A Study of Residual Radiation in the Proposed Irradiation Physics Area

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This document explores the radiological implications of delivering a 400 MeV beam to the former MuCool Testing Area, where a Device Under Test (DUT) might be irradiated. We take the DUT to be just upstream of the final absorber, in 1 m^3 volume of vacuum, surrounded on all sides by thick radiation shielding, such as 1 m of concrete. The through-hole for the beam is taken to be 7.62 cm radius, matching the 6” inner diameter of the pipe leading into the absorber.

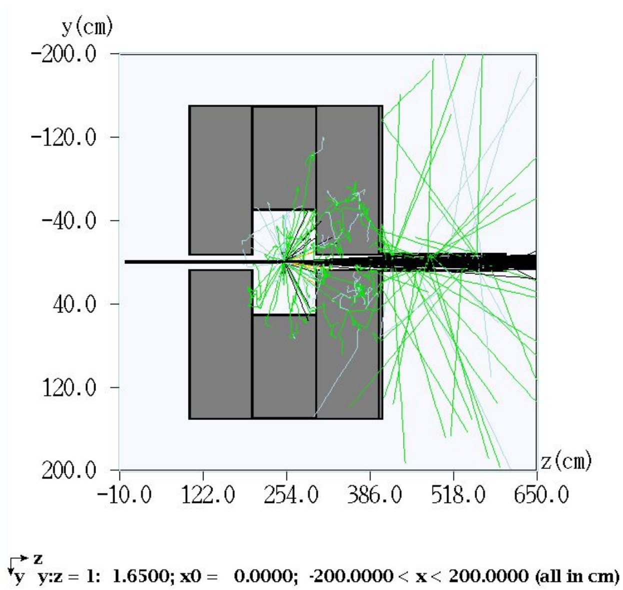

Fig. 1: The MARS model in elevation view. Beam enters from the left, strikes the 0.9 cm Si target in the center of the shielding cave, and outgoing secondaries exit the cave, illuminating the inside of the pipe into the final absorber (not shown).

A target of silicon 0.9 cm thick (0.1 radiation lengths[1]) is of particular interest, as this would largely mimic the silicon tracking detectors being proposed as customers at the facility. We also examine the case of a badly scattering target, a cylinder of iron 45 cm in thickness, to help understand the λworst case scenario.

We employ a MARS[2] model to estimate the levels of residual activity in the inner and outer faces of the shielding cave, as well as the permanently installed wall of the radiation enclosure.

Short-Term Residual Activity (mrem/hr)
After 12 hours of irradiation at 5×10^{12} protons/second, and various cooldown times:

Outside surfaces at **1 hour**	10% X_0 (0.9 cm Si)	10% λ (4.65 cm Si)	45 cm Fe (worst case)
10 Upstream wall	1.815E-01	7.028E-01	5.436E+00
6 Side walls	6.062E+00	6.347E+00	3.155E+01

Outside surfaces at **1 day**	10% X_0 (0.9 cm Si)	10% λ (4.65 cm Si)	45 cm Fe (worst case)
10 Upstream wall	5.660E-02	1.165E-01	1.159E+00
6 Side walls	9.604E-01	9.668E-01	4.997E+00

Inside surfaces at **1 hour**	10% X_0 (0.9 cm Si)	10% λ (4.65 cm Si)	45 cm Fe (worst case)
3 Upstream wall	1.084E+02	1.017E+02	1.869E+03
5 Side walls	4.428E+02	4.515E+02	2.369E+03
7 Downstream wall	5.443E+02	4.870E+02	4.256E+02

Inside surfaces at **1 week**	10% X_0 (0.9 cm Si)	10% λ (4.65 cm Si)	45 cm Fe (worst case)
3 Upstream wall	1.507E-01	1.410E-01	2.294E+00
5 Side walls	1.190E+00	1.271E+00	4.646E+00
7 Downstream wall	1.827E+00	1.638E+00	1.086E+00

These results suggest that regardless of target geometry, a cave shielding thickness of one meter of concrete sufficiently mitigates the radiation field in the experimental enclosure, outside of the cave, to permit safe access the following day. Further, the cave itself might be accessed within a week of the most recent irradiation.

Long-term Residual Activity

Total remaining activity in the permanently installed material, such as the downstream wall of the enclosure and the beam pipe through it which leads to the final absorber, is estimated by a MARS run and an analysis of the residual activity for the permanently installed parts of the enclosure immediately around the irradiation cave. The resulting cooldown curve of remaining activity has quite a complex shape; See Fig. 2.

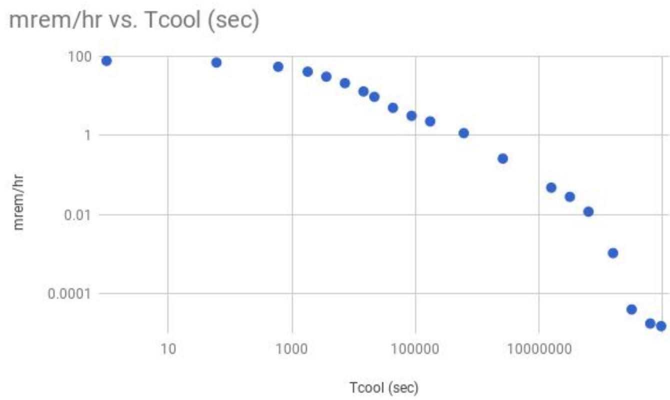

Fig. 2: An example time series showing the cool-down of residual activity after various elapsed times, as given by MARS. The times range from 1 second to 30 years, and are spaced in intervals convenient to general purposes.

To derive the activity after steady running at 5×10^{12} protons/second for 12 hours once per week for 52 weeks, the cool-down curve is approximated with a linear interpolation and then sampled at 7-day intervals from one to 52 weeks. The sum of these values is approximately the 1-year activity which could be expected. The error introduced by this method is approximately half an order of magnitude; the interpolation is expected to be above and below the actual curve, at different places over the relevant 1-year period.

After one week of cool-off, this steady running schedule gives these residual activity levels: (Results are in mrem/hr, and presented for the same target material scenarios as above.)

Permanent installations **1 year**	10% X_0 (0.9 cm Si)	10% λ (4.65 cm Si)	45 cm Fe
8 beam pipe	7090	6680	7.28
9 Downstream wall	14.1	13.4	5.90

Given the facility usage scenario explored here, we expect the downstream wall of the enclosure may become activated to about 10 mrem/hour regardless of the geometry of the DUT. Although actual running in expected to be less aggressive, this suggests that improved shielding in the downstream wall would be prudent.

The beam pipe into the final absorber is expected to bear the brunt of scattered primary and secondary particles, becoming appreciably activated in the expected use case of thin targets. Mitigation strategies which might be tried include fitting the inside of this pipe with a sacrificial sleeve.

References

[1] http://pdg.lbl.gov/2011/AtomicNuclearProperties/HTML_PAGES/014.html

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