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<Technical Report> Scattering Effectiveness of Monoenergetic Neutrons in the Various Shielding Materials

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Abstract

In neutron shielding, the scattering effect is equally important as the attenuations in shielding materials. In the present study, the scattered dose equivalent was measured using a Rem counter for water, paraffin, borated paraffin, ordinary and heavy concrete, lead, iron, and tissue equivalent material in three different angles; 45°, 90°, and 135°, respectively.

The measurements were performed for the neutron, having the energies of 0.5, 1, 2, 5, and 18 MeV, which are produced from the Van de Graaff accelerator.

The scattered dose equivalent ratios were increased with increasing the thickness of scattering materials and saturated at a certain thickness although they were different from one to other materials under study. The ratios were large for lead and iron while they were small for the hydrogen containing materials such as water and paraffin *etc.*

요 약

중성자의 차페를 고려할 경우 중성자의 차폐물질에 대한 감쇄와 마찬가지로 산란효과가 중요함으로 이번 실험에서는 각종 방사선 차폐 물질인 납, 철, 콩크리트, 물, Paraffin, 및 borated paraffin 등에 대해서 산란등가 선량을 Rem counter를 사용하여 측정하였다.

중성자선원은 Van de Graaff 가속기에서 얻은 0.5, 1, 2, 5, 및 18 MeV의 중성자를 사용했으며 산란방향은 45°, 90° 및 135°의 3방향에 대해서 각 energy별로 측정하였다.

산란선은 산란체의 두께에 따라 증가하여 어느 이상의 두께에서는 포화상태가 되어 그 이상 증가하지 않았으며 납과 철이 제일크고 수소함유량이 많은 물, paraffin 등이 낮은 값임을 알았다.

1. Introduction

During the last decade neutron generators have found widespread use in various type of physical, chemical and biological research. In neutron shielding for the neutron generator, the scattering effect by shielding material must be taken into account with the same respect to the attenuation of neutron. Particularly, in radiation protection its effects will be more important in estimation of neutron exposure dose obtained from the personal neutron detector carrying on the surface of the human body.[1,2]

There are many types of nuclear interaction of neutron with matters, and it depends a great deal on the neutron energy. This makes it difficult to calculate theoretically the scattered dose equivalent of neutron. An experimental approach was thus attempted in this work: it was simply measured by a Rem counter, regardless of interaction of neutrons with matter for the purpose of obtaining fundamental data in view of choice of neutron shielding materials and estimation of neutron exposure dose on the radiation workers.

For the various shielding materials these measurements were performed using monoenergetic neutrons, having the energies of 0.5, 1, 2, 5, and 18 MeV, in three different angles: 45°, 90°, and 135°, respectively.

2. Experimental Procedure

The scattering effects of various shielding materials were measured for monoenergetic neutrons produced from the Van de Graaff accelerator[3] (High Voltage Engineering Co., Type AN 400).

The scattering effectiveness of neutron for various shielding materials such as water, paraffin, borated paraffin, lead, iron, heavy and ordinary concrete and tissue equivalent phantom for the neutron has been measured. The details of scattered material used except phantom are described elsewhere[4] and the phantom was made of lucite plate of 3 mm in thickness with its volume of $50\times30\times10\ cm^3$. Tissue equivalent liquid composition in phantom consists of 56.9% water, 28.4% glycerol, 7.6% urea, and 7,1% suerose by weight.[5]

Since the quantity, dose equivalent, is required for the radiation protection of the occupational workers, it was measured with the neutron Rem counter[6] (20th Century Co., Type NRC Ⅱ) for various shielding materials of interest. The detectors used consists of a BF_3 propotional counter surrounded by a shield made of polyethylene and boron plastic that gives the approprite amout of moderation and absorption to the impinging neutrons to obtain rem response.[7]

The experimental arrangements are shown in Fig. 1.

Narrow beam geometry with water tank and lucite collimator are used in this experiment. The magnet itself was shielded with 30 cm thick-water tank to diminish the background radiation which stems from neutron

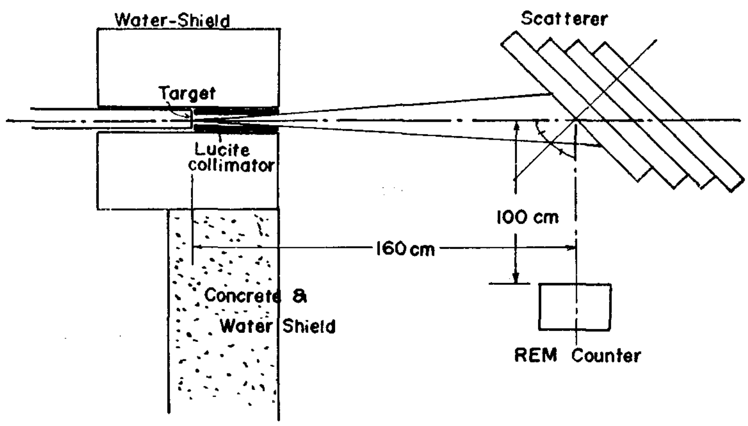

Fig. 1. Arrangement of the experimental apparatus using the Van de Graaff accelerator

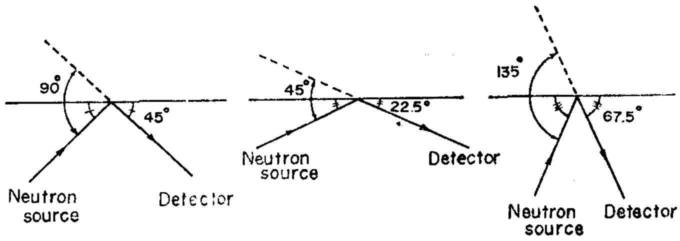

Fig. 2. Scattering angle on the arrangement of experimental apparatus

scattering by the magnet in the Van de Graaff accelerator. The Rem counter was mounted in line with center of scattered material slab and with height of the neutron beam. The first slab of scattered material was placed at the distance of a hundred centimeter from the counter, the next slabs were successively placed at the back of the slabs already present. In this way the scattered thickness could be increased, while the counter remained in the same position. Consequently it is not necessary to make correction of inverse square law.

In the measurements of the dose equivalent for different angles of 45°, 90°, and 135°, a law of reflection in the optics was employed as shown in Fig. 2. Using a lucite bar collimetor the scattered area was restricted at 20 cm in diameter and Rem counter was not shielded in order to prevent registration of scattered neutrons with the shielding material.

Furthermore, in order to eliminate the scattered dose equivalent from the floor, the Rem counter was placed on the grating floor which has large basement of 4 meters depth and the nearest distance from the Rem counter to concrete wall was 7 meters.[4]

The background of the Rem counter was decided without scattered material slab and the output of neutron generator was monitored by an ionization chamber and BF_3 proportional counter, keeping constant value within ± 1 percent fluctuation during the measurements.

The relative dose equivalent ratios, $(DE)_s/(DE)_p$, was obtained by measuring primary dose equivalent at the position of scattered meterial slab.

3. Results and Discussion

In this experiment the ratio of the scattered to primary dose equivalent was expressed as a function of slab thickness for various scattered material since the quantity of scattered dose equivalent was closely related to the thickness of scattering material.

In Figs. 3-14 the ratios of scattered to the primary dose equivalent for 0.5, 1, 2, 5, and 18 MeV neutrons are given as a function of the slab thickness in cm and scattering angle. The ratio for paraffin and borated paraffin was

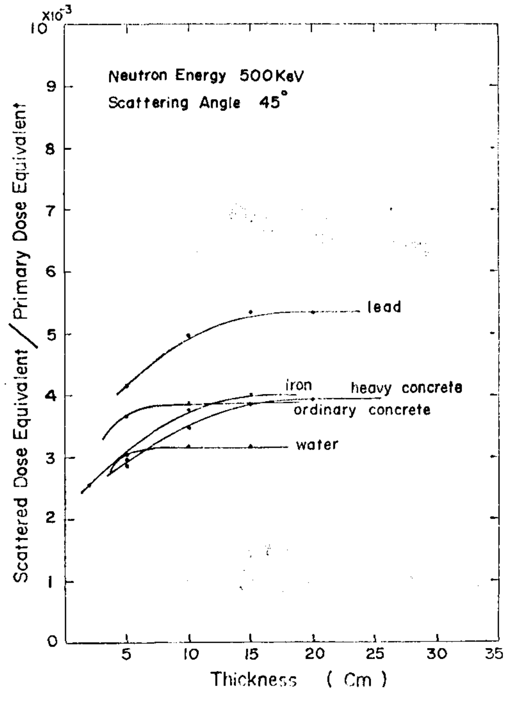

Fig. 3. Scattered dose equivalent ratios as a function of scatterer thickness for 500 keV neutrons(scattering angle; 45°)

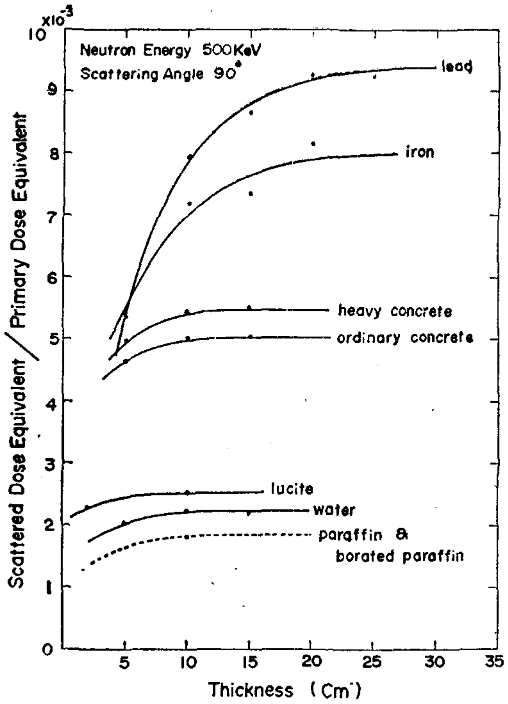

Fig. 4. Scattered dose equivalent ratios as a function of scatterer thickness for 500 KeV neutrons (scattering angle; 90°)

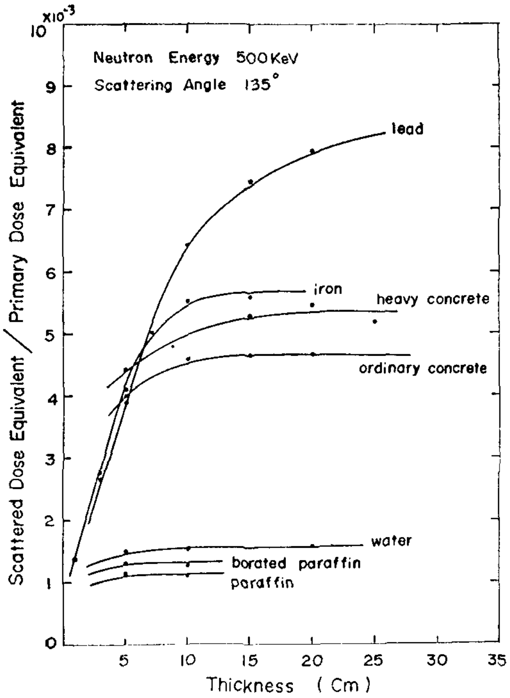

Fig. 5. Scattered dose equivalent ratios as a function of scatterer thickness for 500 KeV neutrons (scattering angle; 135°)

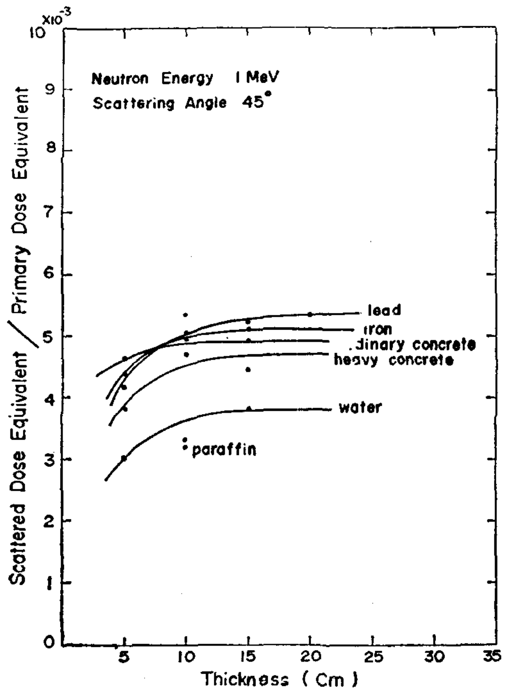

Fig. 6. Scattered dose equivalent ratios as a function of scatterer thickness for 1 MeV neutrons(scattering angle; 45°)

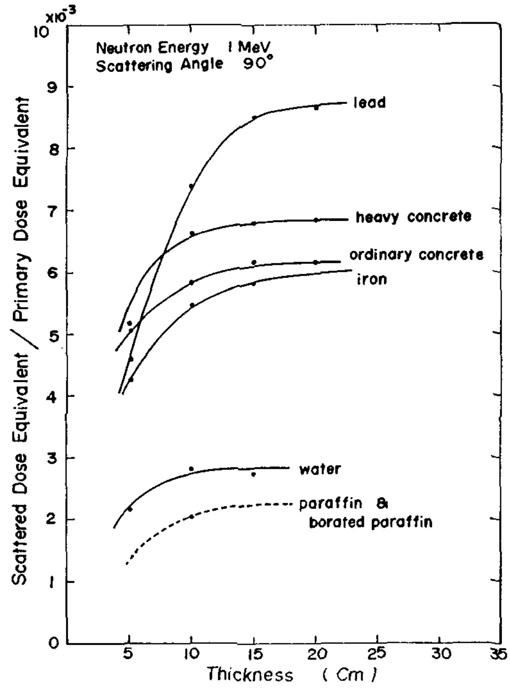

Fig. 7. Scattered dose equivalent ratios as a function of scatterer thickness for 1 MeV neutrons(scattering angle; 90°)

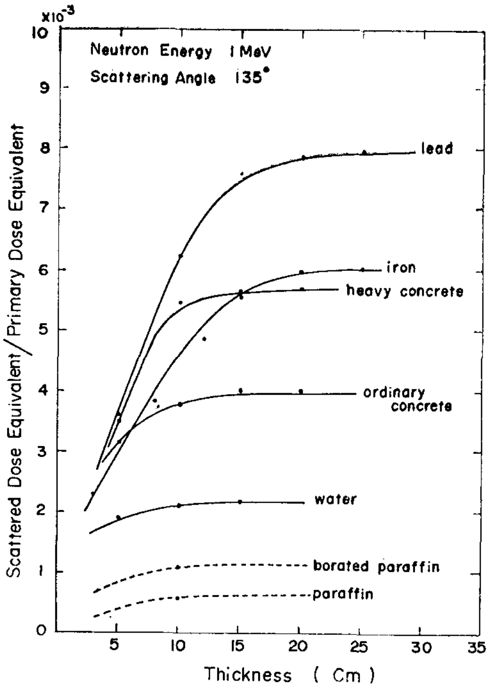

Fig. 8. Scattered dose equivalent ratios as a function of scatterer thickness for 1 MeV neutrons(scattering angle; 135°)

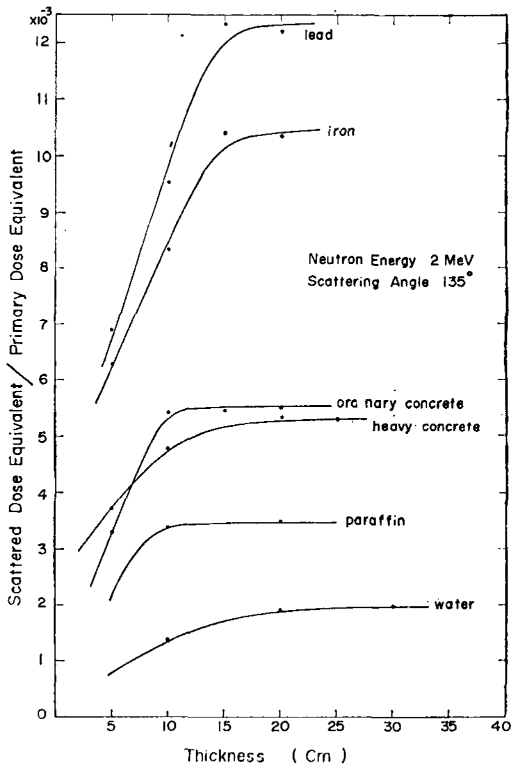

Fig. 9. Scattered dose equivalent ratios as a function of scatterer thickness for 2 MeV neutrons(scattering angle; 135°)

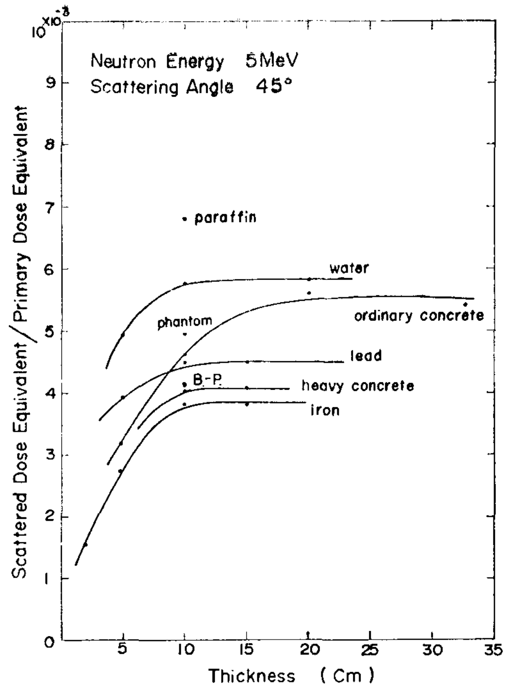

Fig. 10. Scattered dose equivalent ratios as a function of scatterer thickness for 5 MeV neutrons(scattering angle; 45°)

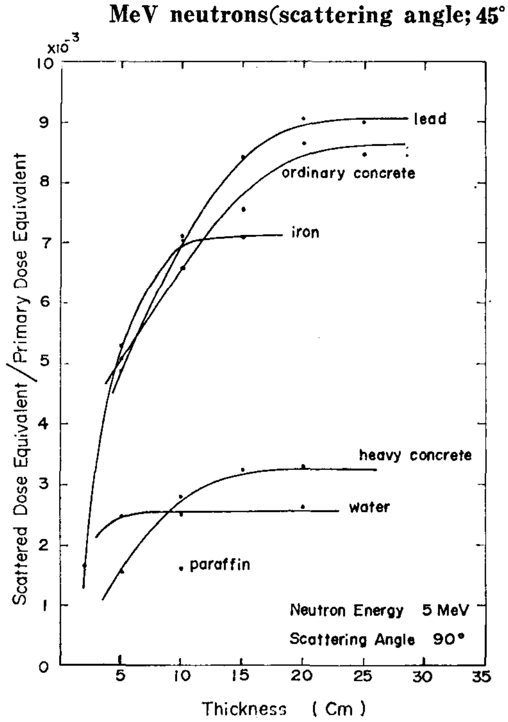

Fig. 11. Scattered dose equivalent ratios as a function of scatterer thickness for 5 MeV neutrons(scattering angle; 90°)

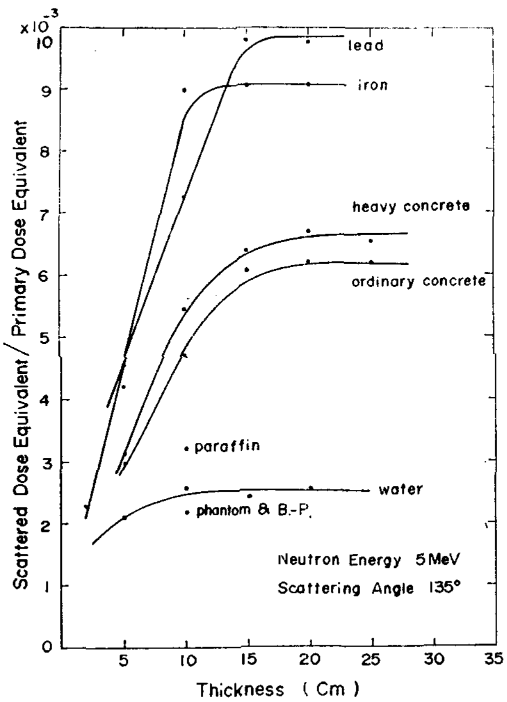

Fig. 12. Scattered dose equivalent ratios as a function of scatterer thickness for 5 MeV neutrons(scattering angle; 135°)

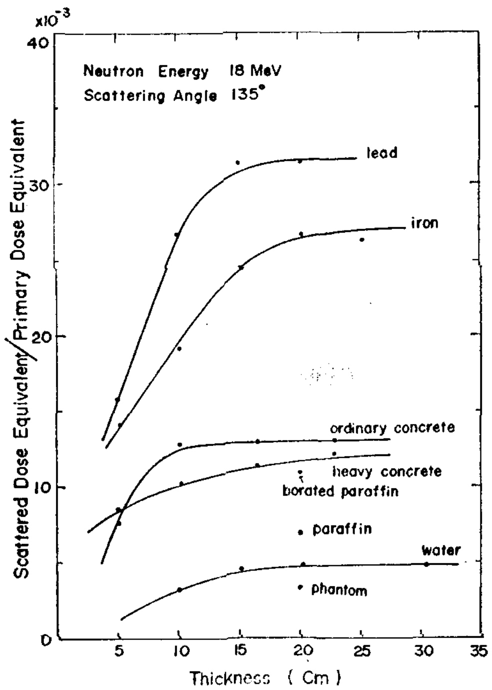

Fig. 14. Scattered dose equivalent ratios as a function of scatterer thickness for 18 MeV neutrons(scattering angle; 135°)

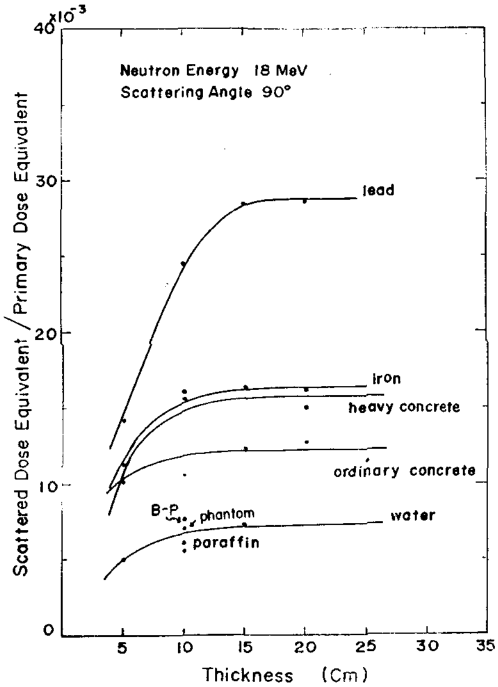

Fig. 13. Scattered dose equivalent ratios as a function of scatterer thickness for 18 MeV neutrons(scattering angle; 90°)

measured only at the thickness expected to be saturated, by comparing with the value of water, respectively.

As shown in each figures, the ratios of the scattered to primary dose equivalent were large for lead and iron while they were small for the hydrogen containing materials such as paraffin and water *etc.* These ratios were also increased with increasing the scattering angle.

In lead and iron the ratio of the scattered to primary dose equivalent to the 90° and 135° direction was approximately equal values while the ratio of 45° direction was small. For example, in the case of 135° direction the scattered dose equivalent of 1 MeV neutron was smaller than that of 0.5 MeV neutron and also for 5 MeV neutron it was small compared to that for 2 MeV neutron. Evidently, there is no direct linearity between the values and neutron energy, but still the values are increased with the neutron energies. It is doubt that this fact is owing to the experimental errors or to the distinct physical phenomenon. Elucidation study on this phenomenon is not approached in this paper. Although there is a increasing tendency of scattering ratio with the neutron energy, the increase is not remarkable ranging $3\text{-}6\times10^{-3}$ in case of forward scattering (*i.e.* 45° direction). Also in the measurement of forward scattering, the values for 18 MeV neutron could not be obtained because of the significant fluctuation of the measured values. The reason of fluctuation may be attributable to the fact that the detector and scattering material is too closely located.

In the case of 90° and 135° direction, these ratios could be divided roughly into three groups, namely, the ratio for water, lucite, borated paraffin, and paraffin showed low values, that for ordinary and heavy concrete, medium, and for lead and iron the highest among them. Except for 18 MeV neutron the ratio of scattered to primary dose equivalent did not vary remarkably with increasing neutron energy. Accordingly, in case of 90° direction, this ratio had appeared to be nearly of the same value up to 5 MeV neutron but at 18 MeV neutron it was increased suddenly,

4. Conclusion

The present results are obtained under the condition of the irradiation fields which are 20 cm in diameter, that is, scattered area is about 314 cm^2. In so far as the scattered dose equivalents are proportional to the scattering area, a ratio of scattered to primary dose equivalent per unit area is of the order of 10^{-4} -10^{-5} approximately. Summing up this study, the results are as follows;

1) The ratio of scattered to primary dose equivalent to the incident neutron is found to be of the small value in water, paraffin, and lucite which have lower atomic numbers.

2) In the case of estimation of neutron exposure dose from the results of neutron personal dosimeter which is attached on the surface of radiation worker, one should consider the scattered dose equivalent reflected from the human body as well as the scattered angles of incident neutron if the accurate data essentially needed.

3) The data obtained suggest strongly that the experimental equipment of neutron generators or other neutron sources should be heavily shielded for the radiological safety. Furthermore, in design and installation of the equipment, the supporting materials and scattering angles should be also considered since they influence the scattered dose equivalent significantly.

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