1972
international book year

KFKI-72-67

IAEA/SM-167/29

S. Makra
J. Pálfalvi
P. Zaránd

# CALCULATION AND COMPARISON OF LEAKAGE NEUTRON SPECTRA



*Hungarian Academy of Sciences*

CENTRAL
RESEARCH
INSTITUTE FOR
PHYSICS

BUDAPEST

2017

KFKI-72-67

IAEA/SM-167/29

# CALCULATION AND COMPARISON OF LEAKAGE NEUTRON SPECTRA

S. Makra, J. Pálfalvi and P. Zaránd
Health Physics Department
Central Research Institute for Physics, Budapest Hungary

To be presented at the "Symposium on Neutron Monitoring for Radiation Protection Purposes", organized by the IAEA, in Vienna, 11-15 December, 1972.

ABSTRACT

Spectra of monoenergetic, fission and reactor sources after passing through various shields were calculated and compared with literature data. The following shields were considered: iron, from 30 cm to 180 cm thickness, and polythene and borated polythene, from 5 cm to 45 cm thickness.

The object of our work is to determine the extent of agreement between spectra obtained in different laboratories by various calculation or measuring techniques and to investigate the effect on leakage spectra of different parameters, such as the measurement or calculation geometry, input spectra, shield composition, etc.

РЕЗЮМЕ

С помощью программы MUSPALB, разработанной в ЦИФИ, были произведены расчеты спектров нейтронов после прохождения через железо, чистый полиэтилен и боросодержащий полиэтилен. В качестве источников нейтронов при расчетах, нами были использованы реактор ВВР-С, а также источники нейтронов расщепления и моноэнергетических нейтронов. Толщина слоя в случае железа изменялась от 30 до 180 см, а в случае полиэтилена - от 5 до 45 см. Рассчитанные нами спектры с помощью кода SPECTRANS сравнивались с результатами измерений и расчетов, описанных в литературе. Целью исследований являлось определение зависимости остаточных спектров нейтронов, полученных после прохождения через поглотители при одинаковых толщинах и составах материалов, от разных параметров, как например: от техники и геометрии вычислений и измерений, от спектров источников, материалов добавок в поглотители и т.д.

KIVONAT

Számitásokat végeztünk a KFKI-ban kifejlesztett MUSPALB program segitségével vason, bórozott illetve tiszta polietilénen áthaladt neutronok spektrumára. A számitásokban forrás spektrumként VVR-Sz reaktor, hasadási valamint monoenergiás neutron források szerepeltek. Vasnál 30 cm - 180 cm-ig, polietilénnél 5 cm - 45 cm-ig terjedő rétegvastagságokat vettünk figyelembe. Az általunk számitott spektrumokat a SPECTRANS kód segitségével összehasonlitottuk mért és számitott irodalmi adatokkal. Vizsgálatunk célja az volt, hogy megállapitsuk, hogyan függenek, azonos vastagság és anyag mellett, a kifolyási spektrumok különböző paraméterektől ugymint: a számitások és mérések geometriája és technikája, forrás spektrumok, ötvöző anyagok stb.

## Introduction

Most neutron dosimeters are not at present as sophisticated as could be desired, one of their chief disadvantages being their poor response. This shortcoming makes extrapolation a necessity; that is, the dose due to neutrons of energies not detected by the dosimeter has to be estimated from neutrons of another energy. Obviously, extrapolation must be based on a full and proper knowledge of the spectrum.

The importance of leakage neutron spectrum calculations in this respect has been pointed out, and such spectra published, by several authors /1-7/. Leakage neutron spectra have been calculated and applied for dosimeter evaluation in this institute over a number of years /8-11/, and since 1970 this work has been supported by the International Atomic Energy Agency, under a Research Agreement entitled Nuclear Accident Dosimetry. The work reported here was carried out in 1972, in the framework of an I.A.E.A. Research Contract entitled Determination of Neutron Spectra Behind Different Shields.

This paper presents some results of our own spectrum calculations and comparisons of these with spectra taken from the literature. The object of both is to determine

---

Work supported by the International Atomic Energy Agency under Research Contract No. 1115/RB

the extent of agreement between spectra obtained in different laboratories by various calculation or measuring techniques and to investigate the effect of different parameters on leakage spectra, such as measurement or calculation geometry, input spectra, shield composition, etc.

## Leakage spectra

In the following the spectra of neutrons which have been passed through iron and polythene slabs will be discussed; monoenergetic, fission and reactor source spectra are considered. Our own calculations, made by the MUSPALB albedo code /12/, are based on a geometrical model in which the source is taken as planar, emitting neutrons with a cosine angular distribution. Both source and shielding slab are assumed to be infinite in two dimensions, and the leakage spectra are integrated over the half space.

To compare different neutron spectra a code named SPECTRANS /13/ has been written. This code, designed to simplify evaluation work, makes a neutron spectrum library by compiling standardized neutron spectra from either $\varphi$/E/ or E.$\varphi$/E/ input spectra, each output spectrum being given in 48 energy intervals for further calculations.

In each standardized energy interval SPECTRANS fits a Lagrange polynomial of degree five or three, makes a linear interpolation, compares results and selects the one which approximates best the input spectrum. The code also calculates dose equivalent and kerma spectra and has the standardized spectra drawn on a plotter.

In some cases it is desirable to have a knowledge about neutron spectra belonging to a slab thickness not represented in the library. If we know two spectra produced by neutrons passed through different, but fairly close thicknesses of a given shielding material, the SPECTRANS code can compute the leakage spectrum for any intermediate thickness on the assumption that the attenuation is exponential in the whole energy range. The error deriving from such an interpolation is not significant in most practical cases. It can be seen on inspection of Fig. 1, for example, that the deviation between the calculated and interpolated spectra is slight and, considering that most of the dose arises from intermediate neutrons, can in fact be neglected.

Plots of spectra are normalized to unit area to facilitate comparison. Spectra expressed in relative units are adequate for this purpose, since for dosimeter evaluation it is the shape of the spectrum that is of interest rather than its absolute value. On the other hand, most spectra taken from the literature are expressed in arbitrary units and thus do not allow attenuation values to be compared.

Leakage spectra through iron

Some spectra which have been used as input for iron slabs are displayed in Fig. 2. In spite of the marked differences between the source spectra, the leakage spectra for iron slabs are similar provided the slab thickness is great enough. This facilitates comparison of different results and allows the application of a leakage spectrum obtained for a specific case for assemblies of another kind. The three spectra transmitted through a 50 cm Fe slab, that are presented in Fig. 3 bear out this finding. For thicknesses above $\sim$100 cm the shape of the leakage spectra hardly differ from each other; the dependence on input spectrum is negligible, and dependence on slab thickness is quite low /Fig. 4 /.

Some results obtained for 30-cm iron slabs are compared in Fig. 5. Two of the spectra were measured at the Dubna /USSR/ IBR fast reactor /14/, while the third is our calculation for a fission source. Differences in the measured spectra are due to variations in the slab compositions, thus alloyed steel was used at the measurements. Results for 50 cm thick slabs have been compiled in Fig. 6 /15/. On the grounds of the previously mentioned fact, that differences in input spectra hardly influence leakage spectra, it is most likely that the observed deviations are due to differences in calculation and measurement technique.

The same can be stated for 170-cm slab results /see Fig. 7/. Spectra for light water systems are shown in Fig. 8, one of which was calculated for a WWR-S reactor, while the other was measured at a similar /WWR-M/ system /16/.

The main conclusion that can be drawn from comparison of these spectra is that there is no systematic deviation between our own and literature data, but on the other hand the scatter of results reported from different laboratories is, in several cases, high. These differences seem to be higher than could accrue from differences in source spectra, geometry and other parameters, and still higher than is allowable for the use of dosimeter evaluation. Spectrum shape, however, depends on a few parameters only; for moderate thicknesses two kinds of input spectrum - "slow" and "fast" - are satisfactory, while for thicknesses greater than 40-50 cm the input spectrum has virtually no influence on the leakage spectrum. In the latter case the only parameter is the slab thickness, and even the dependence on this parameter is small once the thickness is above ~100 cm.

Leakage spectra through polythene

Polythene and borated polythene, being commonly used shielding materials, are of great practical interest. We have calculated spectra of neutrons passed through polythene for monoenergetic, fission and reactor sources /17/.

A comparison of the results for monoenergetic sources with those calculated by F.J. Allen et al. with a Monte Carlo technique /18/ for a 5 cm thick slab is presented in Fig. 9. One main conclusion is the negligible influence of boron content on spectrum shape over 10 eV.

Allen's results also permit investigation of the effect of incidence angle on the spectra /Fig. 10/. The flux of the virgin neutrons at perpendicular or nearly perpendicular incidence /$70^o$-$90^o$/ is greater, while at $10^o$ incidence markedly smaller, than that computed with the MUSPALB code, which is for a cosine angular distribution. The next plots /Fig. 11/ demonstrate that the same effect operates for the first few energy groups, though the agreement is quite good at lower energies, showing that the slowing-down spectrum is not sensitive to the angular distribution of the source neutrons in this case. Some results are shown for 1 MeV source energy in Fig. 12.

Further results of the MUSPALB calculations are presented in Figs. 13 and 14. It is evident that for thicknesses greater than 20 cm spectrum shape is virtually independent of slab thickness for hydrogeneous materials.

## Conclusions

This investigation of spectra demonstrates that for most shields having great enough thickness - and this is the case for most operating reactors - the effect of several parameters on the leakage spectrum can effectively be ignered. Owing to this fact, time-consuming calculations for dosimeter evaluation need not be carried out for each particular case, but typical spectra like those presented here are satisfactory.

References

1/ BENEZECH, G., BRICKA, M., DOLIAS, M.: Radiation Dosimetry, Vol.2. p. 269. Proc, International Summer School on Radiation Protection, Beograd 1971.

2/ FASSÓ, A., BRICKA, M., NGUYEN VAN DAT: Proc. 16th Congr. on Rad. Protection, p. 466. Firenze, 1970.

3/ CROSS, W.G., ING, H.: Annual Meeting of the Health Phys. Soc. New York, 1971.

4/ SCHRAUBE, H., BURGER, G.: GSF-Bericht P 24 /1970/

5/ PIESCH, E.: Proc. Conf. Advances in Physical and Biological Radiation Detectors, 399. I.A.E.A., Vienna, 1971.

6/ DELAFIELD, H.J., BOOT, S.J., DENNIS, J.A.: AERE-R 7008 /1972/

7/ DELAFIELD, H.J., BOOT, S.J., DENNIS, J.A.: AERE-R 7009 /1972/

8/ MAKRA, S.: KFKI-70-6-HP report /1970/ and lecture No. 107, Second IRPA congress, May 3-7 1970, Brighton, England

9/ MAKRA, S.: Radiation Dosimetry, Vol. 2. p. 281. Proc. Internat. Summer School on Rad. Prot., Beograd 1971.

10/ MAKRA, S., BÉKÉS, E.: Proc. Conf. Advances in Physical and Biological Radiation Detectors p. 425. I.A.E.A., Vienna 1971.

11/ MAKRA, S., ZARÁND, P.: KFKI-71-82 /1971/

12/ VERTES, P.: KFKI-70-37 RPT /1970/

13/ PALFALVI, J., ZARAND, P.: KFKI-72-65 /1972/

14/ BONDARENKO, I.I. et al: Energie Atomique 18, 6, p. 49 /1965/

15/ DEVILLERS, CH.: in ORNL-RSIC-29 p. 41. Compiled by MASKEWITZ, B.F., JACOBS, V.Z.

16/ BOLDIREV, G.N., et al: Proc Conf. Problems of Reactor Shielding Vol. 6. p. 154. Melekess, USSR, 1969. /in Russian/

17/ MAKRA, S.: Conf. on personnel dosimetry, Potsdam, 10-14 Oct. 1972 /in press/

18/ ALLEN, F.J. et al: BRL report No. 1130 /1961/

Figure captions

1/ Spectra behind a 30 cm iron slab; of the spectra marked "fission through 75 cm $H_2O$" one /solid line/ is interpolated from values for 20 and 40 cm iron, while the other /x/ is a direct calculation for 30 cm thickness.

2/ Some source spectra used in the comparison of leakage spectra.

3/ Three spectra illustrating the only slight influence of differences in source spectra on the leakage spectrum.

4/ Spectra behind iron slabs of various thicknesses as calculated by the MUSPALB code. It can be seen that at $E \gtrsim 0.5$ MeV spectrum shape is virtually independent of slab thickness for thicknesses greater than 100 cm. Input is a light water reactor spectrum; parameter: slab thickness.

5/ Spectra transmitted through 30 cm iron or steel slabs. The calculation for a fission spectrum and pure iron /solid line/ is compared with two spectra measured at the IBR fast reactor; the "Fe-Mn" curve /dotted line/ is for a ferro-manganese steel, while the "Fe alloy" curve /dashed line/ is for a steel containing Mn, Cr, Ni, and Co.

6/ Spectra behind a 50 cm iron slab. Solid line: own calculation /differences due to deviations in input spectra are negligible/; IBR: measured, denoted by Dotted and dashed lines: calculations for the "Harmonie" reactor /15/

7/ Spectra behind a 170 cm iron slab. Solid line: own calculation two other spectra: calculations for the "Harmonie" spectra.

8/ Leakage spectra of light-water-moderated, enriched uranium reactors behind a 30 cm iron slab; solid line: calculation for the WWR-S reactor, dashed line: measured at the WWR-M reactor.

9/ Spectrum of 5 MeV neutrons transmitted through a 5 cm thick polythene slab. The solid line is our own calculation for source neutrons with cosine angular distribution, while the step functions for normal incidence are taken from Allen et al. /18/.

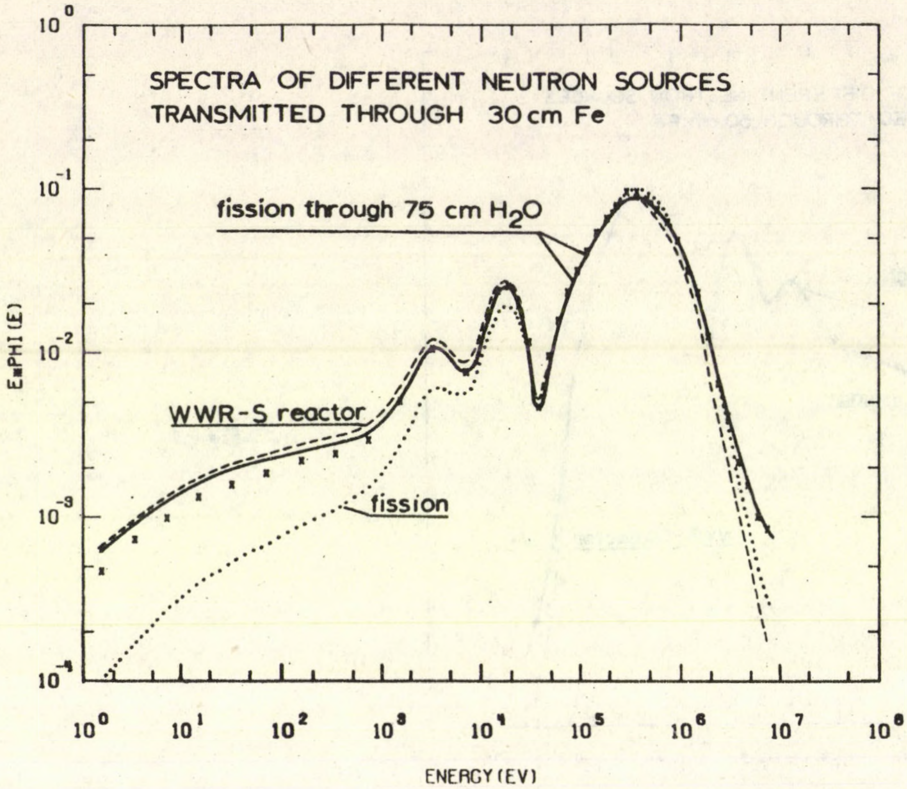
10/ Spectra of 5 MeV neutrons transmitted through a 10 cm thick polythene slab for various incidence angles.

11/ Spectra of neutrons transmitted through a 20 cm thick polythene slab.

12/ Spectra of 1 MeV neutrons transmitted through 5 cm and 10 cm polythene slabs.

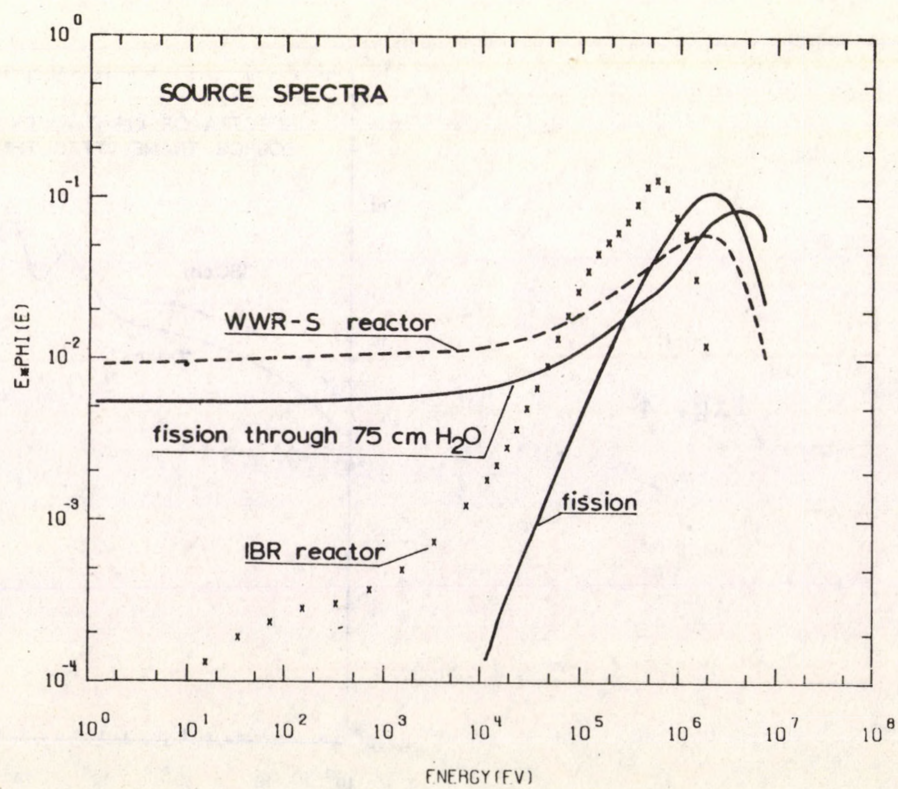
13/ Spectra of fission neutrons transmitted through borated polythene slabs. Parameter is the slab thickness. Both flux density /solid line/ and dose equivalent /dashed line/ spectra are plotted.

14/ Spectra of fission neutrons transmitted through polythene slabs. Spectra are not plotted for thicknesses over 20 cm as they are virtually independent of slab thickness.



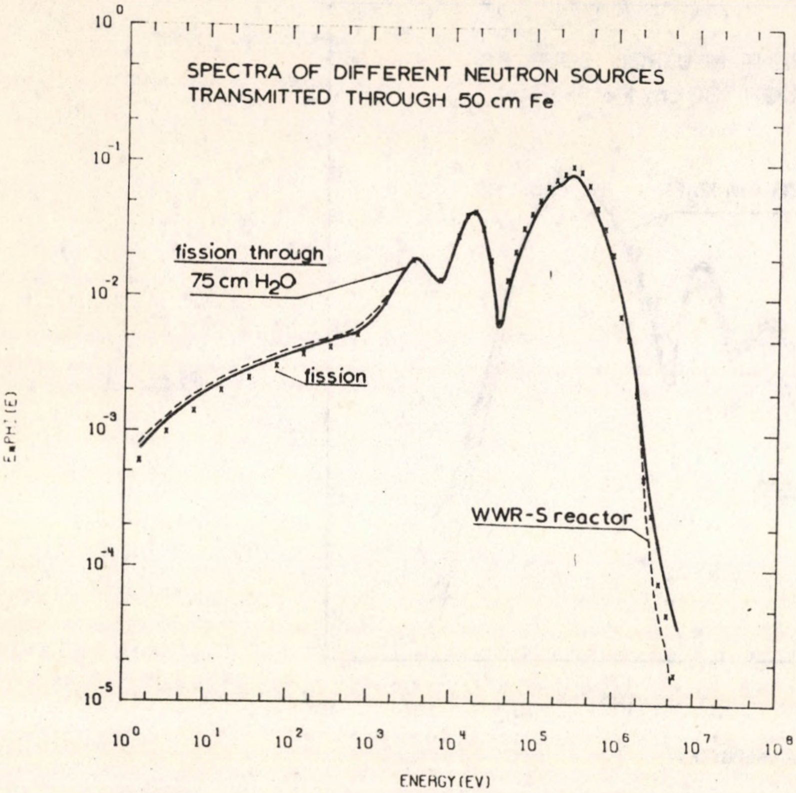
SPECTRA OF DIFFERENT NEUTRON SOURCES
TRANSMITTED THROUGH 30 cm Fe
fission through 75 cm H2O
WWR-S reactor
fission
E*PHI(E)
ENERGY(EV)


Fig. 1



SOURCE SPECTRA
WWR-S reactor
fission through 75 cm H2O
fission
IBR reactor
E*PHI(E)
ENERGY(EV)


Fig. 2




00000005

Fig. 3

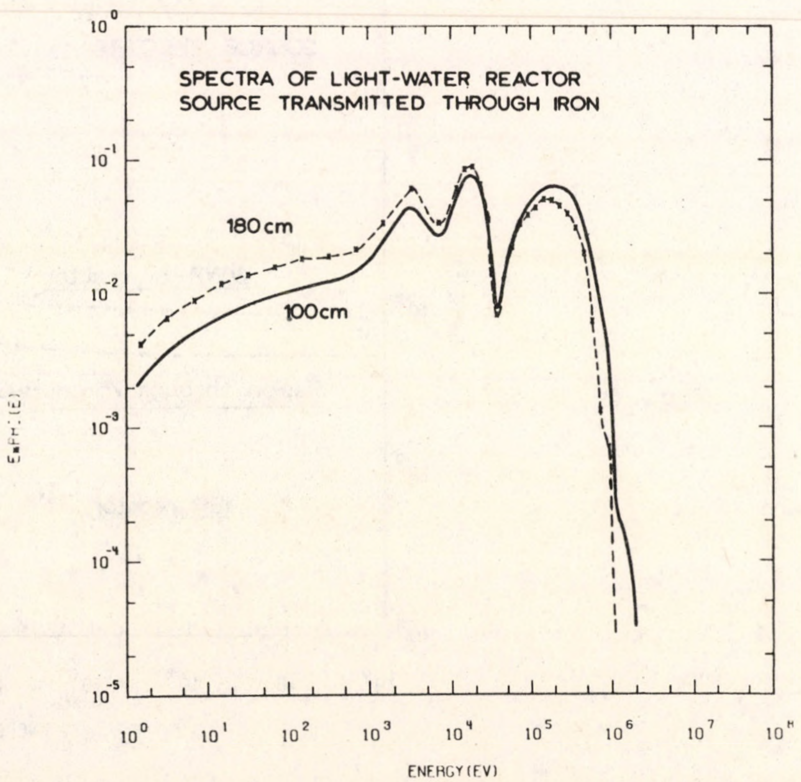



Fig. 4

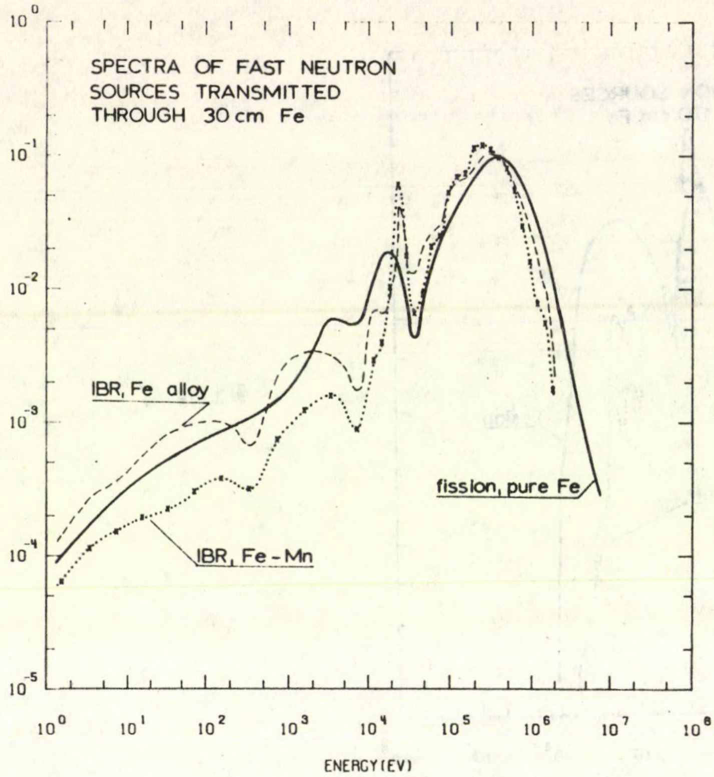
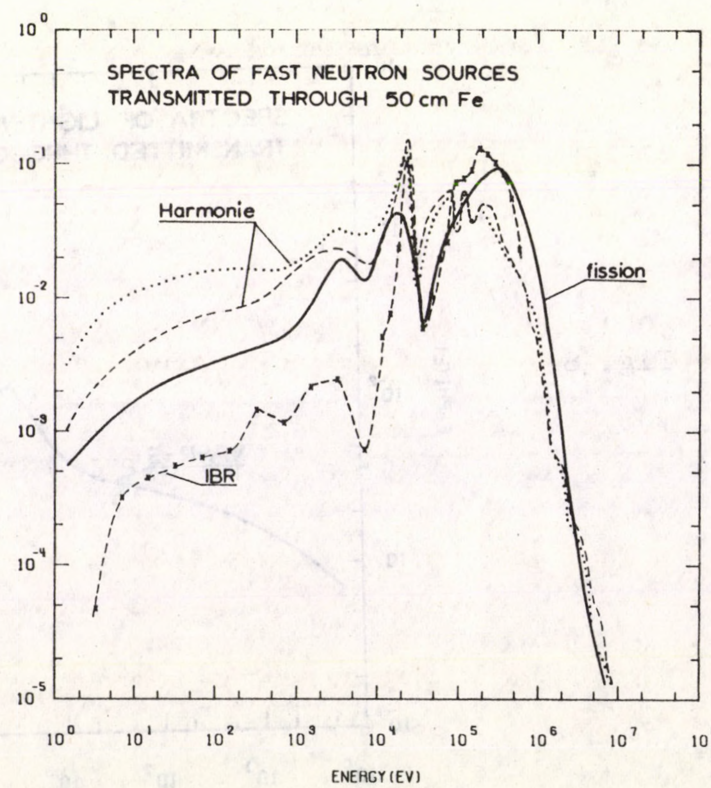

SPECTRA OF FAST NEUTRON
SOURCES TRANSMITTED
THROUGH 30 cm Fe
IBR, Fe alloy
fission, pure Fe
IBR, Fe-Mn
E*PHI(E)
ENERGY(EV)

Fig.5

Fig. 6


SPECTRA OF FAST NEUTRON SOURCES
TRANSMITTED THROUGH 50 cm Fe
Harmonie
fission
IBR
E*PHI(E)
ENERGY(EV)

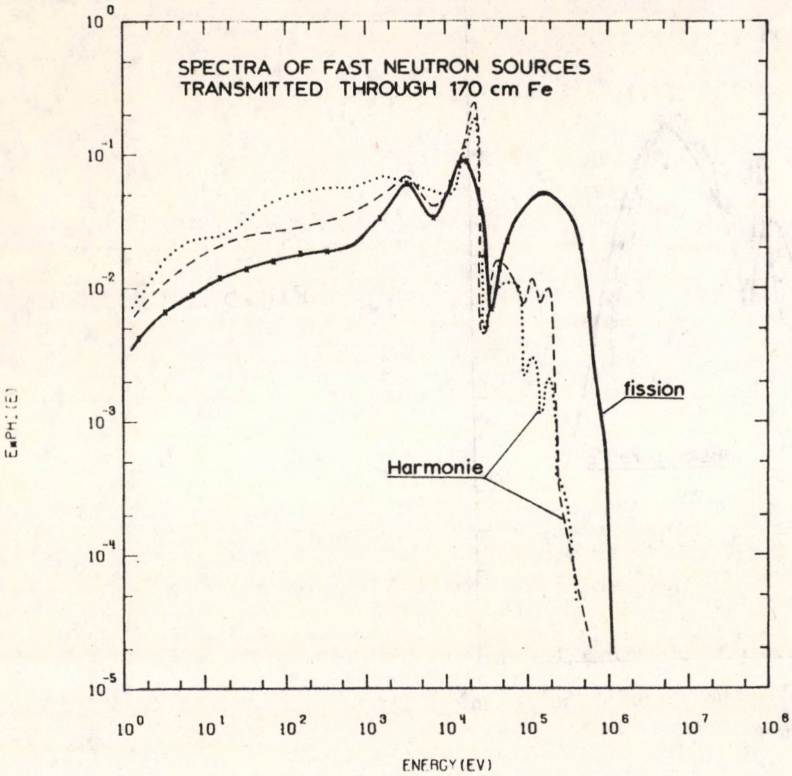

SPECTRA OF FAST NEUTRON SOURCES
TRANSMITTED THROUGH 170 cm Fe
fission
Harmonie
E*PHI(E)
ENERGY(EV)

Fig. 7

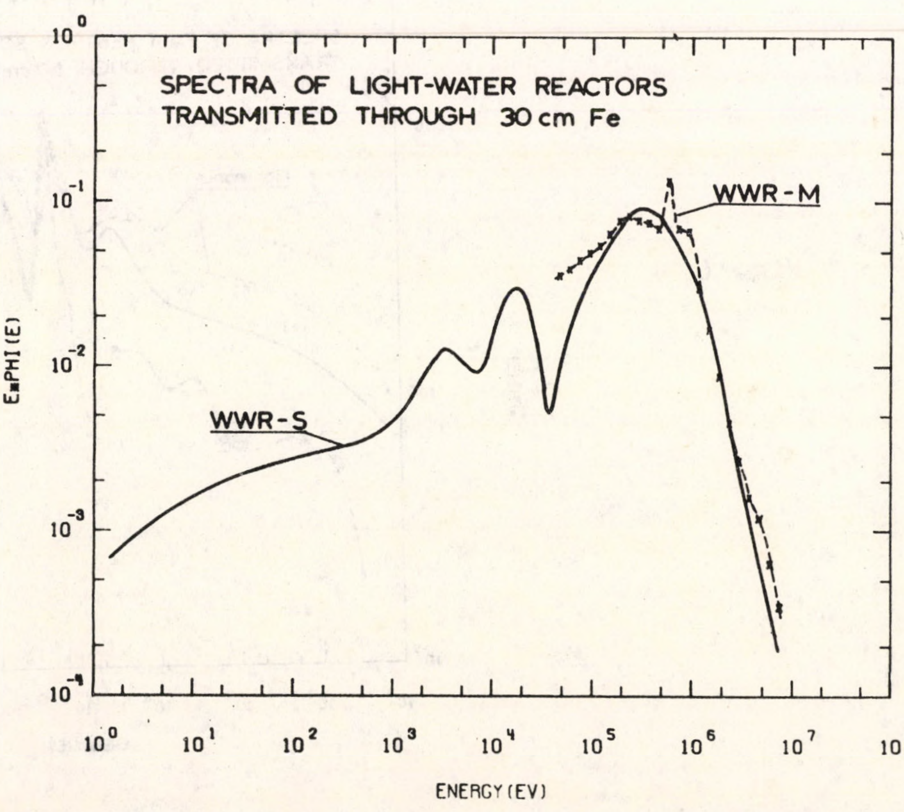
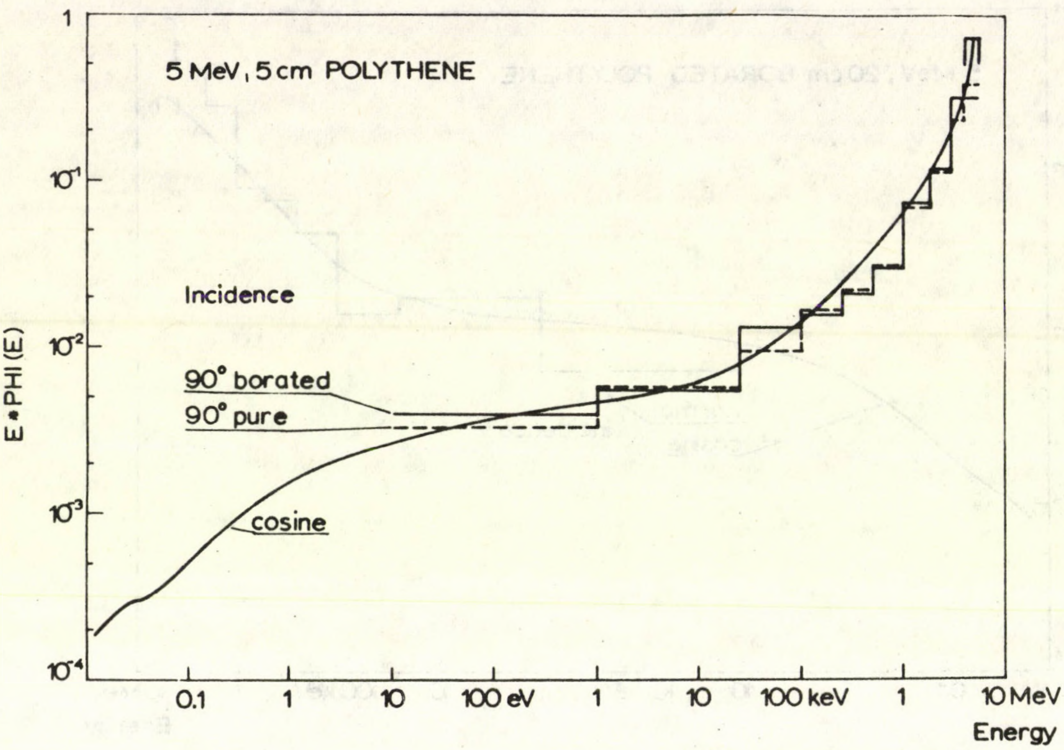
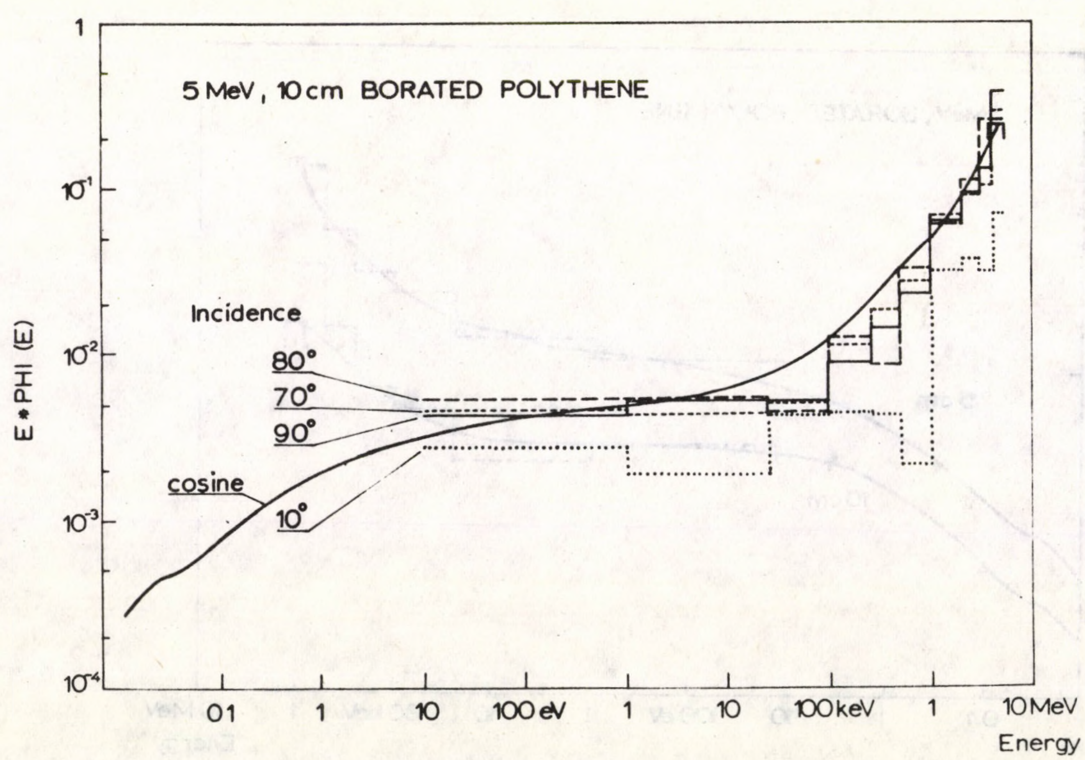

SPECTRA OF LIGHT-WATER REACTORS
TRANSMITTED THROUGH 30 cm Fe
WWR-M
WWR-S
E*PHI(E)
ENERGY(EV)

Fig. 8



5 MeV, 5 cm POLYTHENE
Incidence
90° borated
90° pure
cosine
E*PHI (E)
1
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
0.1
1
10
100 eV
1
10
100 keV
1
10 MeV
Energy


Fig. 9



5 MeV, 10 cm BORATED POLYTHENE
Incidence
80°
70°
90°
cosine
10°
E*PHI (E)
1
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
01
1
10
100 eV
1
10
100 keV
1
10 MeV
Energy


Fig. 10

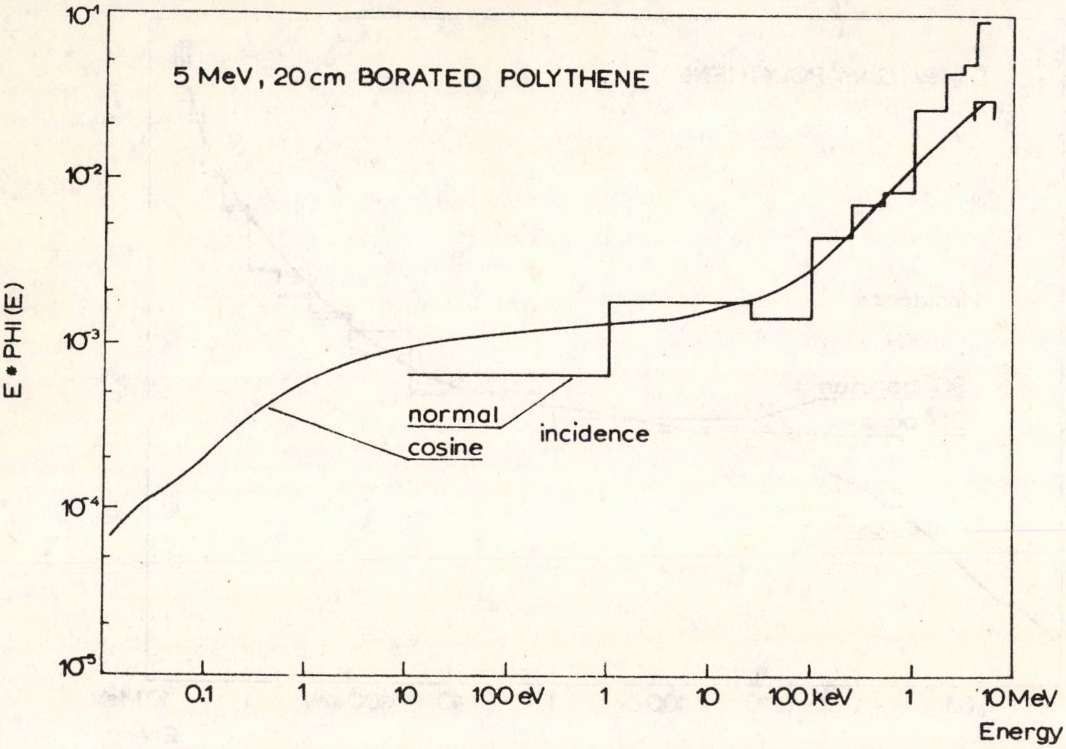

5 MeV, 20 cm BORATED POLYTHENE
E * PHI (E)
normal
cosine
incidence
0.1
1
10
100 eV
1
10
100 keV
1
10 MeV
Energy

Fig. 11

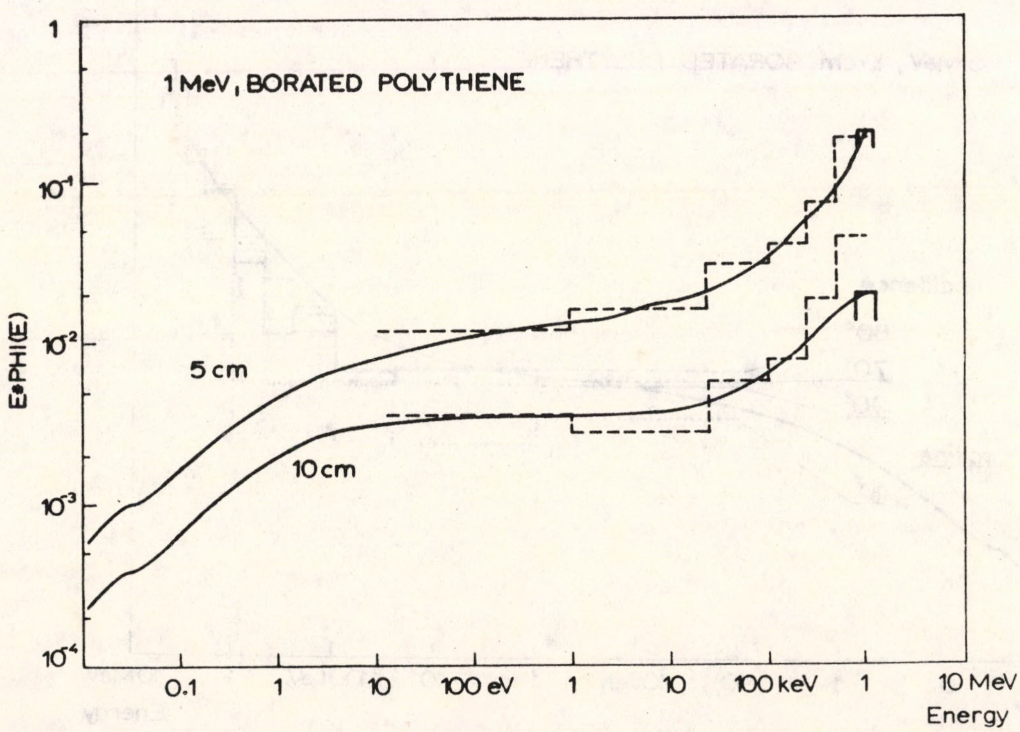
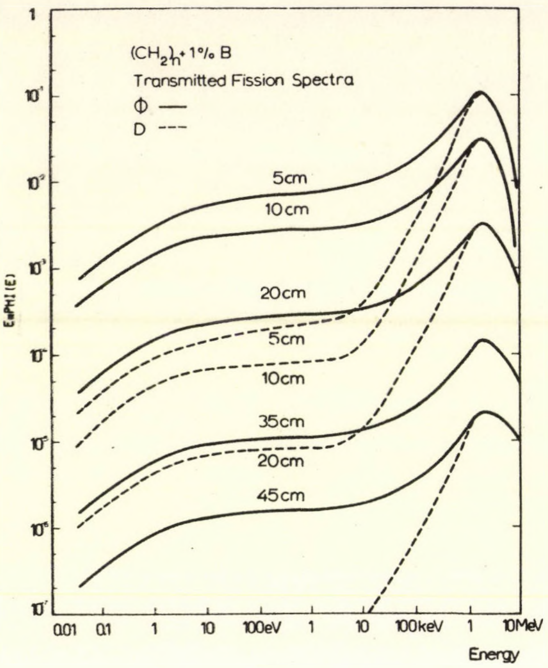
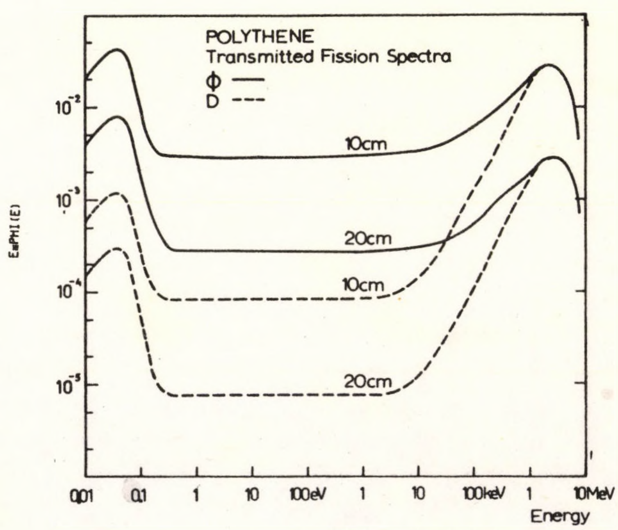

1 MeV, BORATED POLYTHENE
E*PHI(E)
5 cm
10 cm
0.1
1
10
100 eV
1
10
100 keV
1
10 MeV
Energy

Fig. 12



$(CH_2)_n$ + 1% B
Transmitted Fission Spectra
Φ ——
D ---
5cm
10cm
20cm
5cm
10cm
35cm
20cm
45cm
EⅹPHI(E)
0.01
0.1
1
10
100eV
1
10
100keV
1
10MeV
Energy


Fig. 13



POLYTHENE
Transmitted Fission Spectra
Φ ——
D ---
10cm
20cm
10cm
20cm
EⅹPHI(E)
0.01
0.1
1
10
100eV
1
10
100keV
1
10MeV
Energy


Fig. 14

61.988

Kiadja a Központi Fizikai Kutató Intézet
Felelős kiadó: Szabó Ferenc igazgatóhelyettes
Szakmai lektor: Fischer Ádám,
Koblinger László
Nyelvi lektor: T. Wilkinson
Példányszám: 455 Törzsszám: 72-7575
Készült a KFKI sokszorositó üzemében,
Budapest, 1972. november hó