Appendix 14

Tritium Production in Cooling Water Systems at the NSLS

Introduction

The NSLS Complex operates several accelerators, each resulting in beam losses during normal operation. In the energy range that these accelerators operate, production of tritium and other spallation products of the oxygen atom in the water molecule are possible. Prior monitoring of cooling water has not indicated detectable levels of tritium in cooling water systems (see section 4.14.9.2), the purpose of this document is to calculate tritium concentrations that are produced during NSLS operation.

Background

High-energy particle interactions in water can produce radioactivity from spallation reactions in the oxygen atom. Short-lived radionuclides such as C-11 ($T_{1/2}$ = 20 min.), N-13($T_{1/2}$ = 10 min.),, and O-15 ($T_{1/2}$ = 2.1 min.), are produced at the greatest rate, but because of their rapid decay, they have little radiological significance. Although tritium is not produced to the same extent, its longer half-life provides an opportunity for build-up over time.

Tritium Production

Values for radionuclide production in water are provided by Table XXXIb (p. 133) by Swanson.[1]. For tritium, the maximum value at saturation A_S is:

$$A_S = 0.2 \text{ Ci/KW} \qquad (1)$$

Utilizing the highest average power loss point during NSLS operations, we will evaluate the potential for tritium generation from the Booster beam terminating in a beam stop. The Booster operates up to 1 GeV with a beam intensity of 1 x 10^{10} e/s, or a total power of:

$$P = I\,V = 1 \times 10^{10} \text{ e/s} \times 1 \text{ Amp}/6.25 \times 10^{18} \text{ e/s} \times 1 \times 10^{9} \text{ V} = 1.6 \text{ watts} \qquad (2)$$

Therefore, assuming that the beam power is fully available to generate tritium in water, the saturation value for the booster loss is :

$$A_S = 0.2 \times 1.6 \times 10^{-3} = 0.32 \text{ mCi (tritium)} \qquad (3)$$

This value is based on the assumption that 100% of the beam power is deposited in the water cooling system and that the accelerator operates continuously until saturation is

[1] "Radiological Safety Aspects of the Operation of Electron Linear Accelerators", IAEA Technical Report Series # 188

reached (~ 50 years). Both of these assumptions are extremely unrealistic and will be further evaluated.

Power Deposition

Tritium production in water has been previously reported for high power electron accelerators such as SLAC and is associated with water-cooled targets or beam dumps. Because of the low power of the NSLS beam operations, the dumps are not cooled, and there are no targets. However, because of synchrotron radiation heating, the ring vacuum pipe is cooled, and therefore a small fraction of the bremsstrahlung and high-energy neutron components may interact in the water. Because of the small size of the water mass compared to the mass of the structural elements of the ring and machine components, almost all of the lost beam energy will be absorbed in the structural elements of these components. Although no rigorous calculation calculating the energy deposited directly in water has been performed, it is clear that this value is quite low. For purposes of this calculation, we will assume that 0.1% of the beam power is deposited in water. Therefore:

$$A_S = 0.32 \text{ mCi x } 0.001 = 0.32\ \mu\text{Ci (tritium) at saturation} \qquad (4)$$

Tritium Production at Shorter Operating Times

Tritium production at constant operation is essentially linear in the early years of operation and reaches 50% of saturation values at the end of one half-life (12.3 years). Therefore, at the end of the first year of operation assuming 300 hours of operation[2], the tritium production A would be:

$$A = 0.32 \text{ x } 0.5 \text{ x } 1/12.3 \text{ x } 300/8760 = 4.5 \text{ x } 10^{-4}\ \mu\text{Ci (end of first year)} \qquad (5)$$

Tritium Concentration in Cooling Water

The total volume of water in the cooling system is approximately 4000 gallons or ~ 15000 liters. Therefore the concentration of tritium at the end of one year is:

$$\text{Tritium Concentration} = 4.5 \text{ x } 10^{-4}\ \mu\text{Ci} / 15000 \text{ l} = 3 \text{ x } 10^{-8}\ \mu\text{Ci/l} = 3 \text{ x } 10^{-2}\ \text{pCi/l} \qquad (6)$$

This can be compared to the minimum detectable level for tritium in water of about 200 - 300 pCi/l and the current permissible laboratory administrative limit for discharging tritiated water to the sewer of 10,000 pCi/l (see SBMS Liquid Discharges Subject Area).

Conclusion

[2] The injection systems only operate for the time required to fill the storage rings, typically about 10 minutes per fill or about 300 hours/year.

Tritium production in the cooling water is not significant and will not be detectable even after years of operation. There is no need for additional engineering safeguards or administrative controls to address this potential hazard. However, periodic analyses of cooling water will be continued.