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CALCULATION OF A CONCRETE SHIELDING FOR AN ILU-8 D ELECTRON ACCELERATOR

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ABSTRACT

A concrete shielding for an electron accelerator of 1 MeV is suggested to replace its structural steel shielding. The thickness of such a shield is calculated. The calculational model used is based on standard and transmission curves given in the literature.

The calculated concrete shielding is generally adequate to attenuate the accelerator produced radiation to a level of 0.1 mrad/h or less at any point outside of the vault enclosure.

1. Introduction

In this paper a concrete shielding is calculated for an ILU-8 D electron accelerator. This kind of accelerator is built in the Bodker institute in Russia and is shielded by structural steel. Because of the advantage of concrete over steel as a shielding material a concrete shielding for this electron accelerator is suggested.

2. The Electron Accelerator ILU-8 D Main Parameters

The high frequency electron accelerator ILU-8 D is designed and manufactured in Russia. The beam of the accelerated electrons has the following parameters:

electron energy	0.7 - 1 MeV,
maximum electron beam current	30 mA,
current pulse duration	0.7 msec,
pulse repetition	2 - 50 Hz,
duration of continuous run	16 h/day.

The accelerator is supplied with a multi-sided extraction device with two extraction windows located 50 cm apart from each other, fig. (1).

By this accelerator the treated product either in form of a tube, film, or others, should be of materials having small index number Z. There is an aluminium water cooled collector target under the product to collect electrons that cross the product. It collects also electrons if there is no product.

Principally all materials will not have an induced activity after irradiation because the energy of the accelerated beam is much lower than the photonuclear reaction threshold.

3. Allowable Radiation Levels

In designing a shielding for an electron accelerator we must take into consideration the accelerated electrons, the X-ray generated due to stopping of electrons by the treated material, and the beam collected just under the irradiated product. The calculations should be made on the basis of providing sufficient shielding to reduce detectable radiation on the outside walls of the facility to a level of 0.1 mrad/h. This value is based on the NCRP limit of 0.5 rad/year for general public in an uncontrolled area [1]. Thus the following limits are set for the concrete shield design:

- the dose rate on the outer surface of the shielding should be less than 0.1 mrad/h,
- the dose rate outside the monitored zone should be less than 0.03 mrad/h.

4. Estimation of the Radiation Level for the Designed Concrete Shielding

We considered a shield in which all walls made of normal concrete of average density 2.3 gm/ccm, the first floor and ceiling from armoured concrete and the door from structural steel. The electron beam is decelerated by a target of steel. The estimation of radiation level is done at certain points on the outer surface of the concrete shield. These check points are marked in fig. (1). They are chosen because the radiation level at them has the highest value according to the geometric factor if the source is considered as a point source.

The radiation level estimation at the check points is done according to the method described in [2]. The radiation level at any arbitrary point around the

ILU 8 D concrete shielded accelerator is determined by the beam parameters:
- electron energy, E_o = 1 MeV,
- average beam current, I = 30 mA,
- the material of the target is steel,
- the amount of egress angle, Θ, with respect to the beam fall direction,
- the thickness of the shielding,
- the distance from chosen point to target.

For the dose estimation at any point x, we used the equation:

$$D_x = (D_o \cdot t \cdot I)/d^2 \qquad (1),\text{ where}$$

D_x is the dose rate in rad/h at point x, D_o is the X-ray power at one meter from the target in rad.m^2 /h.mA, t is the area occupancy factor (normally t = 1), d is the distance between X-ray source and reference point x in meters, and I is the electron beam current in mA.

D_o in equation (1) is determined from standard curves given in [2]. If Θ in degrees denotes the value of the angle between the direction of the beam and the line connecting the target to the reference point, then these standard curves (as those curves shown in fig. (2) from [2]) give for the two target materials of Z = 13 and Z = 26 the relationship between D_o and Θ at different constant values of the electron energies in MeV. Thus for any reference point x of known value for d in meters, Θ in degrees, and D_o from standard curves the dose value D_x can be determined.

The reduction factor K is then determined by dividing the value of D_x by the maximum permissible dose limit rate, H. Hence we get K from:

$$K = D_x / H \qquad (2),\text{ where}$$

H = maximum desired intensity at outside of wall = 0.1 mrad/h as mentioned before.

Having fixed the value of the reduction factor K, the thickness of the concrete shielding is then determined from another transmission curves given in [2]. These transmission curves (as those curves shown in fig. (3) and fig. (4) from [2]) give the relationship between the thickness of the shielding material either concrete, steel or lead in cm and the value of the angle Θ in degrees for the two target materials of Z = 13 and Z = 26 at constant values of the electron energies, E_o, in MeV and constant K values.

5. Shielding Calculation Details

By the calculation method just described, we estimated the thickness of the concrete shielding at two reference points, thickness of facility floor, and the thickness of the facility door made of structural steel. The results were as follows:

a) Reference point A on side wall (lower vault), fig. (1):

Θ = 115°, d = 2.5 m

From standard curves in fig. (2) from [2] for Z = 26 and electron energy, E_o = 1 MeV we get

D_o = 800 rad.m^2 /h.mA

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For $I = 30$ mA and $t = 1$ we get from equation (1):
$D_x = 3.8\ 10^3$ rad/h
From equation (2): $K = 3.8\ 10^7$, and from transmission curves in fig. (3)[2], with $Z = 26$ and electron energy, $E_o = 1$ MeV, then:
The Concrete thickness of shielding side wall will be equal to 103 cm.

b) Reference point C on roof, fig. (1):
$\Theta = 160^\circ$, $d = 4.8$ m
From standard curves in fig.(2)[2] for $Z = 26$ and electron energy, $E_o = 1$ MeV we get:
$D_o = 5.8\ 10^2$ rad.m^2/h.mA
For $I = 30$ mA and $t = 1$ we get from equation (1):
$D_x = 7.5\ 10^2$ rad/h
From equation (2): $K = 7.5\ 10^6$, and from transmission curves in fig.(3)[2], with $Z = 26$ and electron energy, $E_o = 1$ MeV, then:
The concrete thickness will be equal to 85 cm.
But since there is a concrete middle roof 20 cm thick, so the concrete shielding for the roof should be 65 cm thick.

c) Estimation of the door thickness:
$\Theta = 50^\circ$, $d = 2.5$ m
From standard curves in fig. (2)[2] with $Z = 26$ and electron energy, $E_o = 1$ MeV we get
$D_o = 1.4\ 10^3$ rad.m^2/h.mA
From equation (1): $D_x = 6.7\ 10^3$ rad/h
From equation (2): $K = 6.7\ 10^7$, and from transmission curves in fig.(4)[2], with $Z = 26$ and electron energy, $E_o = 1$ MeV, then:
Thickness of the door made from structural steel will be equal to 37 cm.

d) Dose level in the technological channels and thickness of the facility floor

There are two technological channels each of diameter 4 cm and a slit type channel of dimension 5x100 cm^2. The two technological channels are used to let wires and pipes through the shield wall, while the slit is used to get in and out the irradiated films. The three channels relative to the target are almost on the same level. Since slit opening is greater than that of the two technological channels, the dose level at the slit opening will be greater than that at the technological channel opening. The dose level at the slit opening, point F, is partly as a result of the direct X-ray coming from the target and partly due to the reflection of the X-ray on the floor shielding.

The dose level at the point F, fig. (1), can be estimated by the formula [3]:

$$P_r = (a \cdot P_o \cdot S \cdot \cos\Theta)/(2 \cdot \pi \cdot d^2) \qquad (3)$$

If $P_r = 0.1$ mrad/h = the permitted dose level on the outside surface of the shield wall and $d = 5.3$ m, $\Theta = 65^\circ$ and $S = 1$ m^2, the reflection area on the floor. a in equation (3) is the transmission coefficient of the concrete, where $a = 0.15$ from [3]. The dose level at the target area, P_o, that gives the allowable dose level at point F is given from equation (3) to be:

$P_a = 0.28$ rad/h

Using equation (1) the dose level at the point F is determined without taking into account the reduction in dose level due to the concrete shielding floor:

$$D_f = (D_a \cdot t \cdot I)/d^2$$

For $t = 1$, $I = 30$ mA, $d = 5.3$ m, and $D_a = 1000$ rad.m^2 /h.mA. Hence, $D_f = 1068$ rad/h.

The reduction factor of the concrete floor is then:

$K = 3.8\ 10^3$

Using transmission curves given in [3] for the relationship between K and the shield thickness at different constant electron energies for different shielding materials. For a concrete floor shielding and for the above K value with 1 MeV electron energy we determined from these transmission curves given in fig. (5) and taken from [3] the following value:

Thickness of the concrete floor = 40 cm.

6. References

[1] National Council on Radiation Protection (NCRP), Report No. 51, "Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities".

[2] Barkova, V.G., Chudaev, V.Ja, (1987), "Shielding Protection against Bremsstrahlung from Light Targets (0.5-3 MeV)", Report No. 87-116, Institute of Nuclear Physics, Novosibirsk, Russia.

[3] Protopopova, G.M., Chudaev, V.Ja, (1987), "Shielding Protection against Bremsstrahlung of the Electron Accelerator with Energy 0.5-3 MeV", Report No. 87-115, Institute of Nuclear Physics, Novosibirsk, Russia.

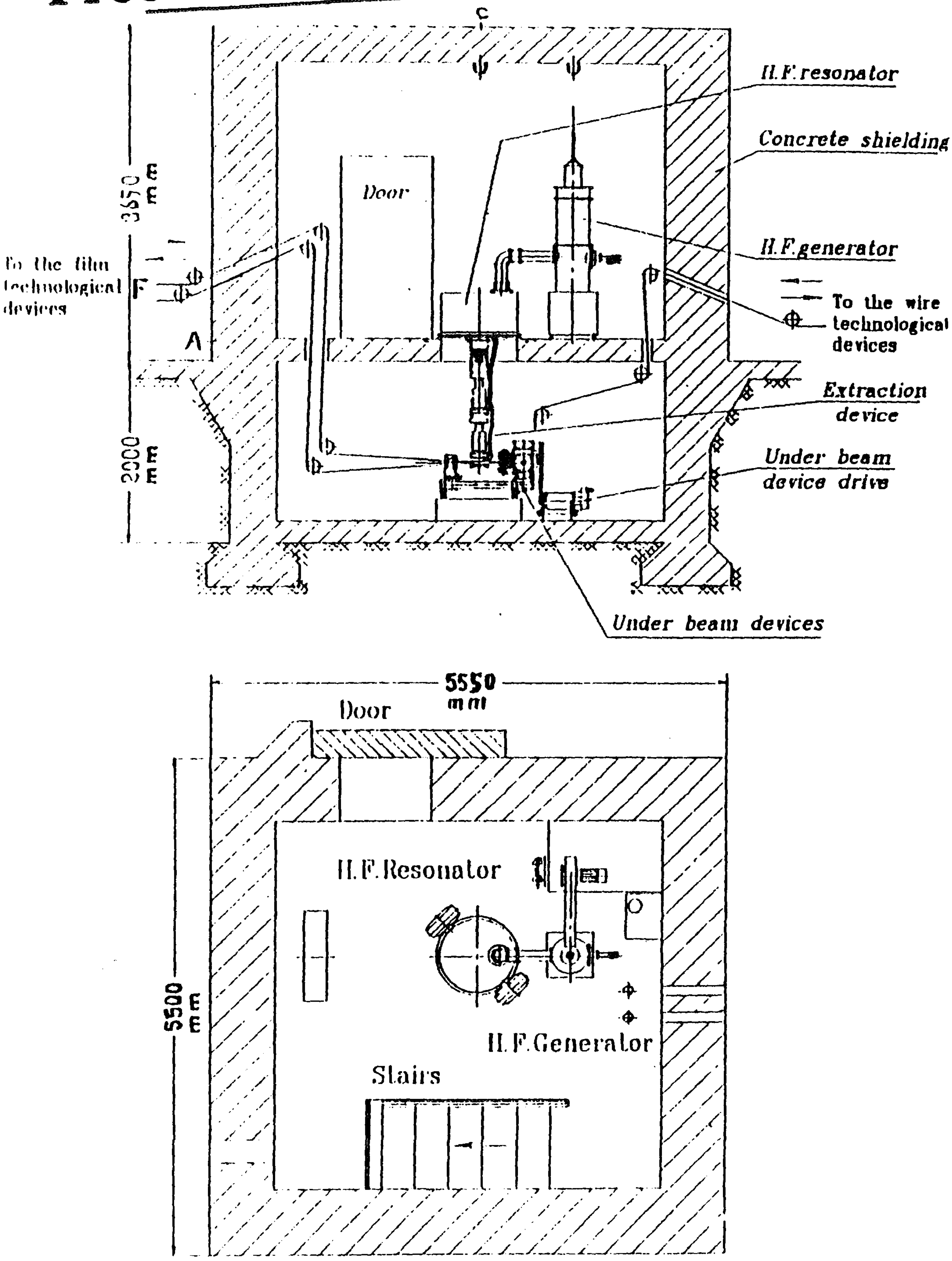

Fig. (1)

Scale 1: 50

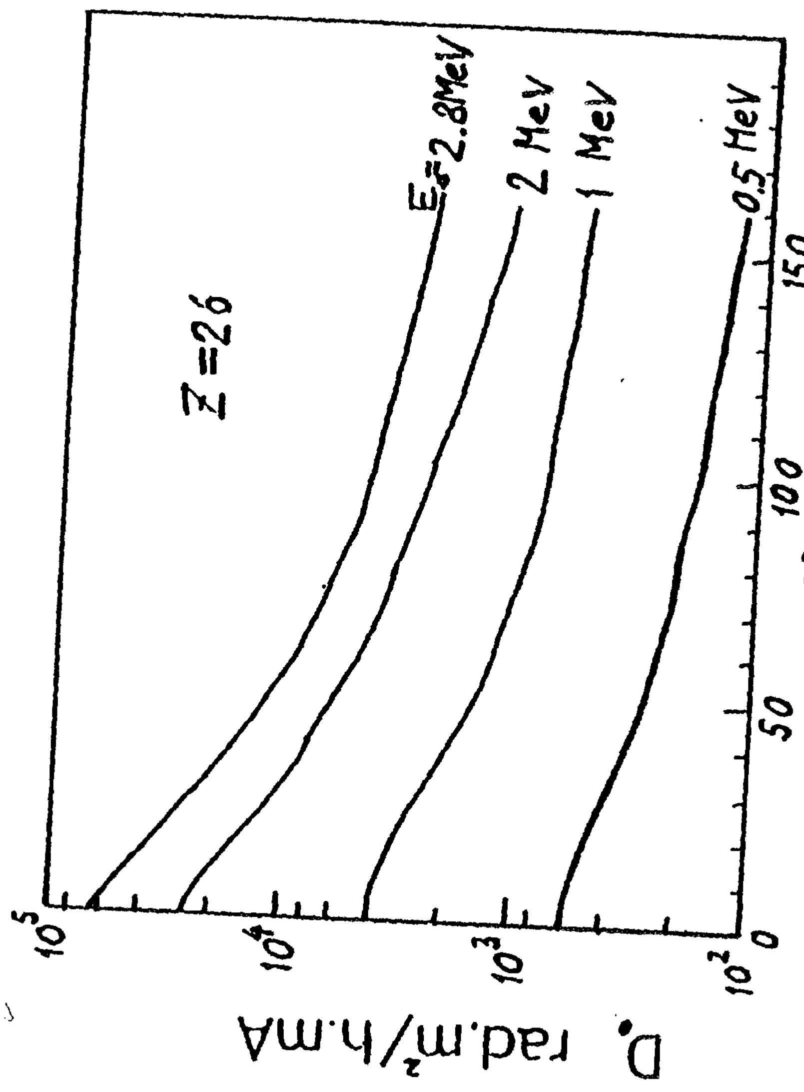

Fig.(2) from ref. [2]:standard curves

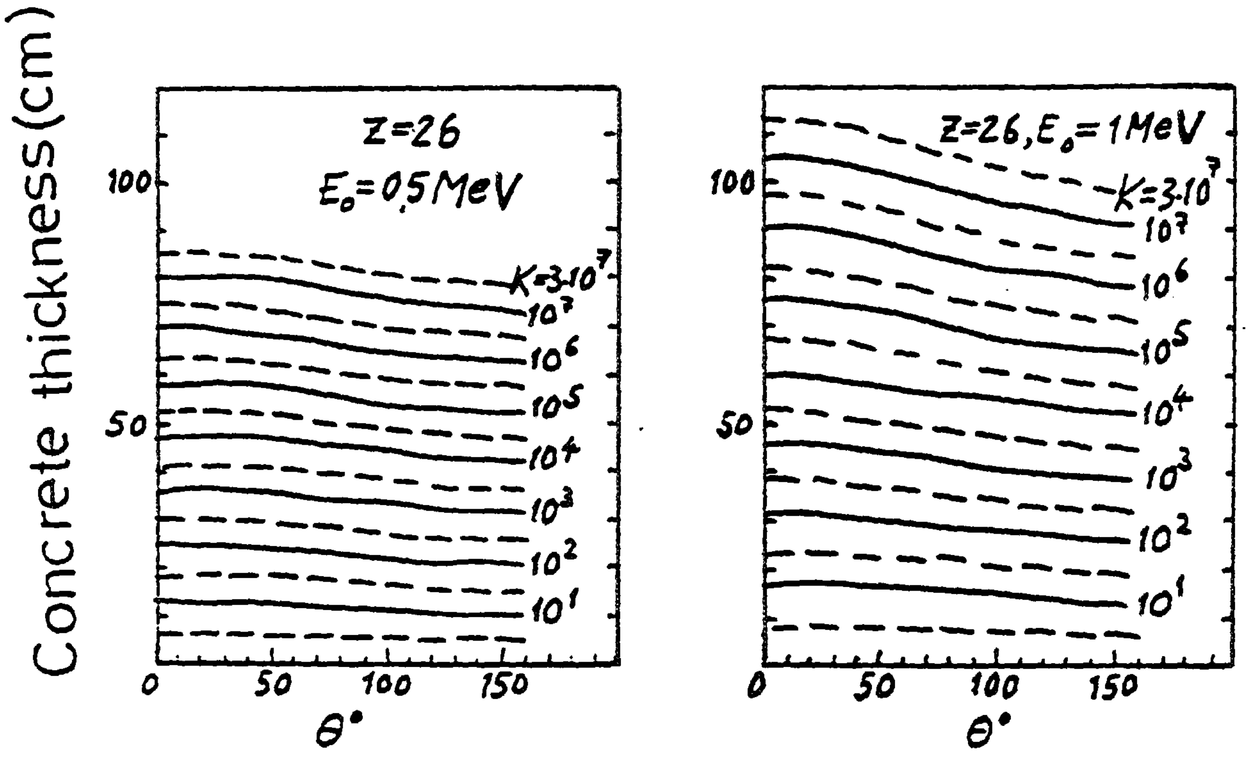

Fig.(3) from ref. [2]: Transmission curves

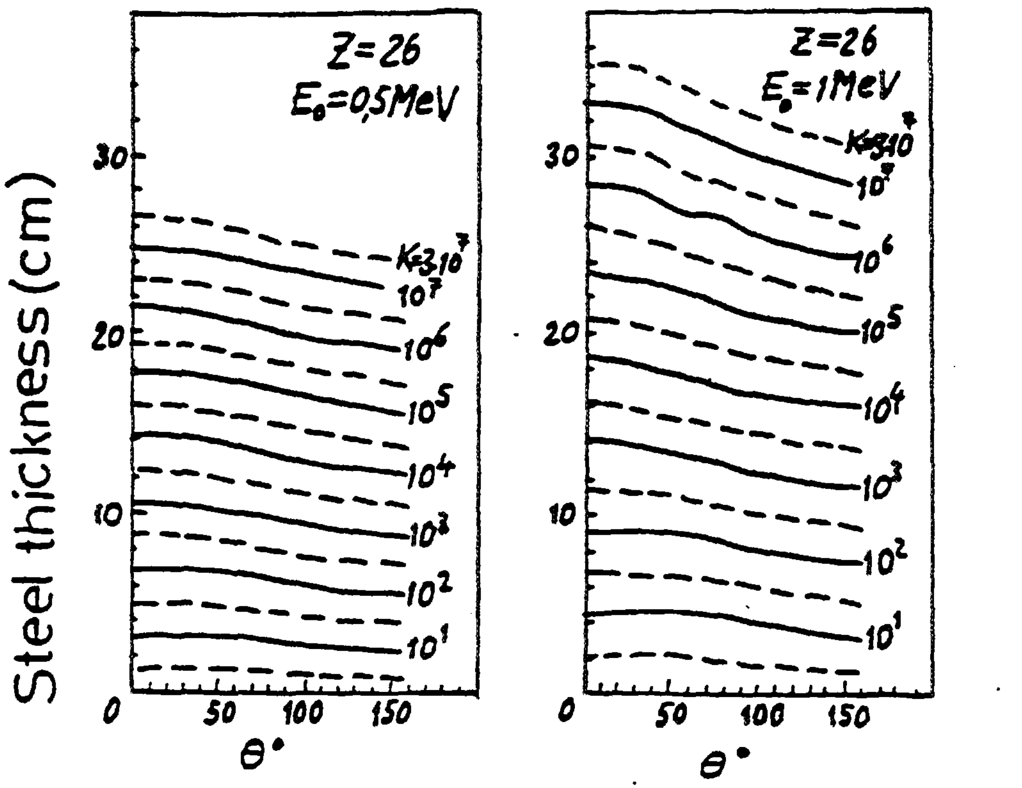

Fig.(4) from ref.[2]:Transmission curves

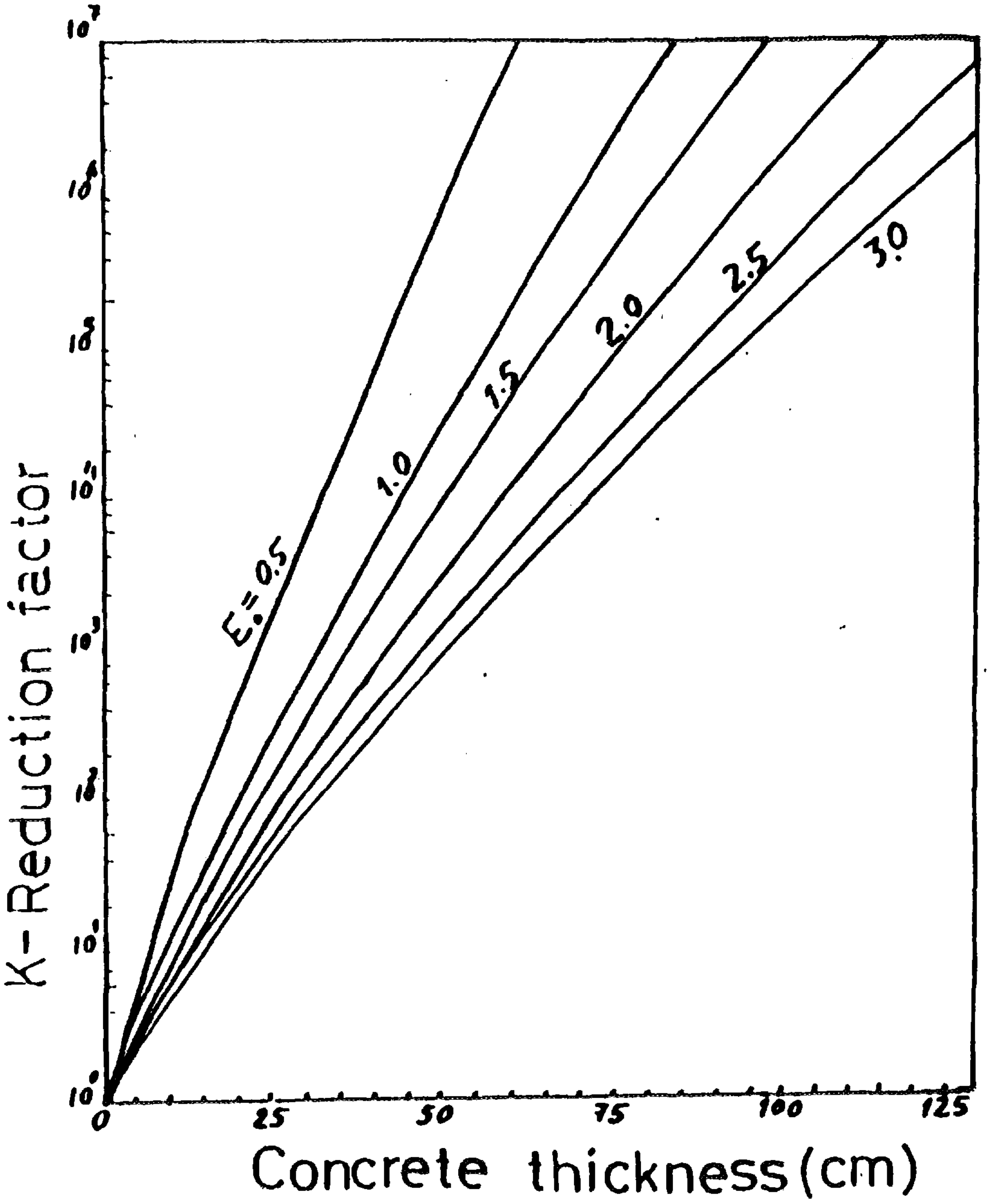

Fig.(5) from ref.[3]: Transmission curves