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Laboratori Nazionali di Frascati

LNF-88/15(P)
14 Marzo 1988

M. Pelliccioni and A. Zanini:

CALCULATION OF DOSE EQUIVALENT INDEX, EFFECTIVE DOSE EQUIVALENT AND AMBIENT DOSE EQUIVALENT FOR THE GIANT-RESONANCE NEUTRON SPECTRA PRODUCED AT AN ELECTRON ACCELERATOR

Extended version of the paper presented at the
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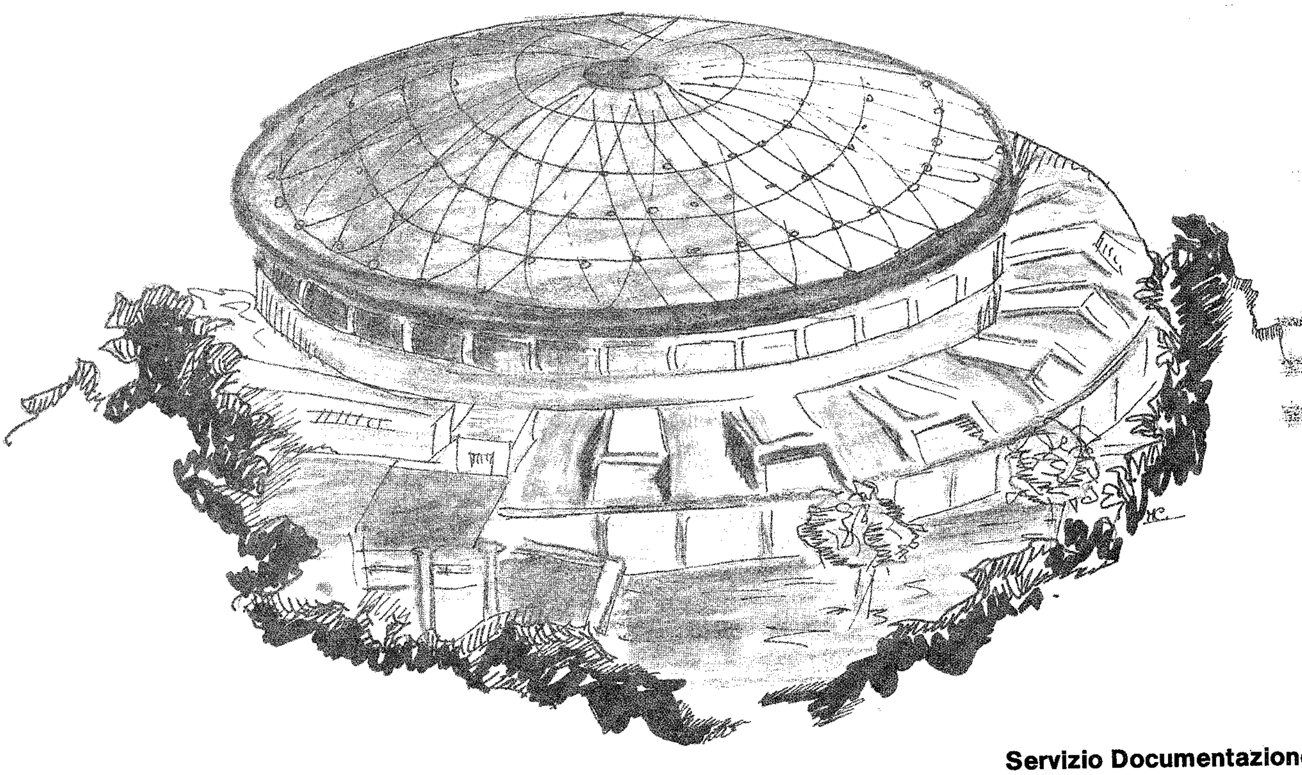

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ABSTRACT

The ANISN code has been used in this study to evaluate the attenuation of neutron beams of various spectra incident normally on slabs of different kinds of concrete. Spectra of the most common sources (Am-Be and Cf-252) and those of giant resonance neutrons, produced at electron accelerators, were studied. The concretes examined had densities between 2.1 and 4.64 g.cm^{-3}. The calculations were made in terms of the deep dose equivalent index, the effective dose equivalent and the ambient dose equivalent. Values of attenuation length in the various materials were derived from the attenuation curves. The results found should allow for useful evaluations in every day practice for the health physicist.

INTRODUCTION

The existing situation regarding which operational radiation protection quantities should be used for individual and environmental external radiation monitoring is very confusing. In fact, the trends are different depending on whether the recommendations of the ICRP[1], the European Directives, the individual national legislations, or the more recent recommendations of the ICRU[2] are followed.

It is not the intent of this paper to present the various quantities recommended nor to discuss their relative advantages or disadvantages.

While waiting for the matter to be clarified, however we thought it would be interesting to evaluate the differences resulting from the use of one or another of these quantities in various radiological applications.

In a previous paper[3] we studied these differences in the case of the attenuation of monoenergetic neutron beams in ordinary concrete. The results obtained using the operational quantities recommended respectively by the ICRP (deep dose equivalent index) and by the ICRU (ambient dose equivalent) were compared to those concerning the effective dose equivalent , the quantity by which the dose limits are recommended.

The differences between the deep dose equivalent index, evaluated in unidirectional geometry, and the ambient dose equivalent appear always extremely small and the values of these quantities are always conservative with respect to those of the effective dose equivalent. The differences, moreover, tend to disappear as the thickness of the shield increases and the energy of the neutrons decreases.

In the present paper the comparison is repeated studying the attenuation of a number of heterogeneous neutron spectra of practical interest in concrete absorbers of various compositions.

NEUTRON ATTENUATION CALCULATIONS

As it is widely known one of the main components of the radiation field around high energy electron accelerators are the so-called giant resonance neutrons. These neutrons are produced when a high energy electron beam is absorbed in matter by means of the (γ,n) (γ,2n) (γ,np) processes, mainly by photons with energies around 20 MeV. Their spectra depend on various parameters and above all on the material in which the reactions take place. A satisfactory approximation can be made for these spectra in the energy interval between 0.1 MeV and about 10 MeV by the function[4]:

$$N(E)dE = A\sqrt{E}\ \exp(-E/T)dE \qquad (1)$$

where the values of the parameters A and T can be assumed as shown in Table I, according to whether targets of low or high atomic number are considered.

Because of the considerable interest in the radiation protection problems posed by the above mentioned component of the radiation field around electron accelerators, its attenuation in concrete shields was studied, using different radiation protection quantities. The elementary composition of the various kinds of concrete taken into consideration is shown in Table II.

The study was also extended to the neutron spectra of Am-Be and Cf sources. The spectra of these very common sources are similar enough to those of giant resonance neutrons to be often substituted for these in order to simplify dosimetric evaluations(4).

TABLE I - Parameters for neutron spectra.

	A ($MeV^{-1/2}$)	T (MeV)	$\bar{E}$ (MeV)
Al-target	0.030	3.0	3.9
Heavy target	0.48	1.0	1.8
Am-Be source			4.3
Cf-source			2.0

TABLE II - Elementary composition of the different type of concrete (from Ref. 5)

Type:	Ordinary	Magnetite	Barytes	Magnetite and steel	Limonite	Serpentine
Density ($g. cm^{-3}$):	2.35	3.53	3.35	4.64	4.54	2.1
Element	Partial Density ($g. cm^{-3}$)					
H	0.013	0.011	0.012	0.011	0.031	0.035
O	1.165	1.168	1.043	0.638	0.708	1.126
Si	0.737	0.091	0.035	0.073	0.067	0.460
Ca	0.194	0.251	0.168	0.258	0.261	0.150
C						0.002
Na	0.040					0.009
Mg	0.006	0.033	0.004	0.017	0.007	0.297
Al	0.107	0.083	0.014	0.048	0.029	0.042
S	0.003	0.005	0.361			
K	0.045		0.159		0.004	0.009
Fe	0.029	1.676		3.512	3.421	0.068
Ti		0.192		0.074		
Cr		0.006				0.002
Mn		0.007				
V		0.011		0.003	0.004	
Ba			1.551			

The same three radiation protection quantities used in the previous paper(3), that is the effective dose equivalent, the deep dose equivalent index and the ambient dose equivalent, were also used for this comparison.

As concerns the neutron quality factor, the older values recommended by the ICRP[6] were employed, disregarding the recent statement of the ICRP itself[7] and the new values proposed by ICRU [8].

A parallel neutron beam normally incident on a semi-infinite slab of the shielding material was considered in all cases.

The one dimensional ANISN code[9], adopting the FLUNG library for the cross sections[10], was used for the calculation.

The neutron fluxes to the various depths were then multiplied by the appropriate conversion coefficients to obtain the effective dose equivalent[11], the deep dose equivalent index[11] and the ambient dose equivalent[12]. For the effective dose equivalent, the extreme cases of unidirectional and isotropic irradiation were examined.

In computing the total dose the contribution by capture gamma rays produced within the slab was also included.

RESULTS AND DISCUSSION

The results, which are certainly of practical use to health physicists, are shown in Fig. 1 to 16.

As for the comparison between the various radiation protection quantities involved, practically the same results of the previous paper dedicated to monoenergetic neutrons, were found here as well. Those results are summarized in the introduction to this paper and therefore no further comment is called for.

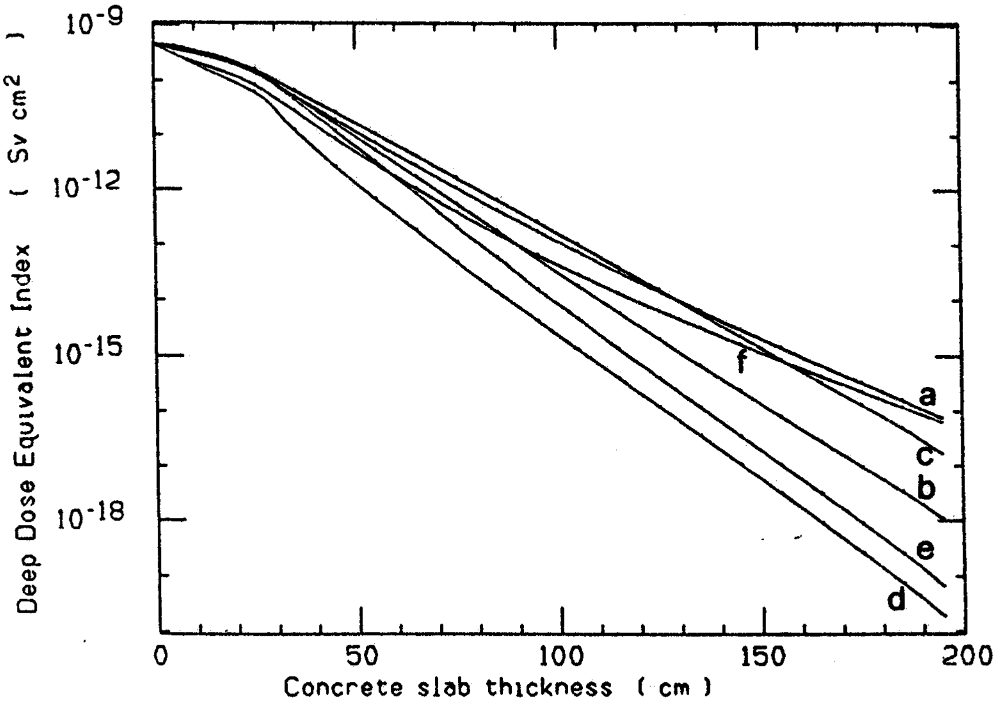

FIG. 1 - Attenuation in terms of deep dose equivalent index of a Am-Be neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key: a, ordinary (ρ=2.35 g.cm^{-3}); b, magnetite (ρ=3.53 g.cm^{3}); c, barytes (ρ=3.35 g.cm^{3}); d, magnetite and steel (ρ=4.64 g.cm^{3}); e, limonite and steel (ρ=4.54 g.cm^{3}); f, serpentine (ρ=2.10 g.cm^{3}).

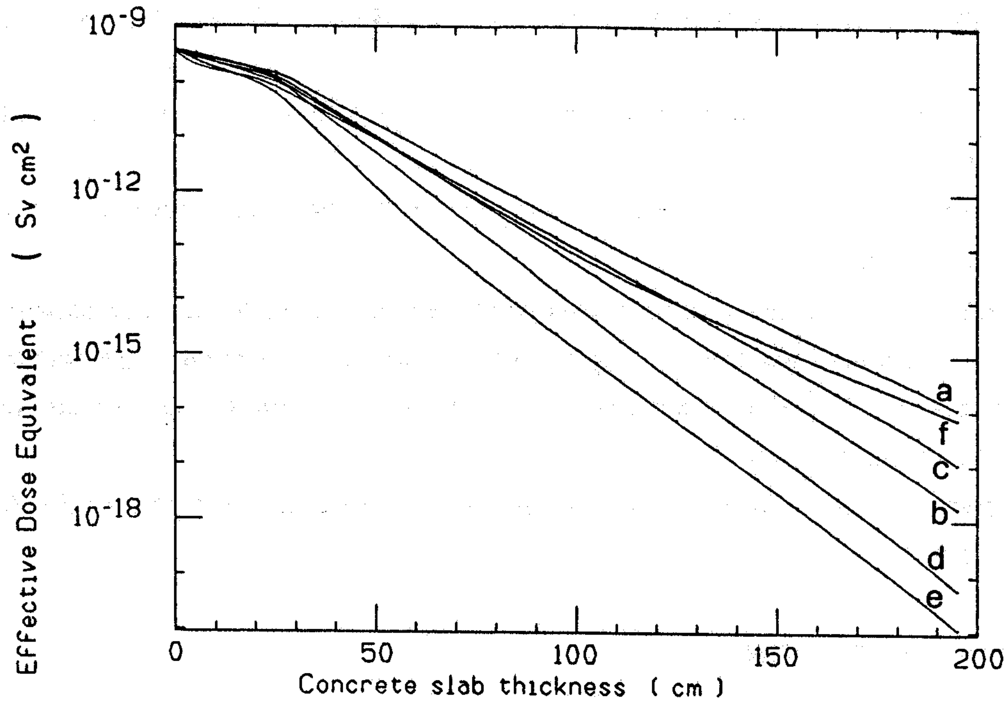

FIG. 2 - Attenuation in terms of effective dose equivalent (A-P) of a Am-Be neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

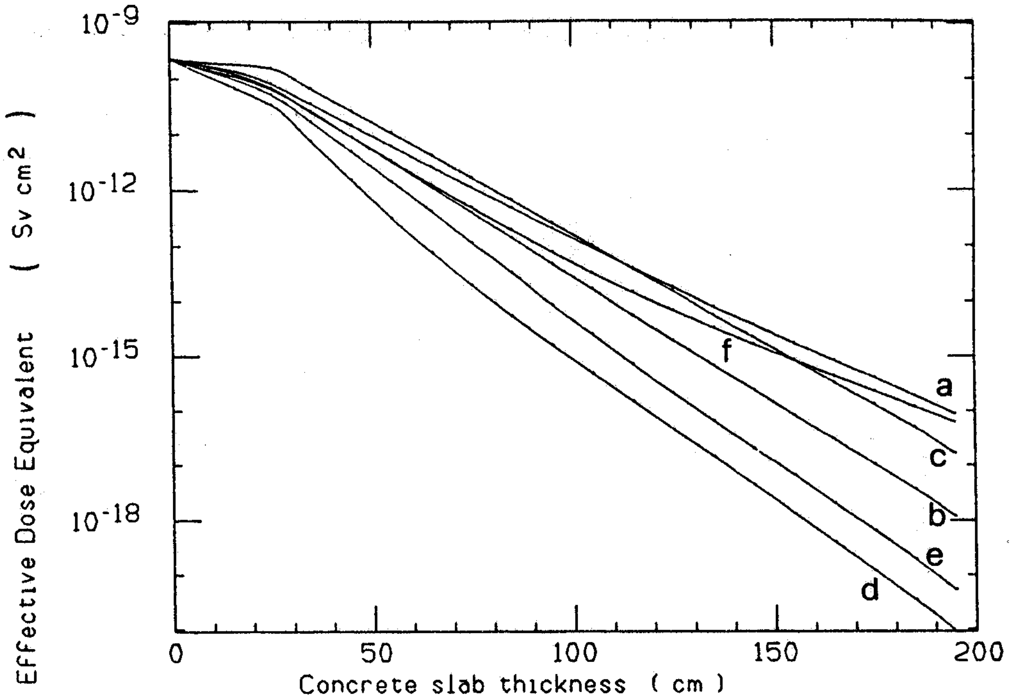

FIG.3 - Attenuation in terms of effective dose equivalent (ROT) of a Am-Be neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

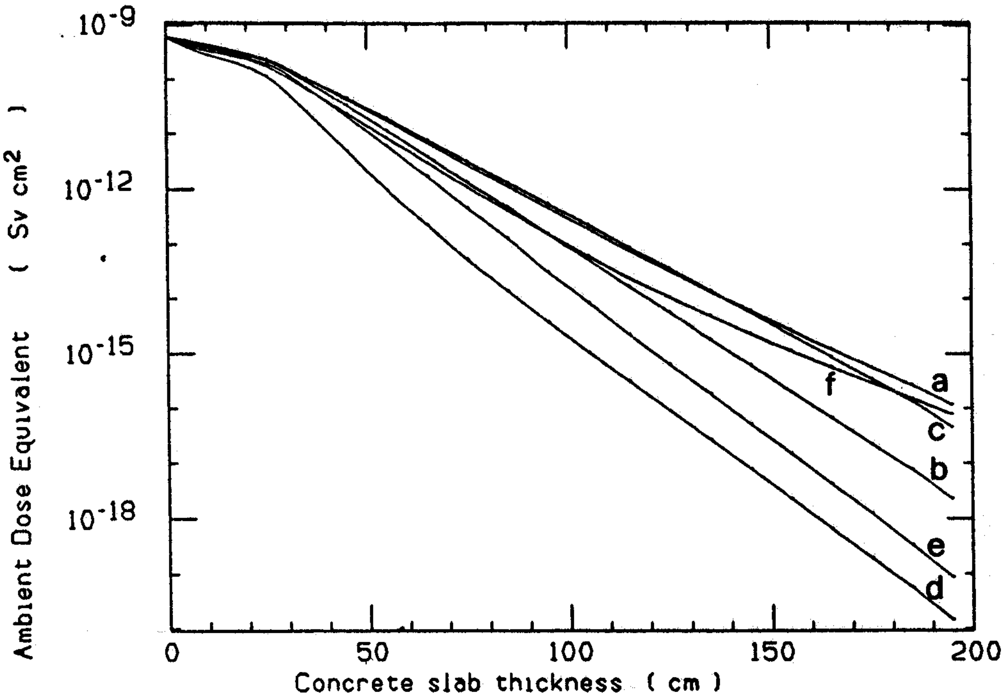

FIG.4 - Attenuation in terms of ambient dose equivalent of a Am-Be neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

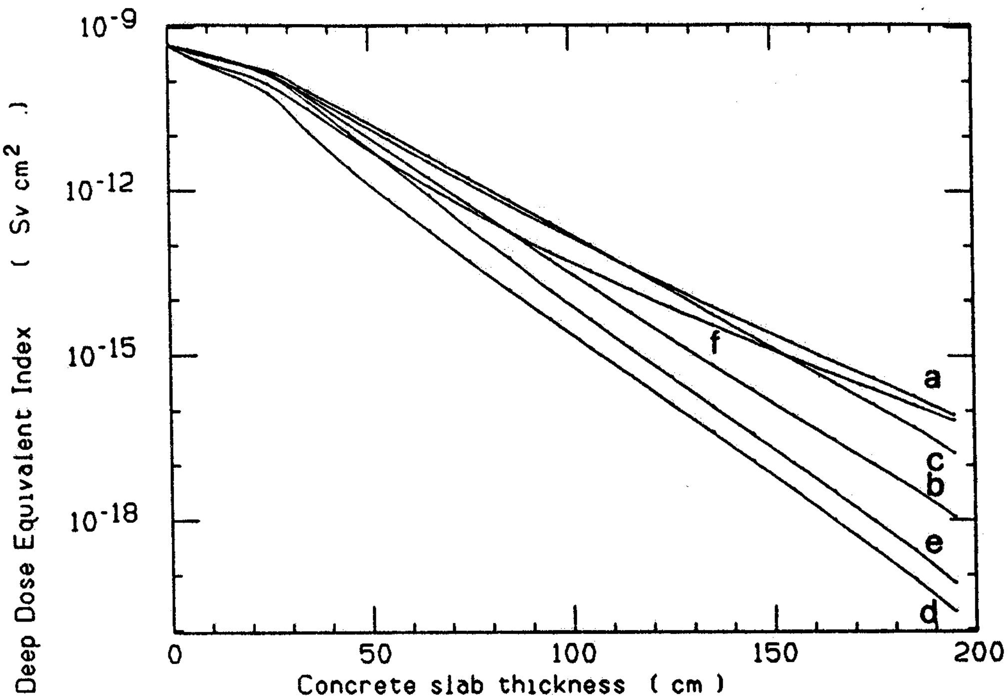

FIG. 5 - Attenuation in terms of deep dose equivalent index of a Cf-252 neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

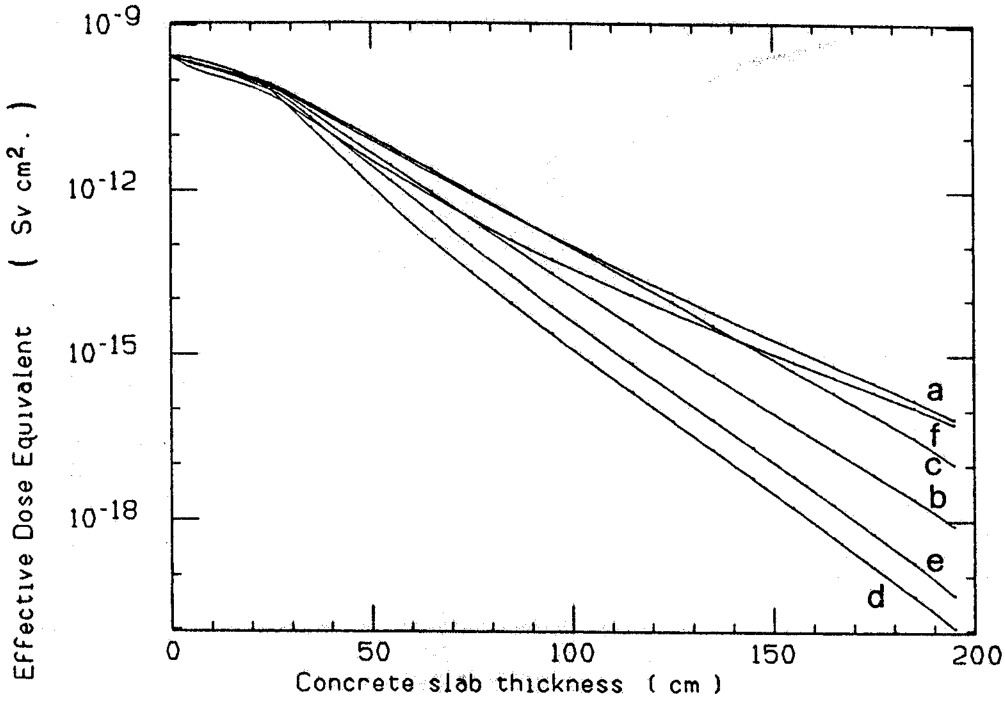

FIG. 6 - Attenuation in terms of effective dose equivalent (A-P) of a Cf-252 neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

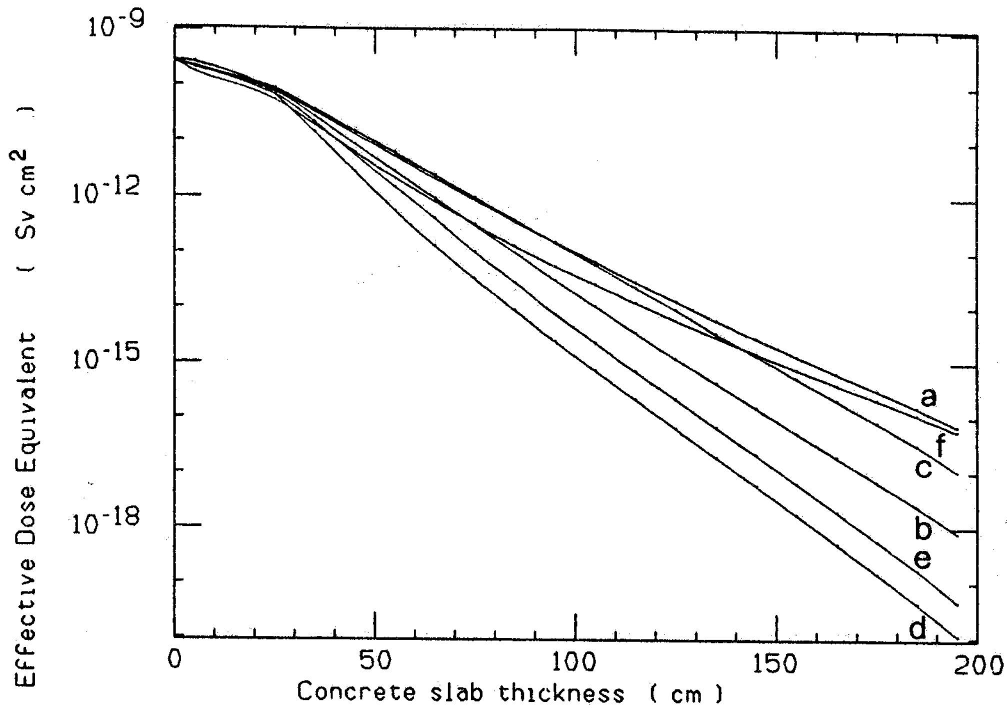

FIG. 7 - Attenuation in terms of effective dose equivalent (ROT) of a Cf-252 neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

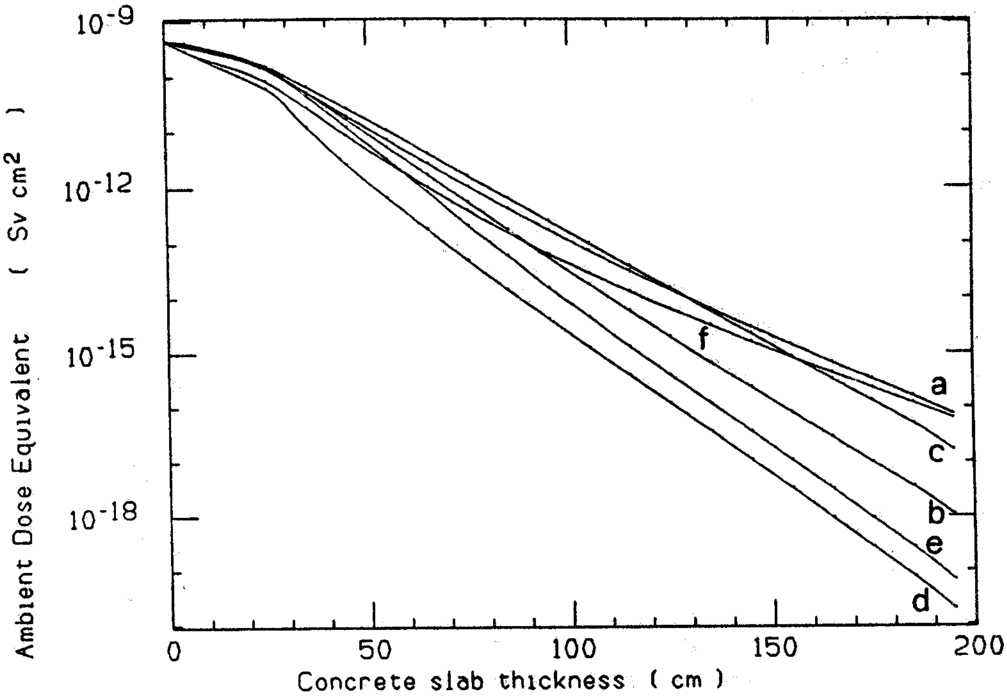

FIG. 8 - Attenuation in terms of ambient dose equivalent of a Cf-252 neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

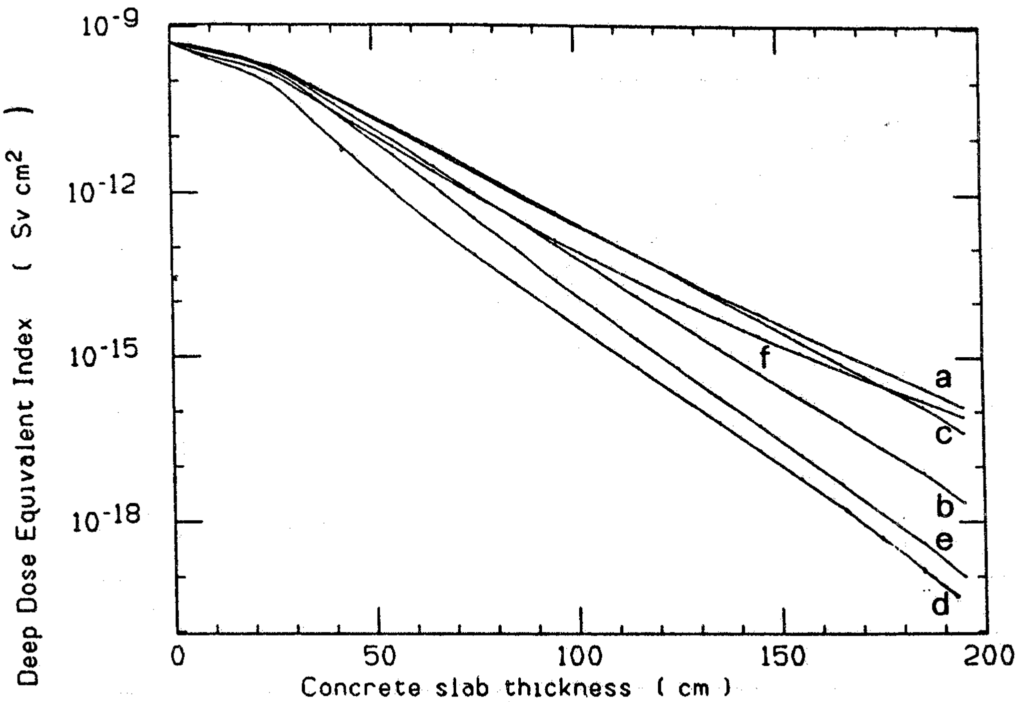

FIG.9 - Attenuation in terms of deep dose equivalent index of a low Z giant resonance neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

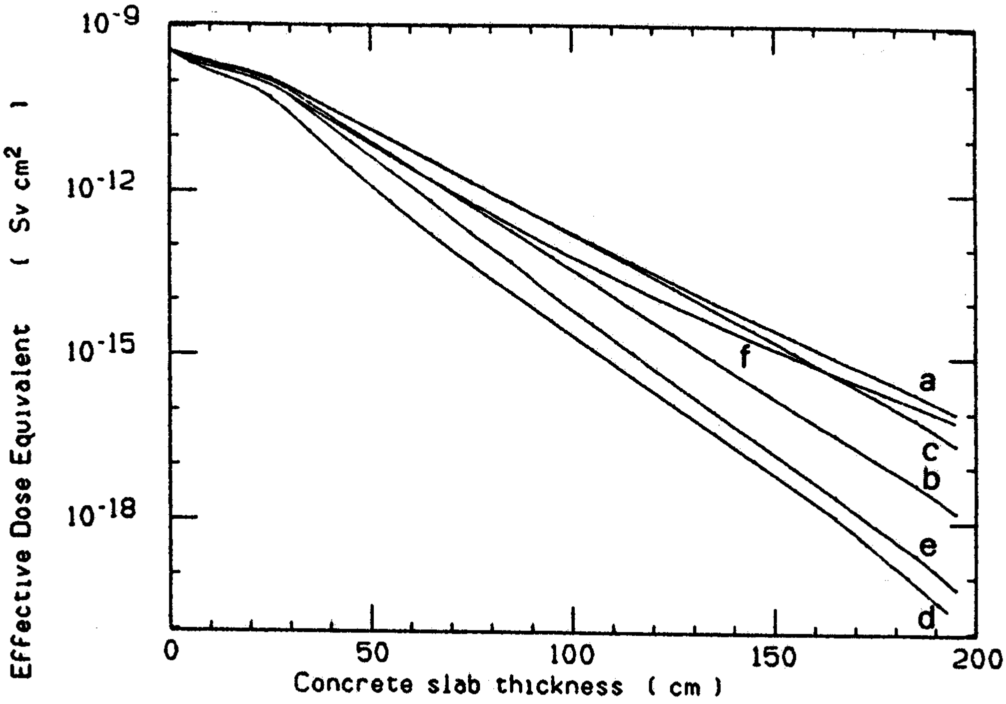

FIG. 10 - Attenuation in terms of effective dose equivalent (A-P) of a low Z giant resonance neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

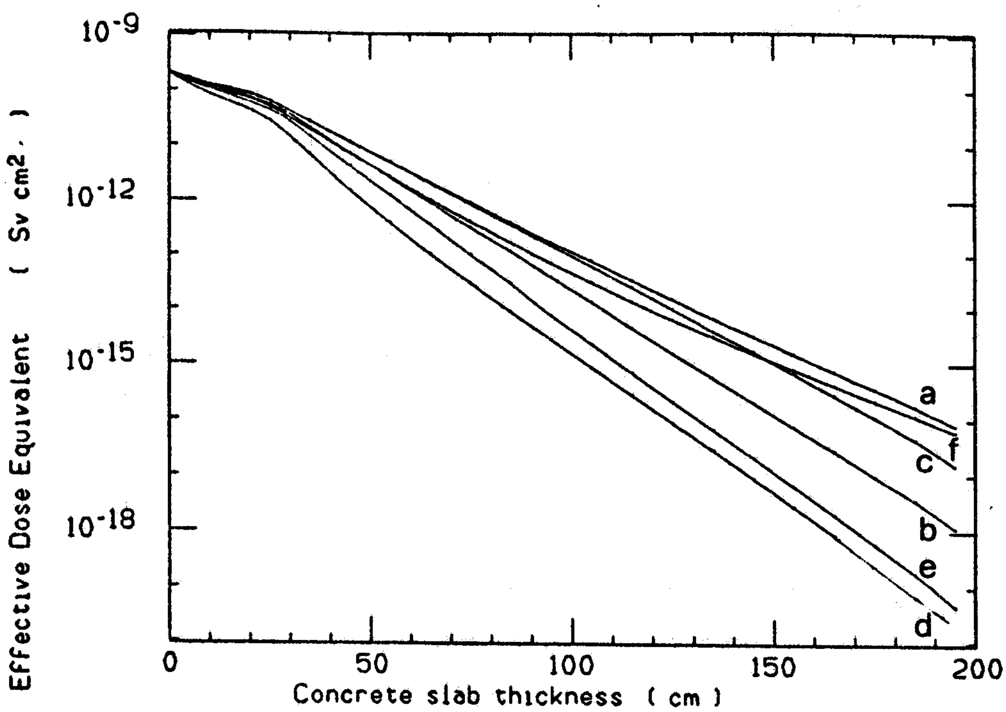

FIG.11 - Attenuation in terms of effective dose equivalent (ROT) of a low Z giant resonance neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

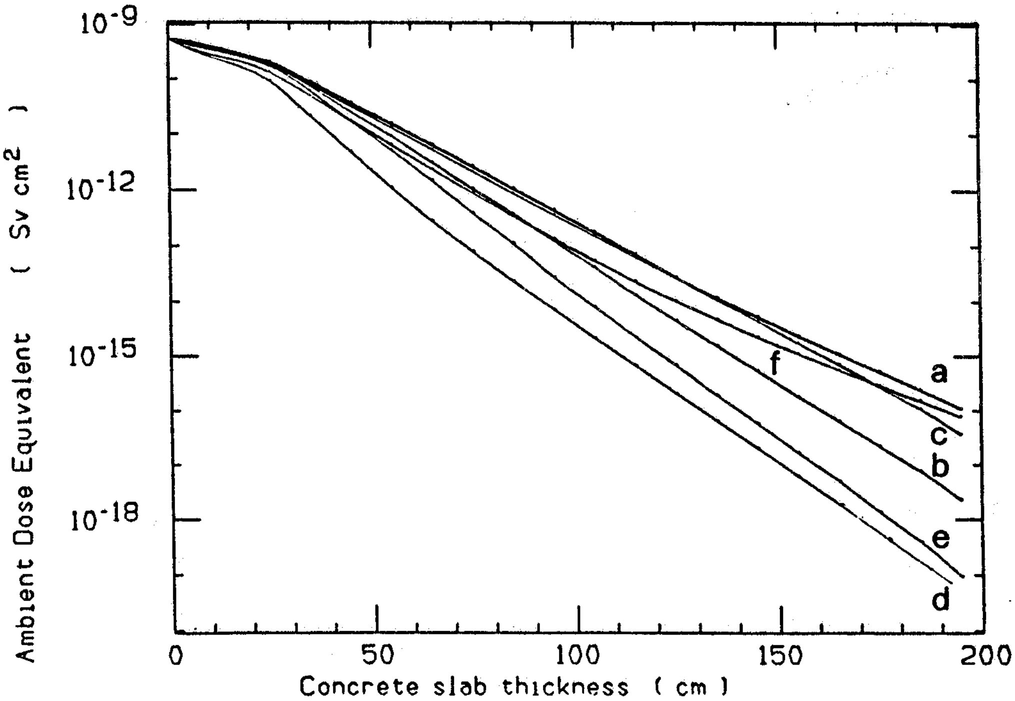

FIG. 12 - Attenuation in terms of ambient dose equivalent of a low Z giant resonance neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

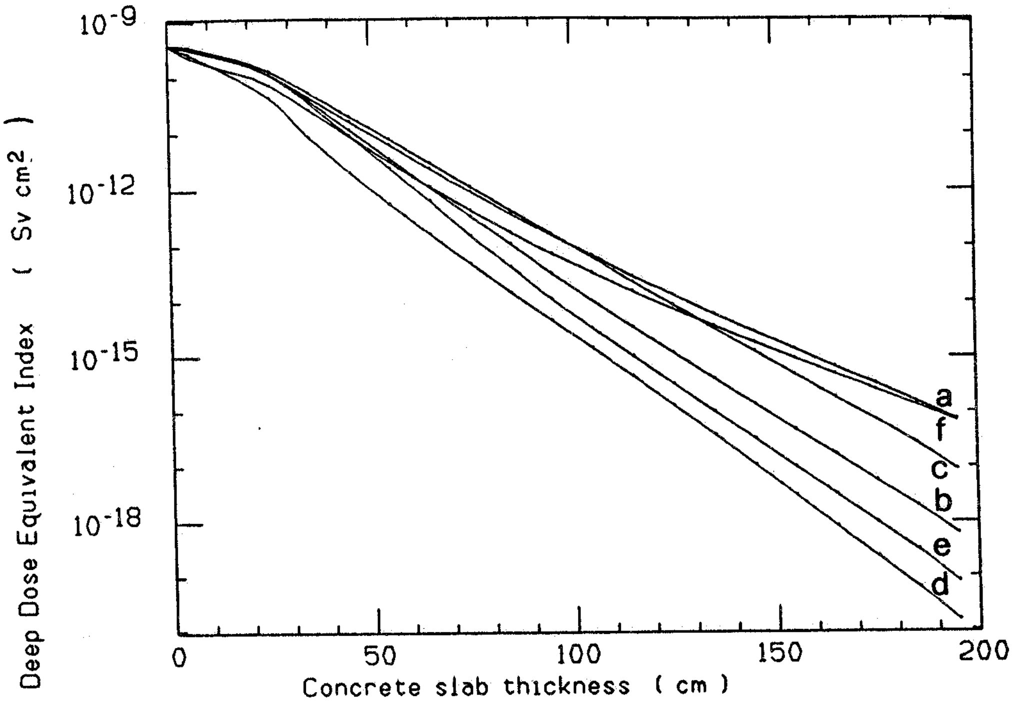

FIG. 13 - Attenuation in terms of deep dose equivalent index of a high Z giant resonance neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

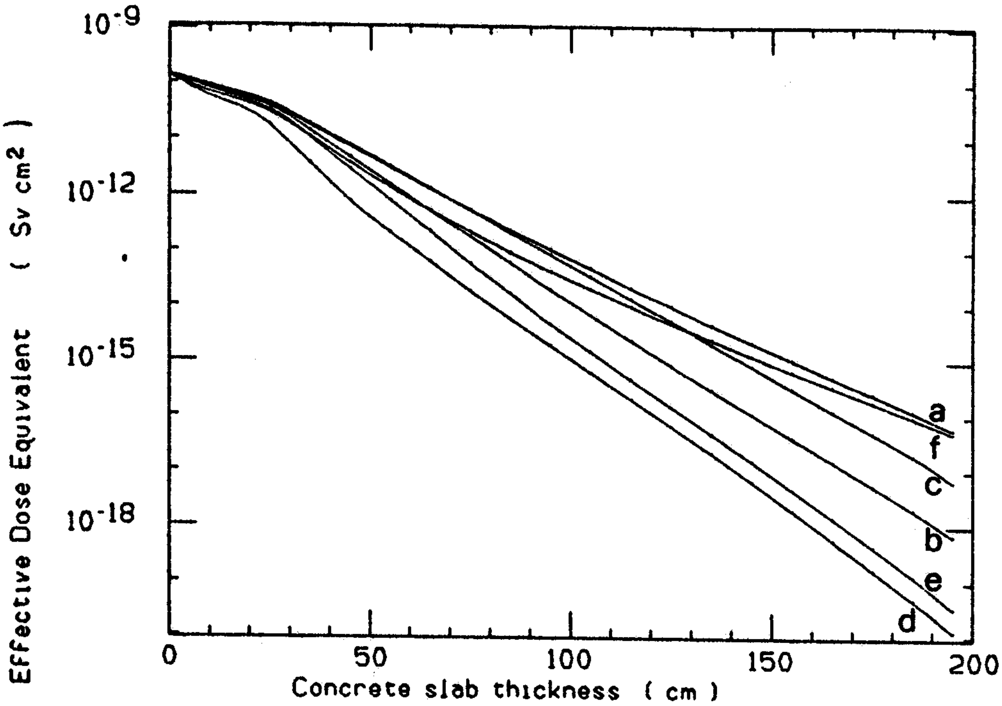

FIG. 14 - Attenuation in terms of effective dose equivalent (A-P) of a high Z giant resonance neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

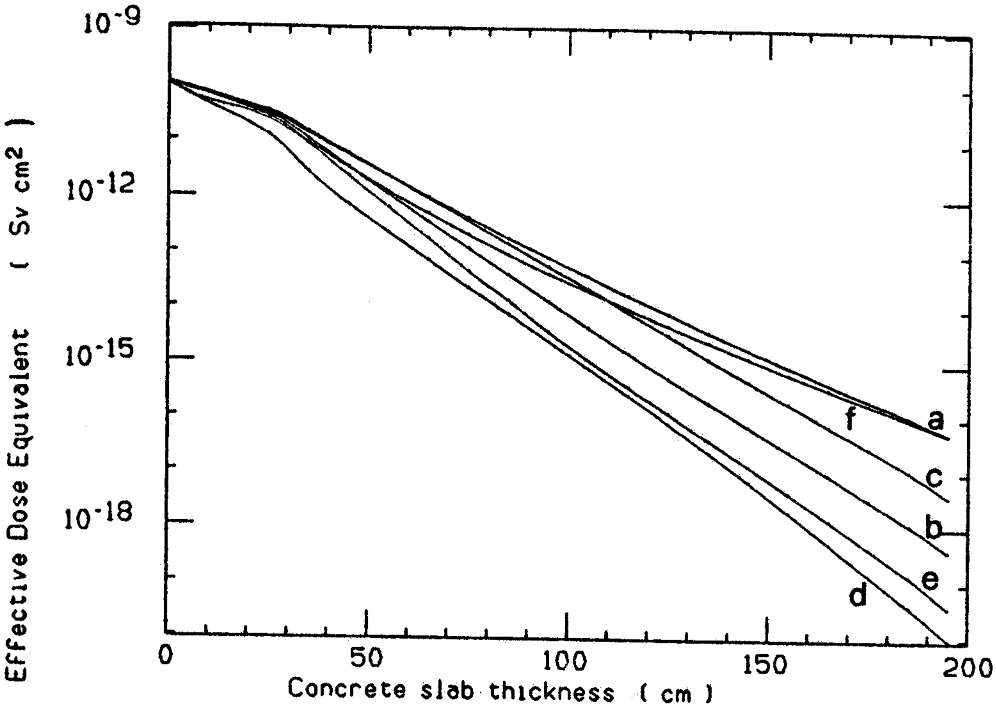

FIG. 15 - Attenuation in terms of effective dose equivalent (ROT) of a high Z giant resonance neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

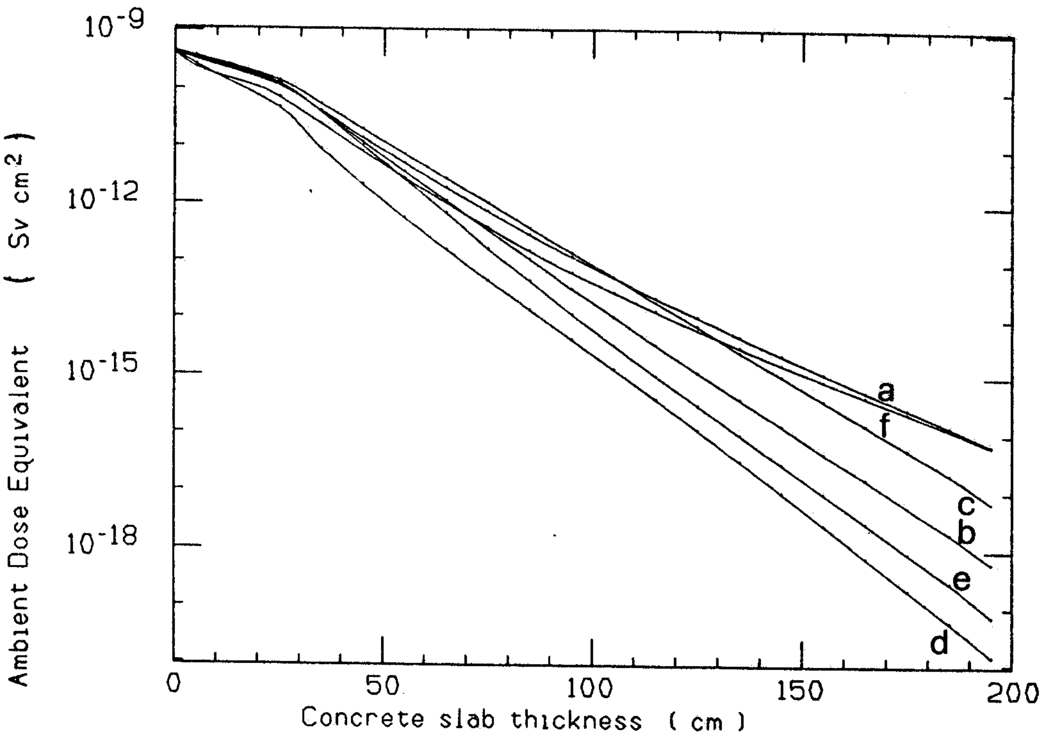

FIG. 16 - Attenuation in terms of ambient dose equivalent of a high Z giant resonance neutron beam incident normally on semi-infinite slabs of concrete of various densities. Key as Fig.1.

It would be interesting at this point to try to estimate the values of some parameters useful for a simple evaluation of the shield thickness and for a comparison with the results of other authors.

We have tried to approximate the decreasing portion of these curves with simple exponentials, introducing $e^{-x/\lambda}$ transmission factors, where the parameter λ represents the attenuation length. In Table III the values of λ obtainable for the four spectra, for the various absorbers, and for the different radiation protection quantities taken into consideration, are shown. These values are those which best approximate the curves for thickness greater than about 70 $g.cm^{-2}$. In Table IV the values of λ which correspond to deeper thickness, between about 300 and 400 $g.cm^{-2}$, are also shown. In order to conservatively calculate the thickness of a shield it seems more suitable to use these last values, which are systematically greater than the previous ones.

As can be seen, the smallest values are obtained in the case of the deep dose equivalent index while the highest ones correspond to the effective dose equivalent in rotational geometry.

A comparison with the results of other authors can be attempted only for the attenuation curves in ordinary concrete, the sole material, among those studied, for which data is readily available. Nevertheless this a not so simple task owing to the behavior of the curves, which, because their slopes change continuously, are only approximately exponential.

Summaries of the data and attenuation curves found in ordinary concrete for monoenergetic neutrons, and for numerous neutron spectra including giant resonance neutrons, have been published in the IAEA technical report n. 188[13] and in the NCRP report n. 51[14].

TABLE III - Attenuation lengths for various neutron spectra in the different types of concrete.

	$d(g.cm^{-3})$	H_I (cm)	H_E (A-P)(cm)	H_E (ROT)(cm)	H*(cm)
Al target	2.10	12.0	12.4	12.9	11.9
	2.35	11.8	12.1	12.6	11.7
	3.35	11.7	11.8	11.9	11.6
	3.53	9.1	9.2	9.5	9.1
	4.54	8.5	8.6	8.7	8,5
	4.64	8.0	8.1	8.3	7.9
Heavy target	2.10	13.1	13.6	14.1	13.2
	2.35	12.3	12.6	13.1	12.5
	3.35	10.8	11.0	11.1	10.6
	3.53	9.0	9.2	9.4	9.0
	4.54	8.3	8.4	8.5	8.2
	4.64	8.3	8.5	8.7	8.2
Am-Be source	2.10	11.7	12.1	12.7	11.6
	2.35	11.6	11.9	12.4	11.5
	3.35	11.8	11.9	11.9	11.7
	3.53	9.1	9.2	9.4	9.0
	4.54	8.1	8.2	8.4	8.0
	4.64	7.7	7.8	8.0	7.7
Cf source	2.10	13.1	13.5	14.0	13.1
	2.35	12.0	12.4	12.9	12.1
	3.35	11.1	11.3	11.4	11.0
	3.53	9.1	9.2	9.5	9.0
	4.54	8.6	8.8	9.0	8.5
	4.64	8.2	8.3	8.3	8.1

TABLE IV - Attenuation lengths calculated at thickness greater than 300 $g.cm^{-2}$ for various neutron spectra in the different types of concrete.

	$d(g.cm^{-3})$	H_I (cm)	H_E (A-P)(cm)	H_E (ROT) (cm)	H*(cm)
Al target	2.10	14.8	15.1	15.4	14.9
	2.35	13.0	13.3	13.7	13.1
	3.35	11.4	11.5	11.6	11.4
	3.53	9.5	9.7	9.9	9.4
	4.54	8.5	8.5	8.6	8.4
	4.64	8.1	8.3	8.4	8.0
Heavy target	2.10	15.4	15.5	15.8	15.6
	2.35	13.7	13.9	14.2	14.1
	3.35	10.8	10.9	11.0	10.7
	3.53	9.4	9.6	9.8	9.5
	4.54	7.7	7.7	7.7	7.7
	4.64	8.6	8.7	8.8	8.5
Am-Be source	2.10	14.6	14.9	15.3	14.9
	2.35	12.7	13.0	13.5	12.9
	3.35	11.4	11.5	11.5	11.3
	3.53	9.2	9.4	9.6	9.1
	4.54	8.0	8.1	8.2	8.0
	4.64	7.9	8.1	8.5	7.9
Cf source	2.10	15.3	15.3	15.7	15.6
	2.35	13.4	13.4	14.0	13.8
	3.35	11.0	11.0	11.1	10.9
	3.53	9.6	9.6	10.0	9.5
	4.54	8.0	8.0	8.1	8.0
	4.64	8.2	8.2	8.3	8.1

In the IAEA technical report , it is stated that for neutrons with energy between 1 and 30 MeV the dose-equivalent tenth-value layer (TVL) varies between 75 and 85 $g.cm^{-2}$ with corresponding λ values between 32 and 37 $g.cm^{-2}$. For the dose equivalent index curves published in the NCRP report, λ values of about 30 $g.cm^{-2}$ could be proposed for monoenergetic neutrons of a few MeV.

The only quantity in terms of which the comparison can be made is the deep dose equivalent index for which slightly smaller values of λ, between 27 and 29 $g.cm^{-2}$ or between 30 and 33 $g.cm^2$ for the deeper thickness, are here found. The differences appear to be within the limits of accuracy of these kinds of calculations.

The discrepancies are apparently more evident if the comparison is made directly for curves related to spectra of giant resonance neutrons for which the values of λ are never less than 32 $g.cm^{-2}$ in the first of the two above-mentioned reports or between 37 and 43 $g.cm^{-2}$ for the spectra studied in the second.

The differences can be attributed however to the different quality of the assumed spectra, which in the cases of the two above reports were chosen on the basis of photo-neutron production on thin targets. These spectra are relatively richer in high energy neutrons than normally occur with thick targets. The relative attenuation curves, therefore, represent a conservative choice if related to neutrons produced in this second kind of target. We can conclude, that the data and the curves found here for the spectra under consideration probably represent a more realistic approximation for practical purposes.

Relevant discrepancies, on the contrary, can be noticed, between the λ values (not greater than 30$g.cm^{-2}$) for the attenuation in ordinary concrete of the Am-Be spectrum and the results of some measurements (40 $g.cm^{-2}$[15] or 47.6 $g.cm^{-2}$[4]) carried out with this kind of source. These differences can probably be explained by different geometric conditions and perhaps also, but to a lesser extent, by the possibly different composition of the concrete involved.

In order to better understand the matter and to explain the above mentioned discrepancies, tridimensional calculations are in progress by Monte Carlo codes (Morse, MCNP).

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