MIPP Hadron Calorimeter–Memo
27 April 2003
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Estimate of Radiation Damage to the MIPP Hadronic Calorimeter

We estimate the total radiation damage to the hadronic calorimeter using a simple back-of-the-envelope calculation and then a slightly more sophisticated approach. Given that our knowledge of radiation resistance of any particular scintillator, waveshifter, fluence combination is poor, a more exact calculation would not be worth the trouble. Both estimates give similar results and both calculations show that there should be only a no effect, although we are getting close to where some small damage might become evident. Our assumptions are:

1. The number of particles incident on the calorimeter is 1.33×10^6 spills$\cdot125\times10^3$ particles/spill = 1.66×10^{11} particles [1]. Note that we neglect particles absorbed in the target.
2. All particles have a momentum of 120 GeV/c, clearly an overestimate.
3. The beam area at the calorimeter is 12.3 cm^2. This comes from the following argument:
   (a) The beam at the target is 1 cm in radius.
   (b) The calorimeter is 80′ or 2438 cm downstream of the target.
   (c) The beam is diverging with an angle of 0.4 mrad: $r_{\rm tgt} + 2438\ {\rm cm}\cdot0.4\times10^{-3} = 1.98$ cm.

   Note that we have neglected any spreading of the beam due to the action of the spectrometer magnets.

The total flux at the calorimeter is then:

$$f = 1.66\times10^{11}/12.3\ {\rm cm}^2 = 1.35\times10^{10}\ {\rm cm}^{-2}.$$

The energy deposited in the scintillator by the hadronic shower is

$$120\ {\rm GeV}\times0.0363 = 4.36\ {\rm GeV},$$

where 0.0363 is the sampling fraction of the calorimeter. Assuming that the energy is deposited uniformly in depth in the first six interaction lengths, or roughly 40 layers, then the energy deposited per cm of scintillator per 120 GeV/c particle is

$$\frac{120\ {\rm GeV}\times0.0363}{40\ {\rm layers}\times0.50\ {\rm cm}} = 0.218\ {\rm GeV/cm}.$$

Over the course of the run the energy per layer of scintillator is

$$1.35\times10^{10}\ {\rm cm}^{-2}\cdot0.218\ {\rm GeV/cm} = 2.84\times10^9\ {\rm GeV/cm}^3.$$

Converting to Gy (J/kg, or 100 Rad) gives:

$$2.88\times10^9\ \mathrm{GeV/cm^3}\cdot\frac{10^9\ \mathrm{eV/GeV}\cdot1.602\times10^{-19}\ \mathrm{J/eV}}{1.03\times10^{-3}\ \mathrm{kg/cm^3}} = 457\ \mathrm{Gy}.$$

A slightly more sophisticated calculation goes as follows. The maximum dose deposited in a lead calorimeter has been simulated in [2] and is $3.8\times10^{-10}p^{0.885}$ Gy/incident particle/cm^2. Over the course of the experiment this corresponds to

$$120^{0.885}\cdot1.35\times10^{10}\mathrm{cm}^{-2}\cdot3.8\times10^{-10} = 355\ \mathrm{Gy}.$$

This result is consistent with our back-of-the-envelope number.

A word of caution. Both calculations assume that the flux over the calorimeter is uniform and is at least of the same lateral extent as the hadronic shower itself. This is clearly not the case and hence these results represent an overestimate. Also, the shower's energy is not uniformly deposited in depth, as we have assumed here. Note that the radiation dose from a year and a half of running of *HyperCP* was much less than that predicted here, so we have not included the dose from that experiment.

Where do we expect harm to occur? The calorimeter is composed of Kuraray SCSN-81 PS scintillator read out with Bicron single-clad BCF-92 waveshifting fibers. Hence it is fairly robust. Although much research on radiation resistance to scintillators has been done the past fifteen years or so, our understanding of the problem is still incomplete and predictions are quite sensitive to a variety of factors. Nevertheless, it has been fairly well determined that scintillators such as SCSN-81 do not show any damage a doses less than 1,000 Gy, although they are rendered essentially useless at doses greater than 10,000 Gy [3]. So we expect to see no signs of damage if the total proton budget is indeed that assumed here.

References

[1] Email from Raja, April 2, 2003.

[2] N.V. Mokhov, Inclusive Simulation of Hadronic and Electromagnetic Cascades in the SSC Components, SSC-SR-1033, June 10, 1988.

[3] A. Byon-Wagner, Radiat. Phys. Chem. 45, 263 (1993).