Monte Carlo simulation related to soil activation at Booster E7

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Kin Yip

Experimental Support and Facilities Division

Collider-Accelerator Department
The author has used the simulation package MCNPX version 2.7.0, a particle transport code written by Los Alamos National Laboratory to compute the neutron fluxes (essentially the only concern for soil activation). The simulation computational process is very CPU intensive. The author has installed and configured the MCNPX simulation to run in parallel-processing mode using CRAY-MPICH in the NERSC (National Energy Research Scientific Computing Center) supercomputers. Each of the following simulation has used ~240 cores for about 10 hours.

The number of atoms per cc per year is given by:

\[
\frac{\phi}{\lambda} \times N_i \times N_p \quad [\text{Equation 1}]
\]

where \( N_i \) is the number of atoms per interaction (which is 0.075 for \(^3\text{H}\) and 0.02 for \(^{22}\text{Na}\)), \( N_p \) the number of protons, \( \lambda \) the interaction length (60 cm is used here in this note) and \( \phi \) is the neutron flux for neutrons with kinetic energy > 20 MeV. From the above equation and the BNL standard leaching model (https://sbms.bnl.gov/sbmsearch/subjarea/40/1r09e011.pdf), we can convert between neutron flux (in the unit of cm\(^{-2}\) per incident proton) and the soil activation for \(^3\text{H}\) and \(^{22}\text{Na}\) (in pCi/L) interchangeably.

Here, we have used a MCNPX simulation model built by a SULI student in 2012 around B6. Since the B5 and B7 magnets are more or less the same as the E7 magnets, we hit protons at B5 and B7, analyze the neutron fluxes in backward and forward directions and treat them as the neutron fluxes around E7. With Kip Gardner’s guidance, at each location, protons hit the front surface of the upper pole of the dipole magnet from its lower edge to 1 mm up, and the horizontal range is from -1 cm to 1 cm from its horizontal center, both in uniform distributions.

In this note, we consider the soil activation of loss of \( 4 \times 10^{11} \) or \( 8 \times 10^{11} \) protons per cycle (~4 seconds) at E7 continuously (24 hours a day) for 5 months. This amounts to a total loss of \( 1.296 \times 10^{18} \) or \( 2.592 \times 10^{18} \) protons. With the above-mentioned equation and leaching model, the neutron flux (> 20 MeV) needs to be \( 1.17 \times 10^{-8} \) or \( 5.85 \times 10^{-9} \) cm\(^{-2}\) per incident proton in order to give rise to a soil activation level of 1000 pico-Curie/L for \(^3\text{H}\), which is our upper tolerance. Therefore, we would like to cap E7 to where the neutron fluxes fall below \( 1.17 \times 10^{-8} \) or \( 5.85 \times 10^{-9} \) cm\(^{-2}\).

In the MCNPX simulation, we divide the entire area of 2500 square feet into 101\( \times \)101 grids. Contour lines are formed by joining grids with the same level of neutron fluxes at beam height.

The results are shown in Figure 1 when the proton hit the B7 dipole magnet and Figure 2 when the proton hit B5 dipole magnet in the form of contour of neutron fluxes at beam height. Figure 1 gives us an idea how much backward the soil activation cap should cover. **Only the neutron fluxes inside the soil should be examined.** The author has used the red lines to indicate the distance between where the proton hit the dipole magnet and where the neutron
fluxes fall below \(5.85 \times 10^{-9}\) cm\(^2\) per incident proton (assuming the loss intensity of \(8 \times 10^{11}\) protons per cycle), which is about 7.7 m.

The side boundary or the width can be taken from both figures, which is probably > 8 m. Nevertheless, from Figure 2, even the neutron fluxes at about 12.8 m from where the proton hits B5 dipole, it still has not gone below \(5.85 \times 10^{-9}\) cm\(^2\) per incident proton. Practically, we may need to use the traditional methodology of extending the cap area to where the tunnel turns.

Figure 1: The contours of neutron fluxes at beam height of \(1.17 \times 10^{-8}\) or \(5.85 \times 10^{-9}\) cm\(^2\) per incident proton when the proton beam hits the dipole magnet B7. Only the neutron fluxes inside the soil should be examined. The two red lines indicate the distance between where the hitting position and the place where the neutron fluxes fall below \(5.85 \times 10^{-9}\) (assuming the loss intensity of \(8 \times 10^{11}\) protons per cycle), which is about 7.7 m.
Figure 2: The contours of neutron fluxes at beam height of $1.17 \times 10^{-8}$ or $5.85 \times 10^{-9}$ cm$^2$ per incident proton when the proton beam hits the dipole magnet B5. Only the neutron fluxes inside the soil should be examined.