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ESTIMATE OF THE RADIOACTIVITY PRODUCED IN THE COOLING WATER OF A TARGET ASSEMBLY AND ITS HANDLING

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An estimate has been made of the radioactivity to be expected from the oxygen spallation of the cooling water in a tightly shielded 300 GeV target assembly.

This calculation was made to help decide whether or not to vent the H_2 and O_2 produced by the radiolysis of the cooling water.

The calculations were made assuming,

1. beam parameters, $E_p = 300$ GeV

$i_p = 1 \times 10^{13}$ p/sec

2. tight shield around the target (see part 1 of Calculations).

The table below gives the rate of radioactivity production as well as radioactivity and radionuclide concentration at equilibrium.

Radio-nuclide	Production Rate, Ci/min	Equilibrium Radioactivity, Ci	Nuclides at Equilibrium
H-3	3.1×10^{-5}	3.0×10^{2}	6.2×10^{21}
Be-7	7.9×10^{-4}	8.7×10^{1}	2.1×10^{19}
C-11	3.0	8.7×10^{1}	5.8×10^{15}
N-13	4.2	6.2×10^{1}	2.0×10^{15}
O-14	6.6×10^{1}	9.5×10^{1}	3.0×10^{14}
O-15	1.0×10^{2}	3.0×10^{2}	2.0×10^{15}

Conclusions. It is just possible that one may operate the system by venting into the atmosphere and diluting the evolving gases with about 10-100 cu.ft/min. of clean air. This figure is based on the tritium evolution. Hence, the recommendation is not to invest in hydrogen-oxygen recombiners until their need is proven experimentally.

Calculations.

1. Ratio of track lengths in water and in steel.

Tight shield. Real geometries are impossible mixtures of voids, collimators, solid steel, copper and water. Therefore, an idealized mixture of water and iron is used here. The shield is iron and the area of the cross-section (perpendicular to the beam direction) is 10% water, 90% steel[1]. The cooling paths are assumed to extend parallel to the beam direction along 50% of the shield length.

$$\frac{\text{water track length}}{\text{total track length}} = \frac{V_{water}}{V_{total}} = 0.050$$

This ratio follows from a consideration of a random distribution of tracks in a volume V, having a subvolume V'.

2. Ratio of oxygen spallation stars to all stars.

The important non-elastic cross-sections are,

Fe, σ_{ne} = 760 m b ref. 2

O, σ_{ne} = 310 m b ref. 2

H, σ_{ne} = 30 m b ref. 3

and H_2O, σ_{ne} = 370 m b.

It is assumed here that all cross-sections (p, n, π, ...) are equal and energy independent.

The macroscopic cross-section Σ is defined as,

$$\Sigma = \rho N\sigma/A$$

where, ρ, σ, A are the density, cross-section and molecular weight of the substance and N is Avogadro's number. Obviously, the dimension of Σ is L^{-1}.

Then, we get

$$\Sigma(Fe) = \frac{7.86 \times 6.022 \times 10^{23} \times 760}{55.85} = 0.0644 \text{ cm}^{-1}$$

$$\Sigma(H_2O) = \frac{1. \times 6.022 \times 10^{23} \times 370}{18.0} = 0.0124 \text{ cm}^{-1}$$

and,

$$\frac{\text{water stars}}{\text{all stars}} = \frac{0.050 \times 0.0124}{0.050 \times 0.0124 + 0.95 \times 0.0644}$$

$$= 0.010$$

3. Nuclide creation per incident proton.

The oxygen spallation cross-sections were taken from Brunix's work[4].

Nuclide	Cross-Section mb	Nuclides per incident proton
H-3	34	1.1
Be-7	10	.32
C-11	10	.32
N-13	7	.22
O-14	11	.35
O-15	35	1.1

where,

$$\frac{\text{nuclides}}{\text{incident proton}} = \frac{\sigma\ (\text{nuclide})}{\sigma_{ne}\ (\text{water})} \times \frac{\text{water stars}}{\text{all stars}} \times \frac{\text{all stars}}{\text{incident proton}}$$

$$= \frac{\sigma\ (\text{mb})}{370\ \text{mb}} \times 0.010 \times \frac{1200}{\text{incident proton}}$$

$$= .032\ \sigma(\text{mb})/\text{incident proton}.$$

Here, we adopt again the conservative value of 4 stars per GeV of kinetic energy of the incident proton[5].

4. Rate of nuclide and radioactivity production. Radioactivity at equilibrium.

The rate of nuclide production is calculated from the proton current and the ratio (nuclides/incident proton) calculated and tabulated in the previous section.

At equilibrium, the radioactivity equals the rate of production.

The radioactivity produced per minute is a convenient number to estimate ventilator needs should one choose to dump the activity in air after appropriate dilution.

Nuclide	Half-life	Radioactivity Production	Radioactivity at Equilibrium	Nuclides at Equilibrium
	sec	Ci/min	Ci	Total Number
H-3	3.88×10^{8}	3.1×10^{-5}	3.0×10^{2}	6.2×10^{21}
Be-7	4.58×10^{6}	7.9×10^{-4}	8.7×10^{1}	2.1×10^{19}
C-11	1.22×10^{3}	3.0	8.7×10^{1}	5.8×10^{15}
N-13	6.0×10^{2}	4.2	6.2×10^{1}	2.0×10^{15}
O-14	6.0×10^{1}	6.6×10^{1}	9.5×10^{1}	3.0×10^{14}
O-15	1.2×10^{2}	1.0×10^{2}	3.0×10^{2}	2.0×10^{15}

The proton current is assumed to be 1×10^{13}/sec.

5. Handling of the Radioactivity.

There are various possible ways to handle this radioactivity. The extremes are (1) holding it until all the activity has decayed to tolerable levels and (2) continuous dilution and venting.

The five radionuclides divide themselves in three very distinct categories, e.g.,

a. long-lived, difficult to concentrate, H-3

b. chemically active and easy to concentrate in deionizer resins, Be-7

c. short-lived, very low concentration in cooling water, C-11, N-13, O-14 and O-15.

6. Venting.

We will consider venting into the atmosphere since it is likely to be the most economical way to handle this radioactivity.

a. H-3. The MPC (maximum permissible concentration)[6] of H-3, in areas occupied by the general population, is 6.7×10^{-8} μCi/ml. The directive of R. R. Wilson[7] is understood to require reduction of this MPC to 6.7×10^{-9} μCi/ml.

Hence,

$$6.7 \times 10^{-15} \frac{\text{Ci}}{\text{ml}} = \left(3.1 \times 10^{-5} \frac{\text{Ci}}{\text{min}}\right) \times \left(\frac{0.15 \text{ m} \times 5}{2\pi \times 1.8 \times 10^{3} \text{m}}\right) \times \left(\frac{1}{\dot{V}}\right)$$

where, $\dot{V}$ = dilution volume per unit time needed for adequate dilution of the H-3.

The second factor is the ratio of the exposure to the gaseous discharge averaged over one year. This factor is five times the ratio of the diameter of the exhaust pipe divided by the circumference of the greatest inscribed circle in the NAL site and centered on the target area closest to the site boundaries. The factor of five takes into account the winds blow from all directions with equal probability, within a factor of five, if averaged over one year[8]. Then, the volume of air needed is,

$$\dot{V}\ \frac{ml}{min} = \frac{3.1 \times 10^{-5} \times 0.15 \times 5 \times 10^{15}}{2\pi\ 1.8 \times 10^{3} \times 6.7} = .12 \times 10^{6}\ \frac{ml}{min}$$

$$= .12\ m^3/min$$

$$= 4.3\ cu.ft/min.$$

This is a rather modest air flow.

b. Be-7. As mentioned above, the Be-7 will be removed by the deionizing resins and it will be disposed of at the resin recycling plant.

c. Short-lived gases. Finally, let us consider the other four nuclides. The number of C-11, N-13, O-14 and O-15 nuclides present in the water is rather small. It may be derived from the expected radioactivities at equilibrium.

Radionuclide	Nuclides at Equilibrium	Nuclides per Water Molecule*
H-3	6.2×10^{21}	1.6×10^{-6}
Be-7	2.1×10^{19}	5.5×10^{-9}
C-11	5.8×10^{15}	1.5×10^{-12}
N-13	2.0×10^{15}	5.3×10^{-13}
O-14	3.0×10^{14}	7.9×10^{-14}
O-15	2.0×10^{15}	5.3×10^{-13}

* A minimum size water cooling system of thirty gallons (= 3.8×10^{27} H_2O molecules) is assumed.

Due to the minuteness of their concentration, the short lived gasses are not expected to come out of solution of their own accord. However, other dissolved gasses would provide a carrier. Hence, the classical solution is to keep the cooling system closed and use a recombiner to avoid the release of any hydrogen and oxygen. However, there is a simpler and perhaps far cheaper system[10] that may permit the harmless release of the tritium.

7. Conclusions.

A water cooling system for target assemblies can seemingly be designed and operated without a recombiner. Hence, recombiners should not be built until their need is verified experimentally.

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REFERENCES

1. J. O'Meara, private communication.
2. G. Belletini, et al., "Proton-Nuclei Cross-Sections at 20 GeV", Nucl Phys 79, 609 (1966).
3. O. Benary, et al., "NN and ND Interactions -- A Compilation", UCRL-20 000 NN (August 1970).
4. F. Brunix, "High Energy Nuclear Reaction Cross-Sections", CERN 61-1 (Jan. 1961).
5. M. Awschalom, "Calculation of the Radionuclide Production in the Surroundings of the NAL Neutrino Laboratory", NAL-TM-292A (March 11, 1971).
6. AEC Manual, Chapter 0524.
7. R. R. Wilson, directive to M. Awschalom, June 15, 1971.
8. H. Moses and M. A. Bogner, "Fifteen Year Climatological Summary Jan. 1, 1950 - Dec. 31, 1964", ANL-7084 (1967).
9. Handbook of Chemistry and Physics, Chemical Rubber Co., 48th ed. (1967).
10. P. Gollon, "A Low Cost Method to Safely Vent Radioactive Gasses from the Cooling System of a High Power Beam Stop", NAL-TM-410 (Feb. 15, 1973).