KFKI-70-37 RPT

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CALCULATION OF MULTIGROUP SPECTRA OF NEUTRONS TRANSMITTED THROUGH MULTILAYER SHIELDING

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BUDAPEST

CALCULATION OF MULTIGROUP SPECTRA OF NEUTRONS TRANSMITTED THROUGH MULTILAYER SHIELDING

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ABSTRACT

Albedo operator formalism is used for computation of 26-group neutron transmission. The resulting code - MUSPALB - can calculate not only the transmitted and reflected neutron spectra of a multilayered slab but also the spectra inside the shielding. The code is written in FORTRAN-IV for the ICL-1905 computer.

1. Formalism underlaying the calculation

In the present work albedo operator formalism is applied to calculation of neutron transmission in non-multiplying media with respect to slab geometry. The general description of this formalism has been published in an earlier paper [1].

Let us consider a slab of thickness d with two opposite surface F_a and F_b. As shown in [1], if $\phi_\xi^-(v,\underline{\Omega})$ is the ingoing and $\phi_\xi^-(v,\underline{\Omega})$ is the outgoing neutron distribution over the surface F_ξ/ ξ = a or b/, then, assuming source free medium, the outgoing distribution can be related to the ingoing, as

$$\phi_{a\,b}^{-}(v,\Omega) = T(d)\ \phi_{b\,a}^{+}(v,\Omega) + B(d)\ \phi_{a\,b}^{+}(v,\Omega) \qquad /1/$$

where $B/d/$ and $T/d/$ are linear operators. When two slabs of thickness d_1 and d_2, are joined the operators of the slab $d_1 + d_2$, on the side of slab d_1 are

$$B(d_1)+(d_2) = B(d_1) + T(d_1')\ B(d_2)\ \frac{1}{1 - B(d_1)B(d_2)}\ T(d_1) \qquad /2a/$$

$$T(d_1 + d_2) = T(d_2)\frac{1}{1 - B(d_1)\ B(d_2)}\ T(d_1) \qquad /2b/$$

The operators on the side of slab d_2 are denoted by $B/d_2 + d_1/$, $T/d_2+d_1/$ they can be obtained by exchanging d_1 and d_2 in /2/. $B/d_2 + d_1/$,

$T/d_2 + d_1/$ are not identical with $B/d_1 + d_2/$, $T/d_1 + d_2/$, respectively, unless both slabs are of the same material.

Albedo method allows the neutron distribution to be determined at the interface between d_1 and d_2 , as follows:

$$\phi_{d_1 \to d_2}(v,\Omega) = \frac{1}{1-B(d_1)B(d_2)} T(d_1)\,\phi_a^+(v,\Omega) + B(d_1)\frac{1}{1-B(d_2)B(d_1)} T(d_2)\,\phi_b^+(v,\Omega) \qquad /3a/$$

$$\phi_{d_2 \to d_1}(v,\Omega) = B(d_2)\frac{1}{1-B(d_1)B(d_2)} T(d_1)\,\phi_a^+(v,\Omega) + \frac{1}{1-B(d_2)B(d_1)} T(d_2)\,\phi_b^+(v,\Omega) \qquad /3b/$$

In the following, multigroup representation and the set of functions /4, 8/ from [1] are used. Since only the first term expansion /4.3'/ of [1] is retained, the indiced corresponding to the angular variables can be omitted.

Thus, if neutrons are incident at one side of a source free slab system, the currents of the outgoing neutrons are given by:

$$J_q^{a^-} = \sum_{p=1}^{G} \beta_{qp} J_p^{a^+} \qquad /4a/$$

$$J_q^{b^-} = \sum_{p=1}^{G} \tau_{qp} J_p^{a^+} \qquad /4b/$$

where

$$J_q^{a^\pm} = \int_{v_{q+1}}^{v_q} dv\, f(v) \int_0^1 d\mu\, \mu\, \phi^{a^\pm}(v,\mu) \qquad /5a/$$

$$J_q^{b^\pm} = \int_{v_{q+1}}^{v_q} dv\, f(v) \int_0^1 d\mu\, \mu\, \phi^{b^\pm}(v,\mu) \qquad /5b/$$

$/f/v/$ is a group averaging weight functions/. Hence we can obtain relation between the ordinary albedos by calculating of β_{qp} , τ_{qp} the matrix elements of reflexion and transmission operators, respectively.

The flux and the net current can be calculated by the relations

$$\phi_q = 2\left(J_q^+ + J_q^-\right) \qquad /6a/$$

$$J_q = J_q^+ - J_q^- \qquad /6b/$$

2. Method for albedo matrix calculation

Our code uses Peierls integral equation method calculation of albedo matrix [2] . In plane geometry the system of integral equations is:

$$\psi^a_{qp}(x) = \delta_{qp}\sqrt{3}\,E_3\left(\Sigma_q|x-x_a|\right) + \frac{1}{2}\int_{x_a}^{x_b} dx'\,E_1\left(\Sigma_q|x-x'|\right)\cdot$$

$$\left\{\Sigma_o^{q\to q}\psi^a_{qp}(x') + F^a_{qp}(x')\right\} + \frac{3}{2}\int_{x_a}^{x_b} dx'\,\mathrm{sign}(x-x')\,E_2\left(\Sigma_q|x-x'|\right)\left\{\mu^{q\to q}\,\Sigma_o^{q\to q}\,J^a_{qp}(x') + I^a_{qp}(x')\right\} \qquad /7a/$$

$$J^a_{qp}(x) = \delta_{qp}\sqrt{3}\,E_4\left(\Sigma_q|x-x_a|\right) + \frac{1}{2}\int_{x_q}^{x_b} dx'\,\mathrm{sign}(x-x')\,E_2\left(\Sigma_q|x-x'|\right)\left\{\Sigma_o^{q\to q}\,\psi^a_{qp}(x') + F^a_{qp}(x')\right\} + \frac{3}{2}\int_{x_a}^{x_b} dx'\,E_3\left(\Sigma_q|x-x'|\right)\left\{\mu^{q\to q}\,\Sigma_o^{q\to q}\,J^a_{qp}(x') + I^a_{qp}(x')\right\} \qquad /7b/$$

$$\beta^a_{qp} = \frac{1}{2}\sqrt{3}\int_{x_a}^{x_b} dx'\,E_2\left(\Sigma_q|x_a-x'|\right)\left\{\Sigma_o^{q\to q}\,\psi^a_{qp}(x') + F^a_{qp}(x')\right\}$$

$$-\frac{3}{2}\sqrt{3}\int_{x_a}^{x_b} dx'\,E_3\left(\Sigma_q|x_a-x'|\right)\left\{\mu^{q\to q}\,\Sigma_o^{q\to q}\,J^a_{qp}(x') + I^a_{qp}(x')\right\} \qquad /8a/$$

$$\tau^a_{qp} = 3E_4\left(\Sigma_q|x_a-x_b|\right) + \frac{1}{2}\sqrt{3}\int_{x_a}^{x_b} dx'\,E_2\left(\Sigma_q|x'-x_b|\right)\left\{\Sigma_o^{q\to q}\,\psi^a_{qp}(x') + F^a_{qp}(x')\right\}$$

$$+\frac{3}{2}\sqrt{3}\int_{x_a}^{x_b} dx'\,E_3\left(\Sigma_q|x'-x_b|\right)\left\{\mu^{q\to q}\,\Sigma_o^{q\to q}\,J^a_{qp}(x') + I^a_{qp}(x')\right\} \qquad /8b/$$

To obtain a numerical solution the above equations are transformed into algebraic equations by taking

$$\int_{x_a}^{x_b} dx(\ldots)\,f(x) = \sum_{k=1}^{N} f(x_k)\int_{x_{k-1/2}}^{x_{k+1/2}} dx(\ldots)$$

Equations /7/ can be solved by iteration.

3. Group constants

The macroconstants of shielding media are calculated using the 26-group constant system of Abagyan et al [3] . Fast calculation is achieved by

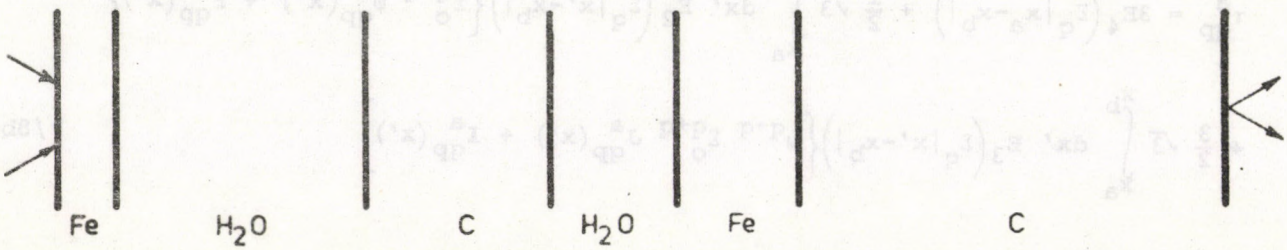
constructing on magnetic store a library of this system of group constants. This library and the corresponding subroutine are the FORTRAN versions of those which are described in [4].

4. The organisation or the work with MUSPALB

The efficiency of MUSPALB is highly dependent on the organization of its work. Calculation of the albedomatrices by means of Peierls integral equation requires most of the computing time, and takes about 10 - 20 min on ICL-1905 computer depending on the requierd accuracy. Accuracy for a given number of iteration depends on the thickness in mean free path of the shielding layer. The thinner the layer, the faster the calculation. For this reason a maximum width in mean free path is specified at the input. If, the thickness for a given energy group in mean free path of the layer being considered is more than the specified maximum, then the layer is automatically divided into thinner parts and the addition formula /2/ are applied.

Calculation by the formula /2/ requires about 30 sec. The whole calculation can be optimized by computing the albedo matrices for some basic layers only and these being stored on a magnetic tape. /This tape can be preserved for any length of time/.

The optimal organization can be illustrated by considering the following system /Fig. 1/.



The albedo matrices of the layer 1 cm Fe 2 cm H_2O and 3 cm C are calculated by Peierls integral equation and stored on a magnetic tape, this takes about 45 min. The complete system of Fig. 1 can be constructed from those basic layers after eight calculations by formula /2/, and six readings of albedo matrices from magnetic tape /each reading takes about 10 sec/. Thus the albedo matrices of the system of Fig. 1 can be computed in 5 min given that the basic albedo matrices are already on magnetic tape. It is evident that any system which can be constructed from basic layers may be calculated in a very short time. In principle the number of incident neutron spectra used in the calculation may be as large as it is desired without sig-

nificant by increasing the computing time, although in practice this is slightly limited by the fast storage capacity of the computer.

5. Calculation of neutron spectra inside the shielding

Using two additional scratch tapes MUSPALB can calculate not only the spectra of transmitted neutrons but also spectra inside the shielding providence the layers from which such a calculation should start are specified in the input by their serial numbers. When the program's "building up" of the system reaches the specified place, the albedo matrices for formula /3/ are stored on the first scratch tape. When the system has been "built up" the process is repeated for the opposit direction, and in thus way we get a reflexion matrix corresponding to $B/d_2/$ in formula /3/. This matrix is stored on a second scratch tape. By means of these two scratch magnetic tape the spectrum calculation of spectra of internal points can be easily executed.

6. Main subroutines of the MUSHIPS

1. INPUT - specifies variables controlling the calculation, and composition and thickness of the shielding layers; these are printed out.
2. ABGROUP - calculates the macroscopic cross-sections for a given material composition.
3. PMALB - solves the Peierls integral equation for a group.
4. ALBGROUP - calculates the multigroup albedo matrices.
5. SUMALB - adds the albedomatrices by the formula /2/.
6. FLUXUS - calculates and prints out the internal neutron spectra.
7. OUTRES - calculates the transmitted and reflected neutron spectra from the transmission and reflexion matrices of the calculated system, and prints out.

There are two versions of the code depending on whether or not the computation is performed using albedo matrices stored on a magnetic tape: the complete version contains all subroutines requeired for albedo matrix calculation, whereas the short version omits these subroutines by using stored albedo matrices.

7. Input description

The input format is almost free, i.e. the numbers can be punched in free position, separating them by two spaces. The only restriction is that

the number of items in a line is limited. The two versions require different inputs.

Input description of the complete version

LINE	FORMAT	VARIABLES	DESCRIPTION
1	IO	M	Number of incident neutron spectra
2	10F0.0	//AL/I,J/, I=1,26/,I=1,M/	Incident neutron spectra
3	10A8		Title
4	10IO	NG	Number of groups /≤ 26/
		NS	maximum group change in a collision /≤10/
		NMIX	number of different mixtures / ≤ 5/
		KO	maximum width in mean free path
		N	maximum number of mesh points /≤50/
		KS	index of fission spectra /≤5/
		IAT	0 or -1 the incident spctrum is a fission spectrum only /corresponding to KS/, otherwise |IAT| = number of incident spectra, if IAT < 0 then the last incident spectrum is always a fission one.
		L	= 0
5	2F0.0,IO	EPS	accuracy of the iterated flux
		BLIB	Liebmann overrelaxation coefficient /it is generally 1.5 - 1.7/
		ITMAX	maximum number of iterations /≤ 100/
6	A4,IO	NAME/I/, NE/I/,	Name and number of the elements in the i-th mixture
7	A4,IO,F0.0	/ND/J/, NK/J,I/	name, library tape number, nuclear density in $10^{24}/cm^3$ of the j-th element in the i-th mixture
		RO/J,I/, J = 1, NE /I/ I = 1, NMIX/	
8	5IO,F0.0	/ND/I/, HD/I/, I = 1,KM/	mixture identification number azd thickness of the i-th layer

If the system is calculated directly without storing and searching the albedo matrices on magnetic tape, then no more input is needed for a given problem. The calculation is determinated correctly if the first four characters of the last line are: LAST.

If the calculation is indirect as described in 4., then the following input is necessary:

LINE	FORMAT	VARIABLES	DESCRIPTION
9	2I0	KM, NFL	number of layers in the system and number of internal places where the neutron spectra is to be calculated
10	12/I4,I2/	/ND/I,LUI/I/, I = 1,KM/	serial number of the record on the magnetic tape which contains the albedo matrices; 0 if no spectra calculation is needed after the i-th layer IAT = LUI /I/, otherwise
11	10I0	/KFL/I/, I = 1,NFL/	the serial number of region after which internal spectrum calculation is required
12	10F0,0	/ST/I/, I = 1,NG/	weights for spectrum averaging

The input of the short version is, as follows:

1	5I0	NG, NS, KM, NFL, M	number or groups, maximum group change, number of region, number of internal points where spectrum calculation is required, number of incident neutron spectra.
2	Identical with line 2 of the complete version.		

The next three lines are identical with lines 10, 11, 12 of the complete version.

8. Output description

The output always contains a description of the system, i.e. the composition and thickness of the layers in the order that they follow in the shielding.

The output for transmitted spectra comprises: total thickness of the system; incident spectra; reflected and transmitted spectra; weighted average of the spectra.

The output for internal spectra comprises: distance from the beginning of the system; incident spectra; spectra of neutrons travelling to right and to left, respectively; flux and current; weighted average of all spectra.

In the future the automatic plotting of the spectra will be also facilitated.

9. Operating instructions

In the first version of MUSPALB there are two switches. If switch 1 is on then the macrogroup constants are printed out. If switch 3 is on then the calculated albedo matrices are not stored on magnetic tape.

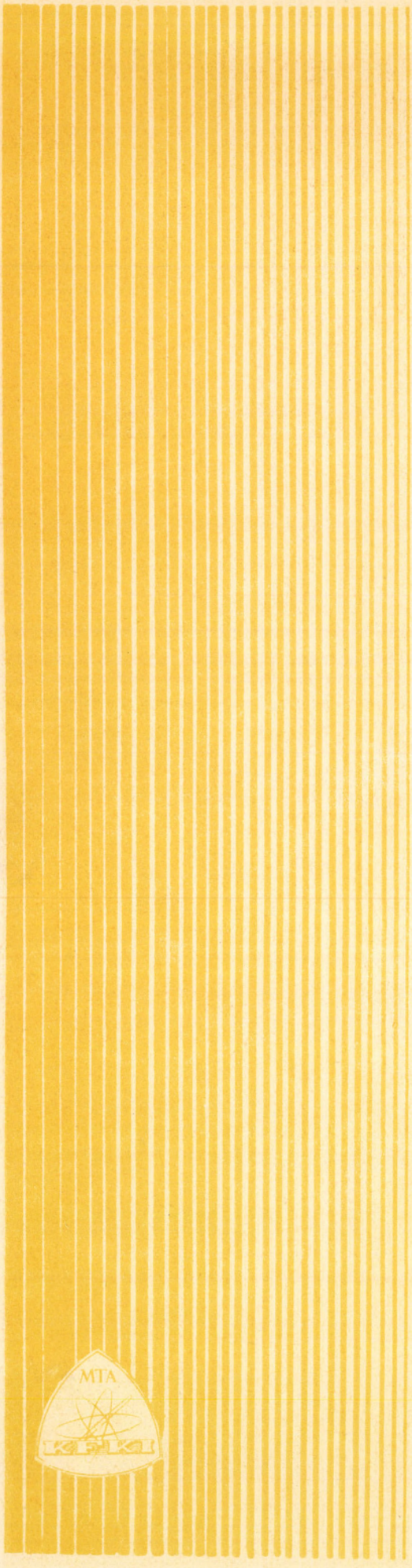
REFERENCES

[1] P.Vértes, Nukleonik 10. 148 /1967/

[2] P.Vértes, Nukleonik 12. 67 /1969/

[3] Abagyan et al, Group Constants for Reactor Calculations Atomizdat, 1964 /in Russian/

[4] P.Vértes, report KFKI 14/1968



Printed in Central Research Institute
for Physics, Budapest, Hungary
Kiadja a KFKI Könyvtár Kiadói Osztály
O.v.: Dr.Farkas Istvánné
Szakmai lektor: Makra Zsigmond
Nyelvi lektor: Timothy Wilkinson
Példányszám: 155 Munkaszám: 5277
Készült a KFKI házi sokszorositójában
Felelős vezető: Gyenes Imre