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NEUTRON REFLECTION AND FLUX VERSUS DEPTH FOR CONCRETE

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RDT & E Project No. 1A022601A086
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND
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NEUTRON REFLECTION AND FLUX VERSUS DEPTH FOR CONCRETE

Frank J. Allen
Arnold Futterre
William Wright

Terminal Ballistics Laboratory

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FOREWORD

This is the first of a series of reports, each one of which presents calculated results for neutron reflection and flux versus depth for a single material. In each case eight incident energies: 0.1, 0.25, 0.5, 1.0, 2.0, 3.0, 5.0 and 14.0 MEV and four incident angles for each energy: 0, 30, 45 and 70° are considered. Materials which will be treated in the series of reports include concrete (present report); Nevada Test Site soil dry, 50% saturated and 100% saturated; iron; and water.
NEUTRON REFLECTION AND FLUX VERSUS DEPTH FOR CONCRETE

ABSTRACT

Detailed calculated results on neutron reflection and flux versus depth for concrete are given in the form of machine printouts. The angular and energy distributions of the reflected neutrons along with the energy-dependent and total flux at various depths are contained in tabular form on the printouts. Neutron number current, number flux and dose transmission as functions of thickness are also given in tabular form on the printouts.

A table of summary information on reflection is presented. This contains number current, number flux, dose and energy reflection factors as functions of incident energy and angle.

A few figures are presented to illustrate graphically the meaning of the various tabular results.
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INTRODUCTION

A systematic study of neutron transport in common materials is in progress at the Ballistic Research Laboratories. Primary emphasis has been placed upon the dose transmitted through various thicknesses of these materials when monoenergetic neutrons strike a laterally infinite slab, not necessarily homogeneous, at a fixed angle of incidence. The principal results are given in Reference 1.

The Monte Carlo machine program which calculates these results also calculates number current, number flux, dose, and energy reflection and transmission; reflected and transmitted angular and energy distributions; and energy-dependent and total flux versus depth. Only a small fraction of this information has been reported previously in conjunction with the dose transmission results. The present report presents the calculated results just mentioned for a single material - concrete. The reason for tabular presentation of the detailed results is simply that a much larger number of pages would be required to display equivalent information graphically. The gross results for reflection are given in a single table discussed in the following section.

SUMMARY DATA ON REFLECTION

Table 1 gives the number current, number flux, energy, and dose reflection factors (albedos) for eight incident energies and four incident angles. "Flux" and "factor" are defined in the next section. The slab thickness for which the entries in Table 1 are calculated is 24 inches. This is sufficiently thick so that the results differ imperceptibly from the corresponding results for a slab of infinite thickness.

The composition assumed for concrete is based on that given in Reference 2. The atoms of all elements other than hydrogen, oxygen, aluminum, and silicon were replaced by silicon atoms. Table 7 gives the elemental composition assumed in the machine calculations. Moderate changes in the composition of the concrete, except for the hydrogen content, would not greatly alter the results given.
A neutron cutoff energy of 10 electron volts was used for all of the calculations. Below this energy neutron trajectories were no longer followed in the machine program.

DESCRIPTION OF MACHINE PRINTOUTS

Two distinct types of machine printout are included in this report. For each incident neutron energy and angle, there are two printouts and these are placed side by side. We now describe the meaning of the information on the two types of printout, denoting them by Type 1 and Type 2. Although the actual printout sheets are not so labelled, no difficulty will be experienced in distinguishing between the two.

A. Description of Type 1 Printout

The problem calculated is defined by the fifth line of the machine printout, which gives the slab configuration, and the first two numbers of the fourth line, which give the neutron's incident energy (in MEV) and the cosine of the angle between the incident direction and the slab normal. The third number in the fourth line is the energy cutoff, that energy (in MEV) below which neutron trajectories are no longer traced in the Monte Carlo program. On the second line of the machine printout, the first two numbers are the run number, used for indexing purposes, and the number of neutron histories used in the Monte Carlo program. The fifth number in the second line is the number of mean free paths the incident neutron would have to traverse to emerge from the rear face of the slab without having suffered an interaction.

The third and fourth numbers on the second line designate the set of energy intervals and angular intervals, respectively, which are used in the calculation. A transmitted or reflected neutron emerges from the slab with a definite energy and direction; this precise information would be very difficult to utilize. Therefore, a set of energy and angular intervals are utilized and the emergent neutron is placed in the appropriate interval. Several energy "sets" have been used. The energy intervals, of which the various sets are composed, are shown in Table 2. The sets are designed to make full use of the ten energy intervals available in the machine program for all source energies. Thus the intervals used must vary with the source energy. The scheme devised
was that of refining the remaining upper energy intervals when decrease of the source energy makes the highest energy interval in a given set devoid of neutrons. This method provides the most detailed spectral information at the highest available emergent neutron energies, that is, in the most important part of the spectrum. At the same time, the lower energy intervals are constant from set to set (the sets are ordered: 2, 2A, ..., 2E), thus allowing inter-comparison as the source energy is changed.

Tables 4 and 5 and the diagram accompanying Table 5 show the angular intervals which have been used. \( \Theta_1, \Theta_2, \Theta_1', \) and \( \Theta_2' \) are the end points of the angular intervals shown in these tables. The \( \Theta_2541 \) histogram has been used for normally incident neutrons, the \( \Theta_0 \) histogram for slant incident neutrons.

The seventh and eighth lines of the ORDVAC printout give the position, in centimeters of internal interfaces which subdivide the slab into eight regions. They are used by the Monte Carlo transport code to provide a spatial breakdown of certain events which take place within the slab.

The remaining entries on the Type 1 machine printouts are explained with the aid of the following notation.

Let \( T_{ij} \) = fraction of neutrons transmitted into the \( i^{th} \) energy group and \( j^{th} \) angular sector.
\( R_{ij} \) = fraction of neutrons reflected into the \( i^{th} \) energy group and \( j^{th} \) angular sector.
\( D_i \) = flux to dose conversion factor for \( i^{th} \) energy group (see Table 2).
\( D_E \) = flux to dose conversion factor for source energy (see Table 3).
\( \Omega_j \) = number of steradians in \( j^{th} \) angular sector (see Tables 4 and 5).
\( \Theta \) = angle of incident neutrons with respect to slab normal.

\( \sec \Theta_j \) = mean value of secant for neutrons in the \( j^{th} \) angular sector; actually the secant of the mean angle is used.
Subscripts \( i \) and \( j \) refer to the \( i^{th} \) energy group and \( j^{th} \) angular sector, respectively.

The flux-to-dose conversion factors in Tables 2 and 3 are based on Reference 3.

Then, \( F = \) incident flux per neutron = Sec \( \Theta \)
\( D = \) incident dose per neutron = \( D_{E} \) Sec \( \Theta \)

The quantities in the Table "Number of Scattered Neutrons vs. Energy" are then given by:

\[
(Number \text{ Transmission Factor})_i = \sum_{j=1}^{12} T_{ij} \quad i = 1, 2, \ldots, 10
\]

\[
(Number \text{ Flux Transmission Factor})_i = \frac{1}{F} \sum_{j=1}^{12} T_{ij} \sec \Theta_j \quad i = 1, 2, \ldots, 10
\]

\[
(Dose \text{ Transmission Factor})_i = \frac{D_i}{D} \sum_{j=1}^{12} T_{ij} \sec \Theta_j \quad i = 1, 2, \ldots, 10
\]

The corresponding quantities for the reflected neutrons are obtained by replacing \( T_{ij} \) by \( R_{ij} \).

The quantities in the Table "Number of Scattered Neutrons vs. Angle" are given by:

\[
(Number \text{ Transmission Factor})_j = \sum_{i=1}^{10} T_{ij} \quad j = 1, 2, \ldots, 12
\]

\[
(Number \text{ Transmission Factor/Steradian})_j = \frac{1}{\Omega_j} \sum_{i=1}^{10} T_{ij} \quad j = 1, 2, \ldots, 12
\]

\[
(Dose \text{ Transmission Factor/Steradian})_j = \frac{\sec \Theta_j}{D \Omega_j} \sum_{i=1}^{10} T_{ij} D_i \quad j = 1, 2, \ldots, 12
\]

The corresponding quantities for the reflected neutrons are again obtained by replacing \( T_{ij} \) by \( R_{ij} \).
The quantities listed on the lines following the Table "Number of Scattered Neutrons vs Angle" are all defined when the word "Factor" is defined. Wherever the word "Factor" is used, the operation of dividing the quantity in question by the corresponding incident quantity is implied.

The final two quantities listed are not fractions, but are the mean energy of the scattered transmitted neutrons and of the reflected neutrons.

Table 0 is a list of abbreviations used on both the Type 1 and Type 2 machine printouts. It is believed that the abbreviations used will quickly become clear so that constant reference to the list will not be necessary.

The Type 1 printouts in the present report contain little or no information on transmission. This is because the slab is thick and, except for a few machine runs, no statistical efficiency improving technique was utilized in the calculations. The main machine printout contains detailed information on transmission for various depths within the slab. The Type 2 printout contains the most important part of this information.

B. Description of Type 2 Printout

The entries in the top three lines are identical to some of the entries previously defined for the Type 1 printout; they serve to identify the problem.

Fluxes and doses are defined as before. Note, however, that the word "factor" is not used on the Type 2 printout. All entries on this printout are given on a per incident neutron basis. That is, the phrase "per neutron" (or the abbreviation "per NT") on this printout means "per incident neutron."

The first two tables on this printout are the fluxes broken down into ten energy groups. The energy interval spanned by each group is given in Table 2; the last entry in the second row of the printout specifies the relevant energy set in Table 2.

The first table, "Scattered Flux per Neutron at Region Boundaries in Energy Groups," gives the energy-dependent fluxes due to scattered neutrons (uncollided excluded) at what are termed "region boundaries." The slab configuration through which the machine program traces neutron trajectories is divided into eight sub-slabs by means of seven interior interfaces. Each time
a neutron crosses such an interface its contribution to the flux (in the energy interval appropriate for the crossing in question) is recorded. A neutron may cross an interior interface any number of times. Generally speaking, however, once a neutron gets more than a few inches from a given interface, it seldom recrosses that interface. Thus, for most of the interior interfaces the number of recrossings is approximately the same as would take place in the interior of a semi-infinite medium of the same material.

In the Type 2 printout all fluxes (and doses) calculated except those in the first row of entries of the first table "Scattered Flux per Neutron at Region Boundaries in Energy Groups" involve the secants of the actual angles at which the neutrons cross the various interfaces, except that for angles whose secant is greater than eight, the value eight is substituted for the secant. In the first row of entries of the first table, and in all cases on the Type 1 printout, the fluxes and doses calculated are based on an average value of the secant for each of the angular regions into which neutrons are grouped. The Type 1 printout fluxes are usually about 3 or 4% higher than the Type 2, the value depending on the actual angular distribution. (This is apart from the difference between "Flux Transmission or Reflection Factor" and "Flux Transmitted or Reflected per Incident Neutron" in accordance with the previously given definitions of these terms.) It is readily shown* that the fluxes calculated with the greatest value of the secant limited to eight are, on the average, six percent low for an isotropic distribution; the error is smaller for a distribution which is peaked forward (which is almost always the case for transmitted neutrons). Thus fluxes and doses listed on the Type 2 printouts average about 4 to 6% low, while those on the Type 1 printout average 1 or 2% low.

The second table, "Scattered Flux Transmitted per Neutron in Energy Groups Versus Thickness", again contains the energy-dependent fluxes, but this time only a neutron's first crossing of an interface is tallied. Thus, for example, the

---

* The authors are indebted to Dr. M. Kalos, United Nuclear Corporation, for this demonstration.
entries in the 4" row (left hand or index column reads 4") for a 24" thick slab constitute the energy-dependent fluxes which would be transmitted per incident neutron by a 4" thick slab - just as though the slab being treated in the machine program were only 4" thick. This method allows the calculation of eight problems simultaneously.

In the third or bottom table in the printout, the entries are not broken down by energy group. The first four columns contain information similar to that in the immediately preceding paragraph; each row corresponds to a slab whose thickness is specified in the index column, the remaining thickness of the slab actually treated having no effect on the table entries. Each column in this table bears its own heading. The first column represents the number (we use this interchangeably with the term number current) transmitted per incident neutron, including the uncollided. The second and third columns are the flux and dose per incident neutron, again including the uncollided. The fourth column gives the uncollided contribution to the flux per incident neutron*. The uncollided contribution to the number current is obtained from the entries in this column upon dividing by the secant of the incident angle; the uncollided contribution to the dose is obtained upon multiplication of the entries by the flux-to-dose conversion factor at the source energy from Table 5. (The machine program interpolates in a table in obtaining source energy flux-to-dose conversion factors.)

The final column in the bottom table provides information analogous to that in the first table, i.e., the result of every crossing of an interface by each neutron is contained therein. The uncollided contribution is also included here. Thus, the second and fifth columns of the bottom table represent a total over all energy groups (plus the uncollided) of the flux due to neutrons' first crossings of the various interfaces, and due to all crossings of the interfaces, respectively. The difference represents the effect of crossings other than the first.

* At each interface, the uncollided flux in this column is based on an integral number of neutrons (or zero). This does not affect any other entries on the printout. When splitting is used, uncollided as well as scattered neutrons are split upon crossing a splitting surface.
In the first and third tables of the Type 2 printout, the first row of entries corresponds to zero inches, i.e., the incident face, the machine suppressing the zero. Since the first table refers to scattered neutrons only, the first row entries in this table are due solely to reflected neutrons. The first four columns of the third table refer to transmitted neutrons, so reflected neutrons are not included at the incident face (first row entries). The entry in the first row of the final column of the bottom table represents the sum of the fluxes due to the incident neutrons and the reflected neutrons.

DISCUSSION

The machine printouts are arranged in order of increasing energy; for each energy, they are arranged in order of increasing angle with respect to the slab normal. The incident energies (in MeV) for which results are given are: 0.1, 0.25, 0.5, 1.0, 2.0, 3.0, 5.0 and 14.0. The incident angles (degrees) are: 0, 30, 45 and 70. Following the thirty-two sets of printouts so arranged, there are a few miscellaneous printouts. The latter were calculated after a "splitting" technique had been added to the basic Monte Carlo machine program. The flux distributions are reliable to much greater depths for the split runs (which require much more machine time) but the information on reflection is not significantly improved by splitting.

Figures 1 - 4 have been included to show graphically the meaning of some of the tabular results. Figure 1 is a reflected energy histogram illustrative of information contained on the Type 1 printout. The reflected energy distributions are seen to vary slowly with incident angle for a given incident energy, there being relatively more reflected neutrons near the source energy at the larger angles of incidence. Figure 2 is also obtained from a Type 1 printout and is typical of reflected angular distributions generally. For the normal incidence curve shown on Figure 2, there are twelve points whereas on the curves for slant incidence there are four points. Since for the case of normal incidence the reflected neutron distribution has no azimuthal dependence, the twelve available angular regions are all used to obtain the dependence of the reflected distribution upon the polar angle. For slant incident neutrons there
is an azimuthal dependence; this has been suppressed in Figure 2 by integration over the azimuthal angle. This accounts for the greater dispersion of the plotted points for the normal incidence curve as compared with that of the slant incidence curves.

Figures 3 and 4 are obtained from the Type 2 printout. The shapes of the curves in Figure 3 are typical for flux versus depth plots for various materials, incident angles and incident energies. The curves for neutron energies near the source energy peak a little sooner than those for lower energies since fewer collisions are required for energies near the source energy. Peaking occurs on the order of a mean free path inside the slab and the rate of decrease after the peak is very nearly the same for all neutron energies. This is in accord with the fact that a quasi-equilibrium neutron distribution becomes established after a penetration distance of a few mean free paths*. In Figure 4 the shapes of the curves are again similar. This figure illustrates the difference between flux versus depth (slab thickness 24") and flux versus thickness in which case the slab thickness is equal to the value of the abscissa just as though the remainder of the 24" were not present. The difference between the two curves in Figure 4 represents the increase in flux due to neutrons bouncing back and forth across a surface on the slab interior.

The total flux is always much better determined statistically than are the fluxes in the various energy groups. The fact that the rate of fall off after reaching the peak is about the same for all groups and for the total can be used in graphing the behavior of the flux in a particular energy group. Knowing the behavior of the energy-dependent fluxes enables one to calculate the volume distribution of any desired type of neutron interaction within a slab.

For certain problems which require detailed input information, it would be preferable to have the information in the form of analytical expressions fitted to the data since the handling of detailed information via tables is

*The bending down of the curves indicates a slow softening of the spectrum.
cumbersome, especially in hand computations. Many of the more important results conform to general patterns as depicted by the curves in the illustrative figures. Thus, one might expect a reasonable degree of success in fitting the results to analytical expressions. However, the tabular printouts contain a diversity of frequently useful information so that a large number of fits would be required. Those likely to be the most generally useful are not obvious at present. Further, each prospective user must place his own demands on the accuracy with which the analytical expressions fit the data, and the range over which each fit is valid. Therefore, the authors feel that the tabular display of results chosen is the most appropriate form of presentation.

FRANK J. ALLEN

ARNOLD FUUTERER

WILLIAM WRIGHT
FIG. 1. NEUTRON REFLECTED ENERGY SPECTRUM

SLAB MATERIAL = CONCRETE
INCIDENT ENERGY = 3.0 MEV
THICKNESS = 24 INCHES
\( \theta_0 \) = ANGLE OF INCIDENCE

F = ARBITRARY NUMBER
BASED ON RUN NOS. 657-660

\[ F = 83 \quad \theta_0 = 0^\circ \]

\[ F = 86 \quad \theta_0 = 30^\circ \]

\[ F = 83 \quad \theta_0 = 45^\circ \]

\[ F = 54 \quad \theta_0 = 70^\circ \]
FIG. 2. NEUTRON REFLECTED ANGULAR DISTRIBUTION

SLAB CONFIGURATION = 24" CONCRETE
INCIDENT ENERGY = 1.0 MEV
INCIDENT ANGLES:
- $0^\circ$
- $30^\circ$
- $45^\circ$
- $70^\circ$

BASED ON RUN NOS. 649-652

NOTE: SINGLE CURVE DRAWN THROUGH POINTS FOR $0^\circ$ AND $30^\circ$ ANGLES OF INCIDENCE.
FIG. 3. ENERGY DEPENDENT FLUX VS. DEPTH
AND
TOTAL FLUX VS. DEPTH
SLAB CONFIGURATION = 24° CONCRETE
INCIDENT ENERGY = 2 MEV
ANGLE OF INCIDENCE = 0°
NEUTRON ENERGIES
○ - 2.0 MEV
● - 10.0 EV - 1.0 KEV
□ - 1.0 - 1.5 MEV
△ - 1.5 - 2.0 MEV
▽ - 10.0 EV - 2.0 MEV
HOLLOW SYMBOLS - RUN NO. 653
SOLID SYMBOLS - RUN NO. 22-S
DEPTI (INCHES)
FLUX
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
FIG. 4. TOTAL FLUX VS. DEPTH
AND
TOTAL FLUX VS. THICKNESS
SLAB MATERIAL - CONCRETE
SLAB THICKNESS FOR DEPTH PLOT = 24"
INCIDENT ENERGY = 2 MEV
ANGLE OF INCIDENCE = 0°
▼ = TOTAL FLUX VS. DEPTH
◉ = TOTAL FLUX VS. THICKNESS
HOLLOW SYMBOLS - RUN NO. 653
SOLID SYMBOLS - RUN NO. 22-8
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ENERGY SETS AND FLUX TO DOSE CONVERSION FACTORS

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### Table 5

**Histogram $\theta \phi$**

| Sector | $\cos \theta_1$ | $\cos \theta_2$ | $\theta_1$ | $\theta_2$ | $\bar{\theta}$ | Sec $\bar{\theta}$ | Solid Angle | $|\phi_1|$ | $|\phi_2|$ |
|--------|-----------------|-----------------|------------|------------|-----------------|-------------------|-------------|------------|------------|
| 1      | 1.0             | 11/12           | 0          | $25^o33.4'$| $11^o47'$      | 1.0215           | $\pi/6$     | 0          | $\pi$     |
| 2      | 11/12           | 2/3             | $23^o33.4'$| $48^o11.4'$| $35^o52'$      | 1.2340           | $\pi/6$     | $2\pi/3$  | $\pi$     |
| 3      | 11/12           | 2/3             | $23^o33.4'$| $48^o11.4'$| $35^o52'$      | 1.2340           | $\pi/6$     | $\pi/3$   | $2\pi/3$  |
| 4      | 11/12           | 2/3             | $23^o33.4'$| $48^o11.4'$| $35^o52'$      | 1.2340           | $\pi/6$     | 0          | $\pi/3$   |
| 5      | 2/3             | 1/3             | $48^o11.4'$| $70^o31.7'$| $59^o22'$      | 1.9625           | $\pi/6$     | $3\pi/4$  | $\pi$     |
| 6      | 2/3             | 1/3             | $48^o11.4'$| $70^o31.7'$| $59^o22'$      | 1.9625           | $\pi/6$     | $\pi/2$   | $3\pi/4$  |
| 7      | 2/3             | 1/3             | $48^o11.4'$| $70^o31.7'$| $59^o22'$      | 1.9625           | $\pi/6$     | $\pi/4$   | $\pi/2$   |
| 8      | 2/3             | 1/3             | $48^o11.4'$| $70^o31.7'$| $59^o22'$      | 1.9625           | $\pi/6$     | 0          | $\pi/4$   |
| 9      | 1/3             | 0               | $70^o31.7'$| $90^o$     | $80^o16'$      | 5.9150           | $\pi/6$     | $3\pi/4$  | $\pi$     |
| 10     | 1/3             | 0               | $70^o31.7'$| $90^o$     | $80^o16'$      | 5.9150           | $\pi/6$     | $\pi/2$   | $3\pi/4$  |
| 11     | 1/3             | 0               | $70^o31.7'$| $90^o$     | $80^o16'$      | 5.9150           | $\pi/6$     | $\pi/4$   | $\pi/2$   |
| 12     | 1/3             | 0               | $70^o31.7'$| $90^o$     | $80^o16'$      | 5.9150           | $\pi/6$     | 0          | $\pi/4$   |

![Histogram Diagram](image-url)
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The density corresponding to this composition is 2.26 grams per cubic centimeter. This is a slight change from the 2.30 grams per cubic centimeter quoted in Reference 2, and is due to replacement of various minor constituent atoms by silicon atoms in the calculations.

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REFERENCES


MACHINE PRINTOUTS
RUN NUMBER | INC. ENERGY | COS. THETA | CUTOFF EGY | ENERGY SET
---|---|---|---|---
G37 | 10000000 | 10000000 | 00000100 | 2E

SLAB CONFIGURATION: CONCRETE

SCATTERED FLUX PER NEUTRON AT REGION BDS. IN ENERGY GRPS.

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SCATTERED FLUX TRANS./NT. IN EGY. GRPS. VS. THICKNESS

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| 4  | 60499999 | 94002373 | 7512630 | 15600001 | 187948273 |
| 8  | 32599999 | 50254476 | 35292706 | 02400000 | 92608401 |
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INC. ENERGY COS. THETA CUTOFF EGY INC. FLX/NT INC. DOSE/NT
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SLAB CONFIGURATION: CONCRETE

REGION THICKNESSES (CENTIMETERS):
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NUMBER OF SCATTERED NEUTRONS VS. ENERGY

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33
### Slab Configuration: Concrete

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34
### Slab Configuration

**Concrete**

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**SLAB CONFIGURATION:** CONCRETE

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### SLAB CONFIGURATION: CONCRETE

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### Summary Statistics

- **1102.205236**
### Slab Configuration: Concrete

#### Scattered Flux Per Neutron at Region BDS* in Energy Grps*

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**SLAB CONFIGURATION**: CONCRETE

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41
## SLAB CONFIGURATION CONCRETE

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**Note:** The data tables represent various scattering fluxes and energy cutoffs for different regions and thicknesses, indicating energy, cosine of angle, and other parameters for neutron scattering studies in a concrete slab configuration.
### RUN NUMBER 642

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*Note: UNC. NO.*FLUX refers to the uncertainty in the number of flux per neutron, TTL.FLX/NT. refers to the total flux per neutron, REGION BDS. refers to the region based dose.
| RUN NUMBER HISTORIES ENERGY SET ANGLE SET SLANT MFP |
|-----------|----------|-------|----------|----------|
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| INC* ENERGY COS* THETA CUTOFF EGY INC*FLX/NT INC*DSE/NT |
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NUMBER OF SCATTERED NEUTRONS VS. ENERGY

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MEAN ENERGY SCAT.TR.NT.

MEAN ENERGY REFLECT. NT.

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### SLAB CONFIGURATION

**CONCRETE**

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### Slab Configuration: Concrete

**Scattered Flux Per Neutron at Region BDS In Energy Grps.**

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**Scattered Flux Trans. Per NT. In Egy. Grps. Vs. Thickness**

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48
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- RUN NUMBER: 645
- HISTORIES: 1000
- ENERGY SET: 2E
- ANGLE SET: 2541
- SLANT MFP: 29.051208

### INC. ENERGIES, CUTOFF, EGY
- INC. ENERGIES: 0.500000, 1.000000, 0.00010
- CUTOFF: 1.000000
- EGY: 2.400000

### SLAB CONFIGURATION
- CONCRETE

### REGION THICKNESSES (CENTIMETERS)
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- 2.5400
- 2.5400
- 10.1600
- 10.1600
- 10.1600

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**CONCRETE**

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**REGION BDS.**

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**CONCRETE**

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SLAB CONFIGURATION: CONCRETE

REGION THICKNESSES (CENTIMETERS):

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NUMBER OF SCATTERED NEUTRONS, ENERGY ABS. |

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| 2402.205236 | .22616 |
### Slab Configuration: Concrete

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#### Scattered Flux Trans. Per NT. in EGY. GRPS. vs. Thickness

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54
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- Histories: 1000
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- Angle Set: θ
- Slant MFP: 43.059912

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- Slab Configuration: Concrete

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### Slab Configuration (continued)

### Slab Configuration (continued)

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- Mean Energy: 2402.205236
### Slab Configuration: Concrete

#### Scattered Flux Per Neutron at Region BDS in Energy Groups

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#### Scattered Flux Trans. Per NT. in EGY. GRPS. VS. Thickness

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**SLAB CONFIGURATION**

**CONCRETE**

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**SLAB CONFIGURATION CONCRETE**

**SCATTERED FLUX PER NEUTRON AT REGION BDS. IN ENERGY GRPS.**

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### Energy Set Parameters
- $\Delta E$ = 0.66030
- $\phi$ = 0.00010
- $\gamma$ = 1.154694
- $\delta$ = 4.387839

### Slab Configuration
- **Concrete**

### Region Thicknesses (Centimeters)
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- 2.5400
- 5.0800
- 10.1600
- 10.1600
- 10.1600
- 10.1600

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### Mean Energy
- Scatters + Trans. = 3803.405236
- Reflected + Trans. = 0.054360

### Number
- Total Flux = 712000
- Reflected Flux = 1.242060
- Reflected Factor = 0.812843
- Reflected Energy Absorbed = 612944
- Number of ARS = 0.002000
- Energy Cutoff Factor = 286000
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**SLAB CONFIGURATION**

**CONCRETE**

**SCATTERED FLUX PER NEUTRON AT REGION BDS8 IN ENERGY GRPS.**

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**SCATTERED FLUX TRANS./NT. IN EGY. GRPS. VS. THICKNESS**

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**SLAB CONFIGURATION CONCRETE**

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### Slab Configuration: Concrete

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#### Scattered Flux Trans. Per NT. in Egy. Groups vs. Thickness

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- Cutoff Egy: 0.000010
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### Slab Configuration
**Concrete**

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- 2.5400
- 5.0800
- 10.1600
- 10.1600
- 10.1600

### Number of Scattered Neutrons vs. Energy

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### Slab Configuration: Concrete

#### Scattered Flux Per Neutron at Region BDS* in Energy GRPS*

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#### Scattered Flux Trans. Per NT. in EGY* GRPS* vs. Thickness

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**SLAB CONFIGURATION**: CONCRETE

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- 2.5400
- 5.0800
- 10.1600
- 10.1600
- 10.1600

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65
### Slab Configuration: Concrete

#### Scattered Flux Per Neutron at Region BDS, in Energy Groups

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#### Scattered Flux Trans. Per NT, in Egy, Groups vs. Thickness

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**SLAB CONFIGURATION**

**CONCRETE**

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**NUMBER OF SCATTERED NEUTRONS VS. ANGLE**

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**REGION THICKNESSES (CENTIMETERS):**

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### SLAB CONFIGURATION

#### CONCRETE

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SLAB CONFIGURATION CONCRETE

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| 10.1600 | 10.1600 |

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### SLAB CONFIGURATION CONCRETE

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28

### ANGLE SET

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### INC. ENERGY

3.000000

### COS. THETA

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### CUTOFF EGY

.000010

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### Slab Configuration

**Concrete**

### Scattered Flux Per Neutron at Region BDS in Energy Grps.

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**Concrete**

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### Mean Energy

- **Energy**: Mean energy
- **(S+U) No.**: Total number
- **(S+U) Dose**: Total dose
- **Unscat.**: Unscattered neutrons
- **Scat. No.**: Scattered neutrons
- **Scat. No.Flux**: Scattered flux
- **Scat. Dose**: Scattered dose
- **Scat. Egy**: Scattered energy

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### Slab Configuration

**Concrete**

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## SLAB CONFIGURATION

### CONCRETE

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**INC.ENERGY**
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**COS. THETA**
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**CUTOFF EGY.**
00001010

**ENERGY SET**
2A

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**SLAB CONFIGURATION**

**CONCRETE**

---

**SCATTERED FLUX PER NEUTRON AT REGION BDS• IN ENERGY GRPS.**

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**SCATTERED FLUX TRAN. PER NT. IN EGY. GRPS. VS. THICKNESS**

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### SLAB CONFIGURATION

**CONCRETE**

**REGION** | **THICKNESSES (CENTIMETERS)** | **TOTAL** | **TOTAL**
---|---|---|---
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10.1600 | 10.1600 | 10.1600

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**Notes:**
- The table contains data on neutron histories, energy, angle, and slant MFP.
- The slab configuration details include concrete region thicknesses in centimeters.
- Data on the number of scattered neutrons vs. energy and angle is provided.
- Various factors and doses are calculated for different sectors and energy groups.
### SLAB CONFIGURATION

#### SCATTERED FLUX PER NEUTRON AT REGION BDS IN ENERGY GROUPS

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| 4      | .17028425  | .15123702   | .10370408  | .09877146   | .26315250  |
| 8      | .07454208  | .07289392   | .08292060  | .04237999   | .16629779  |
| 12     | .03754409  | .03818609   | .02973243  | .03163945   | .10873073  |
| 16     | .01695927  | .02678049   | .02706013  | .00801052   | .02656695  |
| 20     | .01487620  | .00596199   | .00810353  | .00725575   | .01201425  |
| 24     | .00209855  | .00496635   | .00215065  |            | .00228723  |

#### SCATTERED FLUX TRANS. PER NT. IN EGY. GROUPS VS. THICKNESS

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| 8      | .04124476 | .05267749 | .03762923 | .04389342 | .18849223 |
| 12     | .02795934 | .02307352 | .03501777 | .02368047 | .14940025 |
| 16     | .00802367 | .02041354 | .01263479 | .02963189 | .05260236 |
| 20     | .00691005 | .00620413 | .01331847 | .00650236 | .02546976 |
| 24     | .00237899 | .00496635 | .00215065 |            | .00228723 |

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- **1000**
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- **14.000000**
- **1.000000**
- **.000010**
- **1.000000**
- **7.000000**

#### SLAB CONFIGURATION
**CONCRETE**

### REGION THICKNESSES (CENTIMETERS)
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- 2.5400
- 5.0800
- 10.1600
- 10.1600
- 10.1600
- 10.1600

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## SLAB CONFIGURATION CONCRETE

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**NUMBER OF SCATTERED NEUTRONS VS. ENERGY**

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**NUMBER OF SCATTERED NEUTRONS VS. ANGLE**

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| REGION BDS | SCATTERED FLUX TRANS PER NT IN EGY GRPS VS THICKNESS | 1 2 3 4 5 |

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| REGION BDS | TOTAL NO TRANS/NT TOTAL FLUX TRANS/NT TOTAL DOSE TRANS/NT UNCNO FLUX TRANS/NT TTL FLX/NT REGION BDS |

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**SLAB CONFIGURATION**

**CONCRETE**

**REGION THICKNESSES (CENTIMETERS)**

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### Slab Configuration - Concrete

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**Scattered Flux Trans. Per NT. in Egy GRPs vs. Thickness**

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### Slab Configuration: Concrete

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102
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- **Energy Set**: 1000
- **Angle Set**: 0°
- **Slant MFP**: 45.799011

### Inc. Energy
- **COS. Theta**: 1.000000
- **Cutoff Egy**: 1.000101
- **Inc. FLX/NT**: 1.4142071
- **Inc. Dose/NT**: 5.3739870

### Slab Configuration
- **Concrete**

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- **(S+U) No. Trans.**: 38.03405236
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SLAB CONFIGURATION CONCRETE

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#### SCATTERED FLUX PER NEUTRON AT REGION BDS. IN ENERGY GRPS.

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SUMMARY OF RESULTS

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A table of summary information on reflection is presented. This contains number current, number flux, dose and energy reflection factors as functions of incident energy and angle.

A few figures are presented to illustrate graphically the meaning of the various tabular results.

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