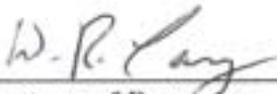


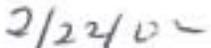
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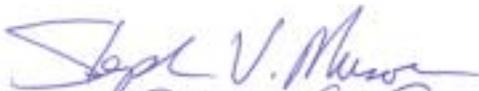
# Radionuclide Production in Soil From 60 MeV Electrons at the Accelerator Test Facility, Building 820

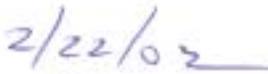
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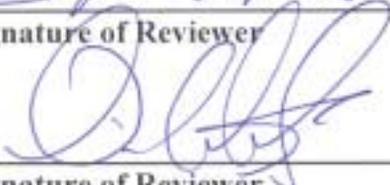
Note: This report will be appended to the Accelerator Test Facility Safety Assessment Document as a USI.

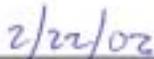
  
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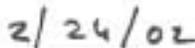
  
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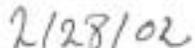
  
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# Radionuclide Production in Soil From 60 MeV Electrons at ATF

## Introduction

A reorientation of the ATF beam line 1 resulted in a 90° bend toward the floor and the creation of a new stop to terminate the beam in. Because this orientation results in the forward directed beam pointed to the soil beneath the building, it was judged to be worthwhile to evaluate the potential for tritium and Na-22 production in soil. In a previous note from Hu to Gmur dated 1/10/02, the tritium production rate from neutron capture in naturally occurring deuterium was evaluated. In this note, we will also evaluate tritium and sodium-22 production from high energy neutron spallation.

## Background

Activation in soil from the operation of accelerators has become an important issue at BNL. Considerable effort has been made at RHIC, BLIP, and the AGS to provide controls to minimize the production and dispersal of tritium in the soil, and questions are often raised about the steps that accelerators in the NSLS Complex have taken to prevent tritium production from its operations. (Note: tritium analyses were conducted of cooling water samples in 1997 and 2001; all values were below MDL.) It should be noted that there are several reasons why the potential for production of radionuclides in soil at the NSLS is very much lower than at our sister facilities such as AGS and RHIC. These factors can be used to qualitatively estimate the differences in radionuclide production in soil between these facilities.

One important reason is that the NSLS accelerates electrons rather than protons. The ability of electrons compared to protons to create non-elastic reactions in target materials is inherently smaller by a factor of about 100. Non-elastic reactions are required if spallation products such as tritium are to be produced in significant quantities. Secondly, the NSLS operates at much lower power levels than the proton facilities at BNL. For example, the x-ray ring at NSLS operates with a circulating beam of  $\sim 1 \times 10^{12}$  electrons at 2.8 GeV produced once every 12 hours. The AGS operates with a 30 GeV beam of greater than  $1 \times 10^{13}$  protons produced every few seconds. Therefore, the AGS has  $\sim 10^6$  greater beam power than the X-ray ring averaged over a 12 hour operating period. Combining the two factors, overall, the x-ray ring has  $\sim 10^8$  less capability to produce residual radiation during a normal 12 hour operating period than the AGS does. Other NSLS accelerators such as SDL and ATF operate with higher beam power (but lower energies) than the storage ring, but still operate at several orders of magnitude less power than the AGS.

It is also possible to quantitatively estimate the level of induced tritium produced in the soil from electron beam interactions in a target. High energy electrons interacting in matter lose their energy primarily through production of bremsstrahlung radiation directed in the forward direction. The bremsstrahlung photons lose energy primarily

through interaction with atomic electrons, but some fraction of the photons will produce non-elastic collisions in a nucleus, thereby releasing high energy neutrons which can cause non-elastic interactions in other nuclei.

These high energy neutrons can produce radionuclides through spallation of the target nucleus. These production rates can be estimated through the following methodology.

In the ATF stop, the electron beam strikes a faraday cup and generates a bremsstrahlung beam that is intercepted by a 2" thick lead stop. In addition, there is a 12" concrete floor above the soil. Most of the neutrons will be created in the lead which represents a thick target of about 9 radiation lengths. The attached figure 1 provides an estimate of the high energy neutron ( $E > 25$  MeV) production rates at  $90^\circ$ . Rohrig in attachment #2 (Ref. 1) has estimated that the dose at  $0^\circ$  is about four times as great as the rate at  $90^\circ$ . Using the value from attachment 1 at 100 MeV

$$H_{\text{HEN}} = 4 \times 0.1 = 0.4 \text{ Sv/hr-KW at 1 m}$$

The total power of the electron beam is  $60 \text{ MeV} \times 1.5 \text{ nA} = 9 \times 10^{-2}$  watts. The neutron fluence to dose equivalent for HEN =  $4 \text{ n/cm}^2\text{-s}$  per mRem/hr. Therefore, the HEN fluence  $\Phi$  at 1 m from the lead is:

$$\Phi = 0.4 \text{ Sv/hr-KW} \times 1 \times 10^5 \text{ mRem/Sv} \times 9 \times 10^{-5} \text{ KW} \times 4 \text{ n/cm}^2\text{-s/mRem/hr} = 14.4 \text{ n/cm}^2\text{-s}$$

Neutrons created in the lead must penetrate through 12" of concrete before entering the soil. The attenuation length in concrete for neutrons in this energy range is  $55 \text{ g/cm}^2$ .

$$\Phi = 14.4 \times e^{-12" \times 2.54 \times 2.35 / 55} = 3.9 \text{ n/cm}^2\text{-s at 1 m}$$

We assume the soil starts at approximately 1/2 m from the target. Correcting for geometry, the fluence at the beginning of the soil is:

$$\Phi = 4 \times 3.9 \text{ n/cm}^2\text{-s} = 15.7 \text{ n/cm}^2\text{-s}$$

The tritium production rate A can be calculated from:

$$A = N\sigma\Phi(1 - e^{-\lambda t})$$

The cross section  $\sigma$  for tritium production from spallation in oxygen and silicon is taken as 10 millibarns (mb) from attachment 3 from reference 2. The number of target atoms per gram in soil ( $\text{SiO}_2$ ) with density 1.6 g/cc is N:

$$N = 6.02 \times 10^{23} \text{ molecules per gram-mole} \times 3 \text{ atoms/molecule} \div 60 \text{ g/ g-mole}$$

$$N = 3 \times 10^{22} \text{ atoms / g}$$

t is the irradiation time and the tritium decay constant  $\lambda = 0.056 \text{ yr}^{-1}$ .

Therefore the tritium production "A" rate in disintegrations per second per gram of soil from one year of full time operation is

$$A(1 \text{ yr}) = 3 \times 10^{22} \times 10 \times 10^{-27} \times 15.7 \times (1 - e^{-0.056 \times 1}) =$$

$$A(1 \text{ yr}) = 2.56 \times 10^{-4} \text{ d/s/g}$$

The actual operating time for ATF in this mode is approximately 750 hours per year which reduces the production rate in the course of the year to

$$A(1 \text{ yr}) = 2.56 \times 10^{-4} \text{ d/s/g} \times 8.56 \times 10^{-2} = 2.2 \times 10^{-5} \text{ d/s/g} = 6 \times 10^{-4} \text{ pCi/g H}^3 \text{ in soil}$$

The [Accelerator Safety Subject Area](#) provides a methodology for determining the acceptability of induced activity in soil. In the model, all the radioactivity produced in one year is assumed to be located within 1 attenuation length of entry into the soil. This amount of tritium is concentrated within the water in the soil and is then diluted by the average height of rainfall in a year. The computed concentration in the assumed leachate is compared to 5% of the drinking water standard. It should be noted that this is a hypothetical calculation to determine whether engineered rain caps are needed. The ATF beam stop is within a building and the activated soil is covered by the footprint of the building. The beamstop is located ~6 meters from an exterior building wall.

Using this methodology, the concentration in soil is:

$$C(\text{soil}) = 6 \times 10^{-4} \text{ pCi/g} \times 1.6 \text{ g/cc} = 9.6 \times 10^{-4} \text{ pCi/cc}$$

Using the factors for calculating soil water leachate, we get:

$$C(\text{H}^3 \text{ soil water leachate}) = 9.6 \times 10^{-4} \text{ pCi/cc} \div 0.1 \div 55 = 1.74 \times 10^{-4} \text{ pCi/cc} = 0.17 \text{ pCi/l}$$

The Subject Area establishes that calculated H<sup>3</sup> leachate values in excess of 1000 pCi/l would require further safeguards and monitoring. Therefore, no corrective actions are required for this level of tritium production.

The subject area also requires that Na<sup>22</sup> production be calculated. Cross-sections for Na<sup>22</sup> production were not available, so the measurement and calculations for H<sup>3</sup> and production from SLAC RP-2000-07 (Ref. 3) were used to estimate Na<sup>22</sup> productions rates. That report estimates that

$$A_{\text{Sat.}}(\text{Na}^{22}) = 1/2 A_{\text{Sat.}}(\text{H}^3)$$

Using the equations given above, A<sub>Sat.</sub>(H<sup>3</sup>) can be calculated to be

$$A_{\text{Sat.}}(\text{H}^3) = 0.127 \text{ pCi/g}$$

Therefore ,

$$A_{\text{Sat.}}(\text{Na}^{22}) = 6.4 \times 10^{-2} \text{ pCi/g}$$

We can then calculate the production in one year to be:

$$A_{1 \text{ yr.}}(\text{Na}^{22}) = 1.5 \times 10^{-2} \text{ pCi/g or}$$

$$A_{750 \text{ hours}}(\text{Na}^{22}) = 1.28 \times 10^{-3} \text{ pCi/g}$$

Using the methodology described in the subject area for sodium, it can be calculated that the concentration in soil water leachate for  $\text{Na}^{22}$  is

$$C(\text{Na}^{22} \text{ soil water leachate}) = 2.8 \times 10^{-5} \text{ pCi/cc} = 2.8 \times 10^{-2} \text{ pCi/l}$$

which is considerably lower than the action level of 20 pCi/l.

### **Conclusion**

Tritium and sodium-22 production in soil from operation of ATF beam line 1 in the new configuration does not require any additional engineering controls or monitoring.

### **References**

1. Norman Rohrig - "Evaluation of Required Additional Shielding for Hypothetical Accidental Losses from the BNL National Light Source from an Upgraded X-ray Ring Injector" - Feb. 3, 2002
2. W.R. Nelson, A. Fasso, R. Sit, and S.N. Witebsky - "Estimate of Tritium Production in Groundwater near SLC Beam Dumps" Feb. 1998; SLAC RP Note 98/2R
3. James Liu and Sayed Rokni - "Analytical Method in Estimating the Induced radioactivity in Soil around High energy Accelerators" Oct, 2000; SLAC RP Note 2000-07

Attachment 1

NCRP SC 46-8  
 Draft of April 1999  
 KH\NCRP\Reports\SC 46-8

DRAFT REPORT FOR COMMENT - NOT TO BE REFERENCED

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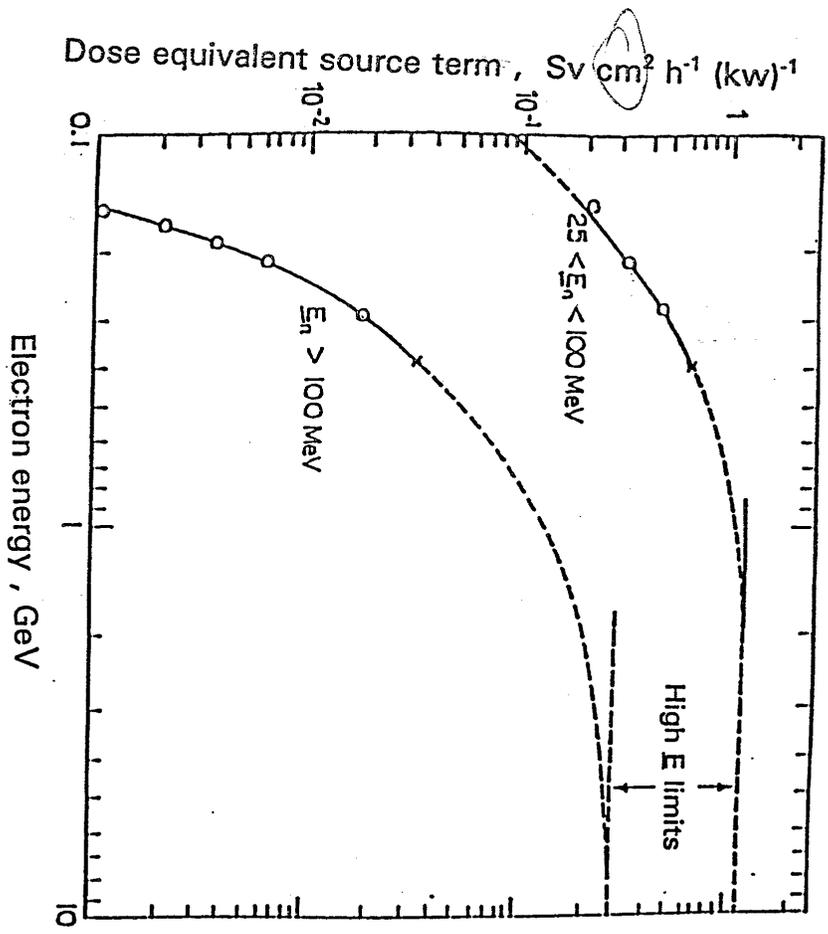


Fig. 4.21. Effective source terms for a thick copper target for neutrons of energy 25 to 100 MeV and for neutrons of energy greater than 100 MeV as a function of electron energy.

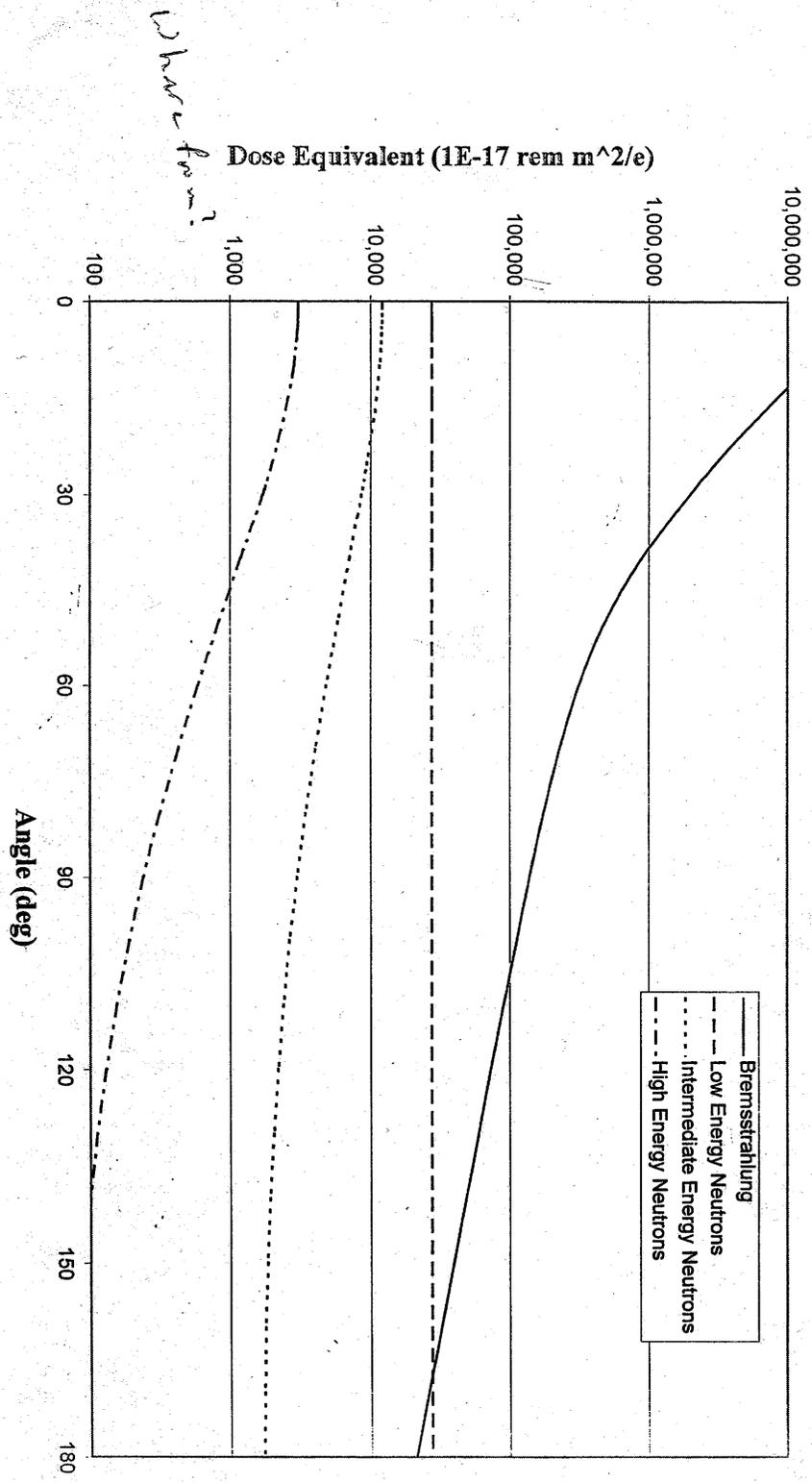


Figure 2: Unshielded Radiation Source Terms

lateral to the dump calculates to be

$$\begin{aligned}
 A_{\infty} &= (2.7 \times 10^{-10} \text{ } ^3\text{H atoms/ml/e}) \times (6.25 \times 10^{12} \text{ e/s}) \times (1 \text{ d/}^3\text{H atom}) \\
 &\quad \times \left( \frac{10^6 \mu\text{Ci}}{3.7 \times 10^{10} \text{ d/s}} \right) \\
 &= 4.6 \times 10^{-2} (\pm 34\%) \mu\text{Ci/ml}
 \end{aligned}$$

for a 50 kW beam running continuously.

#### An Independent Check on FLUKA Using SHIELD11

SHIELD11<sup>[7]</sup> is a fast and easy to use code for performing shielding analysis around a high-energy electron accelerator. It makes use of simple analytic expressions for the production and attenuation of photons and neutrons by electron beams striking thick targets, such as dumps, stoppers, collimators, and other beam devices. The formulae in SHIELD11 are based on the extrapolation (*i.e.*, scaling) of experimental data using rather simple physics ideas and the code has been used at SLAC for many years with great success.

Using the dimensions of the dump and vault provided in Figure 2, the high-energy neutron dose-equivalent rate, at a distance of 42-inches from and 90° to the beam direction, is estimated by SHIELD11 to be 7.4 rem/h/kW. With the conversion factor of  $1.0 \times 10^{-7}$  rem/n  $\text{cm}^{-2}$  recommended by Jenkins<sup>[12]</sup> the fluence rate calculates to be  $1.0 \times 10^6$  n/ $\text{cm}^2\text{s}$  opposite the dump (point P<sub>1</sub> in Figure 2) for 50 kW of beam running continuously.

Now, cross sections for the formation of tritium by high-energy hadrons have been measured for various materials (*e.g.*, see Noguchi *et al.*<sup>[13]</sup>) and the results are summarized in Figure 5.

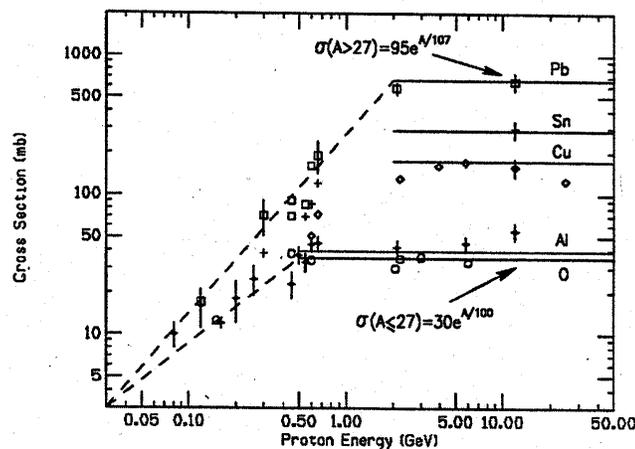


Fig. 5 Tritium formation cross sections as a function of proton energy.