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Estimate of ^{3}H Activity Concentration in Cooling Water Systems Due to Beam-Beam Interactions at RHIC

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I. Method of Estimation

Consider an activating flux of ϕ hadrons per cm^2 per second incident on a water "target" of length l, where l is "short" in comparison to an interaction length. The number of radioisotopes created per unit area per second (of a specific type) is:

$$\frac{\phi l}{\lambda} \times P$$

Where λ is the interaction length and P is the number of radioisotopes per interaction. Multiplying by the target area *A* normal to the incoming flux obtains the number per second. However, the number per second per unit *volume* divides away the *lA* term to give simply:

$$\frac{\phi}{\lambda} \times P$$

It is assumed here that the quantity of interest *is* per unit volume, i.e., a *concentration.*

For production of ^{3}H from spallation in water (from the O in water), a reasonable approximation for P is .07 per "CASIM star", i.e., per interaction of any hadron above about 50 MeV.

Formally one can write down the number of ^{3}H atoms per unit volume per second created in a given cooling system as:

$$(1) \qquad \frac{P}{\lambda V} \int \phi(x,y,z)\,dV$$

where V is the volume of the system.

Now the flux ϕ from beam-beam interactions manifestly *starts off* as a $1/R^2$ falloff since the source is a point. However, much can happen between the source and the target – the point x,y,z somewhere in the cooling system V. For very large angles, the energy spectrum is rather soft, so that if material exists between the vertex and the target the flux will decrease exponentially through (perhaps thick) shielding material. On the other hand, for very energetic hadrons, some amount of shield will increase the flux > 50 MeV (so called "build-up") before it begins to decrease. Furthermore, the presence of magnetic fields can make a difference in some cases, although this should be a small effect in comparison to the presence of significant amount

of bulk matter. The only way to get a "good" estimate is to couple a hadron cascade code to an event generator and simulate at least the positions of the water "close" to the vertex in some detail. This would be a major undertaking.

In this note a very crude approximation is made, namely presence of the surrounding material (and field) is simply ignored. In most geometries, although certainly not all, an examination of the material distribution in relation to the routing of the water pipes would result in the expectation that this approximation would overestimate the radioisotope production.

The source term taken is one that gives good agreement with the Fritioff study by Bill Christie.[1] Specifically, the expression

$$\phi_E = \frac{\frac{dN}{d\eta}}{2\pi R_T^2} \qquad (2)$$

Where ϕ_E is the fluence per interaction, η is the pseudo-rapidity, and R_T the transverse radius given a $dN/d\eta$ value of 250 for abs(η) < 2 and going linearly downward to 0 at abs(η) = 6[2] gives good agreement (about 800 hadrons per cm^2 per second at R_T = 5 cm. and design luminosity)[3] with Ref. [1]

II. Results

Physicists or engineers provided drawings or descriptions of the location/routing in the (multiple) water systems within each detector. This allows evaluation of Eqn. (1) with a flux term given by Eqn. (2). The results, converted to activity concentrations, are shown in Table 1 below.

Table 1. Estimated ^{3}H Activity Concentrations

System	PCi/l for 1 Year Running at Design *L*	Comment
STAR Magnet	< 0.23	Main Coils Only
STAR SVT	4.1	
STAR TPC	0.20	
STAR Electronics	< .09	Closest Point Only
PHENIX Magnet	0.18	
PHENIX MVD***	2.2	(Capacity 4.1 gallons)
BRAHMS Magnet	< 0.40	η = 0 at all points
PHOBOS Magnet PHOBOS Silicon	1.1 21.8	

***Not actually water: FC-25 treated as if it were water.

In this table, a year is 10^7 seconds at the design luminosity (2×10^{26} cm^{-2}sec^{-1}). In two of the cases where upper limits are indicated, the STAR magnet and electronics systems, water

locations in piping and reservoirs far removed from the interaction point were ignored. In the case of BRAHMS, most of the actual locations are at high η, but the configuration is such that significant build-up would be likely. The higher $\eta = 0$ value for the flux was taken to compensate for this possibility.

The highest values in the table are for vertex detectors as is expected. Since PHENIX is the only detector which, as far as is now known, plans extensive running at high luminosity, the most obvious concern would be for the PHENIX MVD detector where 10 years at $\times$ 10 luminosity would be expected to produce ~ 200 pCi/l. (Ten years at normal luminosity obtains the same value in the case of the PHOBOS Silicon system, but the lifetime of this detector is not currently expected to be that long.) Although some "safety factor" should be applied to this number, to account for activity induced by beam-gas interactions, for example, the nominal value is quite far from the Laboratory's Administrative Control Level of 10,000 pCi/l which is half the drinking water standard.

Two water systems associated with the rf cavities are also present within the RHIC tunnel. Here, the dominant source of activation is expected to be beam-gas interactions rather than beam-beam. In background studies to date however, the flux from beam-gas interactions, assuming 10^{-9} Torr in the warm sections, has been found to be comparable to beam-beam flux at standard luminosity.[4] The same approximation was therefore applied to these systems as used in the BRAHMS detector, i.e., the maximum (no material) beam-beam $\eta = 0$ flux as a source. The results for the acceleration and storage systems were, respectively, 0.35 pCi/l per year and 0.58 pCi/l per year.

References/Footnotes

1. W. B. Christie, "Charged and Neutral Particle Fluxes in Silicon Vertex Tracking (SVT) Detector," RHIC/STAR Collaboration Note #15 (1991).

2. The number per cm^2 actually falls exponentially to much larger η values. An η of 6 is about 0.28 degrees with respect to the beam direction.

3. ϕ_E is simply hadrons per cm^2 per (minimum bias) interaction. The flux ϕ is this quantity multiplied by the luminosity.

4. W. B. Christie, "1st Pass Estimate of Detector Backgrounds at RHIC," Proceedings of 2nd Workshop Machine Backgrounds at RHIC, S. White Ed., June, 1996. A.J. Stevens, "Estimate of Beam-Gas Background Rates from Upstream Source Locations in a Simple Detector," RHIC/DET Note 22 (1996).