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SUBJECT: HRT Source Shield Calculations

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HRT SOURCE SHIELD CALCULATIONS

INTRODUCTION

The antimony-beryllium neutron source for the HRT critical experiment will be shielded in the lead-filled HRT sample carrier which will be temporarily located inside a small tank of borated water. The lead carrier will be removed from the water tank and placed over the reactor while loading the source into the reactor.[1]

An estimate of the effectiveness of these shields was necessary because the carrier and water tank were not originally intended to be used as shields for the source.

SUMMARY

Calculations indicate that the proposed shielding arrangement will give a dose rate at the surface of the water tank of about 100 mrem/hr, practically all gammas. This is adequate for transportation and handling, but if the radiation actually proves to be this high, a storage location isolated from normal working areas must be provided. The isolation area need not be large, however, since the calculated dose rate at ten feet from the shielded source is only 3.5 mrem/hr.

For the short time required to transfer the source from the water tank into the reactor, the lead carrier alone will provide sufficient shielding. At one meter from the source shielded by the lead carrier, the dose rate is estimated to be 170 mrem/hr, with neutrons contributing the major part. Thus, with reasonable care, the operation should be carried out without excessive exposures.

The results of the calculations are summarized in Table I.

CALCULATIONS

The HRT antimony-beryllium source (shown on ORNL Dwg. C-25527) is being irradiated in the LITR lattice. At the time of removal from the reactor, the estimated source strengths will be as follows:[2]

0.08 Mev neutrons	8×10^{8} sec^{-1}
1.7 Mev gammas	8.4×10^{12} sec^{-1}
2.06 Mev gammas	7.2×10^{11} sec^{-1}
2.3 Mev gammas	6×10^{9} sec^{-1}

The sample flask holder carrier is shown on ORNL Dwg. D-21590, and the water tank on ORNL Dwg. E-27750.

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[1] C. A. Burchsted and C. L. Segaser, HRT Source Handling Facilities, ORNL CF-56-11-58 (Nov. 15, 1956).

[2] The neutron source strength was estimated by comparison with another antimony-beryllium source of known strength.

TABLE 1

Dose Rates, rem/hr

Type of Radiation / Dose Location And Type of Shielding	.08 Mev Neutrons	Thermal Neutrons	Primary Gammas	Secondary Gammas	Total
Unshielded Source at One Meter	0.10	0	240	●	240
Surface of Carrier Out of Water	3.2	0	2.2	0	5.4
Surface of Borated Water Tank	0	0	0.078	0.020	0.098
One Meter From Source in Carrier-No Water	0.10	0	0.070	0	0.17

Dose at Surface of Lead Carrier

For these calculations the source was treated as a point at the center of a sphere having a radius equal to the thickness of the side walls on the carrier.

Gammas

The flux of primary gammas at the surface of the carrier is given by:

$$\phi_{\gamma i} = \frac{S_{\gamma i} \cdot e^{-\sum \mu_i x}}{4\pi r^2}$$

The wall thickness is 17.86 cm: 15.3 cm of lead and 2.56 cm of steel. Absorption coefficients are tabulated below (mass absorption coefficients from Table 2.3.1, Reactor Handbook I, multiplied by density).

Gamma Absorption Coefficients-μ_i, cm^{-1}

E_i, Mev	μ_i, cm^{-1}		
	Lead	Iron	Water
[redacted]	0.56	0.36	0.054
2.06	0.51	0.32	0.049
2.3	0.50	0.31	0.046

The dose rate due to gammas of a particular group is

$$D_{\gamma i} = B_i \, \phi_{\gamma i}/a_i$$

where "a" is a factor converting flux to dose rate and "B" is a dose buildup factor which accounts for the buildup of scattered radiation. For the gamma energies around 2 Mev and for the number of attenuation lengths through the carrier wall, the buildup factor is about 4. Flux-dose rate conversion factors are shown below.[3] Also, tabulated are the fluxes of primary gammas and the dose rates at the surface of the carrier.

[3] T. Rockwell III, Reactor Shielding Design Manual, Fig. 2.2.

E_i, Mev	a, $\frac{\gamma\text{-hr}}{\text{cm}^2\text{ sec R}}$	$\phi_{\gamma i}$, $\frac{\gamma}{\text{cm}^2\text{ sec}}$	D, $\frac{\text{R}}{\text{hr}}$
1.7	3.5×10^5	1.58×10^5	1.81
2.06	3.0×10^5	0.31×10^5	0.40
2.03	2.8×10^5	0.3×10^3	0.00
			2.21.

The fast (~80 kev) neutrons will stream through the lead with practically no reduction in intensity or energy. Thus at the surface of the carrier

$$\phi_n = \frac{S_n}{4\pi r^2} = \frac{8 \times 10^8}{4\pi\ (17.86)^2} = 2.00 \times 10^5 \text{ n/cm}^2 \text{ sec} \quad .$$

The flux of 80 kev neutrons corresponding to 1 rem/hr is 6.2×10^4 n/cm^2 sec.[4] Thus the neutron dose rate at the carrier surface is

$$D_n = \frac{2.00 \times 10^5}{6.2 \times 10^4} = 3.2 \text{ r/hr} \quad .$$

<u>Dose at One Meter From Unshielded Source</u>

With no shielding around the source, the fluxes are given by

$$\phi = \frac{S}{4\pi r^2} \quad .$$

[4]Ibid., Fig. 2.3.

Fluxes and dose rates one meter from the unshielded source are shown below:

	ϕ, cm^{-2} sec^{-1}	D, r/hr
Fast Neutrons	6.4×10^3	0.10
1.7 Mev gammas	6.7×10^7	223
2.0 Mev gammas	5.7×10^6	19
2.3 Mev gammas	4.8×10^4	0.17
		242

Dose One Meter From Source Inside Carrier

The doses at one meter from the source shielded by the carrier are

$$D_\gamma = 2.21\left(\frac{17.86}{100}\right)^2 = 0.070 \text{ r/hr}$$

$$D_n = 0.10 \text{ r/hr (same as for no shield)} .$$

Dose at Surface of Water Shield

The flux of primary gammas at the outside of the water shield is obtained in the manner indicated above for the flux at the surface of the lead. The effective dose buildup factor is taken as the product of the buildup factors for the lead and for the water. The total dose rate for primary gammas is found to be 78 mrem/hr.

The neutron flux at the surface of the water tank can be estimated by assuming an isotropic source of 0.08 Mev neutrons at the surface of the lead. For a source strength of 2.0×10^5 n/cm^2 sec and with pure water in the tank, the thermal neutron flux at the surface was calculated by age-diffusion treatment to be 22 n/cm^2 sec. This is equivalent to 0.05 mrem/hr. The uncollided flux is insignificant.

In order to reduce secondary gamma production due to neutron capture in the water and outer regions of the lead, boron should be added to the water. With 6.7 gm B/kg H_2O (maximum solubility of H_3BO_3 in H_2O at 20°C), about 95 percent of the absorptions in the liquid will be in boron. For this concentration, the secondary gamma dose rate at the surface will be approximately 20 mrem/hr. (Based on the conservative approximation that all the source neutrons are absorbed and that all the capture gammas escape.) The boron will cause the neutron leakage to be much lower than the already low figure given above for pure water.

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