Radiation Load Estimate for STAR water cooling Pipes

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Introduction

This document will calculate a rather crude estimate for the radiation load that one expects at the inner radius of the STAR TPC anode plane wheel. The purpose of this estimate is to assist the STAR conventional systems manager, B.Miller, in selecting an appropriate water tube material for routing cooling water around the STAR detector. The estimate will be given for the inner radius of the TPC anode plane wheel, at a radius of 50 cm from the RHIC beam line.

The sources of radiation that will be included in this estimate are:

1.) Beam-Beam interactions
2.) Machine "Halo"
3.) Beam gas interactions in the straight sections of the accelerator between Q3 and Q4.
4.) Beam gas interactions in the vacuum pipe that spans the interaction hall.

Radiation load Estimate from Beam-Beam interactions.

The direct hadron flux was estimated by W.B.Christie for AuAu running. The result[1], at a radius of 5 cm from the beam line, was that one expects ~875/cm^2-sec. If one assumes that one machine year is ~10^7 sec., one calculates that the integrated flux, in one years time is ~ 9 x 10^9 /cm^2-yr. Assuming that all of these particles are minimum ionizing (which will lead to a slight under estimate) one calculates that the total energy deposited in material at the 5 cm radius is:

$$(9 \times 10^9 \text{ /cm}^2\text{-yr})(1.73 \text{ MeV/gm-cm}^2) = 1.56 \times 10^{10} \text{ MeV/gm-yr}$$

Dividing this integrated energy deposition per year by the energy per gram for a rad, one calculates:

$$(1.56 \times 10^{10} \text{ MeV/gm-yr})/(6.24 \times 10^7 \text{ MeV/gm}) = 250 \text{ rads/yr (at 5 cm radius)}$$

To extrapolate to the radiation at the inner radius of the TPC wheel one assumes that the pseudorapidity density is fairly constant (out to $\eta \sim \pm 2$) and that the radiation falls off as $1/R^2$. This leads to a radiation dose per year of:

$$((1/50^2)/(1/5^2))(250 \text{ rads/yr}) = 2.5 \text{ rads/yr}$$

For the radiation load due to beam beam interactions when running with protons I'll use the values calculated by A.Stevens[2]. Alan found that the radiation due to 100 GeV protons was essentially equal to the load for AuAu. He found that the radiation load when

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[1]Charged and Neutral Particle Fluxes in Silicon Vertex Tracking Detector. W.B.Christie, STAR Note #15 (1991).
[2]Estimation of the Radiation Environment Near the Interaction Vertex from Beam-Beam Collisions in RHIC. A.Stevens. RHIC Det. Note#11 (1993).

running with 250 GeV proton beams was higher by about a factor of three. This would give a radiation load at the inner radius of the TPC wheel of ~8 rads/year.

Radiation load Estimate from machine Halo

To calculate the radiation load due to machine halo I'll again start with some earlier calculations of A. Stevens[3]. The primary source of machine Halo is due to Au ions that scatter out of the primary collimators, travel along a perturbed orbit down to the triplet set of Quadrupole magnets just upstream of an interaction region, and then impact the side of the beam tube. The estimated particle fluence per cm^2 in the interaction hall, per Au interaction in the triplet quads, at a radius of 50 cm from the beam line is about $2 \times 10^{-3}/cm^2$ - Au interaction. A rough upper estimate on the rate of Au interactions in the triplet Quads is 1.5×10^4/sec. Multiplying this out one calculates that the fluence per cm^2 in the Hall at a radius of 50 cm is:

$(2 \times 10^{-3}/cm^2\text{-Au int.})(1.5 \times 10^4 \text{ Au Int./sec}) = 30 \text{ particles}/cm^2\text{-sec.}$

Multiplying by the canonical 10^7 seconds in a machine year, and assuming that all of these particles are minimum ionizing, one calculates a radiation load of:

$(30 \text{ particles}/cm^2\text{-sec.})(10^7 \text{ sec/yr})(1.73 \text{ MeV/gm-cm}^2)/(6.24 \times 10^7 \text{ MeV/gm})$

$= 8.3 \text{ rads/yr}$

When Alan estimated these particle fluences he used a thin detector in the interaction hall. For a detector like STAR, which has a thick iron magnet poletip between the source of these halo particles and the water hoses of interest in this report, one should account in some way for the multiplying effect that one gets due to the incident particles starting hadronic showers in the material. I'll use a multiplication factor of three to approximate for this showering. One thus gets an estimate of:

~25 rads per yr due to the machine Halo

Radiation load Estimate from Beam gas Interactions

I'll break the estimation of the radiation load due to beam gas interactions into two parts. One part will deal with the beam gas interactions in the long straight sections of beam pipe just upstream of the triplet Quads. The second part will deal with the load due to beam gas interactions in the beam pipe that is within the confines of the interaction Hall itself.

Beam gas interactions in upstream vacuum pipe sections

For the beam gas interactions in the long straight sections of pipe upstream of the triplet Quads I'll again refer to some earlier calculations of A. Stevens[3]. Alan's simulation results indicate that at a radius of 50 cm one expects ~0.02 particles/cm^2-beam-gas Int. For an estimate of the beam-gas interaction rate Alan uses a rate calculation of W.Christie[4]. This calculation indicates that one can expect about 0.6 beam gas interactions per second per cm of pipe. The straight sections upstream from the Quads are ~3500 cm

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[3]Estimate of Beam-Gas Background Rates from Upstream Source Locations in a Simple Detector. A.Stevens, RHIC Det. Note#22 (1996).

[4]Simulation of Beam Gas Backgrounds in the STAR Detector, W.Christie, 2nd Workshop on Machine Backgrounds at RHIC, edited by S.White (1996).

long. One must account for the interactions in these long pipes on each side of the IR. One thus calculates a particle fluence per cm^2 per second of:

(0.02 particles/cm^2-beam-gas Int.)(0.6 beam-gas Int./cm-sec)(7000 cm) = 84 /cm^2-sec

To estimate the radiation load per year I again multiply by the number of seconds in a machine year, assume that all of these particles are minimum ionizing, and divide by the energy deposition per rad to obtain:

(84 /cm^2-sec)(10^7 sec/yr)(1.73 MeV/gm-cm^2)/(6.24 x 10^7 MeV/gm) = 23.3 rads/yr

Multiplying this result by a factor of three to account for hadronic showering in the iron poletips of the STAR magnet one obtains about 70 rads/yr.

Beam gas interactions in the vacuum pipe that spans the interaction hall

The second part of the beam-gas radiation load comes from the interactions that take place in the beam pipe that traverses the IR Hall. Referring back to W.Christie's calculation of the beam-gas interaction rate in ref. 4, one expects an interaction rate (for Au beams) of about 0.6 Int./cm-sec. in each direction. Also shown in ref.4 is an angular distribution for the charge one particles produced in these Au-p collisions (events and distributions provided by R.Longacre). As one would expect, there is a strong kinematic focusing of the particles resulting from these interactions at small production angles. As a result of this kinematic focusing, only particles from interactions that are within ~5 m of the DX magnets, with angles greater than ~ 0.4° relative to the Z axis, and traveling towards the center of the IR have a fair probability to make it out to the radius of the beam pipe and have an interaction. It is the particles produced in these interactions in the beam pipe that will give some radiation load to the detector itself.

R. Longacre determined the mean momentum of these particles which result from the pAu (beam-gas) interactions and have production angles of ~0.4°, and found that they have a mean momentum of ~66 GeV/c. Ron then produced some minimum bias pFe events for me with an incoming proton momentum of 66 GeV/c to allow me to make an estimate of what the radiation load would be due to these interactions in the beampipe. Using the momenta of the charged particles in these pFe events I projected the particles (straight line) out to a radius of 50 cm. The top plot in Fig. 1 shows the number of hits per 100 cm^2 area on the surface of a cylinder with a radius of 50 cm versus the Z position along the cylinder. The data in the plot is integrated over the 20 events. The bottom plot in Fig.1 shows a histogram of the distribution of

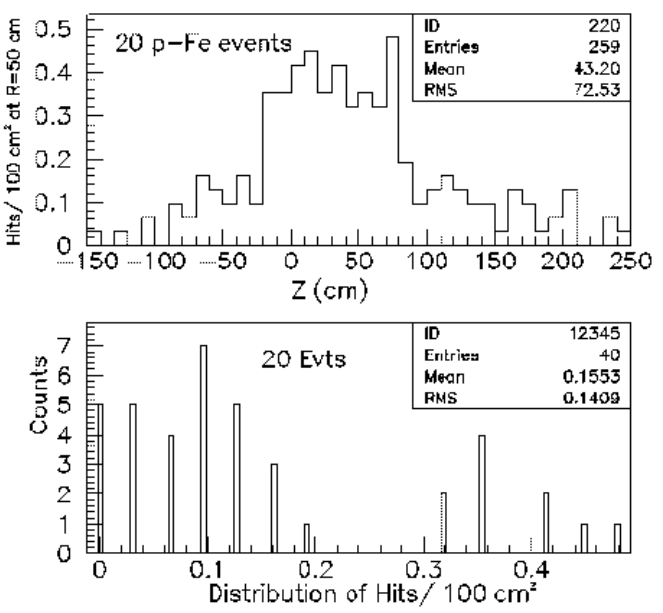

Figure 1. Top plot shows the distribution of the number of hits/100cm^2 vs Z. The bottom plot shows the distribution for the number of hits/100 cm^2.

hits/100 cm^2 (i.e. a projection of the top plot onto the y axis).

From this lower plot in Fig. 1 one sees that the mean number of hits/100 cm^2, averaged over 4 m, is ~0.16. On average, a beam gas (pAu) collision yields ~3 particles with angles ≥0.4°. If one uses these averages to calculate the number of charged particles, per cm^2, per event, one gets:

$$((0.16 \text{ hits}/100 \text{ cm}^2 - 20 \text{ evts})(1/100)(1/20)(3 \text{ evt}^{-1}) \sim 2.4 \times 10^{-4} \text{ cm}^{-2} \text{ evt}^{-1}$$

Multiplying this value times the number of beam gas events per second expected in both directions, within 5 m of the DX magnets one get a value of:

$$(0.6 \text{ pAu int./cm})(2 \text{ rings})(500 \text{ cm})(2.4 \times 10^{-4} \text{ cm}^{-2} \text{ evt}^{-1}) = 0.14 \text{ charged part.} \cdot \text{cm}^{-1}\text{sec}^{-1}$$

multiplying this value by the number of seconds in a RHIC year, by the energy deposited per particle (assuming min. ionizing), and dividing by the energy deposited per rad, one gets a yearly radiation load of:

$$(0.14 \text{ charged part.} \cdot \text{cm}^{-1}\text{sec}^{-1})(10^7 \text{ sec/yr})(1.73 \text{ MeV/gm-cm}^2)/(6.24 \times 10^7 \text{ MeV/gm})$$
$$= 0.04 \text{ rads/yr}$$

It appears that the radiation load from beam gas interactions in the beampipe that spans the interaction region will not be a problem.

Summary

The radiation sources and estimated radiation loads are given in Table 1.

Table 1. Estimated Radiation Loads

Source	Estimated Radiation Load (rads/yr)
Beam Beam Interactions	8
Machine Halo	25
Beam-gas upstream of IR	70
Beam-gas in IR pipe	0.04
TOTAL	103

The reader should keep in mind that there are many assumptions and uncertainties in various parts of the radiation load estimates calculated in this document, and referenced in other documents. As long as any material being considered on the wheel of the TPC can stand radiation loads of 1 krad/yr or more one should be all right.