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**RHIC PROJECT**

Brookhaven National Laboratory

# Radiation Levels at Floor Level from Local Beam Loss in RHIC

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## I. Introduction

This note reports order-of-magnitude calculations of the radiation level on the floor of the RHIC tunnel due to certain classes of uncontrolled beam loss, described in the next section, and beam-gas interactions. The motivation for these calculation is the desirability of locating electronics at the floor level[1].

## II. Sources of Beam Loss

Anticipated sources of beam loss are described in the Conceptual Design Report (CDR) and elsewhere[2]. The vast majority of these losses will occur at the internal dump or some limiting aperture collimator or at a crossing point. The regions immediately dounstream of these locations are relative "hot-spots" - especially at the dump location - and are NOT considered here. Most of the lattice, including the arcs and intersection regions where the dump and/or collimators are not present, are relatively quiet. Nevertheless, some probability of beam loss exists due to errors in beam manipulation, hardware failures, etc. If such failures are slow compared to the response time of the beam abort system (~500 microsec.) but fast compared to the cryogenic system's ability to transport heat from the magnet coils, then the magnet on which the beam loss occurs will quench and the vast majority of the beam will be extracted on the internal dump. Therefore the magnets themselves, for this class of "fast" loss, serve as sensitive (quench threshold ~ 2 mJ/g) beam loss monitors which limit the radiation levels in the immediate vicinity of the beam loss. Another radiation source which will be estimated below are beam-gas interactions. This loss, by definition "slow", is significant only in the warm insertion regions where the gas pressure is $5 \times 10^{-10}$ Torr[3].

## III. Loss on a Magnet

To calculate energy deposition density, the hadron cascade program CASIM[4] was used. A magnet, taken as a 2.4 m long quadrupole, is approximated the following azimuthally symmetric materials:

| | | |
|---|---|---|
| 3.645 cm. < R < 3.810 cm. | Fe | (vac. pipe) |
| 3.810 cm. < R < 4.00 cm. | Helium | |
| 4.00 cm. < R < 5.00 cm. | Fe with rho=6g/cc | (coil approx.) |
| 5.00 cm < R < 13 cm. | Fe | (yoke) |
| 13 cm. < R < 32 cm. | Fe with rho=.15g/cc | (cryostat approx.) |

A 250 GeV/c proton beam[5] with a lateral spread of +/- 0.12 cm. is forced to interact at the midpoint (radially) of the vacuum pipe and uniformly (longitudinally) along the length of the magnet. The lateral spread is about the 2 sigma value for a "typical" beta value (30 m) and the uniform longitudinal loss is intended to simulate a "scraping" beam loss. The maximum energy deposition density in the coil region, averaged over radius but highly restricted in azimuth, is about 0.015 GeV per gram per interacting proton. At 1 meter lateral distance from beam center, approximately the floor level, the maximum energy density in silicon is found to be $1.2 \times 10^{-6}$ GeV per gram per interacting proton.

Assuming a "fast loss" quench level of 2 mJ/g, approximately $10^9$ interacting protons result in a quench. This gives 0.02 rad (Si) at the floor level. Since a given magnet cannot quench very many times per year, the annual radiation burden for this type of loss is very small.

## IV. Very Fast and Very Slow Beam Loss

If beam loss if fast compared to the 500 microsecond abort system response time (~40 revolutions), the entire beam could - in principle - be lost on some magnet. This extraordinarily unlikely event would destroy accelerator components. Assuming $2.28 \times 10^{13}$ protons (4 times day-1 intensity), the calculation above would predict about 450 rad at the tunnel floor level.

Of more concern is very slow loss where a magnet does not quench, but whose effects integrate over time. Any process which slowly blows up the beam amplitude whould result in loss on either the internal dump or a limiting aperture collimator. It is not possible to calculate exceptions to this qualitative statement without detailed knowledge of the accelerator and the loss mechanisms. A crude argument sets the scale for such loss: Suppose 10% of the $2.28 \times 10^{13}$ protons at 250 GeV are "lost" in 10 hours. Suppose further that 90% of this loss occurs where it is supposed to and 10% goes "elsewhere". If the "typical" location in the "elsewhere" part of the lattice sees a local loss 1% of this 10%, then about 25 rad per year exists at the floor at this location for $2 \times 10^7$ seconds per year, a level not likely to be of great concern. This guesstimate is clearly not to be taken seriously, but is made here only for "completeness" in some crude sense.

## V. Beam-gas Interactions

The warm sections of the insertions are assumed to have a vacuum level of $5 \times 10^{-10}$ Torr. The RHIC gas mixture (1986 CDR, page 117) has an effective atomic number of ~3.55. Scaling air density (A~14) by this number gives a mass density at $5 \times 10^{-10}$ Torr of $\sim 20 \times 10^{-17}$ g/cc. Assuming a Au, gas (A=3.55) cross section of 2.5 barns, one derives 166 interactions per meter per second for 4 x day-1 intensity.

CASIM was again used to determine the energy density in Si at 1 m transverse distance. In this case, the geometry included approximations of Q1, Q2, and Q3. A 100 GeV/u Au ion was forced to interact with a mythical A=3.55 nucleus at R=Z=0. The resulting energy density at R=1m is shown in Fig. 1. Approximating the integral of this spectrum as $9 \times 10^{-5}$ GeV/g-ion times 20 meters and again using $2 \times 10^{7}$ sec/year, obtains 95 rads per ring per year, or about 200 rads/year.

## VI. Radiation Damage to Electronics

The subject of radiation damage to electronic equipment is complex and far beyond the scope of this note. However, it should be noted that the quantity calculated here - rads from hadron interactions - cannot be directly compared to rads from electrons or rads from reactor neutrons, and it is the latter sources which are most often used to measure the effects of radiation damage on electronic components. Shown below is a table taken from an old IASBELLE Technical Note[6] which represents a crude comparison between sources scaled to equivalent damage.

Table I

COMPARISON OF SOURCES SCALED TO EQUIVALENT DAMAGE

| | Reactor (neutrons >1 MeV) | EM Source | Accelerator Source |
|---|---|---|---|
| $n/cm^2$ > 1 MeV | $10^{13}$ | - | $\sim 2.5 \times 10^{12}$ |
| rads (CH) | $3 \times 10^{4}$ | - | - |
| rads = rads (Si) | $\sim 5 \times 10^{3}$ | $\sim 10^{6}$ | $\sim 3 \times 10^{5}$ |

An accelerator source is far less damaging per rad than a reactor source because accelerator rads contain a sizable electromagnetic component. On the other hand, an accelerator source is more damaging per hadron/$cm^2$ because the hadron spectrum is harder.

## VI. Summary

Calculations were made for the radiation level at the floor level in RHIC for uncontrolled beam loss and for beam-gas interactions. In the former case, magnet quenching is expected to trigger a beam abort and thereby limit the local radiation level at floor level to $<<1$ rad/year. Beam-gas interactions in the warm insertions may result in about 200 rad/year at 4 times day-1 beam intensity. These estimates do not apply to regions in the lattice near the dumps or limiting aperture collimators.

## VII. Footnotes/References


1. Tom Shea, private communication.

2. A.J. Stevens, "Radioisotope Production in Air and Soil in RHIC", RHIC Tech. Note No. 28, 11/2/87 (appendix A).

3. M. Harrison, private communication.

4. A. Van Ginneken, "CASIM. Program to Simulate Hadron Cascades in Bulk Matter", Fermilab FN-272, 1975. For the approximations made in considering heavy ion interactions, see A.J. Stevens, "Improvements in CASIM: Comparison with Data", AGS/AD/Tech. Note No. 296, 3/8/88.

5. The uncertainties in the calculation overwhelm the difference between protons and Au. Protons are taken for convenience here.

6. G. Bozoki,. R.S. Frankel, J.W. Humphrey, A.J. Stevens, "Radiation Resistance of Electronic Equipment", ISABELLE Tech. Note No. 111, 5/2/79.

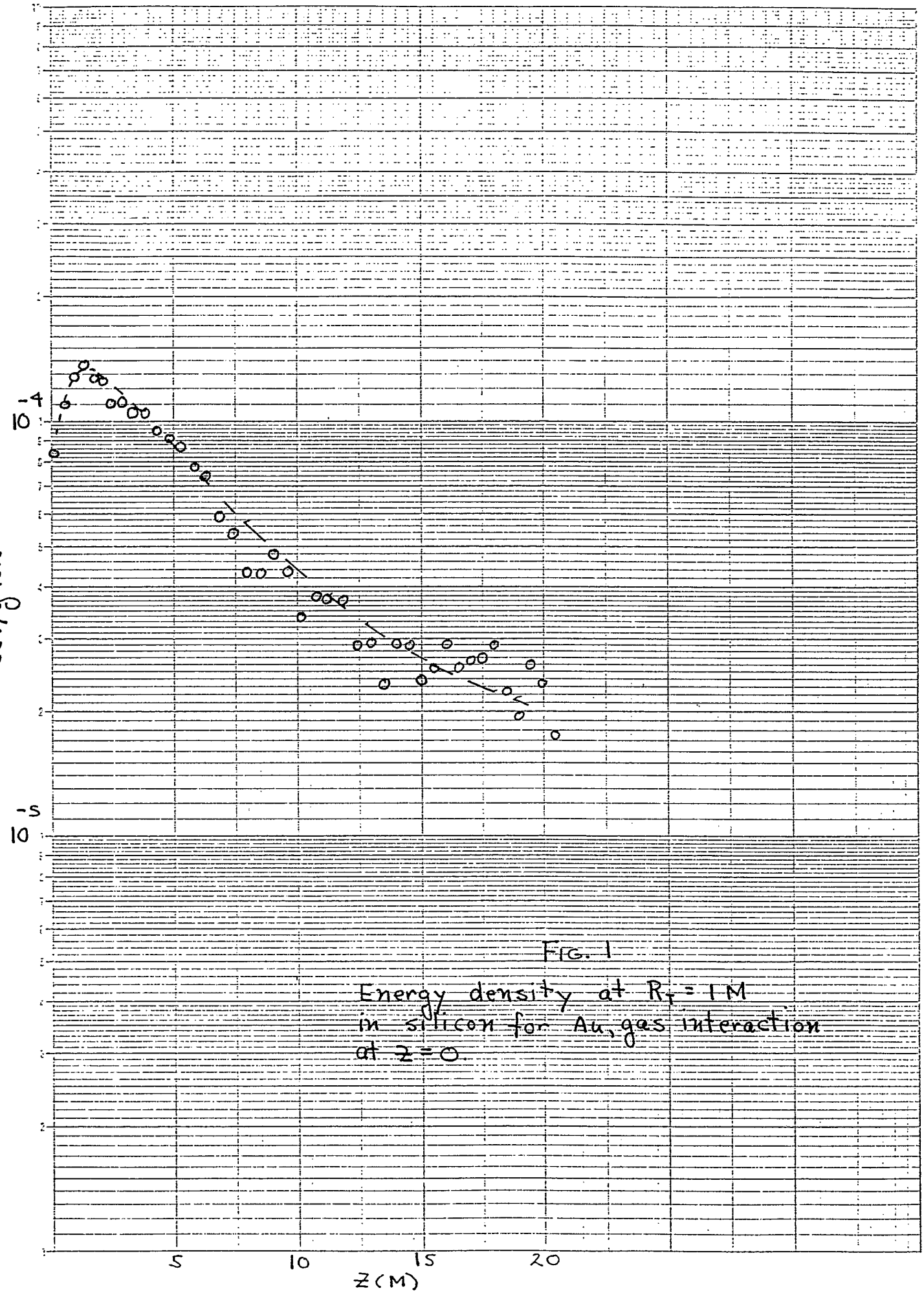


FIG. 1

Energy density at $R_T = 1$ M in silicon for Au, gas interaction at $z = 0$.