

Memo

date: September 22, 2009

Updated: October 28, 2009

to: RSC

from: D. Beavis 

subject: Low Energy Operations of AtR—Potential Soil Activation

The initial memo of Sept. 22 has been updated to reflect the changes requested by the RSC in the meeting of Sept. 31, 2009.

Two errors in the last table were also corrected which do not affect the conclusions.

The analysis for the AGS to RHIC Transfer (AtR) line conducted¹ by the RHIC Project assumed conditions for the beam parameters, integrated beam intensity, and loss locations. The radiation analysis for the transfer line can be found in reference 2. In this note the potential for soil activation along the AtR will be examined for low energy operations, which was not considered in the original analysis.

Estimates of low energy losses have been provided³ by T. Satogata. The estimate of 5% loss in the transfer line is based on operations in FY2008 with 4.6 GeV per nucleon Au beams. The losses used by the RHIC project¹ was .1% integrated over the entire transfer line and .05% at a single point. Losses are expected to increase with the decreasing energy as the transported beam fills more of the beam pipe aperture. The 5% loss estimate for 4.6 GeV/nucleon Au is expected to be conservative⁴. The approach here will be to examine how much local loss can be tolerated in a fixed location and maintain the appropriate soil activation standards. The local losses if monitored during the run can be maintained below the desired limits.

Method of Soil Activation Calculation

The soil activation has typically been estimated at C-AD facilities by calculating the flux of hadrons across the soil-tunnel interface where the flux distribution peaks. Conversion factors have been established to convert the flux per lost nucleon into concentrations of ²²Na and ³H in the soil. These are then converted into concentrations in the groundwater using a simple flushing model. The allowed BNL limit⁵ for concentration of ²²Na and ³H are 1.05*10⁶ atoms per cc and 1.85*10⁷ atoms/cc in the soil, respectively. This is 20 times lower than allowed by the EPA drinking water standard.

The number of lost nucleons times the allowed flux of hadrons ($E > 20$ MeV) per lost nucleon is $\text{Flux} * N_p = 2.1 * 10^9$ had/cm² for ²²Na and $9.87 * 10^9$ had/cm**2 for ³H when the concentrations are at the BNL limits. N_p is the maximum amount of beam that can be lost in a year at a specific location. Beam loss estimates are usually given from either experience or from estimates based on beam optics. The Flux of hadrons with energy greater than 20 MeV depends on the geometry of the shielding beam elements, and loss pattern. Usually simple assumptions are made to provide a conservative estimate.

The ²²Na concentration establishes the maximum amount of beam that can be lost in a localized location and is almost five times more restrictive than ³H. The use of ²²Na will be discussed later when recommendations are made.

Hadron Flux Estimate (E>20 MeV)

A.J. Stevens conducted⁶ a series of MCNPX calculations for protons striking a 3cm radius iron rod 1 meter long. This iron rod as placed inside an earthen tunnel with a radius of 5 ft (152.4) cm. The flux of hadrons with energies greater than 20 MeV were calculated at several depths in the soil starting at a 10 cm depth. The calculations were conducted for four beam energies. The target used for these calculations most likely produces a maximum flux since it has little self shielding and is sufficiently long to generate a substantial hadronic cascade. In this note we will use the results of the 5 GeV proton beam and scale⁷ to other energies. The flux of high energy hadrons 10 cm into the soil is $2 * 10^{-5}$ had/cm² per lost 5 GeV proton.

CASIM results for STAR densities have been used in some cases instead of the calculations from reference 6. The correction factor for going from the 47 MeV cutoff used in CASIM to the 20 MeV cutoff typically used for soil activation is ignored.

Local losses of 5 GeV nucleons should be limited to $1.05 * 10^{14}$ 5 GeV-nucleons to stay below the BNL limit for ²²Na. For Au this gives the local loss limit of:

Energy	²² Na limit on Localized lost Au ions
10.4 GeV per nucleon Au	$3.0 * 10^{11}$
5.0 GeV per nucleon Au	$5.3 * 10^{11}$
2.5 GeV per Nucleon Au	$9.3 * 10^{11}$

Transport Line

The RHIC Project assumed that 0.1% of the beam would be lost in the AtR transport with at most 0.05% in a single location. The estimated total annual localized loss when scaled to 10.4 GeV Au is $1.02 * 10^{12}$ Au ions per year. This exceeds the number above by a factor of 3-4. It should be kept in mind that the table above is for an extreme type of loss that may overestimate realistic losses by a factor of ten. A more realistic simulation will be examined latter. In addition, the RHIC Project used a conservative number for the amount of beam to be transported in AtR. FY09 operations had a total of $1.7 * 10^{16}$ 22 GeV protons transported through AtR compared to the RHIC Project estimate of $2.53 * 10^{17}$ 28 GeV protons. Presently, the maximum

annual number of protons transported in AtR is over a factor of ten lower than the assumptions used in reference 1.

We can compare the initial planned low energy operations for next year to the soil activation limits. In reference 3 the total beam loss is assumed to be a constant 5% independent of energy. This number is based on the conservative estimate of 5% for the 4.6 GeV run in FY08. It is expected to be conservative for higher energies and may or may not be conservative for lower energies. The accuracy of this 5% is being investigated. Assuming that an operational week has a 100% up- time available (as per RSC request) for running beam in AtR for RHIC then there are a total of 168 hours of beam operations per week. Assuming half the beam loss occurs in one location as in reference 1 then the following table can be created in equivalents of 10.4 GeV Au:

Beam Energy (per nucleon)	Localized 1 wk loss- Au 10.4 GeV Equivalents	Annual BNL ²²Na Limit-Au 10.4 GeV equivalents	Annual BNL ³H Limit-Au 10.4 GeV equivalents
3.85 GeV Au	1.25*10 ¹²	3.0*10 ¹¹	1.4*10 ¹²
5.75 GeV Au	2.86*10 ¹¹	3.0*10 ¹¹	1.4*10 ¹²
9 GeV Au	2.46*10 ¹¹	3.0*10 ¹¹	1.4*10 ¹²

Only limited operations at low energy would be possible unless the loss assumptions and radiation pattern are considered conservative.

Two realistic radiation patterns were simulated² in by the RHIC Project, a sparse and a dense magnet lattice. The spare lattice is an approximation of arc magnets spaced 15 meters apart and the beam striking the middle of the magnet 1 mm into the magnet iron. The dense lattice has the magnets much closer together. The CASIM star densities are given in reference 2 at the tunnel wall for both a sparse and dense lattice. The sparse lattice has a high energy particle flux about a factor of 2.5 lower than the source used above. Most of the AtR transport system has a distribution of much shorter quadrupole magnets except for the bends and the sparse lattice should be a reasonable approximation.

The table below has taken credit for this more realistic loss pattern.

Beam Energy (per nucleon)	Localized 1 wk loss- Au 10.4 GeV Equivalents	Annual BNL ²²Na Limit-Au 10.4 GeV equivalents	Annual BNL ³H Limit-Au 10.4GeV equivalents
3.85 GeV Au	5.*10 ¹¹	3.0*10 ¹¹	1.4*10 ¹²
5.75 GeV Au	1.1*10 ¹¹	3.0*10 ¹¹	1.4*10 ¹²
9 GeV Au	1.*10 ¹¹	3.0*10 ¹¹	1.4*10 ¹²

The numbers above suggest that a limited program for low energy operations can be run in the immediate future. However, if it is assumed that these numbers are conservative and a proper monitoring program for beam losses will be incorporated then the AtR should be to operate for the desired two to five weeks without any issues with soil activation.

There are locations along the AtR where the transport is either farther away or closer to the side walls of the tunnels. There are also locations where the tunnel has concrete walls and therefore there is additional reduction in the potential for soil activation. A portion of the upstream U line has a soil cap over it that was placed due to large losses in the proton transport to the V target station.

W Dump

The W beam dump is used to take beam pulses in preparing for injection into RHIC. The W beam dump has a soil cap that extends past the walls of the switching room. The flux of neutrons into the side wall can be estimated from using calculations for the E864 beam dump⁹. Using 60 cm for the thickness of the steel, 0.62 for the attenuation of the marble, and 14 feet to the concrete wall a neutron flux of 2.25×10^{-7} had/cm²/nucleon is obtained. The ²²Na BNL concentration limit would correspond to 1.2×10^{16} nucleons per year into the beam dump. In FY2009 operations⁸ 9.3×10^{14} protons were transported into the beam dump. This is more than a factor of 10 lower and does not take into account the shielding of the concrete wall.

Three removable soil samples are located near the W dump. The analysis of the removable soil samples after FY2008 operations had results¹⁰ that were below the minimum detectable level. The FY2009 results are not yet available.

The low energy running has the equivalent (at 20 GeV) of 3×10^{15} nucleons transferred per week. This is a factor of 4 below the BNL soil requirement if all the beam is placed into the W dump. If a reasonable fraction of the transported beam is placed into the beam dump then there should be no issues related to soil activation from the beam dump. If more beam is required into the dump then it may be necessary to conduct a more careful analysis. The removable soil samples can be sampled after the run.

Comments

For planning purposes it would be good to know that there is a sufficient margin of safety to allow the low energy program can be conducted next year. The BNL limits to protect the groundwater are a factor of 20 more stringent than the EPA drinking water standard. The BNL SBMS subject area provides⁵ for BNL management to provide exemptions to these more stringent standards. It is recommended that this exemption be sought for ²²Na. It is suggested that the limit be raised so that the ³H establishes that maximum allowed beam loss. This would still keep the ²²Na well below the EPA standard in the groundwater.

It is recommended that the C-AD request an exemption for low energy operations of the AtR and be allowed to go to 23.5% of the EPA limit for ²²Na and 5% of the EPA limit for ³H as estimated using the SBMS subject area.

(CK-U-FY10-AU-624)

Such an exemption would provide for many weeks of low energy operations. With effective beam loss monitoring there should be little risk in exceeding the limits for ²²Na concentrations in the groundwater.

Monitoring of the produced activity after the run with removable soil samples will provide additional assurance that the losses did not cause any areas to approach the drinking water standards. **(Ck-U-Fy10-Au-625)**

It is not recommended that capping the transfer line be considered. The use of soil caps in areas that may only marginally need them causes the ^3H concentrations in the soil to increase with time and can create decommissioning issues.

It is recommended that the C-AD request that a review be conducted to examine the appropriateness of using ^{22}Na for groundwater concentrations.

The literature suggests¹¹ the effective velocity of Na in the groundwater is much slower than the velocity of the water. Effectively, the Na concentrations have difficulty getting to any location to be an issue for drinking water. If the Na restrictions are removed then it would be expected that long low energy programs could be conducted.

An update on the loss monitor system should be provided to the RSC. The coverage and sensitivity of the loss monitor system should address how well the system can help operators keep the losses to a minimum and any potential soil activation wells well below the required standards. **(CK-U-FY10-626)**

References

1. M. Harrison and A.J. Stevens, "Beam losses in RHIC", AD/RHIC/RD-52, Jan. 1993, Appendix 8 of the RHIC SAD.
2. A.J. Stevens, "Analysis of radiation Levels Associated with Operation of the RHIC Transfer Line", AD/RHIC/RD-83, Dec. 1994, Appendix 17 of the RHIC SAD.
3. T. Satogata, "RHIC Low Energy Beam Loss Projections", Sept. 9, 2005.
4. An estimate for the FY2007 3.6 GeV run was a loss of 2%, N. Tsoupas to D. Beavis, e-mail of June 8, 2007. Both these loss estimates include the beam losses on the stripping foil in the front end of the AtR. The 1 mil tungsten stripping foil can cause 1-2% Au beam losses. These losses are monitored by two removable soil samples, which did not have levels above the minimum detectable after the FY08 run.
5. SBMS Subject Area on Accelerator Safety, "Design Practice for Known Beam-Loss Locations".
6. A.J. Stevens, "MCNPX 2.1.5 Shielding Estimates in a Simple Tunnel Geometry".
7. D. Beavis, "Extending Routine Operations of RHIC and AtR to Low Energies", August 28, 2009.
8. N. Kling, e-mail to D. Beavis on Sept. 15, 2009.
9. D. Beavis, "Dump It: Conceptual Design of E864 Beam Dump and Shield Walls", AGS/EP&S/Tech. Note 142, Oct. 1992.
10. M. VanEssendelft, e-mail to D. Beavis, May 7, 2009.
11. P.J. Gollan et. Al., "production of radioactivity in Local Soil at AGS Fast Neutrino beam", BNL-43558, Nov. 1984. The paper says "According to data from the US Geological Survey, the sodium ion velocity in BNL soil is expected to be only 1/20 the

water velocity.” No reference was given for the statement. Other FNAL paper often quote effective velocities less than 50% of the groundwater for their rock conditions.

CC:

T. Satogata

D. Phillips

W. Fischer

M. Van Essendelft

N. Tsoupas

V. Schoefer