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Memo

Date: *Sept. 9, 2014*

To: *RSC, D. Phillips A. Pendzick, H. Huang and C. Gardner*

From: *D. Beavis*

Subject: *Soil Activation and the BNL Subject Area*

The potential soil activation from proton beam losses and the subsequent leaching of radioactive products into the ground water creates concerns and limitations on the amount of protons that can be lost in a localized area for C-AD facilities. The BNL action limits and a methodology to calculate the potential for activation products in the ground water are given in the SBMS[1]. The exhibit in the accelerator safety subject area provides an outline for the methods to calculate the potential leachate and how to prevent or reduce it to acceptable levels. Several issues with the present and past exhibits on groundwater will be noted. Recommendations regarding the SBMS exhibit will be made for the committee to consider. The intent is to utilize the recommendations to address the potential for soil activation at the Booster dipole magnet at E7 for the planned proton run in FY2015.

The analysis6 of Job and Casey assumed that all cross sections were energy independent with a threshold of 50 MeV. Nearly all the ^{22}Na is produced from the spallation of Si atoms in the soil. Tritium can be produced from all the nuclei in the soil except for the hydrogen. However, the tritium cross sections can be smaller than the ^{22}Na cross sections, although some of the tritium thresholds can be lower in energy, down to 15-25 MeV. The method of their analysis is based on fundamentals and it seems be prudent to adopt that method for other facilities at BNL.

The guidance was updated in 2012. Before the update the guidance stated that the production probability from a neutron spectrum rapidly falling above 47 MeV was 0.075 tritium nuclides per inelastic interaction and 0.02 ^{22}Na nuclides per inelastic collision. The previous guidance does not reference the source of these numbers. However, their use has been traced back as far as 1987 in several notes written by A.J. Stevens on soil activation for the Booster[2] and RHIC[3]. The numbers can be traced via reference in those notes to a report[4] of P.J. Gollon. That report

[1] Design Practice for Known Beam-Loss Locations, 2012;
https://sbms.bnl.gov/sbmsearch/subjarea/40/40_Exh9.cfm?ExhibitID=6375
[2] A.J. Stevens, Booster Technical Note No. 89, "Booster Soil, Component, and Water Activation", Sept. 1, 1987;
[3] A.J. Stevens, RHIC Technical Note No. 29, ,"Radioisotope Production in Air and Soil at RHIC", Nov. 2, 1987;
[4] P.J. Gollon, "Soil Activation Calculations for Anti-Proton Target Area", TM-816, Sept. 14, 1978.

describes the soil sample as glacial till, which was detailed in a report by M. Awschalom[5]. The glacial till described in footnote 5 has 56.5% oxygen and 25.7% Si by weight. BNL soil composition has been reported[6] as 51.3% ^{16}O and 45.1% ^{28} Si by weight. The material composition is very important in determining the ratio of ^{22}Na to ^{3}H.

It is reasonable to expect that a factor of 2-3 change in $^{3}H/^{22}Na$ ratio can come from the difference in the chemical composition of the soil. The factors quoted by P.J. Gollon are for analysis5 of 400 GeV protons on target with FNAL soil. The energy dependence of cross sections may impact the result for lower energies such as those for RHIC and the Booster, in addition to the chemical composition.

An experiment/analysis performed[7] at BNL for soil activation. Activation of BNL soil samples were conducted near the C-target station. The ratio of leachable tritium to ^{22}Na atoms was 8.27. This does not agree with the value of 3.7 used in the previous guidance in the SBMS. If one takes into account that our soil has almost twice the Si then the difference is increased, as the 3.7 comes from FNAL soil samples. If the microscopic cross sections for tritium [8] and sodium[9] are used and one neglects all minor soil components for BNL soil then a ratio of $^{3}H/^{22}Na$ =0.97 for forward directions and 1.15 for backward directions have been calculated[10]. It is not clear why the test has a result that appears to disagree with the basic microscopic cross sections. It may imply a rapid change with energy, the wrong soil was used in the experiment, the wrong composition is presently being used, or an experimental error. It is not possible to determine the cause of the difference at the time of writing this report. However, there has been very satisfactory agreement in estimating the radionuclides produced in BLIP targets to the equivalent calculations using microscopic cross sections and this should be done for beam losses in the accelerators creating activity in the soil.

The subject area should provide better guidance on how to determine the appropriate length of the soil column that can be leached. Table 1 and 2 in the exhibit should be changed. The 60 cm and corresponding 6 cm given in the tables are not correct. Neither is the concentration factor. Leaching a column of activated soil with water will result[11] in a concentration at the bottom of

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[5] M. Awschalom," Calculation of the Radionuclide Production in the Surroundings of the NAL Neutrino Laboratory", TM-292-A, March 11, 1971.
[6] P.K. Job and W.R. Casey, "Activation Analysis of Soil, Air and Water near the NSLSII Accelerator Enclosure",, NSLSII Tech. Note No. 50, August 15, 2008.
[7] P.J. Gollon et. al.; "Production of Radioactivity in Local Soil at AGS Fast Neutrino Beam, BNL_35660-r,Nov. 6, 1984.
[8] U. Tippawan et.al., "Light ion Production in the interaction of 96 MeV neutrons with Si" and S. Benck et.al. Phys. Med. Boil., pg3427-3447, 1998. A cross section of 7mb will be used for both reactions.
[9] A. van Ginneken, "^{22}Na Production Cross Sections in Soil", FNAL-TM-283, Jan 15, 1971. An average to 25mb will be used based on Figure 4.
[10] This calculation was conducted for 800 MeV protons striking a steel target.
[11] This assumes that there is sufficient water to leach the entire column and that the moisture content of the soil is not being changed.

the column, which is the total radioactive atoms in the column divided by the volume of water that flushed it out. The height of the effective soil column depends on the mean free path of the radiation and the geometry of the tunnel and soil. The tables use an effective column height of 60 cm. The effective column height can be calculated using a simple spread sheet that estimates the attenuation of radiation as a function of height in the soil column of interest.

The effective soil column height can be estimated for the simple example for a radiation source centered in a 150 cm radius tunnel surrounded by soil. If the integration is conducted to calculate the number of ^{22}Na atoms in a vertical soil column directly above the source the result provides an equivalent length of 41cm. If the integration of vertical columns are conducted for the horizontal plane then the results are given for several selected distances (the first 150cm is the tunnel):

Effective Column Height for a 150cm Radius Tunnel

Distance (cm)	Effective column height (cm)
160	218
210	256
260	388
310	320
360	346
410	372
460	396

The effective column heights are larger than the 60 cm used in the subject area.

The following recommendations are made to the committee for consideration in regards to the Booster E7 and the SBMS guidance on soil activation:

1. The department should cease to use the ^{22}Na and ^{3}H production per inelastic collision provided in the earlier version of the accelerator safety subject area exhibit and notes that calculated soil activation at C-AD. The soil composition quoted in footnote 6 should be used for calculations in the short term for potential soil activation.

2. The soil composition should be checked[12] to determine the accuracy of the numbers presented in footnote 6. The subject area guidance should have a suggested range of acceptable soil compositions for shields made from BNL site soil.

3. The ratio of ^{22}Na to ^{3}H should be calculated using the recent activation libraries that can be used with the shielding codes such as MCNPX. This calculation would most likely

[12] The BNL hydrogeologist, D. Paquette, has been contacted to determine the source of the BNL soil composition.

avoid using cross sections that are outdated. The calculation should provide guidance for facilities at low energy such as the Linac (200 MeV) and Booster (500-2000MeV) and also for the higher energy facilities of RHIC (20-250 GeV) and the AGS (1-28 GeV).

4. The short term planning of the E7 beam scrapping of polarized proton for run15 should use the method of P.K. Job and W.R. Casey with their soil composition for the calculation of the production of ^{22}Na and ^{3}H with minor adjustments until the calculations recommended in 4 above are available. The cross sections are primarily from T.A. Gabriel[13] and are taken at 50 MeV. More recently measured tritium and ^{22}Na production cross sections were used in the 800 MeV analysis for the $^{3}H/^{22}Na$ ratio presented above.

5. The moisture content of the soil should be documented if possible. The percentage of tritium that can be produced and leached from the soil may be strongly dependant on the moisture content of the soil as discussed[14] by T.B. Borak et. al.

6. Guidance for the treatment of berm slopes should be provided in the SBMS. These surfaces are likely to shed more water in run-off than flat surfaces.

7. The SBMS guidance should provide a described means of having higher ^{22}Na and ^{3}H concentrations depending on the quality of the calculations to estimate the potential activity.

8. The tables in the subject area should be adjusted or removed. The concentration factor, the 60 cm, and the 6 cm should be eliminated from the table or appropriate replacements used.

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[13] T.A. Gabriel, "Calculation of Long-Lived Activity in Soil Produced by 200 MeV protons", ORNL-TN-2848, Jan. 23, 1970.

[14] T.B. Borak et. al.," The Underground Migration of Radionuclides Produced in Soil Near High Energy Proton Accelerators", Health Physics, Vol23,pp679-687, 1972.