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SUBJECT: Fluxes Obtainable in a Flux-Trap Reactor

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ABSTRACT

The general computational method, described in a previous memorandum[1] and applicable to an idealized flux-trap reactor, is used to obtain numerical values of the required multiplication factor ηf, and of the thermal flux ϕ_c in the center of the internal thermal column, for various radii of the fuel shell and for the following moderators: D_2O, Be, BeO, and C. The results are collected in Table 1, and shown in Fig. 1-4. For any given moderator, Φ_c reaches a maximum for a certain radius. For the four moderators listed above, Table 2 shows this radius, the corresponding central flux ϕ_c (in n/cm^2 per fission neutron emitted) and the multiplication factor ηf, as well as the reactor power required to make the central flux equal to 10^{16} $n/cm^2 sec$. This power varies from 138 Mw for Be to 315 Mw for C.

FLUXES OBTAINABLE IN A FLUX-TRAP REACTOR

In a previous memorandum,[1] we described a general computational method applicable to a flux-trap reactor idealized in the following manner. The fuel is concentrated in a spherical shell embedded in an infinite moderator; that is, the moderator occupies the space inside as well as outside the shell. The shell is "infinitely thin," but "black" for thermal neutrons; that is, the thickness of the shell is small compared with its radius, but large compared with the diffusion length in the fuel. The shell emits ηf fission neutrons for each thermal neutron absorbed. Absorptions at epithermal energies, both in the fuel and the moderator are neglected. In

[1] W. K. Ergen, "Flux Distribution in a Reactor Consisting of a Spherical Shell of Fuel in an Infinite Moderator," CF 57-12-100, Dec. 24, 1957.

this model the fission neutrons emitted from the shell slow down according to the age kernel and then diffuse according to diffusion theory, with the boundary conditions created by the "black" shell.

The flux-trap is formed by the moderator enclosed by the fuel shell. The thermal flux at the center of this flux-trap, normalized to the emission of one fission neutron by the shell, can be computed by means of the last equation in the reference.[1] The result is tabulated in Table 1, for D_2O, Be, BeO, and C moderator and for various values of the dimensionless shell radius $\rho = r/\sqrt{\tau}$, where r is the actual radius and $\sqrt{\tau}$ the slowing-down length. As can be seen, the central flux is much higher for Be and BeO than for D_2O and C, which is largely due to the small diffusion constant of Be and BeO. This forces the neutrons, which reach thermal energies at some distance from the shell, to build up a substantial gradient of flux in the process of diffusing toward the shell. The higher this gradient, the higher the central flux. Table 1 also shows the multiplication factor ηf required to keep the idealized flux-trap reactor critical. ηf was computed from eq. 14 of ref. 1.

As can be seen from the last equation of ref. 1, ϕ_c is inversely proportional to D and, for a given ρ, also inversely proportional to $\sqrt{\tau}$. Hence ϕ_c is proportional to the square of the density. The densities used are those listed in Table 2, as mentioned below. They are identical with the densities listed in Table 1 of ref. 1, except that density 2 was used for C in the present memorandum. The required multiplication factor ηf is independent of the density.

The results shown in Table 1 are also plotted in Fig. 1-4, each figure referring to one of the moderators considered. The central flux reaches a maximum for a certain value of the radius. At smaller radii, the flux-trap principle is not very effective, because the neutrons do not have to travel very far from the point of thermalization to the shell. Hence, they do not build up to give high fluxes at the center. At larger radii, the surface of the shell gets too large, and since the total shell emits one fission neutron in any case, the number of neutrons emitted per cm^2 of the shell becomes too small. Also, for large radii, neutrons suffer excessively from absorption in the moderator before they reach the shell. The required multiplication factor decreases monotonically with increasing radius, as less neutrons are lost at infinity for larger radii.

Table 2 refers to the flux-trap reactor, the radius of which has the value which maximizes the central flux. The central flux is given for the four moderators considered, as well as the required multiplication factor ηf. For the reasons given above, Be and BeO give higher central flux than D_2O or C, but it should be noted that Be and BeO require multiplication factors close to the theoretical maximum obtainable with U^{235} (2.06 obtained when $f = 1$), whereas C and D_2O get by with smaller ηf values. The dimensionless radii ρ, corresponding to these maxima of the central flux, are also listed. It may be seen that these values are always close to two, being largest for the least absorbing moderator, D_2O. The actual radii, in cm, are also recorded.

For a given reactor power of P megawatt, there are 3.1×10^{16} P fissions/sec, or $3.1 \times 10^{16} \times 2.46$ P = 7.63×10^{16} P fission-neutron emissions/sec, or 7.63×10^{16} P ϕ_c n/cm^{2}sec at the center of the flux-trap, where ϕ_c is the value obtained from Table 2. Conversely, one can compute the reactor power P, required to give a flux of 10^{16} n/cm^{2}sec. This power, in Mw,

$$P = 1/7.63 \ \phi_c$$

is listed in Table 2, last column. For Be the power is 138 Mw for the idealized conditions considered here.

The multiplication factor and the dimensionless radius ρ are independent of the density of the moderator. However, the actual radius is proportional to the slowing down length $\sqrt{\tau}$, and hence inversely proportional to the density. The central flux is proportional to the square of the density as mentioned above, and hence the power needed for 10^{16} n/cm^{2}sec is inversely proportional to the square of the density. The multiplication factor is independent of the density. Column 2 lists the density values used.

Table 1

Central Flux ϕ_c in Units of 10^{-4} n/cm^2 per Fission n Emitted and Multiplication Factor ηf

ρ	Φ_c				ηf			
	D_2O	Be	BeO	C	D_2O	Be	BeO	C
1.2	3.508	7.065	6.600	3.027	1.985	2.674	2.527	2.448
1.4	4.123	8.200	7.691	3.533	1.795	2.371	2.249	2.183
1.6	4.578	8.985	8.461	3.895	1.663	2.166	2.059	2.002
1.8	4.864	9.398	8.893	4.104	1.568	2.024	1.926	1.873
2.0	4.989	9.475	9.013	4.169	1.497	1.922	1.829	1.780
2.2	4.975	9.270	8.870	4.114	1.443	1.847	1.758	1.711
2.5	4.758	8.584	8.293	3.865	1.383	1.769	1.682	1.637
3.0	4.102	6.934	6.828	3.212	1.316	1.693	1.605	1.559
3.5	3.359	5.237	5.279	2.512	1.272	1.651	1.560	1.514
4.0	2.696	3.816	3.954	1.908	1.241	1.626	1.533	1.485

Table 2

Idealized Flux-Trap Reactor with Radius Adjusted to Give Maximum Central Flux

Moderator	Density g/cm^3	Central Flux ϕ_c, in Units of 10^{-4} n/cm^2 per Fission n Emitted	Multiplication Factor	ρ (see text)	Radius cm	Power $Mw/(10^{16}\ n/cm^2 sec)$
D_2O	1.1	4.999	1.474	2.08	23.3	262
Be	1.85	9.485	1.944	1.95	19.2	138
BeO	3.0	9.014	1.833	1.99	20.4	145
C	2.0	4.169	1.780	2.00	30.5	315

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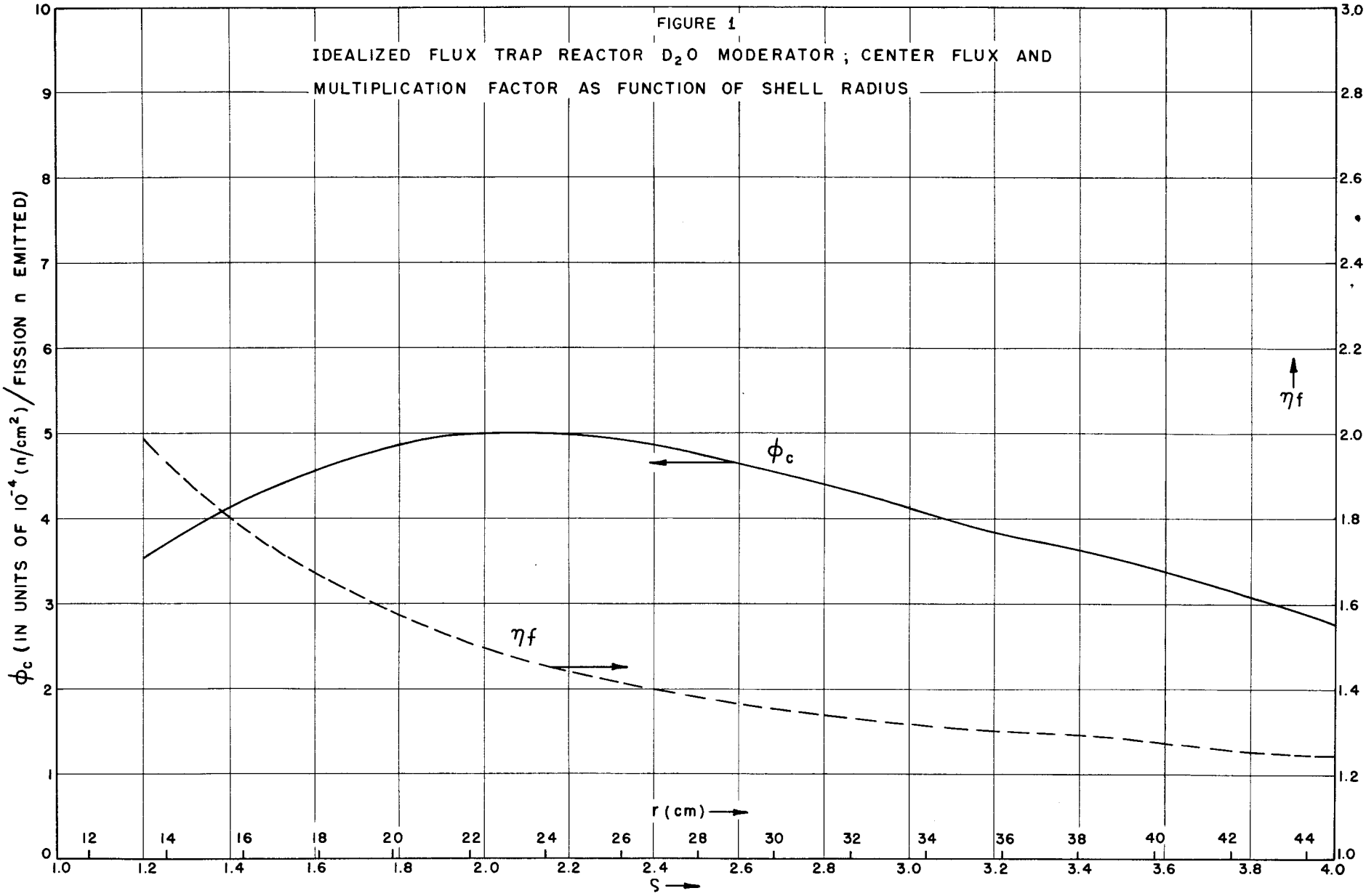

FIGURE 1

IDEALIZED FLUX TRAP REACTOR D_2O MODERATOR; CENTER FLUX AND MULTIPLICATION FACTOR AS FUNCTION OF SHELL RADIUS

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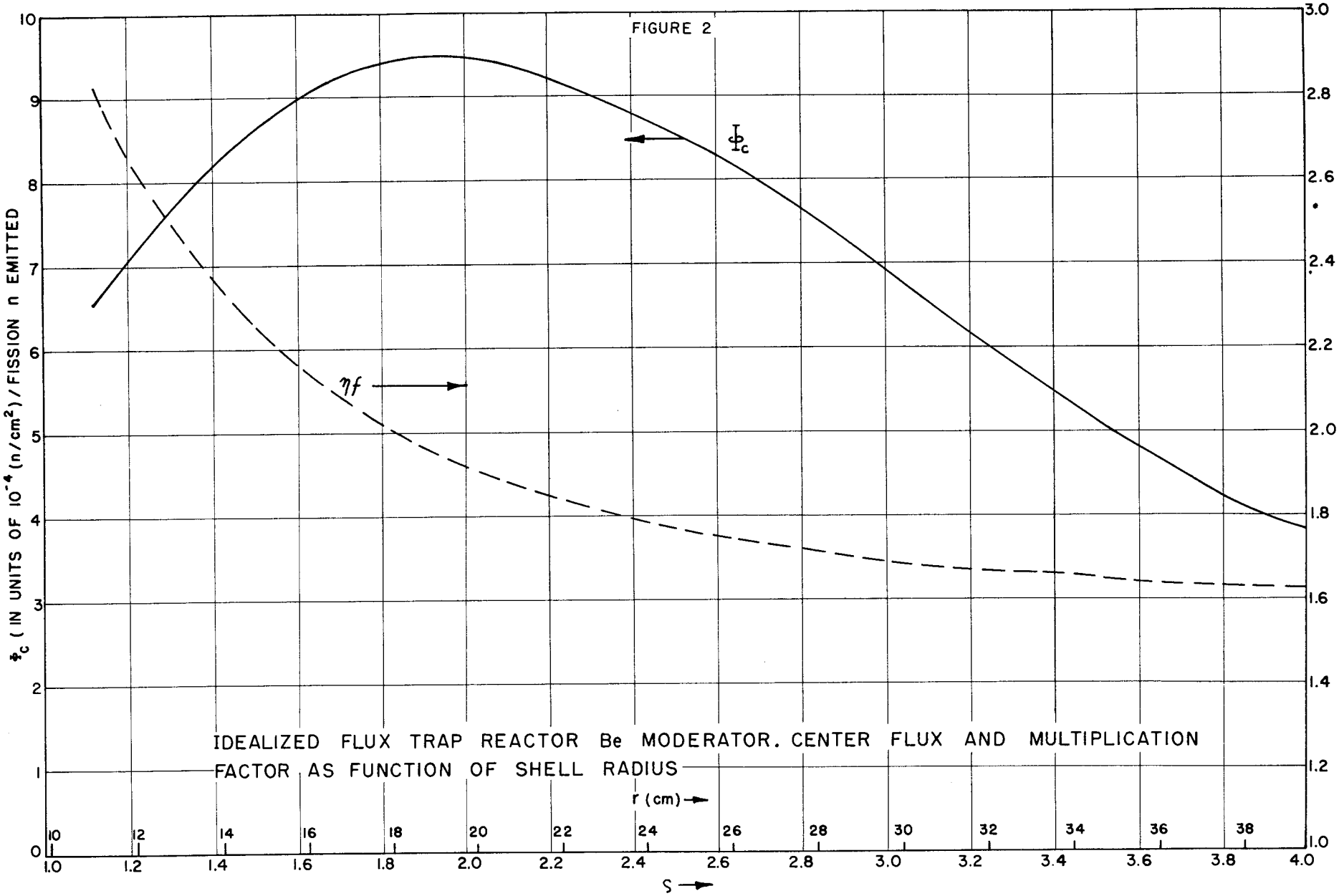

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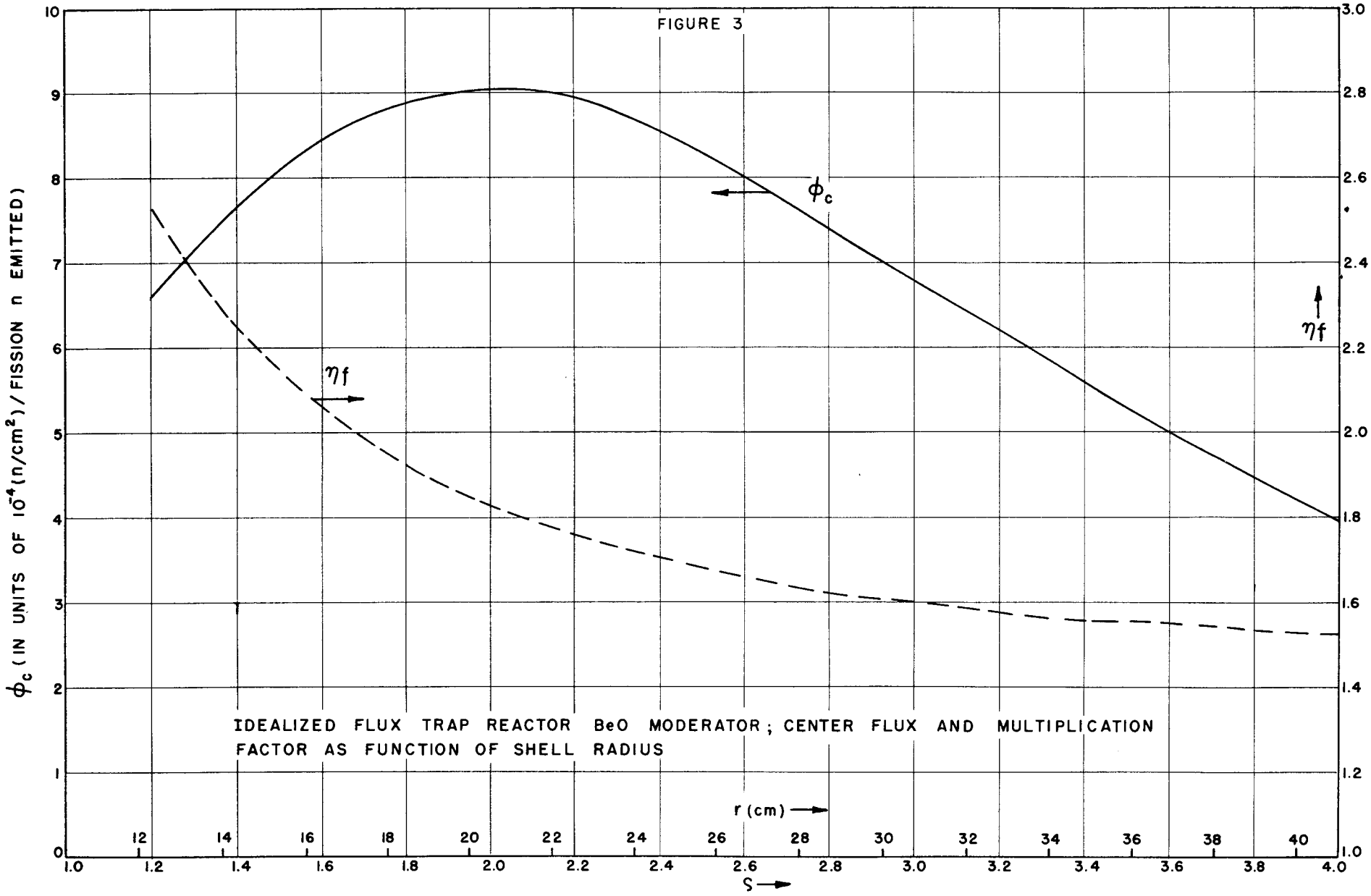

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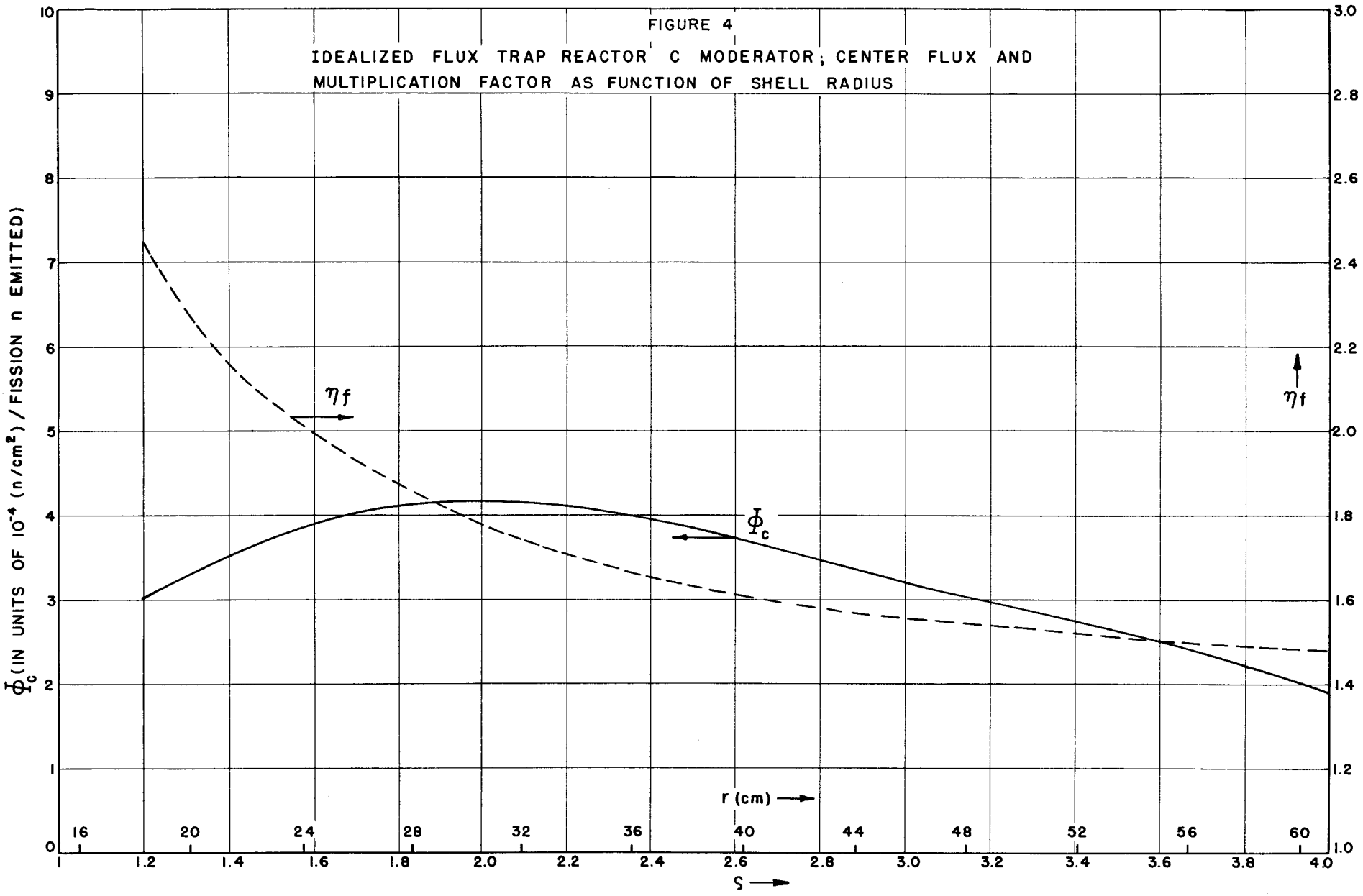

FIGURE 4
IDEALIZED FLUX TRAP REACTOR C MODERATOR; CENTER FLUX AND MULTIPLICATION FACTOR AS FUNCTION OF SHELL RADIUS