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Expected Activation of $SmCo_5$ Beam Line Magnets

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Abstract

Reviewers have asked us to consider whether there will be residual radiation problems if we employ $SmCo_5$ for a pair of vertical bending magnets in the ANU upgrade of the MI8 Line. To explore the problem we will use a simple ratio to known materials in places where we have some experience. We will describe MARS calculations performed by Igor Rakhno using two nominal neutron spectra for iron, ferrite, and $SmCo_5$. Results of a recent residual radiation survey of the relevant portions of the MI8 line are reported and simple calculations will be carried out to relate current experience to that expected for the new vertical bend location.

MARS Calculations

The residual dose (mrem/hr) shown in the Tables below was calculated for two sample secondary neutron energy spectra incident upon a 30 cm long x 20 cm diameter cylinder of the specified material. The expected spallation spectrum was simulated as 1/E while a fast neutron spectrum was simulated as $\exp(-E/E_c)$. The normalization was performed for neutron flux previously calculated around the Main Injector H304 trim magnet, $\approx 3.3\times10^7$ neutron/(cm^2 sec). It corresponds to 1.25×10^{12} proton/sec interaction rate for the MI primary collimator. The rates are at the surface of the cylinder at the longitudinal center.

With a fast neutron spectrum, one predicts a much lower residual radiation level but a much higher ratio of $SmCo_5$ to Iron or Ferrite. The more relevant 1/E spectrum as normalized in this calculation shows a much higher residual radiation level but the ratio to iron (yoke) or ferrite ($Sr0_6Fe_2O_3$) is very modest. As a check of the reasonableness of the calculation, we note that the ratio of Ferrite/Iron is near their ratio of densities. We will apply ratios from these tables to predict the residual radiation for the proposed magnet.

Table 1: MARS Calculation of Residual Radiation with Fast Neutron Spectrum

Material	30 day irradiation + 1 day cooling		5 yr irradiation + 1 day cooling
Yoke	1.7		11
$SmCo_5$	32		120
$SrO_6Fe_2O_3$	1.1		4.2
SmCo5 / Yoke	18.8		10.9
$SmCo_5$/ ferrite	29		28.6

Material	30 day irradiation + 1 day cooling	100 day irradiation + 4 hr cooling	5 yr irradiation + 1 day cooling
Yoke	**1400**	**2450**	**2800**
$SmCo_5$	**3200**	**5650**	**7300**
SrO_6Fe_2O	**790**	**1350**	**1460**
$SmCo_5$/ Yoke	**2.29**	**2.31**	**2.61**
$SmCo_5$/ ferrite	**4.05**	**4.19**	**5**

Table 2: MARS Calculation of Residual Radiation with Spallation Neutron Spectrum

Magnet Design Features

The magnet which has been designed for the vertical bend downstream of Q848 to direct protons from the MI8 line up toward the Recycler Ring level is the PDS design. A 1" thick return yoke (supported by box beams) is used to hold 1/2" thick permanent magnet bricks. A thin, shaped pole tip is held to the yoke by aluminum bars to define a 2" aperture. For our estimate of residual radiation, we compare this to the PDG gradient dipoles in the MI8 Line which have 1" ferrite bricks and thicker poles. We will assume that they are quite similar in the expected exposure to radiation and the actual material in the PDS is less. If we take them to be comparable, we are being conservative.

Expected Radiation

Below we will show the results for a residual radiation survey of the downstream portion of the MI8 Line which includes the region where the PDS dipoles will be located. Under typical, well-tuned operation, we will experience very low losses in this line. Losses have not been carefully limited to the extent that would be possible with ordinary tuning effort. Nevertheless, there are only isolated points where residual radiation levels are higher than 20 mR/hr. If we take 20 mR/hr as a prudent upper limit, one then would expect to calculate an enhancement for the PDS magnet due to the $SmCo_5$. The realistic enhancement would likely be less than times three, taken from the 1/E spectrum calculations. A more extreme case would be using the times 20 for the fast neutron spectrum ratio for 30 day irradiation whereas longer irradiation produces an enhancement of times 11. Noting that the $SmCo_5$ is only about 1/3 of the cross section would make a times 20 enhancement become only times 7 or a times 3 enhancement in the permanent magnet material become times 2 for the PDS magnet. So a very conservative estimate would suggest that we might see 7 x 20 = 140 mR/hr at the upstream face of one PDS magnet with a more realistic estimate being 40 mR/hr. At the expected higher rates from Booster for operation in the NOVA era (2.2/1.3 = 1.7) we could also increase our prediction by that factor.

Recommendation

The enhanced residual radiation due to the Co in the magnet is a potential problem. The large aperture of the MI8 line permits operation with low losses. Without any strong measures, we have achieved low residual radiation in the existing line. The residual radiation at the location where this magnet is to be placed is very low (not recorded). By placing strong loss limits on readings from a suitably placed Beam Loss Monitor (BLM) one can expect to be able to avoid significant activation of these PDS magnets. Were we to experience the levels described above, it would impose little operational problems.

Appendix A – Observed Radiation Levels in the MI8 Line

A survey for residual radiation was carried out in the downstream portion of the MI8 line on 2 December 2009. The area covered was limited by only including the region associated with using Main Injector keys for access. A gate into the MI8 Line radiation area is at the upstream end of this survey

Radiation measurement in MI Portion of the MI8 Line
Measurements on 2 December 2009 at about 10AM BC Brown, K Seiya
Beam off at 5:45 AM so cool down was about 4 hours
Measurements are on contact with top of beam pipe unless otherwise noted.

Location	ResRadiation milliRem/hr	Comment
US 842.3	50	
US 843.1	0.66	
US 843.3	8	
US 844.1	0.9	
US 844.4	0.78	
US 845.1	8	
DS 847.8	12	
DS 849.4	16	
US trim VT849	70	Elliptical beam pipe rotated w/ 2â€H or Ap
DS Q849	30	
US 849.2	10	
DS 849.2	4	
US HT850	5	
DS HT850	3	
DS Q850	4	
DS 850.2 Top	24	
DS 850.2 Bottom	40	
DS 850.2 Aisle	35	
DS 850.2 Wall	30	
US 850.3	28	
DS 850.3	10	
US BNB Dipole	10	
DS BNB Dipole	0.5	
Beam Pipe DS	1	Half way to Q852
Beam Pipe DS	0.8	Most of way to Q852
US Q852	12	
DS Q852	7	
DS HT852	6	
Beam Pipe DS	0.95	
Beam Pipe DS	0.7	

Appendix B – Recycler Ring Magnets Have No Measurable Enhanced Activation

The Recycler Ring optics required addition of three permanent magnet sextupoles in each of two locations. We surveyed these magnets and nearby magnets to see if an enhanced residual radiation could be measured due the $SmCo_5$ used in these magnets. We used the ROTEM survey meter so we had sufficient sensitivity to have seen any large enhancement. We observed only very low residual radiation, as expected. Any enhancement due to different materials is masked by the geometry of the loss patterns

Measurements near Recycler Ring Sextupole Magnets
Measurements on 2 December 2009 BCBrown, K Seiya
These magnets are excited by SmCo5. All see very little activation.
Examined to see if there was enhanced activation compared for adjacent ferrite magnets

Location	Magnet #	ResRadiation mR/hr
213	Sextupole	0.60
213	VDC	0.70
214	Sextupole	0.20
214	Dipole Trim	0.17
214	RGF075	0.10
215	Sextupole	1.20
215	RGD081	1.10
215	MGD004	1.20
327	Sextupole	1.55
327	RGD099	1.25
328	Sextupole	1.03
328	RDF113	1.00
329	Sextupole	0.78
329	RGD013	0.80