Alex. Eng. J., Alex. Univ., Volum 27 No. 2, pp. 1- 14 (1988)

CHARACTERISTICS OF THE PRODUCED GAMMA-RADIATIONS IN IRON IRRADIATED WITH FAST NEUTRONS

M.Abou Mandour and Youssef A. Shatila,
Nuclear Engineering Dept., Faculty of Eng.,
Alexandria University, Egypt.

SUMMARY

A Monte Carlo computer program was developed to precisely calculate the yield and the characteristics of the secondary gamma-radiations produced in an irradiated iron medium by fast neutrons of different initial energies (14.1, and 7.0 Mev) in an arrangement of a normally incident point parallel beam of neutrons to enable the analytical treatment of the gamma-radiation production in the complicated practical irradiation environments. A parametric study of the calculations of the flux - energy and angular distributions of the gamma-radiations in the medium was carried out, considering the neutron's initial energy and the thickness of the medium as the two important parameters. Two types of results were obtained:the first represents the yield and the characteristics of gamma-radiations production at the different points in the medium, and the second type of the results were those giving the net amount and characteristics of gamma-radiations penetrating a finite slab.

I. INTRODUCTION

It is essential in studying the transport of fast neutrons through certain media to take into consideration the effect of secondary radiations produced in the medium as a result of the different types of neutron-interactions. The most important of these interactions are those producing gamma-radiations: (n, γ), $(n,n\gamma)$, $(n,p\gamma)$, $(n,\alpha\gamma)$... interactions. The yield and characteristics of the secondary gamma-radiations must be accurately determined. These gamma-radiations have a large influence in different fields concerning fission reactor-shields, fusion devices, radiation protection, neutron dosimetry, neutron diagnostics, neutron therapy and industrial process analysis. Ignorance or inaccurate determination of these secondary radiations may lead to significant discrepancies between the calculated physical functions and their actual values.

The mathematical model that treats the simultaneous transport of different types of radiation particles has proved to be very difficult because of the vast amount of the needed input nuclear data expressed in the form of differential cross sections and the complexity of the physical laws that describe the coupling process. Because of this complexity, calculations concerning these fields are rare (1-4). The complex problem of the simultaneous calculations for neutrons and their produced gamma-radiations can be solved by carrying the calculations in two steps: the first step is the evaluation of the contributions of the neutrons only by one of the known transport methods or the point kernel method corrected by buildup factors (5-10) and the second step is the separate evaluation of the contributions of the produced gamma-radiations only as an additional source knowing their amounts and source characteristics. This can be achieved, similar to the neutron calculations, either by the elaborate transport methods or by using the point kernel method and incorporating the revised values of the buildup factors (11-15). To carry out this suggested procedure of calculations the detailed data of the gammaradiations are essential. It is the main aim of this paper to carry out a precise and detailed once-for-all calculations to compute the yield and the characteristics of the produced secondary gamma-radiations in a proper irradiation geometry. As a second objective of this paper, the net yield of the secondary gamma-radiations penetrating through finite slabs of different thicknesses due to their irradiation by fast neutron beam were calculated to estimate their significances and to provide results to be used as reference values to be compared with.

2. COMPUTATIONAL METHOD

A Monte Carlo program was developed to simulate the neutrons photons transport in the medium. A neutron history began as it entered the medium then it was followed during its penetration through the medium where its motion parameters (position, energy and direction) were successively changed constituting the medium. The results are given in Fig. 1. The total number of photons produced per incident per unit depth decreases monotonically with the depth. This can be attributed to the decrease in the neutron flux with depth, together with the decrease in the neutron's energy.

The energy spectra W(E) of gamma-radiations produced in the different thin bins were calculated and given in Fig.2 . One notes that the photon spectra possess a generalized shape and differ, only, slightly from each other. This can be explained by investigating the differential cross sections responsible for the gamma-radiation production. The probability function for the emission of a gamma photon with certain energy due to fast neutron interaction with iron nucleus has a discrete nature. The group of possible photon energies emitted, also the relative probabilities for their emission remain nearly the same for the neutron energies in the range from 14.1 MeV to about 4.0 Mev (23).

The second function which is essential in defining the gamma radiations at the different depths in the medium is their angular distribution. The angular distribution $W(\theta)$ for photons produced in the different thin bins constituting the medium were calculated and represented in Fig . 3. It is found that for the first bins there are two well defined peaks in the distribution indicating that the photons in these bins are emitted in two favorable directions. This is because neutrons in these bins have high energies and therefore suffer from forward-peaked scattering and consequently the emitted photons still have their emission according to the type of the interaction from which the neutron suffered, through the mathematical formulation characterizing the particular type of interaction. Once, a neutron suffered from a gamma photon-producing reaction, the history of the neutron was temporarily suspended, while the new born gamma-photon history began and was tracked, through the mathematical formulation describing the transport of gamma-radiations, until its history was terminated either by leakage, absorption or degradation of its energy below a pre-determined cut-off energy. Back to the "parent-neutron", its history was continued once more and it was terminated either by leakage, absorption or degradation of its energy below a pre-determined cutt-off energy.

3. Characteristics of the Produced Gamma-Radiations

The phenomena of gamma-radiation production in an infinite medium is described through the calculations of the number flux at the different depths in the medium together with their energy- and angular-distributions. These physical functions were calculated for different neutron's initial energies. The energies: 14.1 Mev as the average energy of the thermonuclear neutrons of the D-T reaction, 7.0 Mev as the tail of the fission neutron energy spectrum.

The depth-dependence of the amount of gamma-radiation production in the medium was studied by calculating the number of photons produced in each of the thin bins directions calculated relative to directions very near to the initial direction of neutron incidence. As the neutrons proceed to deeper bins, the neutrons, due to their multiple scattering (elastic and inelastic) , have an angular spread in their directions and consequently the photons lose their common reference direction and the two peaks in the distribution go in each other and only one peak is observed.

4. Secondary Gamma-Radiations Penetrating a Medium

Once a photon is produced, it begins to propagate inside the medium which can be of either infinite or finite thickness. The net amount of gamma-radiations transporting through a medium at its different depths and those penetrating through its bounding surfaces were calculated.

The backward, and the forward flux crossing a reference plane located at a certain depth in the medium were given in Fig. 4 for an infinite medium and for a medium of finite thickness where the curve parameter is the slab thickness. For the forward flux the increase in the flux with the slab thickness can be explained due to the increase in the neutron flux. The increase in the backward-flux is due to the decrease in leakage with the increase of the slab thickness.

Both the forward and the backward fluxes show a well defined peak at shallow depths. This can be attributed to the higher number of photons produced in the upermost part of the medium with approximately equal fractions in the forward and backward directions. As the photons penetrate deeper or shallower in the medium, they suffer from an angular spread in their directions, giving rise to their accumulation and consequently to the well defined peak in the corresponding fluxes. Also, for the backward flux, the backscattered photons from the deeper bins contribute to the formed peak at shallow depths.

Both the energy spectra and the angular distributions of the transmitted and reflected photons were calculated for slabs of different thicknesses and are given in Figs 5, 6. As the photons diffuse inside the medium their energy decrease as a result of the compton scattering and consequently most of the high energy photons are redistributed to lower energies in the energy distribution leading to the appearance of lower energy groups and the smoothing of the energy spectrum of photons.

The angular distributions for both transmitted and reflected photons exhibit no fine structure.

Further work aimed at extending the calculations to other materials and fitting these nonlinear results to analytical functions is in progress.

REFERENCES

1. Jaeger R.G. (Ed.), " Engineering Compendium on Radiation Shielding," vol. II, 1975.

2. Yuan Y.L., Gardner R.P. and Verghese K., "Nucl. Tech.,"

77,97-109, 1987.

3. Brown D.R., "ANL-81-62, p. 86, U.S. Department of Energy", 1982.

4. Abou Mandour. M. and Hassan M.H., "Kerntechnik", 51, 1987.

5. Bhatnagar P.K. et al.,"Atmokernenergie. Kerntechnik ,"43 (1983) 280.

6. Deimel E. and Deimel P., "Kerntechnik ," 15(1973 464.

7. Abou Mandour M. and Hassan M.H., "Kerntechnik," 51, 1987.

8. Wohl M.L., "Nasa Tnd-1434," (1962).

9 . Wyman D.R. and Harms A.A.," Nucl. Sci. Eng.," :89(1985) 273.

10. Veselkin A.P. and Netecha M. Ye., "JPRS 51083," pp.96 (1970).

11. Harima Y., "Nucl. Sci. Eng. :83", 299-308 (1983).

12. Harima Y. et al., "Nucl. Science Eng." 94, 24-35, 1986.

13. Abou Mandour M. and Ghanam A., "Kerntechnik: Accepted for publishing,".

14. Tanaka S. and Takeuchi K., "Japan Atomic Energy Research Institute-M ," 84-018, 1984.

15. Trubey D.K. and Harima Y., "Ans Trans.," 53, 1986.

16. Hughes D.J. and Schwartz R.B., "BNL-325, Brookhaven National Laboratory," 1958.

17. Godberg M.D. et al., "BNL-400, Brookhaven National Laboratory," (1962).

18. Bloom S.D. et al., "Nucl. Sci. Eng. : 46", (1971) 255.

19. Dickens J.K., Morgan G.L. and Perey F.G., "ORNL-4798," (1972).

20. Hubbell J.H., "NSRDS-29, National Bureau of Standards," 1969.

21. Hubbell J.H., "NBS, Atomic Data 3," 241-297, 1971.

22. Hubbell J.H., " Int. J. Appl. Radiat. Isot. 33," 1269-1290, 1982.

23. Dickens J.K., Morgan G.L. and Perey F.G., Ornl," 4798 (1972).

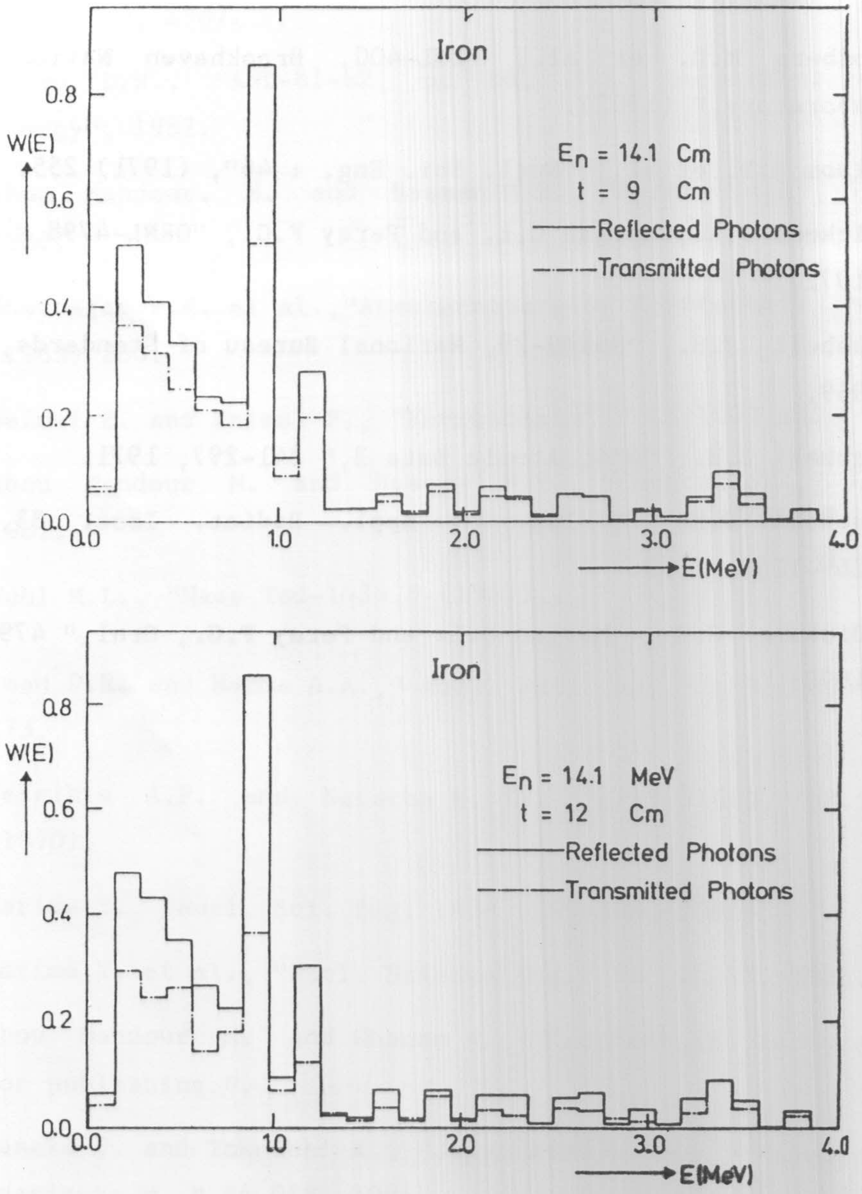

Fig.5 : Energy spectrum of gamma-radiations produced in an iron slab of a certain thickness irradiated with a point parallel normally incident beam of neutrons.

____ Soild histogram gives the spectrum for the photons reflected from the slab.

_.__ Dashed histogram gives the spectrum for the photons transmitted from the slab.

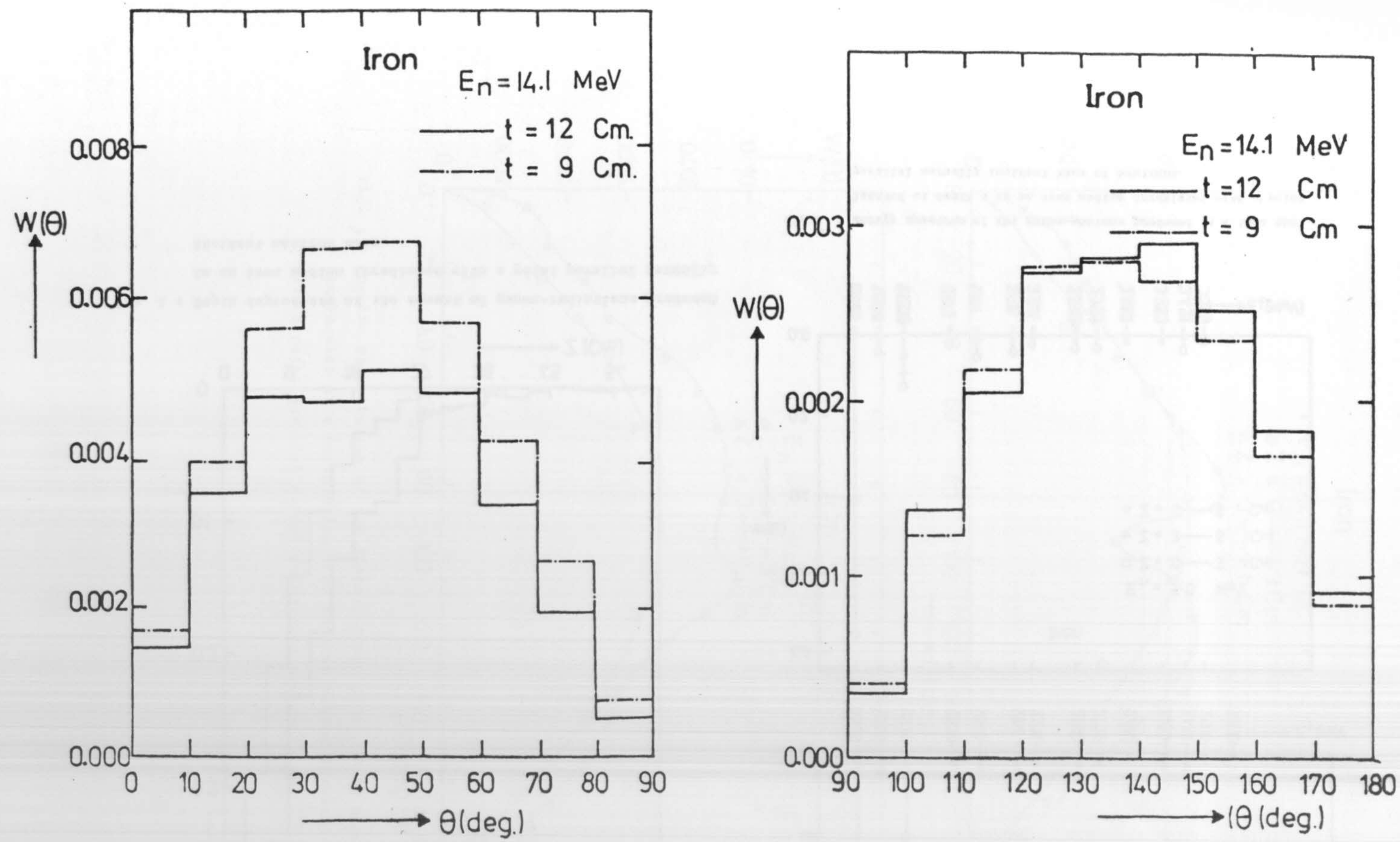

Fig. 6 : Angular distribution of gamma-radiations produced in an iron slab of a certain thickness irradiated with a point parallel normally incident beam of neutrons.

——— Solid histogram gives the distribution for the photons in a slab of thickness of 12 cm.

—·— Dashed histogram gives the distribution for the photons in a slab of thickness of 9 cm.

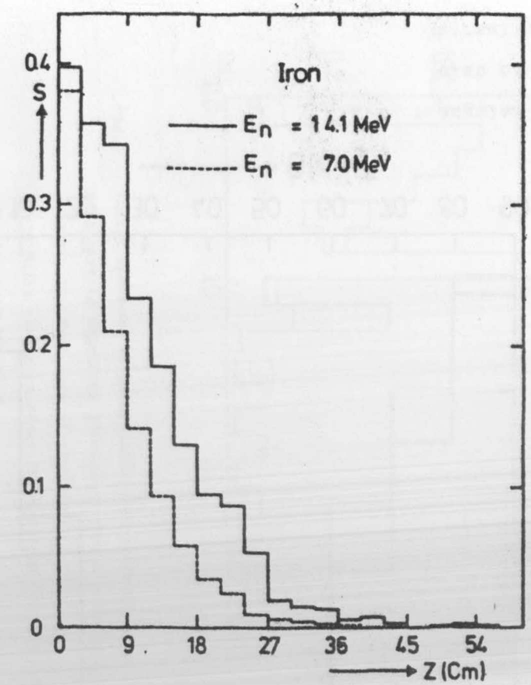

Fig. 1 : Depth dependence of the amount of gamma-radiations produced in an iron medium irradiated with a point parallel normally incident neutron beam.

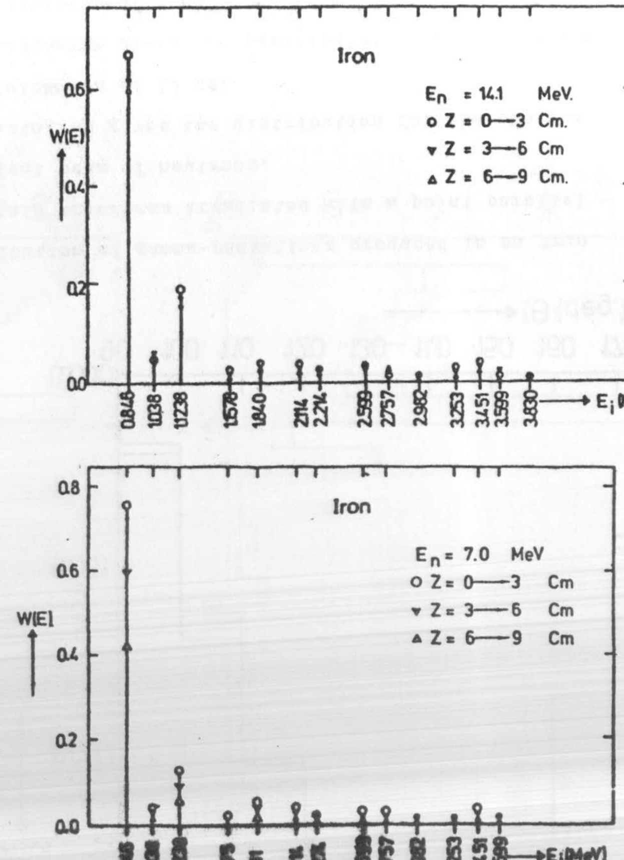

Fig.2 : Energy spectrum of the gamma-photons produced in a thin bin located at depth z in an iron medium irradiated with a point parallel normally incident beam of neutrons.

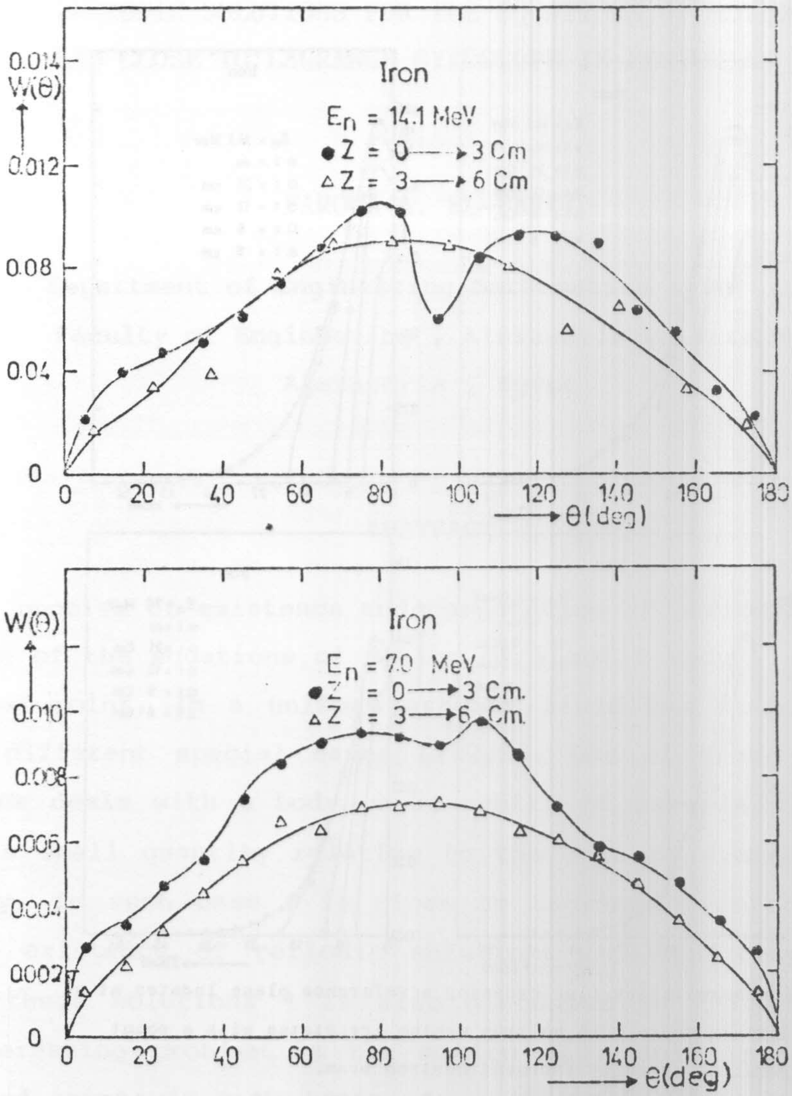

Fig. 3 : Angular distribution of the gamma-photons produced in a thin bin located at a certain depth in an iron medium irradiated with a point parallel normally incident neutron beam.

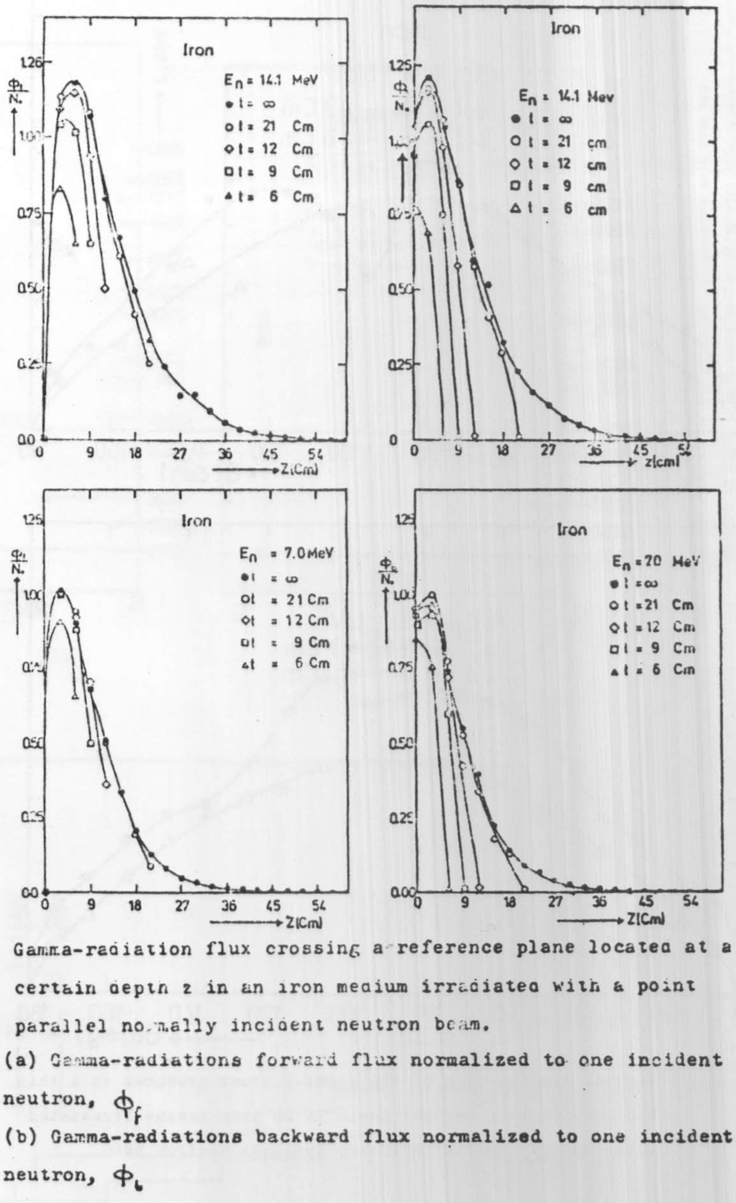

Fig. 4 : Gamma-radiation flux crossing a reference plane located at a certain depth z in an iron medium irradiated with a point parallel normally incident neutron beam.

(a) Gamma-radiations forward flux normalized to one incident neutron, ϕ_f

(b) Gamma-radiations backward flux normalized to one incident neutron, ϕ_b