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COMPARISON OF CALCULATED SHIELDING EFFECTS FOR 8 MATERIALS

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Abstract

The depth dependence of neutron and secondary photon dose equivalents in the inside of 4 meter thick materials of iron, lead, ordinary concrete, heavy concrete, graphite, marble, water and paraffin were calculated for monoenergetic source neutrons of energies less than 400 MeV. Their shielding characteristics are compared and discussed phenomenologically. Calculations were carried out by using the one-dimensional discrete ordinates code ANISN-JR and the cross section library DLC-87/HILO. Systematic knowledge concerning the shielding materials was successfully obtained.

1. Introduction

In recent years, the radiation shielding of high energy accelerators has become one of the important problems as the particle energy and/or the beam intensity get higher. In order to achieve effective shielding, it is necessary to know about the shielding characteristics of various materials for radiation, especially neutrons.

So far, iron, lead, ordinary concrete and water are some of the most widely used shielding materials, and their shielding characteristics have been studied extensively for source neutrons in the wide energy range. Recently, comparison of shielding characteristics between 8 materials was given for dose equivalents at the exit surfaces of shields of varying thickness[1]. (Hereafter the ordinary concrete is abbreviated simply as concrete.) In this paper, iron, lead, concrete with 5.5 % water by weight, heavy concrete with 5.5 % water by weight, graphite, marble, water and paraffin are taken as typical shielding materials. The depth dependence of dose equivalents in the inside of these materials is estimated for monoenergetic neutron sources of energies less than 400 MeV. Calculations were carried out by using the one-dimensional discrete ordinates code ANISN-JR [2] and the cross section library DLC-87/HILO [3]. The calculation procedure and the results are given in section 2 and 3, respectively. Details for them are described elsewhere [1].

2. Calculation Procedure

The ANISN-JR is a refined version of the ANISN[4] which was developed to solve the one-dimensional Boltzmann transport equation for neutrons and photons in materials by using multigroup cross section data, and is used to solve penetration problems under the condition of anisotropic scattering.

The DLC-87/HILO is one of several neutron-photon multigroup coupled cross section libraries which have been offered from the Radiation Shielding Information Center. In this library the cross section data are given in the structure of the 66 neutron energy groups from the thermal energy to 400 MeV and the 21 photon energy groups from 10 keV to 14 MeV. The transport calculations were made for neutrons and secondray photons with scatterings of an S_{16} angular quadrature and a P_3 Legendre cross section expansion. The primary neutron in a group of a specified energy range is normally incident on a shielding material with a slab geometry, and its transitions to elastic and nonelastic channels are evaluated numerically. The attenuation of the secondary photons produced by neutron nonelastic reactions in materials is also obtained. Energy-to-dose conversion factors are quoted from ICRP Publication 21, and then the unit of the dose equivalent was converted from *rem* to *Sv* using the relationship *1 Sv = 100 rem* .

3. Results AND Discussion

3.1. Attenuation of Neutron Dose Equivalent

The depth dependence of the neutron and secondary photon dose equivalents is shown in Fig.1 for iron, lead, concrete with 5.5 % water by weight, heavy concrete with 5.5 % water by weight, graphite, marble, water and paraffin. Here, marble is regarded as pure calcium carbonate, $CaCO_3$. In Fig. 1, solid and broken lines show the variation of neutron and secondary photon dose equivalents, respectively. Numbers on the right of each curve refer to the group number of source neutron energies, and those underlined represent the group numbers for the source neutrons producing the secondary photons. (See Table 1)

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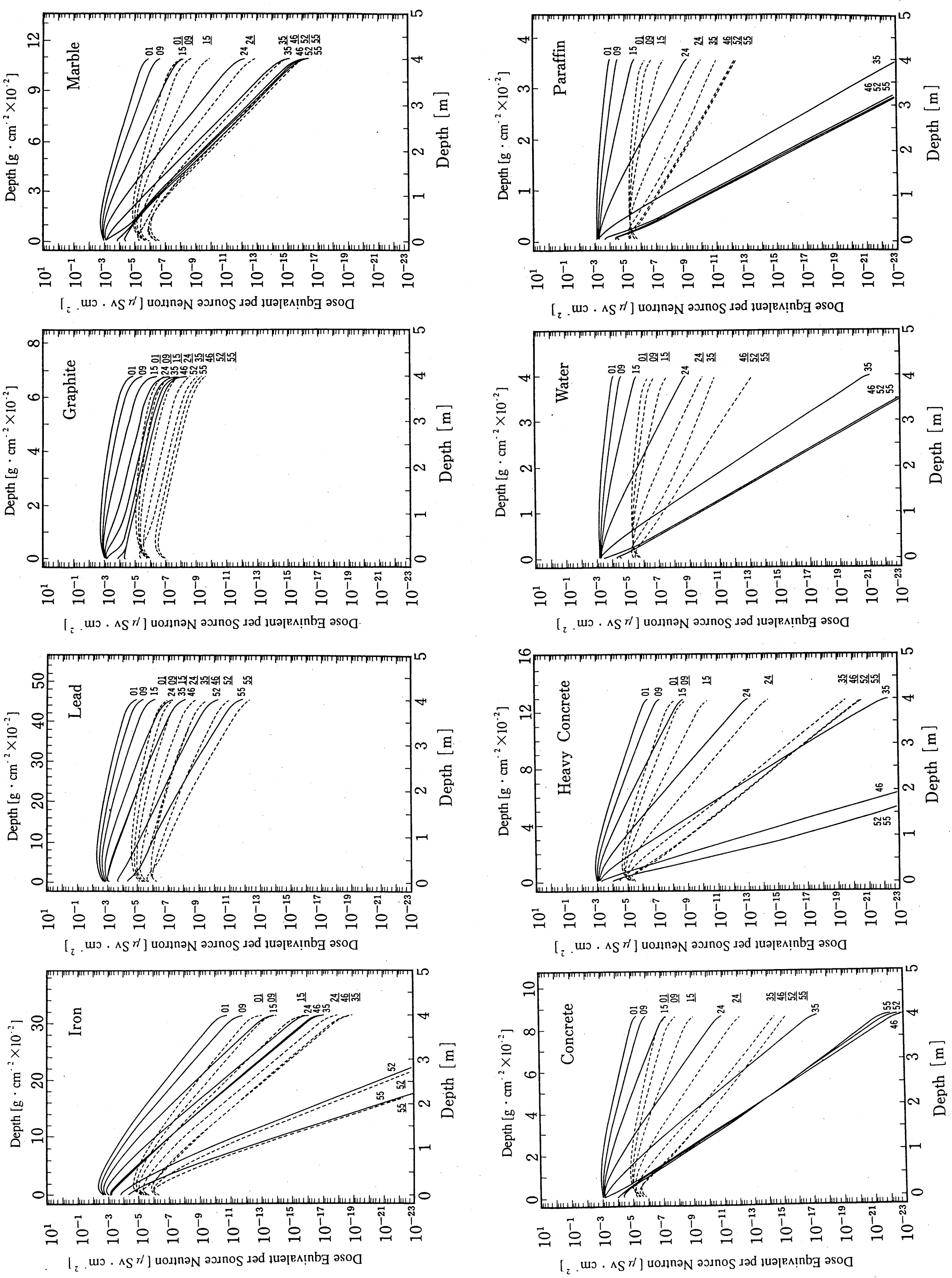

Fig.1 Attenuation of neutron and secondary photon dose equivalents as a function of depth of shielding materials. Solid and broken lines present neutron and secondary photon dose equivalents, respectively. Numerals at the right end of each line mean the group numbers representing incident source neutron energies. (See Ref. 3, as well.)

Table 1 Adopted Energy Groups

Group Nos.	Neutron Energy (MeV)
1	400 -- 375
9	200 -- 180
15	100 -- 90
24	40 -- 35
35	10 -- 8.19
46	1.11 -- 9.07(-1)
52	1.50(-1) -- 8.65(-2)
55	1.50(-2) -- 7.10(-3)

These materials can be divided into three groups by the feature of attenuation curves. The first group which is composed of iron, heavy concrete and concrete, is efficient for the shielding of neutrons and secondary photons in the almost all energy regions, whereas the second group consisting of water and paraffin is efficient for shielding low energy neutrons but not so efficient for shielding secondary photons. The last group consisting of lead, marble and graphite, however, is not efficient for shielding neutrons and secondary photons.

Iron is a very effective shielding material for neutrons at energies above 30 MeV and below 100 keV. For the neutrons of around 1 MeV, however, iron is rather inferior to concrete and heavy concrete. Heavy concrete is also one of the most effective shielding materials, i.e. it is superior to iron for neutrons below 10 MeV. Although heavy concrete is more efficient than concrete in the whole energy region, concrete is widely used because of its lower cost. Water and paraffin are excellent shielding materials for neutrons below a few tens of MeV. Lead and graphite do not seem to be effective shielding materials in the whole energy region. Marble, as a whole, does not have special features. It has a similar attenuation pattern to that of concrete without water as can be supposed easily.

The dose equivalents are reduced steeply at the end of the slabs, which is due to the lack of back scattering from the outside of shielding materials.

3.2. Attenuation of Dose Equivalent by Secondary Photons

Source neutrons incident on shielding materials induce secondary photons by way of a radiative capture process and de-excitation of reaction products. The photon dose equivalents caused by monoenergetic incident source neutrons are shown as a function of material depth in Fig.1 together with neutron dose equivalents. As the secondary photons are inevitably accompanied by neutron penetration in shielding materials, both neutrons and secondary photons should be considered inclusively in shielding problems, i.e. a summed dose equivalent will be important practically. Although photon fluxes are of nearly the same order as neutron ones for all materials and in whole source energy regions, the photon dose equivalents in shielding materials are less than the corresponding neutron ones by 2 orders of magnitude. This is due to the fact that the secondary photon energy is almost independent of the incident source neutron energy and that the flux-to-dose conversion factor of photons is smaller than that of neutrons.

The attenuation characteristics of photon dose equivalents should be considered by combining the attenuation of primary and secondary photons.

Secondary photon dose equivalents of source neutrons above 90 MeV also increase near the vicinity of the surface of shielding materials. However, these have little contribution to summed dose equivalents in this energy region.

4. Conclusions

Quantitative depth dependence of dose equivalents inside each shielding material is almost same as that at its exit surface of varying thickness. Iron, heavy concrete and concrete have excellent shielding effects for neutrons of energies more than a few tens of MeV, and water, paraffin, iron and heavy concrete are efficient shielding materials for neutrons of lower energies. For neutrons in the thermal energy region, iron and heavy concrete are especially efficient.

The shielding materials studied can be classified into the three groups, i.e. heavy elements, hydrogenous materials and others, according to the difference of degradation mechanism of neutron energies.

The attenuation pattern of photon dose equivalents in shielding materials will be considered to result in competing processes between the attenuation of photons due to the density and the supply of secondary photons due to inelastic photon emission processes of neutrons.

In application to practical shielding, we should understand characteristics of each dose equivalent attenuation of incident neutrons, primary and secondary photons in shielding materials.

References

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