Switchyard Total Loss Monitors

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ABSTRACT

The upcoming Integrated Engineering Research Center ("IERC")[1] necessitates the installation of Total Loss Monitors ("TLMs")[2] in the Switchyard beamline due to the proximity of the building to the beamline and limited radiological shielding. This paper briefly describes the proposed TLM layout and estimates the required distance from the beamline and trip limits to provide accordance with desired occupancy classification without artificially limiting available beam to the experiments.

Motivation

The IERC building's proposed location takes the place of the parking lot on the East side of Wilson Hall, in relatively close proximity to the Switchyard beamline. Historically, this parking lot has been considered a "minimal occupancy" area, defined as having a credible occupancy period of less than one hour. As the IERC building will house employees for more than one hour, the areas adjacent to the shielding berms along the building's boundary will need to be re-classified as unlimited occupancy. This re-classification corresponds to a single-pulse accident condition dose of less than 1 mrem and a maximum continuous effective dose rate of less than 0.05 mrem per hour.[3] Since it is cost-prohibitive and conflicts with the IERC project to add significant amounts of shielding, TLMs will be installed to provide active shielding along the length of beamline co-incident with the project boundary. The proposed layout of TLMs are pictured in Figure 1, showing both the enclosure outlines and a rough placement of the IERC building itself.

Each TLM trip limit and distance to the beamline must be determined to satisfy occupancy conditions while still allowing an acceptable amount of operational beam loss. The maximum charge rate trip limit that the TLM electronics can allow is 3000 nano-Coulombs per minute,[4] and TLM location is somewhat constrained by the geometry of the beamline enclosures. Each TLM has its own challenges in determining the above conditions that will be addressed in the following sections.

TLM Charge Estimation

To estimate the charge integrated on a TLM detector for a given beam loss on a magnet, we can scale in both energy and TLM-to-beamline radial distance from past experimental data in the Fermilab Accumulator.[5] The TLM response in nano-Coulombs per proton is shown in Equation 1.

$$TLM_{response}[\frac{nC}{p}] = (\frac{5.5[ft.]}{d[ft.]})^2 * (\frac{E_{beam}[GeV]}{8[GeV]})^{0.8} * \frac{3.2[nC]}{1.0E10[p]}, \tag{1}$$

where "E_{beam}" the beam kinetic energy in GeV, and "d" is the radial distance in air from the loss point to the TLM detector in feet. Note that the data taken in the Fermilab Accumulator did not include any shielding between the loss point and the TLM. Equation 1 should not be used in such a case (such as with TLM2), since any intermediate shielding will change the particle species interacting with the TLM. Thus Equation 1 will only be used to estimate the TLM response for TLM1 and TLM2.

Multiplying Equation 1 by the beam loss rate, we can estimate the TLM reading in nano-Coulombs per minute, the units for the trip settings in the TLM electronics. Since the Switchayrd beam rate is one spill per minute, the TLM response for a given operational loss per spill is:

$$TLM_{rate}[\frac{nC}{min.}] = (\frac{5.5[ft.]}{d[ft.]})^2 * (\frac{E_{beam}[GeV]}{8[GeV]})^{0.8} * \frac{3.2[nC]}{1.0E10[p]} * Loss[\frac{protons}{spill}]. \tag{2}$$

The largest and most consistent operational loss in Switchyard is on the "MLAM" lambertson magnets in Enclosure C. Used in splitting the beam to multiple experiments, the MLAM mangets are inherently lossy due to beam interaction with the septum that separates apertures. To estimate the TLM reading for normal operational losses on the MLAM Lamberston in Enclosure C, a maximum beam intensity of 1E13 protons per spill and 5% continuous beam loss are assumed at a rate of one spill per minute. The 5% loss is an estimate of the worst-case beam loss that would be acceptable operating conditions

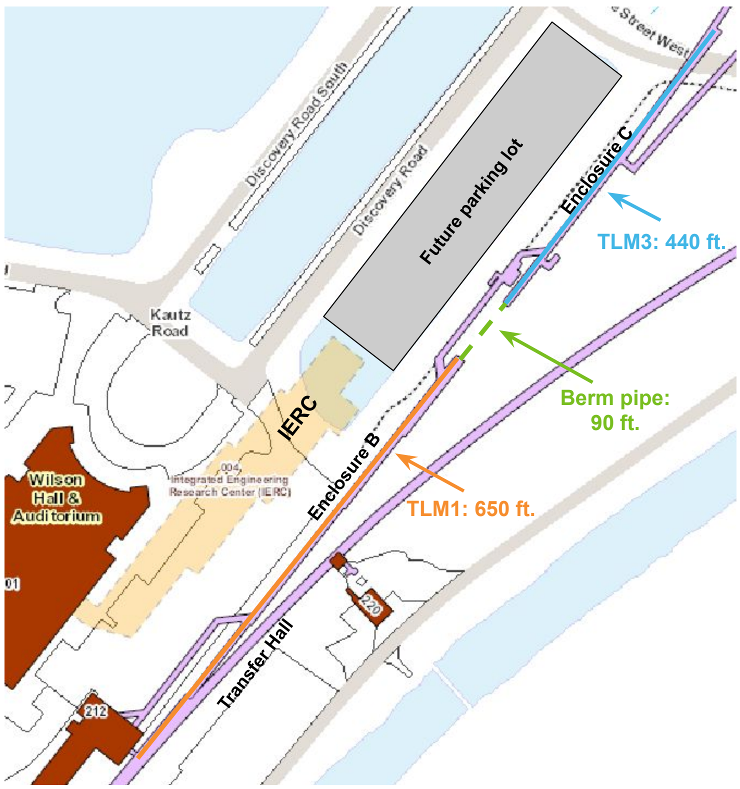

Figure 1. Proposed configuration of two Switchyard TLM detectors to cover the area of the IERC project and provide additional active shielding. The locations of the IERC building and parking lot are only approximate. A small section of berm pipe will lack TLM coverage, but may be covered by a chipmunk array if necessary.

in Switchyard. The TLM response to this loss is plotted in Figure 2 as a function of the radial distance between the magnet and TLM. Also plotted is the 3000 nano-Coulombs per minute maximum trip limit allowed by the current radiation safety system. This result shows that a TLM in Switchyard should be placed at least 3.75 ft. radially from any magnet that may cause a consistent operational loss of up to 5%.

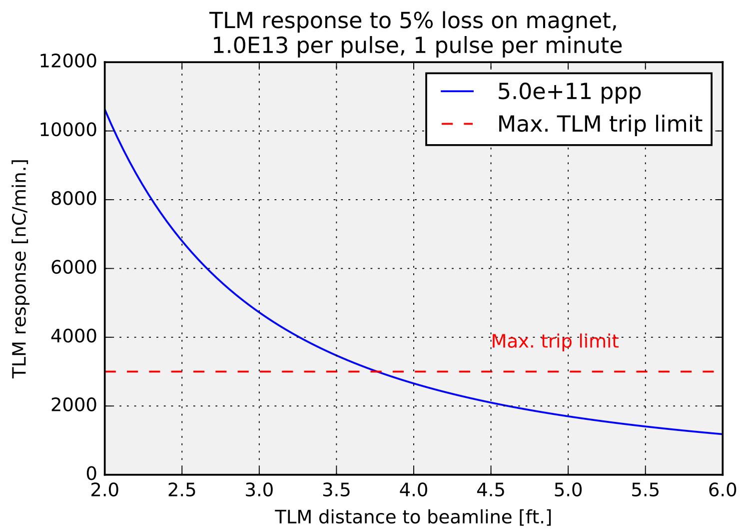

Figure 2. TLM response for 5% continuous loss in Switchard at maximum beam flux vs. detector radial distance from magnet.

As TLM1 does not cover any high-loss beamline components, the maximum allowable operational loss will not be the determining factor for distance and trip setting as it was for TLM2. Instead, these characteristics for TLM1 will be determined by the maximum surface dose rate allowed by a given distance and trip setting, as TLM1 covers an area of reduced shielding.

Estimation of Maximum Surface Effective Dose Rate

In this section, the maximum expected hourly effective dose rate is estimated on the surface of the shielding berm as a function of a given TLM's trip limit. The goal is to determine the TLM1 trip limit that is consistent with the re-classification of the Wilson Hall East parking lot area as "unlimited occupancy". The same methodology will also check that the TLM2 trip level of 3000 nano-Coulombs per minute is compatible with a minimal occupancy classification outside its respective enclosure.

The dose is estimated using the "Malensek" method, which assumes the worst-case peak of the hadronic shower from protons incident upon an iron cylinder of 15cm radius and 90cm length. This method scales from CASIM Monte Carlo simulation data for distance, shielding thickness, and beam energy.[6] The maximum single-pulse effective dose rate per proton of kinetic energy "E" in GeV, and "d" distance in feet in air from the loss point is:

$$H[\frac{mrem}{p}] = (1.0E-5)*(\frac{0.5}{d[ft.]})^2*(\frac{E[GeV]}{1000})^{0.8}*10^{\frac{-t[ft.]}{3.38}} \tag{3}$$

For the purposes of these estimates, we assume the distance in air between the loss point and the shielding is minimal, since the magnets are very close to the enclosure wall; therefore, "d" is taken to be 0.5 ft., which is the outer surface of the imaginary iron cylinder causing the beam loss.

Given the single-pulse worst-case dose per proton $H[\frac{mrem}{p}]$ from the Malensek equation, and the TLM response for a given distance from the beamline using Equation 1, the maximum hourly effective dose rate is computed using the following relationship:

$$D_{max}[\frac{mrem}{hour}] = TLM_{trip}[\frac{nC}{min.}]*TLM^{-1}_{response}[\frac{p}{nC}]*H[\frac{mrem}{p}]*60[\frac{min.}{hour}]. \tag{4}$$

Equation 4 conservatively assumes that there are no other interlocked radiation detectors aside from the TLM protecting an area, and that beam loss occurs such that the maximum TLM response is generated just below the trip point.

Summary of Results

Figure 3 summarizes the maximum hourly dose rate and single-pulse accident dose for weak points in the transverse shielding along the length of Switchyard, as well as each TLM's accident condition response. The shielding thickness is measured in "equivalent feet of dirt" ("e.f.d") and are taken from the Switchyard Shielding Assessment,[7] which represent the minimum amount of transverse shielding at given stations along the line. TLM trip levels and distances to the beamline have been adjusted so the calculated doses correspond with desired occupancy classifications once the IERC building is complete.

Beam energy (GeV):		120			Beam intensity (ppp):		1.30E+13				
Detector	Station	Location	Shielding thickness between TLM and beamline (e.f.d.)	Radial distance in air from TLM to beamline (ft.)	TLM Trip level (nC/min)	TLM Response (nC/p)	Min. Transverse Shielding (e.f.d.)	Max. continuous dose rate (mrem/hr)	Maximum tolerable beam loss	Single-pulse accident dose (mrem)	Single-pulse accident TLM response (nC)
TLM1	200	Transfer Hall	0	2.75	2000	1.12E-08	20	5.96	1.38%	7.21	145,220
	300	Trans. Hall Ext.					20.1	5.57	1.38%	6.74	145,220
	400	Encl. B					22.4	1.16	1.38%	1.41	145,220
	600	Encl. B					22	1.53	1.38%	1.85	145,220
TLM2	1000	Encl. C	0	5	2000	3.38E-09	22	5.04	4.55%	1.85	43,929
	1280	Road D					20.5	14.01	4.55%	5.13	43,929

Figure 3. Summary of dose calculations for each TLM distance-to-beamline and trip limit. Both continuous losses and single-pulse accident condition are considered for weak-points in transverse shielding along Switchyard co linear with the IERC project.

Conclusion

Trip levels and required distance from the beamline have been estimated for two of the three proposed TLM detectors in Switchyard. These numbers provide enough protection for the desired occupancy classification outside each section of beamline while allowing for reasonable operational beam loss. A beam-on radiation study will provide a calibration between TLM response and effective dose as measured outside the enclosure, thereby testing the estimated numbers in this paper.

References

1. Sienkiewicz, K. New Lab Building Passes DOE Milestone. Fermi News, http://news.fnal.gov/2017/04/new-lab-building-passes-doe-milestone/ (2017).
2. Leveling, T. Total Loss Monitor Radiation Safety System. AD Beams Document 4679-v1, https://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=4679 (2014).
3. Cossairt, D. FRCM Chapter 2 - Radiological Standards. ESHQ DocDB Document 444-v15, http://esh-docdb.fnal.gov/cgi-bin/ShowDocument?docid=444 (2018).
4. Conversation with ES&H interlocks department.
5. Leveling, T., Anderson, J. & Czarapata, P. Preliminary Test Results, Dynamic Range Requirements, and TLM Electrometer Requirements for TLM Systems at Fermilab. AD Beams Document 4533-v1, https://beamdocs.fnal.gov/AD-private/DocDB/ShowDocument?docid=4533 (2014).
6. Malensek, A. Experimental Halls Methodology (1991).
7. Geelhoed, M., Higgins, W. S., Schmitt, W. & Vincent, M. P3 to Switchyard Absorber Incremental Shielding Assessment (2017).