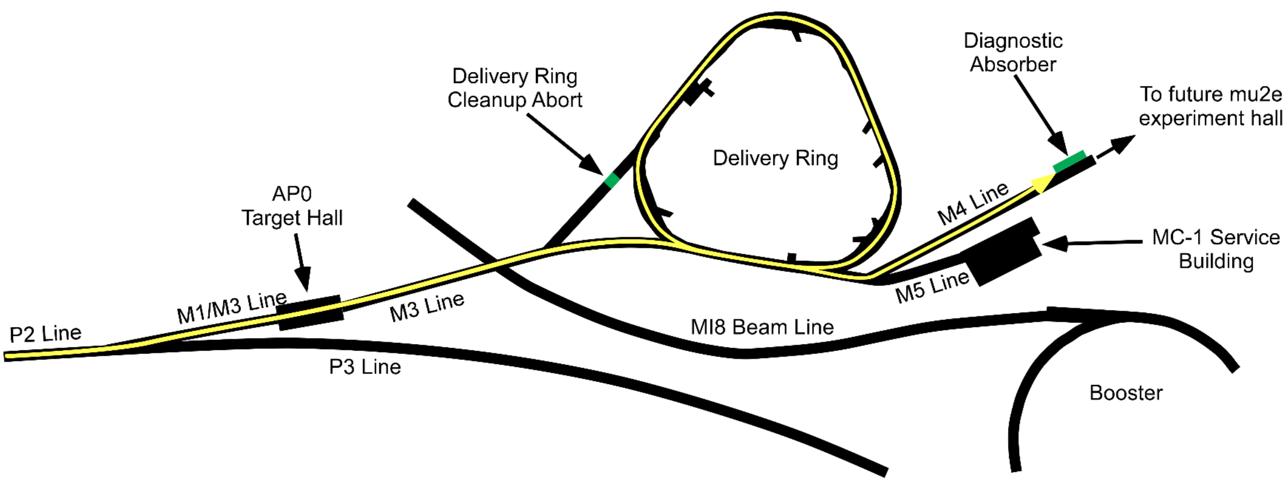


MUON CAMPUS SHIELDING ASSESSMENT FOR 8 GEV BEAM TRANSMISSION TO THE DIAGNOSTIC ABSORBER

Abstract

A Muon Campus Shielding Assessment is required before initiation of 13 watt, 8 GeV proton beam transmission through the M4 beam line to the Diagnostic Absorber.

February 5, 2020

Contents

Introduction

The Muon Campus is scheduled to begin beam operations to the M4 beamline and Diagnostic Absorber (DA) beginning in the spring of 2020. Consequently, a shielding assessment is required.

The purpose of this Muon Campus shielding assessment is to permit the transmission of the 13 watt, 8 GeV proton beam from the Delivery Ring Extraction region V906 vertical bending magnet, partway through the M4 beam line to the HDA01 switching magnet (powered by D:HDA01), through the short DA beam line and to the Diagnostic Absorber (DA). No beam is to be transmitted beyond the HDA01 switching magnet through the M4 beam line. A sketch of the beam line in the vicinity of the DA and the associated shield wall is shown in Figure 1.

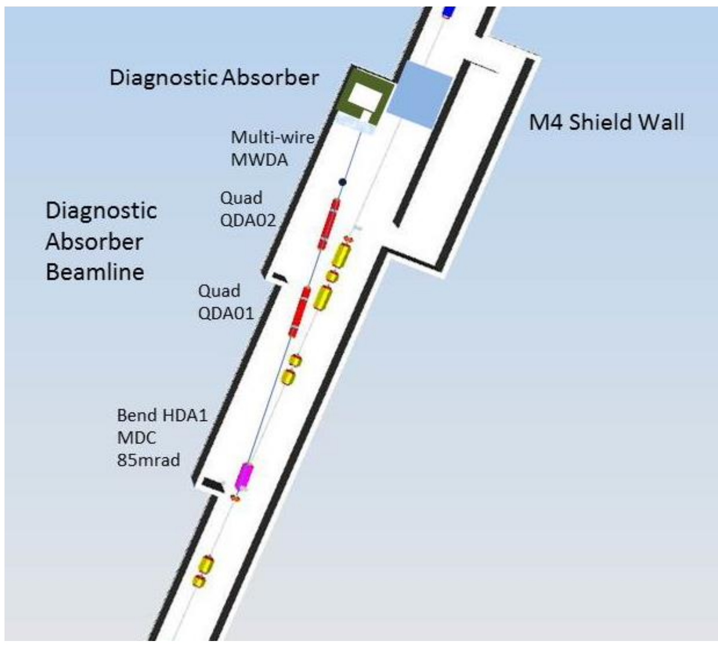


Figure 1: A plan view of the M4 and DA beam lines is shown which includes the position of the HDA01 switching magnet. For purposes of this shielding assessment, beam is to be transported only to the DA. No beam is to be transported further downstream of the switching magnet through the remainder of the M4 beam line.

Previously, at the time the Muon Campus G-2 shielding assessment [1] was prepared, the M4 beam line construction had not been completed. A temporary shield wall labyrinth [3] was installed at the boundary of the Extraction Enclosure and the upstream end of the M4 tunnel enclosure to permit secondary beam transmission to the g-2 storage ring room. An interlocked radiation detector was placed on the gate at this boundary to ensure radiation dose rates were limited to levels permitted for occupancy in the M4 enclosure while secondary beam was delivered to the g-2 storage ring room.

Now, the temporary shield wall labyrinth has been removed, a permanent shield wall has been installed adjacent to the DA and the DA bypass tunnel [9], and a temporary interlocked gate has been installed in the DA bypass tunnel (see Figure 2). The interlocked radiation detector positioned on the Extraction Enclosure gate is no longer required. Functionally, the new shield wall location and DA bypass tunnel gate define the downstream M4 Electrical Safety System (ESS) interlock enclosure boundary. This temporary arrangement permits the continuing operation of the Muon g-2 experiment; it does not permit beam operation to the DA.

The transition to beam operations to the DA requires new gate locations at the 7 foot step and in the upstream branch of the tunnel exit stairway as shown in Figure 2. The temporary interlocked gate shown in the DA bypass tunnel would no longer be required and could be removed. The final interlocked gate configuration required for beam transmission to the DA was shown by MARS simulations [9] to limit radiation dose rates within FRCM limits for 170 watt beam operation (13 times the beam power limit required for this assessment) under both normal and accident conditions.

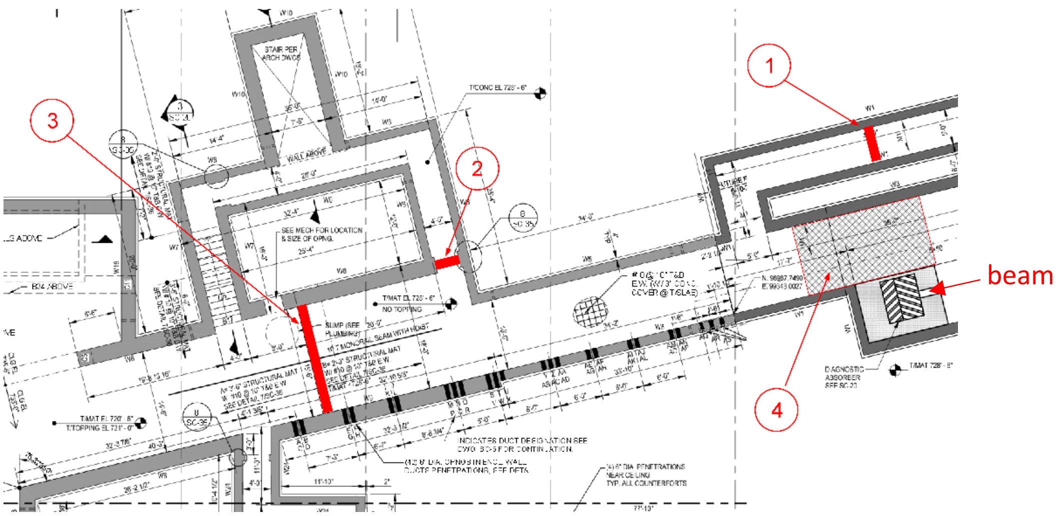


Figure 2: Beam enters the DA as indicated by the red arrow. Item 1 indicates the temporary interlocked gate located at the DA bypass tunnel which is required for the continuation of the muon g-2 experiment but before beam operation to the DA can be permitted. Item 4 shows the location of the new DA shield wall which is adjacent to the DA. Item 2 (gate in upstream branch of tunnel exit stairway) and item 3 (interlocked gate at 7 foot step) show locations of the eventual M4 interlocked gates which will be required for beam transmission to the DA.

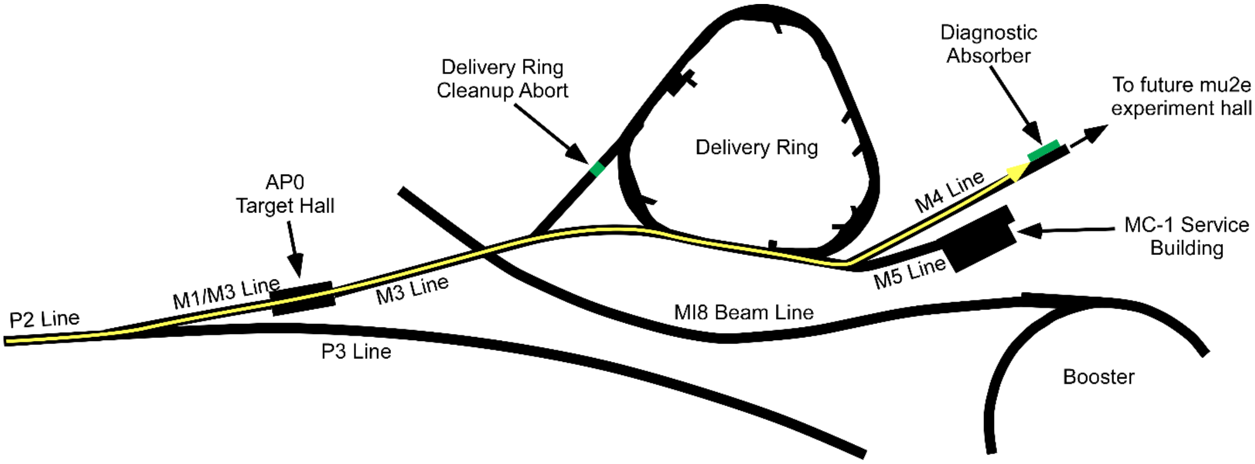
The Extraction Enclosure/M4 boundary gate continues to function as a Radiation Safety System (RSS) boundary to permit access to the M4 enclosure while beam is delivered to the Delivery Ring. No primary or secondary beam is permitted to be extracted from the Delivery Ring to the Extraction Enclosure for this operating mode; access to the Extraction Enclosure is prohibited during this mode of operation.

Operating modes described in Reference 1 continue to be applicable. The new operating modes to be permitted upon acceptance of this shielding assessment are described in the following section.

New Muon Campus Operating Modes

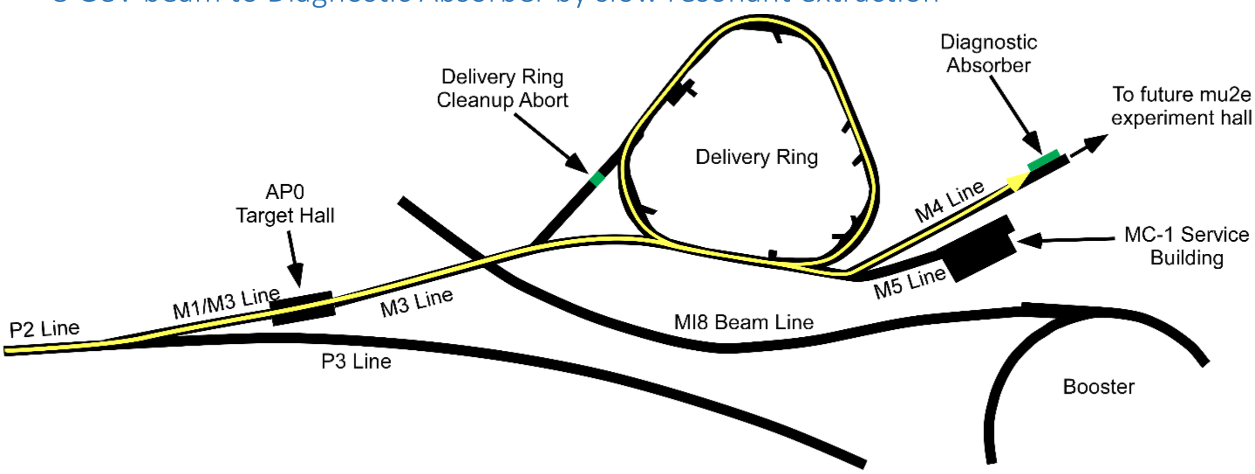
Two new operating modes to be permitted following approval of this shielding assessment are described here. A complete set of Muon Campus operating modes is provided in Reference 4.

8 GeV beam to Diagnostic Absorber by single pulse (fast) extraction



In this mode, beam is extracted from the Delivery Ring in a single pass (beam could be also circulated before extraction) and directed to the Diagnostic Absorber; it can be used during the early commissioning phase of the M4 beam line when the Muon g-2 experiment is idle. Critical devices are used to ensure that 8 GeV protons are not permitted beyond the diagnostic absorber.

8 GeV beam to Diagnostic Absorber by slow resonant extraction



The purpose of this mode is to commission the slow resonant extraction system. It can only be used when the slow resonant extraction system is installed at AP30. At that time, operation of the Muon g-2 experiment may be precluded because kickers required for Muon g-2 will be removed and replaced with extraction septa.

Beam Power Specifications

No primary or secondary beam will have been permitted to the M4 beam enclosure prior to the acceptance of this assessment. The purpose of this assessment is to permit 13 watt, 8 GeV primary protons (3.6E13 protons/hour) to be transported from Delivery Ring to the DA. All beam power limits of the existing Muon Campus Shielding Assessment [1] would continue to be applicable.

Critical Devices and Muon Campus Beam Mode Key Switch

The Muon Campus Beam Mode Key Switch will continue to allow direction of primary beam from the M1 beam line to the AP0 target station (with the resulting secondary beam directed to the Muon g-2 storage ring) or 8 GeV primary proton beam to the Delivery Ring via the M3 line as described in Reference 1.

Beam extraction from the Delivery Ring was previously established in the existing Muon Campus Shielding Assessment [1] in order to allow commissioning of the upstream extraction beam line elements. For that case, magnet power supplies beginning with V906 were required to be locked off to prevent primary proton beam entry into the Extraction Enclosure. This limitation is no longer required following implementation of the new M4 and Mu2e experiment region Critical Device Controllers .

Beam extraction to the DA is controlled by the M4 Critical Device Controller described in Reference 13.

Beam delivery beyond the DA or to the Mu2e Experiment region is prevented by the Mu2e Critical Device Controller described in Reference 13.

Extraction Enclosure and M4 Beam Line Transverse Shielding Design

As-built construction drawings for the extraction enclosure and the M4 beam line are provided in References 6 and 7. Radiation shielding drawings for the entire Muon Campus are documented in FESS drawing set 9-6-10-2 [14]. The nominal earth equivalent shielding thickness for the Extraction Enclosure/M4 beam line region is 16 feet. The shielding requirement for 8 GeV, 13 watt primary proton beam (magnet in enclosure), which limits the worst case accident condition to < 1 mrem/hr, is 13.5 feet [5]. Under the worst case accident condition, effective dose rate should be limited to about 0.2 mrem/hr for a continuous beam loss. The normal condition is expected to be relatively clean beam transmission from the Delivery Ring Extraction region to the DA.

A cross section of the DA within the M4 beam enclosure is shown in Figure 3. In addition to the indicated 16 feet of earth shielding, beam deposited in the DA is further shielded vertically by about 3 feet of DA steel and an additional 13.75 inches of concrete. The transverse density thickness at the berm surface over the beam absorber is approximately 26 feet of earth equivalent shielding. Consequently, by application of Reference 5, the expected effective dose rate at the berm surface due to continuous 13 watt beam operation is less than 1 microrem/hour.

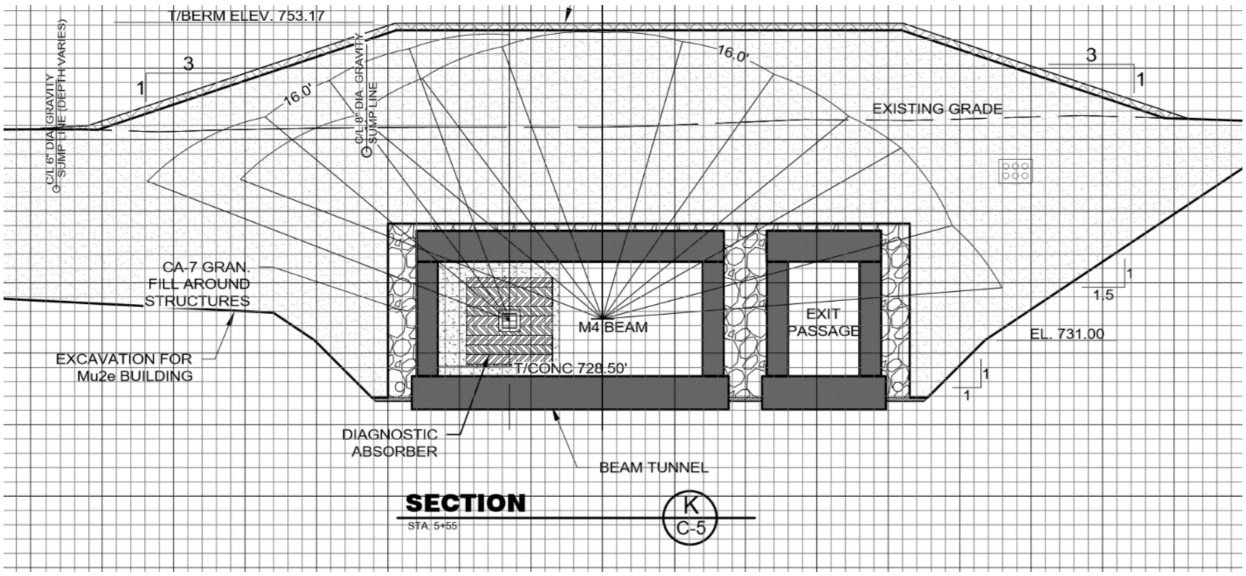


Figure 3: This image is a taken from Radiation Safety Shielding Drawing 9-10-6-2, sheet C9, Section K. The effective dose rate at the berm surface due to 13 watt, 8 GeV continuous operation is estimated at < 1 microrem/hr.

A drop hatch is located in the M4 beam line enclosure just upstream of the DA shield wall bypass tunnel. The construction details of the drop hatch are given in Reference 6 on sheets SC1 and SC17. Cross sections of the drop hatch are shown in Figure 4. The drop hatch has been filled with 16.5 feet of concrete shielding blocks.

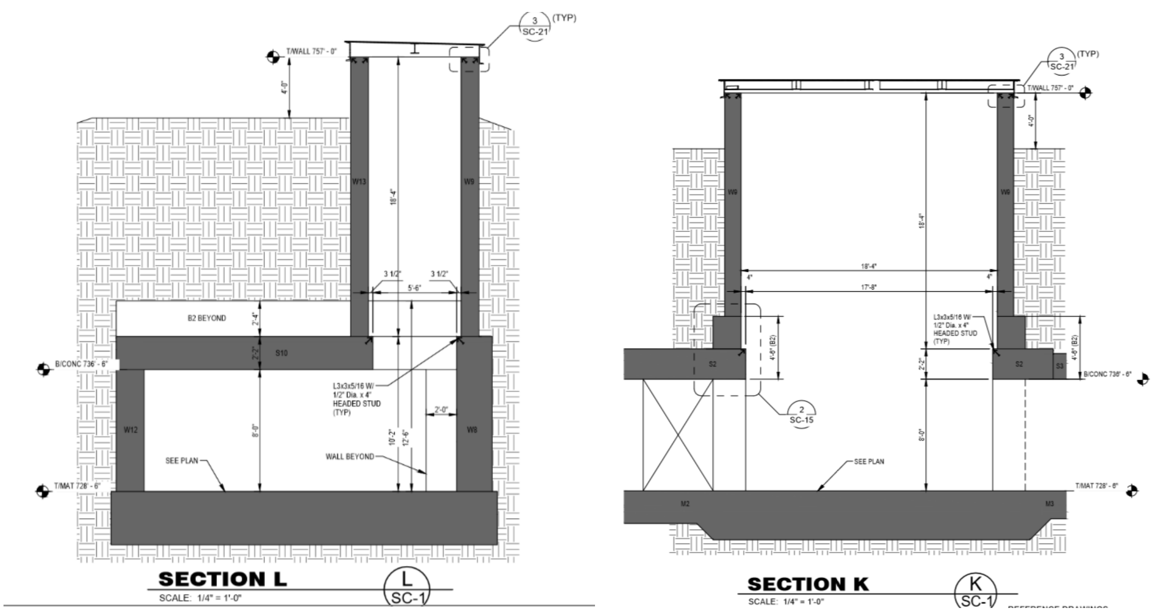


Figure 4: Cross sections of the M4 beam line enclosure drop hatch are shown here. The drop hatch has been filled with 16.5 feet of concrete shielding.

M5 Shield Wall

An 8 kW, 8 GeV proton beam loss at the H918 left bend magnet in the Extraction Enclosure has been considered [15] as the eventual worst case accident scenario for personnel occupancy in the g-2 storage ring room. Various M5 shield wall compositions, wall placements, and interlocked detector mitigations have been considered in a number of MARS simulations. For purposes of this shielding assessment, it is sufficient to consider version 3 and version 6 of Reference 15. From version 3, the worst case effective dose rate in the g-2 storage ring room for an 8 kW, 8 GeV beam loss was 490 mrem/hr. For this case, the shield wall was positioned at the edge of the step in the enclosure. Scaling to 13 watts reduces the effective dose rate to about 0.8 mrem/hr. From version 6 of Reference 15, it was determined that the effective dose rate is further reduced (by a factor of > 20) relative to version 3 arrangement with the shield wall set back from the M5 beam line step by 10 feet. The reduction in effective dose rate is achieved because the shower in the version 3 arrangement was shown to leak under and past the M5 shield wall. With the shield wall set back by 10 feet, the bypassing action is significantly mitigated.

Also from version 6 of Reference 15, the effective dose rate around the M5 beam line beam tube exit was not affected by the 10 foot setback of the M5 shield wall. The effective dose rate due to an 8 kW beam loss on the H918 left bend magnet was about 50 mrem/hr. With a beam power limitation of 13 watts, the effective dose rate would be limited to about 80 μrem/hr for the accident condition.

It would be prudent to install an interlocked radiation detector (chipmunk) at the M5/muon storage ring room gate to ensure the effective dose rate remains below posting levels permitted in the muon storage ring room enclosure while beam is transported to the DA.

Labyrinths and Penetrations

Labyrinths and penetrations which require consideration for this assessment include the following:

- Extraction Enclosure Exit stairway
- Site survey riser penetrations
- Cable penetrations between M4 enclosure and Muon g-2 power supply room
- Extraction Enclosure air stack exhaust

Extraction Enclosure exit stairway

A MARS simulation was made to consider the effective dose rate at the exit of the Extraction Enclosure exit stairway under a normal beam loss condition of 22.4 watts, 8 GeV protons in the 907 collimator, Q908, and Q909 regions [10]. The effective dose rate at the exit stairway was found to be <50 μrem/hr. Under the normal condition considered for this assessment, clean beam transmission is expected. In the event of a continuous 13 watt beam loss accident condition in the vicinity of the exit stairway, the effective dose rate at the exit stairway should be << 1 mrem/hr.

Site survey riser penetrations

There are two site survey riser penetrations which require consideration.

- Extraction enclosure at x=99791.3680, y=98761.6680
- M4 beam line enclosure at X=99424.830, y=98966.510

For any given beam loss intensity, the worst case condition would result at the M4 location since the mouth of the site riser is significantly closer to the beam line. A MARS simulation was made to consider the effective dose rate and shielding requirements for the M4 beam line site survey riser [16]. The beam power lost in the simulation was 1216 watts and resulted in an effective dose rate of 5800 mrem/hr at the exit of the penetration. Scaling the simulation to 13 watts would result in an effective dose rate of about 62 mrem/hr. For mitigation, both of these penetrations will be filled with sand (the effective lengths of the penetrations is 16 feet) prior to initiation of beam operations [18]. Using a tenth value layer for sand of 4.73 feet, the effective dose rate at the exit of the penetration will be reduced to less than 50 μrem/hr.

Penetrations between M4 enclosure and Muon g-2 power supply room

The evaluation of these penetrations has been documented in Reference 17 for an 8 kW beam loss; effective dose rates due to a full beam power loss are well below 1 mrem/hr. No further consideration of these penetrations is required for this assessment.

Extraction Enclosure Air Stack Exhaust

A 14 inch diameter air exhaust stack is located at the upstream end of the Extraction Enclosure. This stack will eventually be used to direct activated air created in the Production Solenoid Room to the environment after maximizing radioactive decay through control of the air transit time from the PS to the exhaust stack. The details of the air duct construction are provided in Reference 6, sheet M2 and are included here in Figure 5.

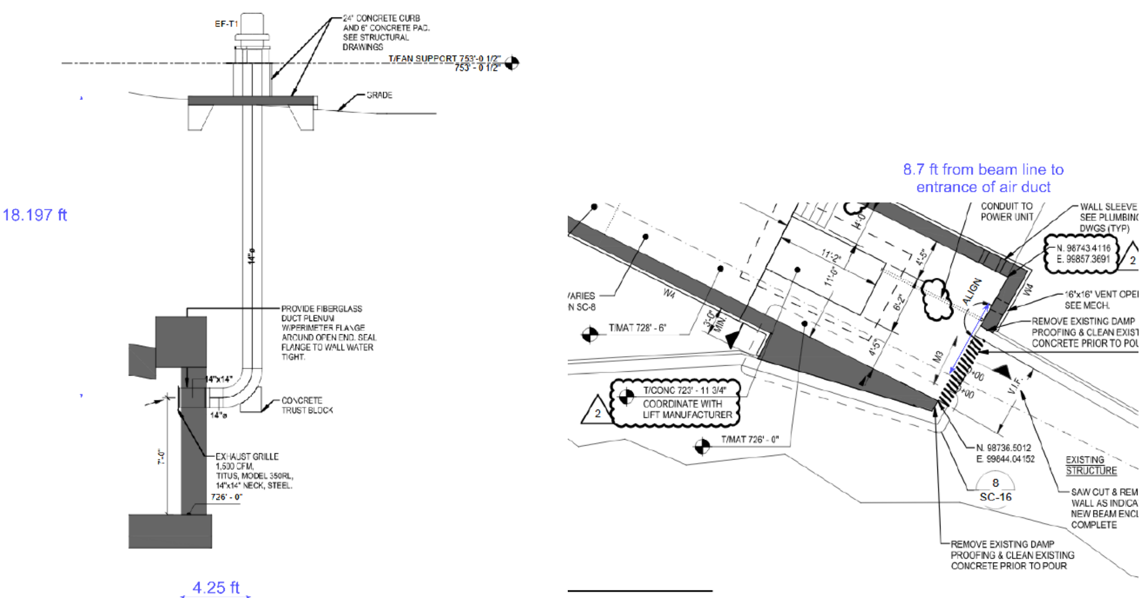


Figure 5: An elevation view of the exhaust stack is shown at left. At right, a plan view of the air exhaust stack location is shown with respect to the M4 beam line trajectory.

A penetration spreadsheet [19] has been prepared to estimate the effective dose rate at the exit of the exhaust stack in the event of a 13 watt accident condition. The effective dose rate is << 1 mrem/hr.

Posting and Radiological Controls for the Extraction Enclosure, M4 Enclosure, and Associated Shielding Berms

The posting and radiological control requirements for normal and accident conditions from Reference 8 are shown in Figure 6 and Figure 7. The effective dose rates considered above for all normal and accident conditions are below 50 μrem/hr and 1 mrem/hr, respectively. The access doors to the Extraction Enclosure and the M4 Enclosure would require the Exclusion Area posting. No additional postings for prompt effective dose rates should be required for Extraction Enclosure and M4 access points. No postings should be required for the Extraction Enclosure, M4, and M5 shielding berms.

Dose Rate (DR) Under Normal Operating Conditions	**Controls**
All interlocked doors or gates leading from non-enclosures into an interlocked Exclusion Area	Signs (EXCLUSION AREA – No Access Permitted with Beam Enabled.)
DR < 0.05 mrem/hr	No precautions needed.
0.05 ≤ DR < 0.25 mrem/hr	Signs (CAUTION -- Controlled Area). No occupancy limits imposed.
0.25 ≤ DR < 5 mrem/hr	Signs (CAUTION -- Controlled Area) and minimal occupancy (occupancy duration of less than 1 hr).
5 ≤ DR < 100 mrem/hr	Signs (CAUTION -- Radiation Area) and rigid barriers (at least 4' high) with locked gates. For beam-on radiation, access restricted to authorized personnel. Radiological Worker Training required.
100 ≤ DR < 500 mrem/hr	Signs (DANGER -- High Radiation Area) and 8 ft. high rigid barriers with interlocked gates or doors and visible flashing lights warning of the hazard. Rigid barriers with no gates or doors are a permitted alternate. No beam-on access permitted. Radiological Worker Training required.
DR≥ 500 mrem/hr	Prior approval of SRSO required with control measures specified on a case-by-case basis.

Figure 6: FRCM Table 2-6 Control of Accessible Accelerator/Beamline Areas for Prompt Radiation Under Normal Operating Conditions (refer to Article 236.2(b))

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Maximum Dose (D) Expected in 1 hour	Controls
All interlocked doors or gates leading from non-enclosures into an interlocked Exclusion Area	Signs (EXCLUSION AREA – No Access Permitted with Beam Enabled.)
D < 1 mrem	No precautions needed.
1 < D ≤ 10 mrem	Minimal occupancy only (duration of credible occupancy < 1 hr) no posting
1 ≤ D < 5 mrem	Signs (CAUTION -- Controlled Area). No occupancy limits imposed. Radiological Worker Training required.
5 ≤ D < 100 mrem	Signs (CAUTION -- Radiation Area) and minimal occupancy (duration of occupancy of less than1 hr). The assigned RSO has the option of imposing additional controls in accordance with Article 231 to ensure personnel entry control is maintained. Radiological Worker Training required.
100 ≤ D < 500 mrem	Signs (DANGER -- High Radiation Area) and rigid barriers (at least 4' high) with locked gates. For beam-on radiation, access restricted to authorized personnel. Radiological Worker Training required.
500 ≤ D < 1000 mrem	Signs (DANGER -- High Radiation Area) and 8 ft. high rigid barriers with interlocked gates or doors and visible flashing lights warning of the hazard. Rigid barriers with no gates or doors are a permitted alternate. No beam-on access permitted. Radiological Worker Training required.
D ≥ 1000 mrem	Prior approval of SRSO required with control measures specified on a case-by-case basis.

Figure 7: FRCM Table 2-7 Control of Accessible Accelerator/Beamline Areas for Prompt Radiation Under Accident Conditions When It is Likely that the Maximum Dose Can Be Delivered (See Article 236.2b for more details).

Groundwater, Surface water, Air Activation and Radiation Skyshine

The most significant groundwater and surface water activation which can be considered for this shielding assessment is at the DA. The maximum star density reported for soil regions surrounding the DA can be found in Reference 11, slides 123 through 127. The maximum star density reported is 3.4E3 stars/cm^3/1.33E11 protons or 2.56E-8 stars/cm^3/proton.

Groundwater activation is calculated from the method provided in Reference 20. As shown in Figure 8, using a 20 year irradiation time at 1E10 protons/second, 2000 hours/year operation, ground water activation eventually reaches 11.7 ppb of the groundwater activation limit.

Diagnostic Absorber Groundwater Calculations without Flushing
(assuming no underdrains or sump pumps)

	^{3}H	^{22}Na	$S_{max}toS_{ave}$=	0.019			
K(atom/star)=	0.075	0.02	dps-to-pCiPlus=	1.17E+06		^{3}H	^{22}Na
L=	0.9	0.135			Buildup	5.47E-02	2.34E-01
ρ(soil)=	2.25	2.25			$t_{1/2}$(yr)=	12.33	2.602
w=	0.27	0.52	*Save(star/cc-p)=		λ=	5.62E-02	2.66E-01
Factor-ave=	2.52E-18	2.24E-19	*Smax(star/cc-p)=	**2.56E-08**	Decay=	1.00E+00	1.00E+00
			H-3_Hydro-xport R(Till)=	**1.00E-09**			
			Na22_Hydro-xport R(Till)=	**1.00E-09**			
			Tirr (yr) =	**1**			
			Tbeam-off (yr) =	**0**			

	Tritium		**Sodium**			
Protons/year	C01 (pCi/cc-y)	C(t)f1 (pCi/cc-y)	C01 (pCi/cc-y)	C(t)f1 (pCi/cc-y)	After Year	**Fraction of Total Limit in Aquifer**
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	1	5.85E-10
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	2	1.17E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	3	1.75E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	4	2.34E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	5	2.92E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	6	3.51E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	7	4.09E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	8	4.68E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	9	5.26E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	10	5.85E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	11	6.43E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	12	7.02E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	13	7.60E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	14	8.19E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	15	8.77E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	16	9.36E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	17	9.94E-09
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	18	1.05E-08
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	19	1.11E-08
7.20E+16	1.82E-01	1.82E-10	1.61E-02	1.61E-11	20	1.17E-08

Figure 8: Using the maximum star density of the activation volume, and assuming 7.2E16 protons per year, the ground water activation level eventually reaches 11.7 ppb of the groundwater activation limit.

Surface water produced near the DA is collected by a collection system which is routed to the Main Ring Pond and on-site collection/storage system. There is no observable unique surface water discharge point near the DA. The surface water activation is calculated from Reference 20. As shown in Figure 9, applying the maximum star density from the groundwater result for the surface water activation calculation results in surface water activation well below surface discharge limits for any conceivable sump pumping frequency.

Diagnostic Absorber Surface Water Calculations with Flushing (with underdrain and sump pumps)

	^{3}H	^{22}Na		
K(atom/star)=	0.075	0.02	$S_{max}toS_{ave}$=	0.019
L=	0.9	0.135	dps-to-pCiPlus=	1.17E+06
ρ(soil)=	2.25	2.25		
w=	0.27	0.52	*Save(star/cc-p)=	
Factor-ave=	2.52E-18	2.24E-19	*Smax(star/cc-p)=	**2.56E-08**
			Hydro-xport R(Till)=	**1.00E-09**
			T_{irr} (yr) =	**1**
			$T_{beam-off}$ (yr) =	**0**

	^{3}H	^{22}Na
Buildup	5.47E-02	2.34E-01
$t_{1/2}$(yr)=	12.33	2.602
λ=	5.62E-02	2.66E-01
Decay=	1.00E+00	1.00E+00

Protons/year	**Tritium** C_0 (pCi/cc-y)	**Sodium** C_0 (pCi/cc-y)	**Fraction of Total Limit on Surface (once a year)**	**Fraction of Total Limit on Surface (once a month)**	**Fraction of Total Limit on Surface (once a week)**	**Fraction of Total Limit on Surface (once a day)**
7.20E+16	1.82E-01	1.61E-02	1.71E-03	1.42E-04	3.29E-05	4.68E-06

Figure 9: Surface water discharge activation is well before the surface water discharge limits for any conceivable pumping frequency.

An estimate of air activation due to beam operation at the DA has been completed [21]. Commissioning the M4 beam line is an intermittent, low frequency activity which will be completed during available study periods when permitted by the physics program. An estimate [22] for the required study time to commission the M4 beam line is approximately 100 hours of 13 watt beam operation over one year. The operating period estimate is intended to provide a basis for the air activation estimate; it is not intended to serve as a limitation. The total air activity estimated to be released for this set of conditions is 0.13 Ci/year.

The effective dose rate at the surface of the berm above the DA for continuous 13 watt operation reported above was < 1 μrem/hr. Relatively clean beam transmission is expected throughout the remainder of the area under assessment. Consequently, there are no conceivable radiation skyshine issues to consider.

Residual Dose Rate at DA

The result of a MARS simulation for residual dose rate at the upstream face of the DA following 30 days irradiation at 170 watts and 1 day cooling time taken from Reference 11 is provided in Figure 10. The effective dose rate at the upstream face of the absorber, scaled to the 13 watt beam power limitation is estimated to be about 76 mrem/hr.

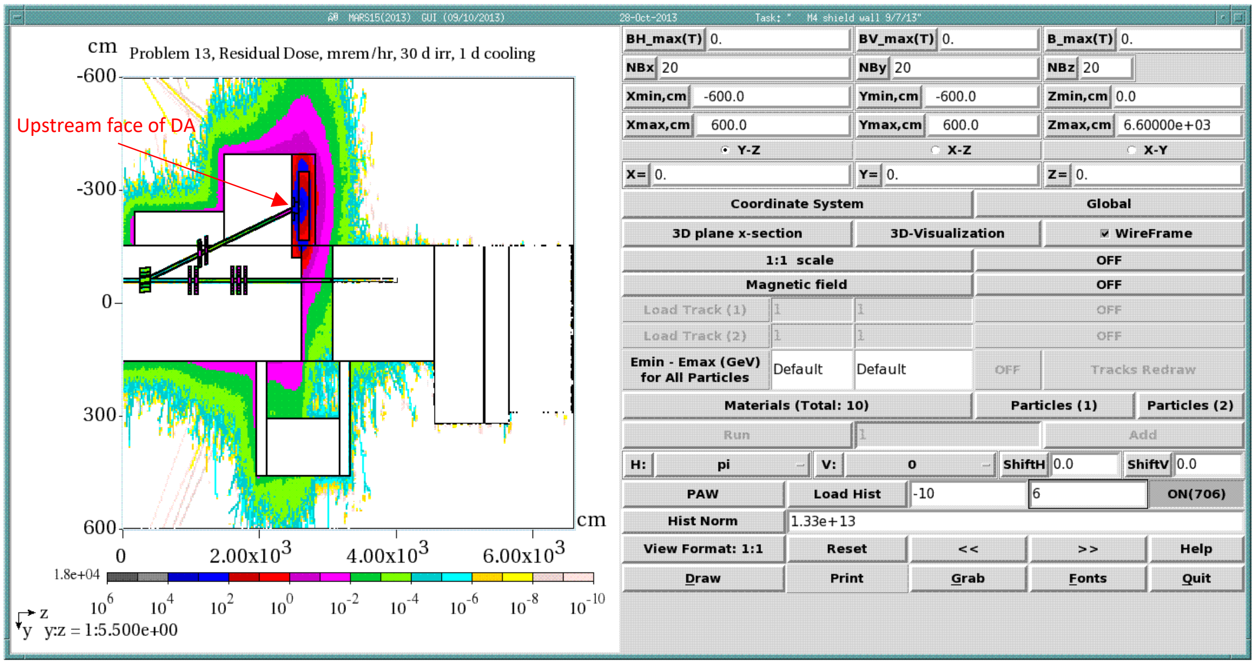

Figure 10: This result of a MARS simulation is copied from Reference 11, PowerPoint slide 122. The H/V image scale is not 1:1. The peak effective residual dose rate (mrem/hr) at the entrance of the DA for 170 watt, 8 GeV proton beam operation is approximately 1,000 mrem/hr. The effective dose rate will be a factor of 13/170 lower or about 76 mrem/hr due to the beam power limitation permitted by this shielding assessment.

Muon radiation exposure potential at the Mu2e experimental area

The trajectory of the beam line directed to the DA is on axis with various regions of the Mu2e experimental area. A MARS simulation (reported in Reference 11) was made to address the exposure potential to occupants of the Mu2e experimental area. Figure 11 shows the result of the simulation. No significant exposure to muons is possible, even at the DA design beam power of 170 watts. No further consideration of muons to the Mu2e region is necessary.

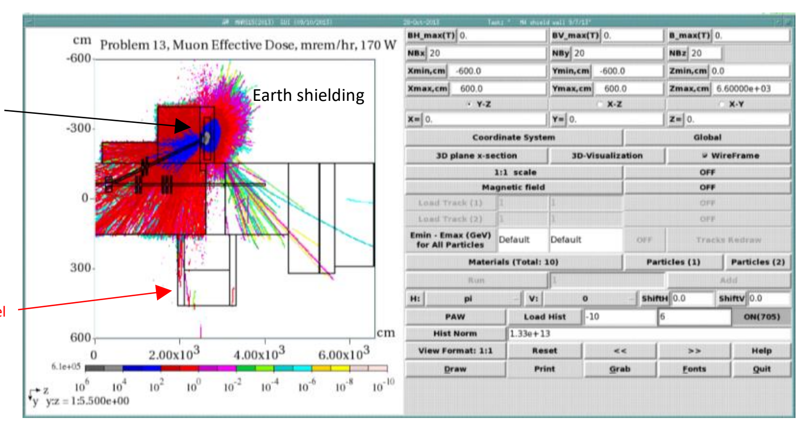

Figure 11: This result of a MARS simulation is copied from Reference 11, PowerPoint slide 121. The H/V image scale is not 1:1. The effective dose rate downstream of the DA due to muons for 170 watt, 8 GeV proton beam operation is indicated. The muon shower is rapidly attenuated in the earth shielding just downstream of the DA. The effective dose rate will be a factor of 13/170 lower due to the beam power limitation permitted by this shielding assessment.

Summary

Radiological parameters for 13 watt, 8 GeV proton beam delivered to the DA have been considered in the shielding assessment. The following actions are suggested:

1. The interlocked radiation detector, formerly located at the Extraction Enclosure/M4 gate (aka the labyrinth gate) should be moved to the downstream side of the DA shield wall during the interim period while Muon g-2 beam operation continues and prior to the transmission of 13 watt, 8 GeV proton beam to the DA.
2. Before beginning 13 watt, 8 GeV beam transmission to the DA, the M4 Radiation Safety System enclosure boundaries are required to be extended to the 7 foot step. The chipmunk mentioned in the preceding item should be moved to the RSS boundary fence at the 7 foot step and near the M4 beam line axis. A second interlocked gate is required at the upstream branch of the exit stairway as indicated in Figure 2.
3. An interlocked radiation detector should be deployed at the M5 enclosure/muon g-2 storage ring boundary fence to limit and monitor radiation effective dose rates due to potential 8 GeV accident conditions which could occur in the extraction enclosure while beam is transported to the DA.
4. The Exclusion Area posting requirements of the FRCM (listed in Figure 6 and Figure 7) should be reviewed and applied as necessary to the Extraction Enclosure and M4 Enclosure access points.

References

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