Important Considerations in the Design of a Shield for a CTR Magnet

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A quantitative study of the shield for fusion reactors operating on the D-T cycle and utilizing a magnetic confinement scheme was carried out [1]. A summary of some of the results follows.

The shield is required to perform three major functions: 1 - reduce the nuclear heating of the cryogenic coils to a permissible level; 2 - reduce the radiation damage to the superinsulation, for a 20 yr. lifetime; 3 - keep the radiation to the magnet to the minimum allowed by a) the tolerable increase in the resistivity of the copper stabilizer and b) the radiation damage to the superconductor. The energy attenuation required by the refrigeration system can be determined by a compromise between its operating and capital cost, the shield cost, and the increase in the magnet cost if the shield thickness is increased. However, an increase in the resistivity of the stabilizer and radiation damage to the superconductor cannot be compromised beyond the tolerable level. Fortunately, the optimum shield thickness from a cost standpoint results in acceptable levels of damage to the superinsulation and magnet stabilizer, as can be seen from figure 1 and results below.

A study of the effectiveness of various compositions in the shield region showed that a mixture of stainless steel and boron carbide results in a minimum shield thickness for the required total energy attenuation. The total <u>energy</u> attenuation varies exponentially with the shield thichness. The attenuation coefficients for the respective shield compositions were a - 0.1445 cm^{-1} for 70% SS plus 30% B_4C, b - 0.1113 cm^{-1} for 70% Pb plus 30% B_4C, c - 0.1283 cm^{-1} for 35% SS plus 35% Pb plus 30% B_4C, and d - 0.0902 cm^{-1} for 100% SS. The blanket was the same for all cases; viz., 50 cm lithium and 20 cm SS.

Increasing the thickness of the shield increases both shield and magnet costs, but lowers the refrigeration power requirements. To minimize the total cost with respect to the shield thickness, consider a toroidal reactor and the following equations.

$$C_M = a_m r_m^m \quad , \quad r_m = r_b + t_s \qquad (1)$$

$$C_S = \pi(t_s^2 + 2r_b t_s)\cdot a_s \qquad (2)$$

$$C_R = a_r e^{-0.6\mu_s t_s} \qquad (3\text{-a})$$

$$a_r = 6000(2\pi r_w W_n e^{-\mu_b t_b})^{0.6} \qquad (3\text{-b})$$

where C_M, C_S, C_R are magnet, shield, and refrigeration costs, respectively, per unit length in the toroidal direction; r_w and r_b are the inner and outer blanket radii; t_s is shield thickness and is the parameter to be optimized; W_n is neutron wall loading; μ_b and μ_s are energy attenuation coefficients in the blanket and shield. We assume that the magnet cost increases with its inner radius to the power m and the refrigeration cost increases with refrigeration capacity to the power of o.6 [3]. The optimum shield thickness, t_{so}, is then

$$t_{so} = \frac{1}{0.6\mu_s} \text{Log}_e \left[\frac{0.6\mu_s a_r}{m a_m (r_b + t_s)^{m-1} + 2\pi a_s (r_b + t_s)} \right] \qquad (4)$$

Table 1 tabulates t_{so} for different values of the parameters in eqns. 4. Except for μ_s, the dependence of t_{so} on these parameters is relatively weak. Changing m from 1 to 2 changes t_{so} by about 3 to 8%. Doubling the wall radius changes t_{so} by roughly 2%. The results show a relatively strong dependence on the wall loading. The optimum shield thicknesses are about 67 and 91 cm, respectively, for 70% SS plus 30% B_4C and 70% Pb plus 30% B_4C. However, using the Lead-B_4C mixture saves about 18 million dollars compared with the SS-B_4C for a major radius of 13 meters, based on material costs for cases 5 and 7 in Table 1. Furthermore, the optimum shield thickness for Lead-B_4C results in better attenuation than in the SS-B_4C case (1.85×10^{-7} and 4.17×10^{-6} MeV/MeV).

Table 1 Effect of the Various Parameters on the Values of Optimum Shield Thickness

case No.	r_w	r_b	$\dot{W}_n$ MW/m^2	m	a_s $\$/cm^3$	a_m^d $\$/cm$	a_r $\$/cm$	μ cm^{-1}	t_{so} cm
1	400	470	0.5	1	0.088[c]	18.96	3.504(+5)	0.1447*	52.9
2	400	470	1.0	1	0.088	18.96	5.312(+5)	0.1447	57.60
3	400	470	10.0	1	0.088	18.96	2.115(+6)	0.1447	73.19
4	400	470	1.0	2	0.088	0.0339	5.312(+5)	0.1447	57.0
5	400	470	1.0	1	0.0352	18.96	5.312(+5)	0.1447	66.97
6	200	270	1.0	1	0.0352	18.96	3.504(+5)	0.1447	66.65
7	400	470	1.0	1	0.0176	18.96	5.312(+5)	0.1113†	91.06
8	400	470	10.0	1	0.0176	18.96	2.115(+6)	0.1113	111.3

* corresponds to μ for a shield sonsisting of 70% SS + 30% B_4C

† corresponds to μ for a shield consisting of 70% Pb + 30% B_4C

c - a_s of .088 corresponds to 6.4 \$/lb for a density of 6.26 gm/cm^3 (70% SS + 30% B_4C) and a_s of .0176 corresponds to 0.92 \$/lb for 70% Pb + 30% B_4C.

d - $a_m = \frac{a'_m}{r_{ref}^m}$ where a'_m and r_{ref} were taken as $\$70\times10^6$ and 5.6 meters [2].

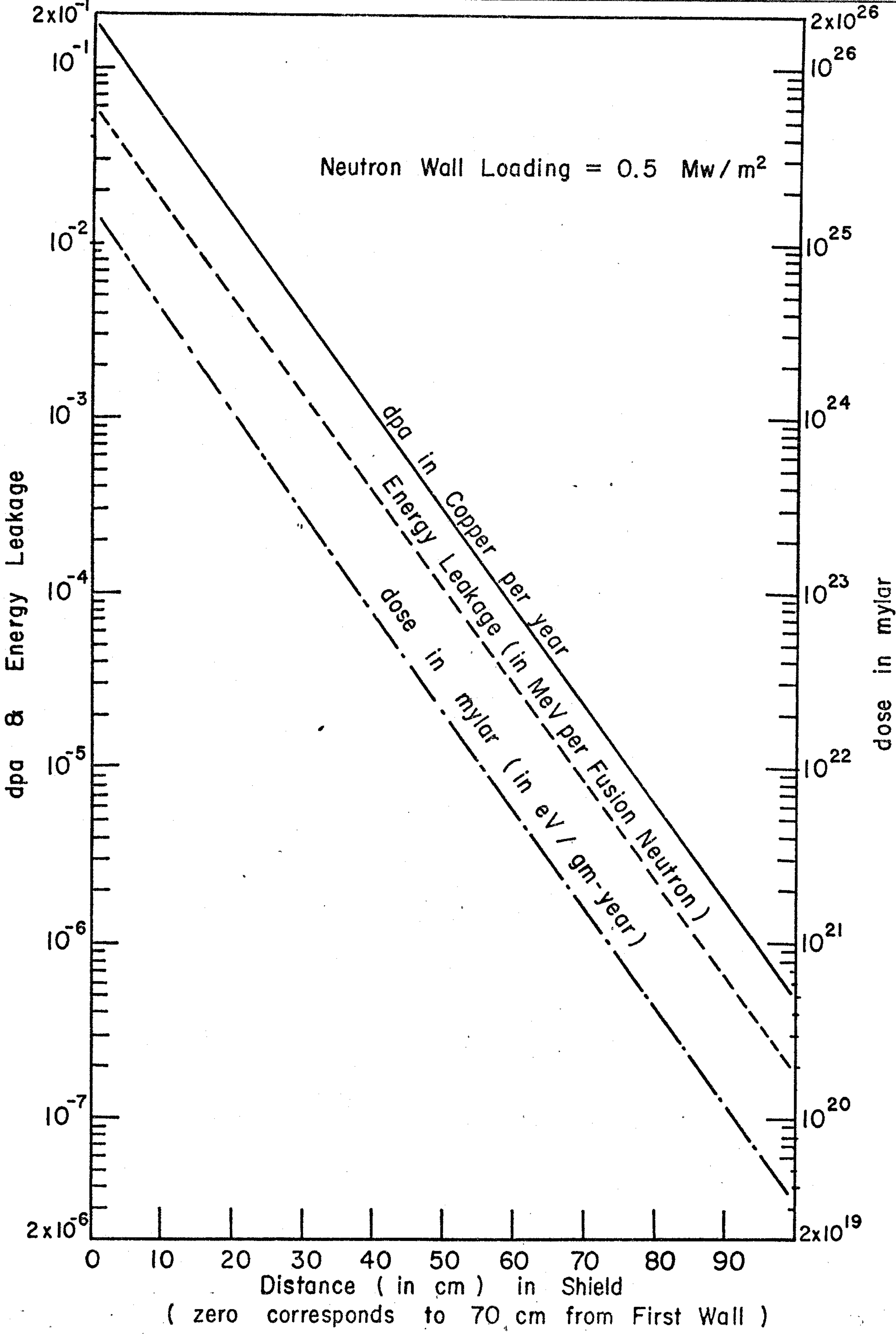

FIG. 1 Comparison of Atomic Displacement in Magnet Stabilizer (Copper) dose in Superinsulation (mylar) & Energy Leakage in a Typical Shield (35% Pb + 35% S.S. + 30% B_4C)

References

[1] M. A. Abdou, "Neutronics and Photonics Design For CTR Blankets and Shields," to be published.

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[3] W. C. Toung and R. W. Boom, "Materials and Cost Analysis of Constant-Tension Magnet Windings For Tokamak Reactors," 4th International Magnet Conference, Brookhaven (Sept. 1972)