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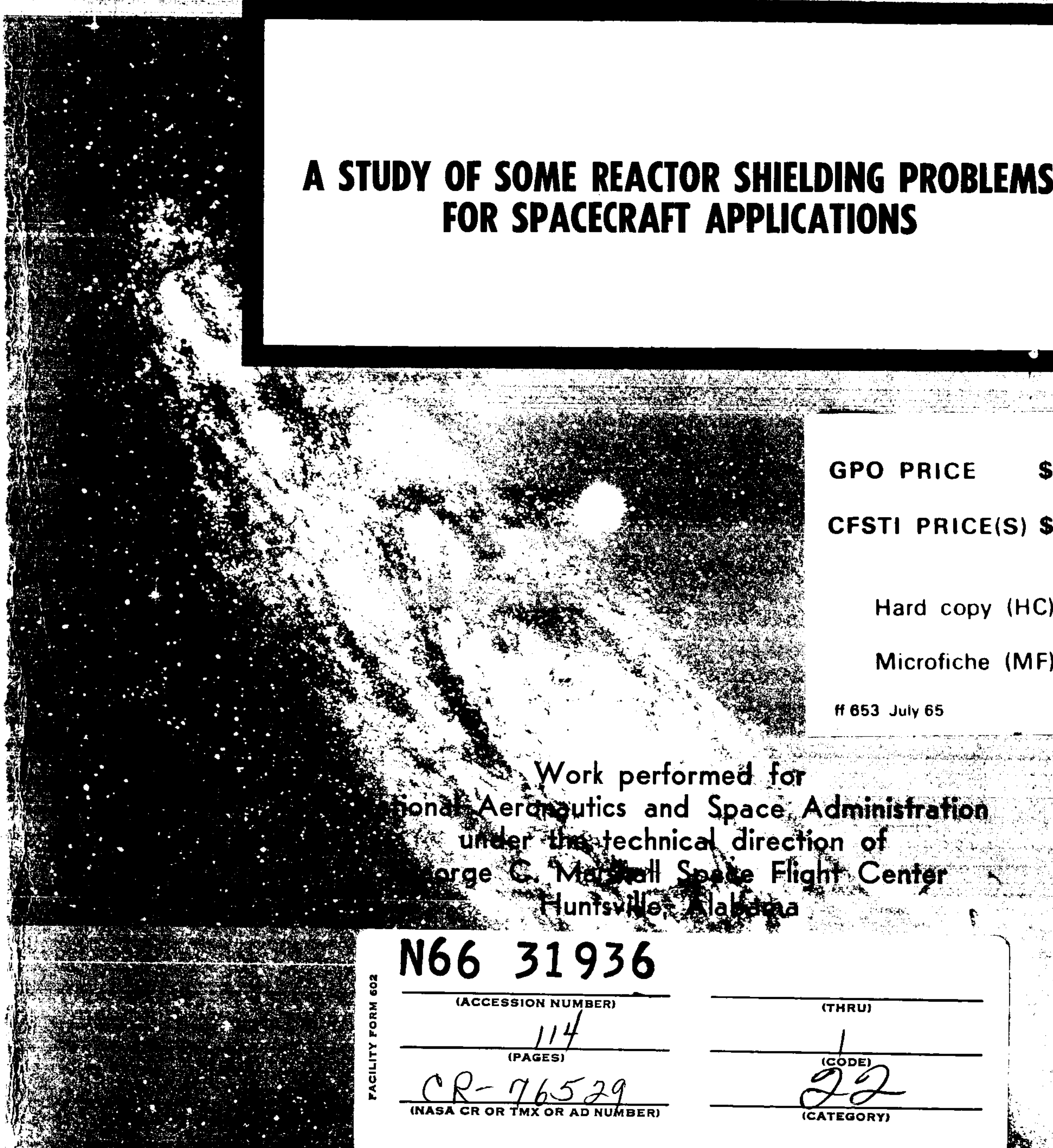

# A STUDY OF SOME REACTOR SHIELDING PROBLEMS FOR SPACECRAFT APPLICATIONS

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George C. Marshall Space Flight Center
Huntsville, Alabama

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GENERAL DYNAMICS | FORT WORTH

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29 OCTOBER 1962

# A STUDY OF SOME REACTOR SHIELDING PROBLEMS FOR SPACECRAFT APPLICATIONS

E. E. JONES
M. B. WELLS

Contract No. NAS8-1573

Work performed for
National Aeronautics and Space Administration
under the technical direction of
George C. Marshall Space Flight Center
Huntsville, Alabama

GENERAL DYNAMICS | FORT WORTH

# ABSTRACT

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Machine programs for computing the single-scattered neutron and gamma-ray fluxes from radiators of reactor-powered spacecraft are described and some calculated results for typical unshielded SNAP-8-powered spacecraft are presented. Calculations to investigate the effect of uniform expansion of a direct-beam shield on the transmitted neutron dose rate in the absence of a scattering atmosphere are reported. The results of some Monte Carlo calculations performed by GD/FW and the Technical Research Group of Syosset, N. Y., to investigate the effects of shield-splitting on neutron transmission through direct-beam shields in the absence of a scattering atmosphere are discussed.

## ACKNOWLEDGMENTS

The authors wish to express their thanks to Mr. L. W. McCleary and Mr. B. R. Uzzell for their help in performing some of the calculations described in this report and to Mr. D. G. Collins for helpful discussions on the use of the Monte Carlo Code K97.

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# I. INTRODUCTION

A number of presently conceived spacecraft designs utilize small nuclear reactors as sources of power. In most of these designs, the reactor powers a turboelectric generating system which supplies electricity to an ion propulsion system and to secondary equipment, such as transmitters and various scientific instruments. An example of this type of spacecraft is shown in Figure 1. Other spacecraft designs utilize a device for direct conversion of heat to electricity. In some vehicles, such as an orbiting satellite, the reactor will be used only as a source of electricity and will not furnish power to a propulsion system. In any event, relatively large radiating surfaces, such as those shown in Figure 1, will be required to dispose of waste heat.

Because of the reactor and the radiators, various parts of the spacecraft may be exposed to high scattered-neutron and -gamma fluxes. It is important, with respect to the design of such spacecraft, to predict the magnitudes of these fluxes so that a shield configuration can be designed which will reduce the neutron and gamma fluxes to allowable levels. It is of particular importance to know the magnitude of these fluxes at such places as the payload and propellant tank.

Both the neutron and gamma fluxes at any point will consist of two components: (1) the flux transmitted along a "line of sight"

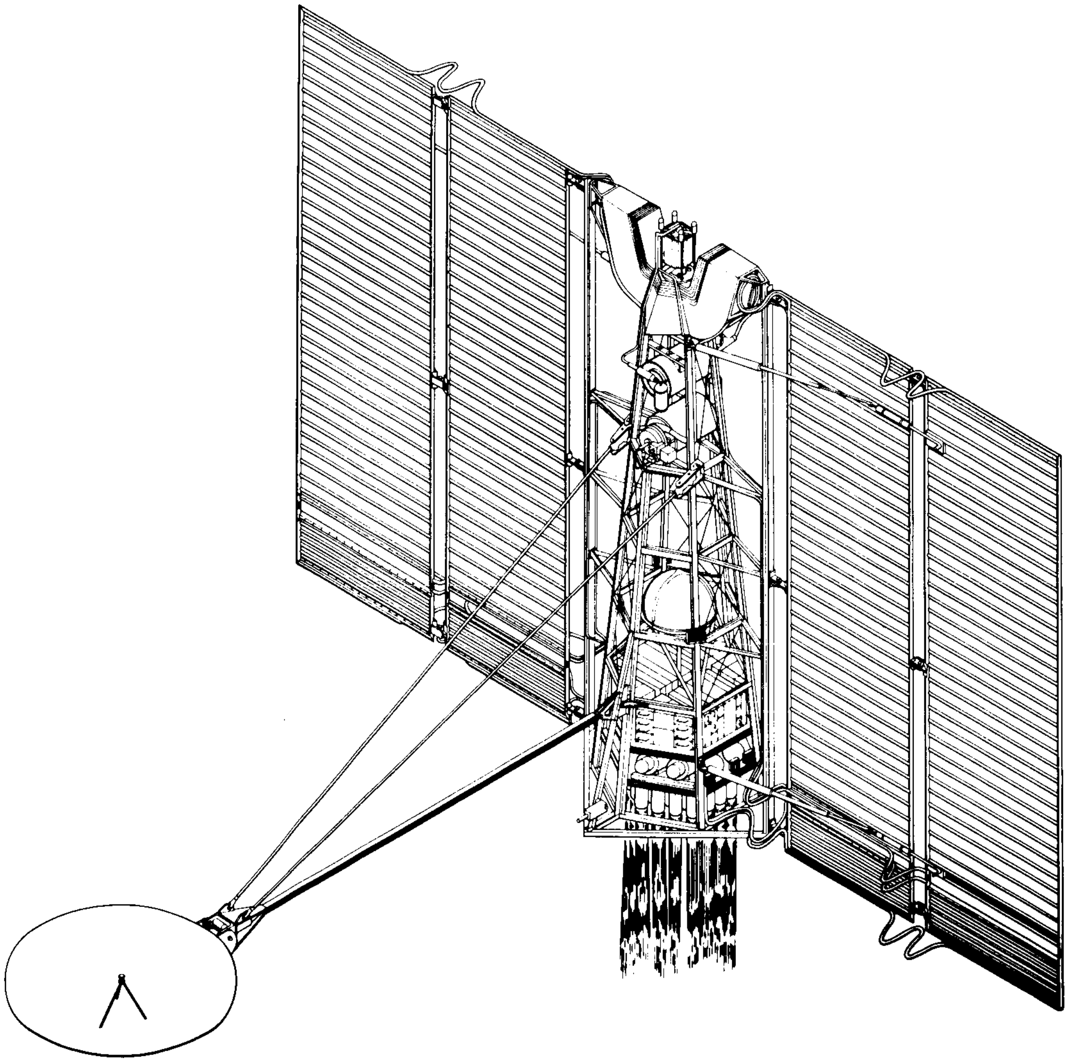


Figure 1. Flat Configuration of 70-kwe SNAP-8 Interplanetary Spacecraft

from source to detector ( a component referred to as the "direct beam" and consisting of the uncollided flux plus that flux which is scattered within any material between the source and the detector) and (2) the flux scattered from the radiator surfaces and structural components. Although the total gamma flux would include a component due to neutron activation of the radiators and structural components, only those methods of calculating and shielding against the radiator-scattered and direct-beam fluxes are discussed in this report.

Particular effort has been directed toward setting up machine programs for calculating the radiator-scattered fluxes. The development and use of these programs are described and some results for typical spacecraft powered by unshielded SNAP-8 reactors are presented.

The problem of shielding against the direct-beam fluxes is considered from the standpoint of minimizing the required shielding by proper placement of the shield and by expanding or splitting the shield. In any case, the desired effect is to increase the transverse leakage of those neutrons and photons which scatter within the shield. Results of calculations performed at GD/FW to investigate the effects of shield expansion are presented and discussed. Calculations performed by the Technical Research Group at Syosset, New York to investigate the effects of shield placement and splitting are also discussed.

It should be pointed out that, thus far, this study has not been concerned with the actual design of specific shields, but has been directed toward setting up methods of analysis and investigating some of the more important aspects of spacecraft reactor shielding. Recommendations are made for continuing this study in order to arrive at an integrated program for spacecraft reactor shield design and to evaluate presently conceived designs.

## II. RADIATOR SCATTERING

Equations for calculating the radiator-scattered neutron and gamma fluxes are developed in this section. The IBM programs for calculating these scattered fluxes are described in terms of calculational procedure, data input, and data output. Results of some calculations for typical spacecraft configurations are also given.

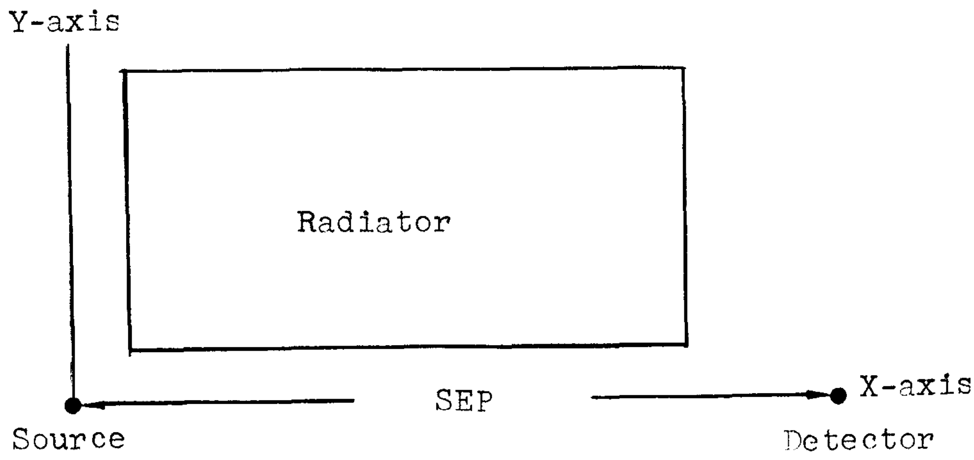
### 2.1 Methods of Calculation

#### 2.1.1 Neutrons: IBM Procedure S06

A FORTRAN program (S06) for calculating the neutron flux scattered from the radiators of reactor-powered spacecraft has been coded for the IBM-7090. This program is described below. The FORTRAN statements for S06 are given in Appendix A. Machine operating instructions are given in Appendix E. Input and output for a sample problem are given in Appendix B.

##### 2.1.1.1 Derivation of Equation for Scattered Neutron Flux

It is assumed that the reactor can be represented by a point source, with the origin of the coordinate system at the source. A simple example of the geometry involved is shown in the accompanying sketch. In all cases, it is assumed that the radiator, source, and detector lie in the same plane.




The radiator can be triangular or consist of rectangular and triangular sections. The base of each section must be parallel to the X axis. Each triangular section must be a right triangle with its area above its base, and the slopes of all hypotenuses must be equal and positive. This geometry was chosen because it lends itself to the analysis of systems such as the one illustrated in Figure 1 and those described in Reference 1.

To derive the expression for the scattered flux, consider the geometry illustrated in Figure 2. For the present, the source, detector, and radiator need not be in the same plane.

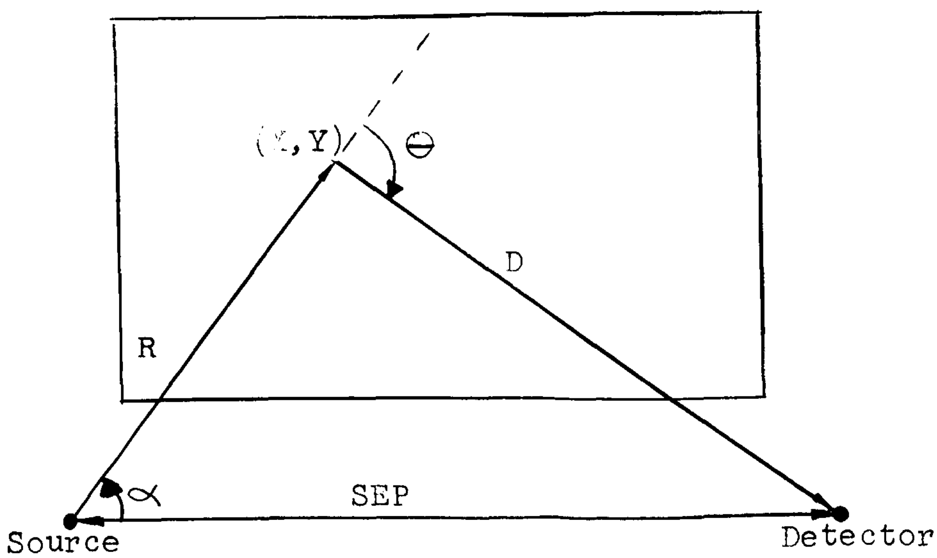



Figure 2. Scattering Geometry

Assume that the radiator is sufficiently thin so that the Z-dependence of the flux at any point in the radiator can be neglected. The flux in energy group L at the point (X,Y) is then given by S(L,X,Y). It is important to note that in this formulation the source is represented by a point source, but that the source term, S(L,X,Y), is calculated by considering the reactor core as a number of point sources distributed throughout the volume of the core.

Next, assume that all the neutrons at (X,Y) are traveling in the same direction. This assumption is consistent with the assumption of a point source and is feasible since the dimensions of the reactor core are small compared to R.

The number of group-L neutrons in the element of volume dXdYdZ at X,Y,Z which undergo single-scatterings through the angle $\Theta$ is given by

$$S(L,X,Y)\Sigma(L,\Theta)dXdYdZ \text{ neutrons/sec-steradian,}$$

where

$\Sigma(L,\Theta)$ = differential scattering cross section of the radiator for group-L neutrons in units of $cm^{-1}$/steradian.

Neglecting energy loss due to scattering, the number of group-L neutrons passing through an element of area dS, which is located at the position of the detector and oriented perpendicular to D, and resulting from single-scattering in dXdYdZ is

$$S(L,X,Y)\Sigma(L,\Theta)dXdYdZ \; e^{-\ell/\lambda(L)} \frac{dS}{D^2} \text{ neutrons/sec,}$$

where

$\ell$ = slant distance in cm from the point (X,Y,Z) to the surface of the radiator, and

$\lambda$ = mean free path in cm of group L neutrons in the radiator.

Assuming the radiator to be sufficiently thin, $\ell$ will be so small compared to $\lambda(L)$ that the exponent may be neglected. The flux (or, more properly, the current) at dS will then be

$$\frac{S(L,X,Y)\Sigma(L,\theta)}{D^2}\, dXdYdZ \text{ neutrons/cm}^2\text{-sec.}$$

Since the detector is omnidirectional, the total single-scattered flux in energy group L is

$$\phi(L) = \iiint_{\text{volume}} \frac{S(L,X,Y)\Sigma(L,\theta)}{D^2}\, dXdYdZ \text{ neutrons/cm}^2\text{-sec.}$$

Since the integrand is independent of Z,

$$\phi(L) = t \iint_{\text{area}} \frac{S(L,X,Y)\Sigma(L,\theta)}{D^2}\, dXdY \text{ neutrons/cm}^2\text{-sec,} \qquad (1)$$

where t = thickness of radiator in cm.

It should be noted that Equation 1 has been derived without any assumptions with regard to the relative orientations of point source, radiator, and detector. As noted in Section 2.1.1, however, it will be assumed that all lie in the same plane and Equation 1 will be evaluated on that basis.

In formulating the expression for the scattered flux, the following assumptions were made:

1. Attenuation by the radiator can be neglected.

2. The neutron spectrum incident on the radiator can be represented by a number of discrete energy groups.

3. The scattered flux will consist only of single-scattered neutrons.

4. Energy loss due to scattering can be neglected.

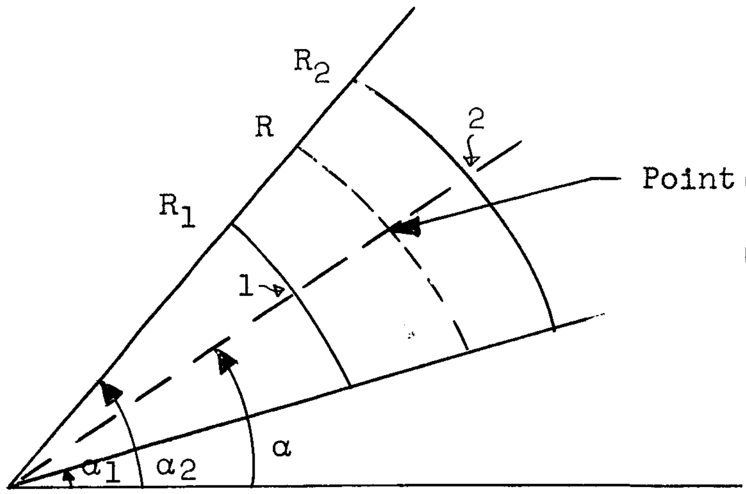
5. The radiation leaking from the reactor can be treated as if emitted from a point source.

2.1.1.2 IBM Calculational Procedure

Program S06 numerically evaluates Equation 1 for any number of energy groups (values of L) from 1 to 15. Since it is desirable to know which sections of the radiator contribute most of the scattered flux, the radiator may be broken up into as many as 20 sub-areas and the flux from each sub-area calculated.

The source terms S(L,X,Y) are supplied to the program as fluxes at points described by R and $\alpha$ about the source (see Fig. 2). The integral in Equation 1 is evaluated by a double application of Simpson's rule for each sub-area. The procedures for evaluating the two terms in the integrand of Equation 1 for a given X and Y are described below.

Source Term S(L,X,Y). The values of $(R,\alpha)$ corresponding to (X,Y) are calculated in conventional fashion. The program then determines the input values of R and $\alpha$ between which the point $(R,\alpha)$ will lie (see sketch). By the use of linear interpolation with




$R_1$, $R_2$, $\alpha_1$, and $\alpha_2$ are input values of R and α.

respect to α, the source terms $S_1$ and $S_2$ at the points (1) and (2) are determined. The source term at (R,α) is then calculated by the expression

$$S(R,\alpha) = 1/2\ (S_1R_1{}^2+S_2R_2{}^2)/R^2. \tag{2}$$

Differential Scattering Cross Sections $\Sigma(L,\Theta)$. The cosine of the scattering angle, Θ, is calculated by the equation

$$\cos\,\Theta = \frac{(SEP)^2 - R^2 - D^2}{2RD}, \tag{3}$$

where $R = (X^2+Y^2)^{1/2}$ and (4)

$$D = \left[R^2 + (SEP)^2 - 2(SEP)X\right]^{1/2}. \tag{5}$$

The differential scattering cross section in FORTRAN terminology is

$$\Sigma(L,\Theta) = \sum_{NU=1}^{NUMAX} ATOM(NU)*SIG(L,\Theta,NU), \tag{6}$$

where * denotes multiplication and

ATOM(NU) = nuclear density of element NU in radiator in nuclei/$cm^3$ (input);

$$SIG(L,\Theta,NU) = \frac{SIGEL(L,NU)}{4\pi} \sum_{LL=1}^{LLMAX} (2LL-1)F(NU,L,LL)P(LL,\cos\Theta); \quad (7)$$

SIGEL(L,NU) = elastic scattering cross section of element NU for group-L neutrons in barns (input);

F(NU,L,LL) = coefficients in Legendre expansion (input);

P(LL,cosΘ) = Legendre polynominals (calculated by the program).

It should be noted that Θ in Equation 3 refers to laboratory system coordinates, whereas most compilations of the coefficients F(NU,L,LL) are for scattering angles in the center-of-mass system. For most radiator materials, the mass number will be high enough to cause the error introduced in the results by use of the F(NU,L,LL)'s in the center-of-mass system in Equation 7 to negligible.

#### 2.1.1.3 Code Description of Radiator Geometry

The radiator configuration is described in XY coordinates, with the origin of the coordinate system always located at the source. The detector then always lies on the X-axis, a distance SEP from the origin. A sub-area is described in FORTRAN by seven quantities:

XO(K) and YO(K) — Coordinates of the lower left corner of the sub-area K. No sub-area can have coordinates (0,0).

NPX(K) and NPY(K) — The number of points in the X and Y meshes for integration. NPX(K) and NPY(K) must all be odd integers.

| | |
|---|---|
| KT(K) | A control number denoting whether sub-area K is rectangular or triangular. (=0 for rectangle, =1 for triangle). |
| DELX(K) and DELY(K) | Intervals between points in the X and Y meshes for sub-area K. |

For a triangular sub-area, NPY(K) and DELY(K) will be put in as zero and their values will then be computed by the program as follows:

$$NPY = 3 + (I-1)2,$$

where I = the index number of a point in the X-mesh which will assume values of 1 through NPX(K).

and

$$DELY = SLOPE(X-XO)/(NPY-1),$$

where SLOPE = the slope of the hypotenuse of the triangular sub-area.

2.1.1.4 S06 Input Data

Definition of Input Quantities. The program input for a single problem will consist of (1) the problem data, (2) one library deck of source data, and (3) one to five libraries of cross-section data. A cross-section data library must be supplied for each element. Although up to 25 cross-section libraries may be loaded at the same time, a single problem can have a maximum of only five elements.

Only one source library can be read in at a time. If several problems are to be run in sequence, they must all use the same source library. All library data for a given sequence of problems must be read in before the problem decks are read in.

The quantities that comprise the problem data, the source-data library, and the cross-section data library are listed and defined below.

Problem Data

| | |
|---|---|
| NA | Number of sub-areas (a positive integer). |
| NUMAX | Number of different nuclei which are treated as scatterers (a positive integer). |
| LLMAX1 | The largest value of LLMAX which is to be used (a positive integer). LLMAX is defined under cross-section data. |
| NE | Number of energy groups (a positive integer). This must be the same in the problem data input, the source library, and all the cross-section libraries used in a particular problem. |
| SLOPE | Slope of hypotenuses of all triangular sub-areas in a particular problem (a decimal number). |
| SEP | Source-detector separation distance in cm (a decimal number). |
| YSLIB | Identification number of source library (a decimal number). Same digits appear in Columns 63 through 68 of source library cards. |
| THICK | Thickness of radiator in cm (a decimal number). |
| NPX(K) | Number of points in X-mesh for sub-area K (a positive integer: NA values). |
| NPY(K) | Number of points in Y-mesh for sub-area K (a positive integer: NA values). |
| KT(K) | Denotes rectangular (KT = 0) or triangular (KT = 1) sub-area (NA values). |
| XO(K) | X-coordinate of lower left corner of sub-area K in cm (a decimal number: NA values). |
| YO(K) | Y-coordinate of lower left corner of sub-area K in cm (a decimal number: NA values). |

Problem Data (cont'd)

| | |
|---|---|
| DELX(K) | Interval between points in X-mesh of sub-area K in cm (a decimal number: NA values). |
| DELY(K) | Interval between points in Y-mesh of sub-area K in cm (a decimal number: NA values). |
| ATOM(NU) | Nuclear density of element NU in nuclei/$cm^3$ (a decimal number with exponent: NUMAX values). |
| YLIB(NU) | Library identification number of cross-section data library for element NU (a decimal number: NUMAX values). |

Source Data

| | |
|---|---|
| NE | Defined under problem data. |
| MMAX | Number of values of R for which source points are defined (a positive integer). |
| NMAX | Number of values of $\alpha$ for which source points are defined (a positive integer). |
| R1(M) | Values of R in cm at which sources are defined (a decimal number: MMAX values in increasing order). |
| ALPHA1(N) | Values of $\alpha$ at which sources are defined; has units of degrees (a decimal number: NMAX values in increasing order). |
| S(L,M,N) | Source terms (flux) for energy group L, radius R1(M), and angle ALPHA1(N) (a decimal number with exponent: NE · MMAX · NMAX values). |

Cross-Section Data

| | |
|---|---|
| LLMAX | Number of terms in Legendre expansion of cross section (a positive integer). |
| NE | Defined in problem data. |
| SIGEL(L) | Total elastic scattering cross section for energy group L (a decimal number with exponent: NE values). |

Cross-Section Data (cont'd)

| | |
|---|---|
| F(L,LL) | Group L coefficients in Legendre expansion of cross section (a decimal number with exponent: NE ∘ LLMAX values). |

Limits on Quantity of Input Data. The quantity of input data is limited by the following maximum values:

| Quantity Input | Maximum Value |
|---|---|
| NA | 20 |
| NUMAX | 5 |
| LLMAX1 | 10 |
| NE | 15 |
| MMAX | 20 |
| NMAX | 20 |
| LLMAX | 10 |
| NPX(K) | |
| Rectangular sub-area | 99 |
| Triangular sub-area | 49 |
| NPY(K) | 99 |

Input Data Formats. Formats for preparing input data are shown in Figures 3 through 5. The first card of the problem deck contains no data. The first card of a source library has a 1 in Column 10. The first card of a cross-section library has a 2 in Column 10. With regard to entering the input on the data sheets, the following rules must be followed:

CONVAIR GENERAL DYNAMICS CORPORATION

# DIGITAL COMPUTER DATA SHEET

PROBLEM TITLE RADIATOR-SCATTERED NEUTRONS WORK ORDER PROGRAM S06

CUSTOMER'S NAME
PHONE
PROJECT
SERIAL NUMBER

| Line | 1–10 | 11–20 | 21–30 | 31–40 | 41–50 | 51–60 | 63–72 (JOB NO. / PROBLEM NO. / CARD NO.) | 73 (LAST DIGIT OF CURRENT YEAR) | 78–80 (CORRECTIONS) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | 0001 | 2 | S06 |
| 2 | NA | NUMAX | LLMAXI | NE | SLOPE | | 0002 | | |
| 3 | SEP | YSLIB | THICK | | | | 0003 | | |
| 4 | NPX(1) | NPX(2) | ...... | | | NPX(NA) | 0004 | | |
| 5 | NPY(1) | NPY(2) | ...... | | | NPY(NA) | | | |
| 6 | KT(1) | KT(2) | ...... | | | KT(NA) | | | |
| 7 | XO(1) | XO(2) | ...... | | | XO(NA) | | | |
| 8 | YO(1) | YO(2) | ...... | | | YO(NA) | | | |
| 9 | DELX(1) | DELX(2) | ...... | | | DELX(NA) | | | |
| 10 | DELY(1) | DELY(2) | ...... | | | DELY(NA) | | | |
| 11 | ATOM(1) | ATOM(2) | ...... | | | ATOM(NUMAX) | | | |
| 12 | YLIB(1) | YLIB(2) | ...... | | | YLIB(NUMAX) | | 2 | S06 |

Figure 3. Format for Problem Data: Program S06

GENERAL DYNAMICS CORPORATION

DIGITAL

PROBLEM TITLE RADIATOR-SCATTERED NEUTRONS PROGRAM S06

| 1–10 | 11–20 | 21–30 | 31–50 | 51–60 | LAST DIGIT OF CURRENT YEAR / DECK NO. / CARD NO. (69–72) | 73 | 78 |
|---|---|---|---|---|---|---|---|
| 1 | | | | | 0001 | L | S06 |
| NE | MMAX | NMAX | | | 0002 | | |
| RI(1) | RI(2) | ..... | | RI(MMAX) | 0003 | | |
| ALPHAI(1) | ALPHAI(2) | ..... | | ALPHAI(NMAX) | | | |
| S(1,1,1) | S(1,2,1) | ..... | | S(1,MMAX,1) | | | |
| S(1,1,2) | S(1,2,2) | ..... | | S(1,MMAX,2) | | | |
| ..... | ..... | | | | | | |
| S(1,1,NMAX) | S(1,2,NMAX) | .... | | S(1,MMAX,NMAX) | | | |
| S(2,1,1) | S(2,2,1) | .... | | S(2,MMAX,1) | | | |
| ..... | ..... | | | | | | |
| ..... | ..... | ..... | | | | | |
| S(2,1,NMAX) | S(2,2,NMAX) | ..... | | S(2,MMAX,NMAX) | | | |
| ..... | ..... | | | | | | |
| ..... | ..... | | | | | | |
| ..... | | | | | | | |
| ..... | | | | | | | |
| ..... | | | | | | | |
| S(NE,1,1) | S(NE,2,1) | ..... | | S(NE,MMAX,1) | | | |
| ..... | ..... | | | | | | |
| ..... | ..... | | | | | | |
| S(NE,1,NMAX) | S(NE,2,NMAX) | ..... | | S(NE,MMAX,NMAX) | | L | S06 |

**Figure 4. Format for Source Library: Program S06**

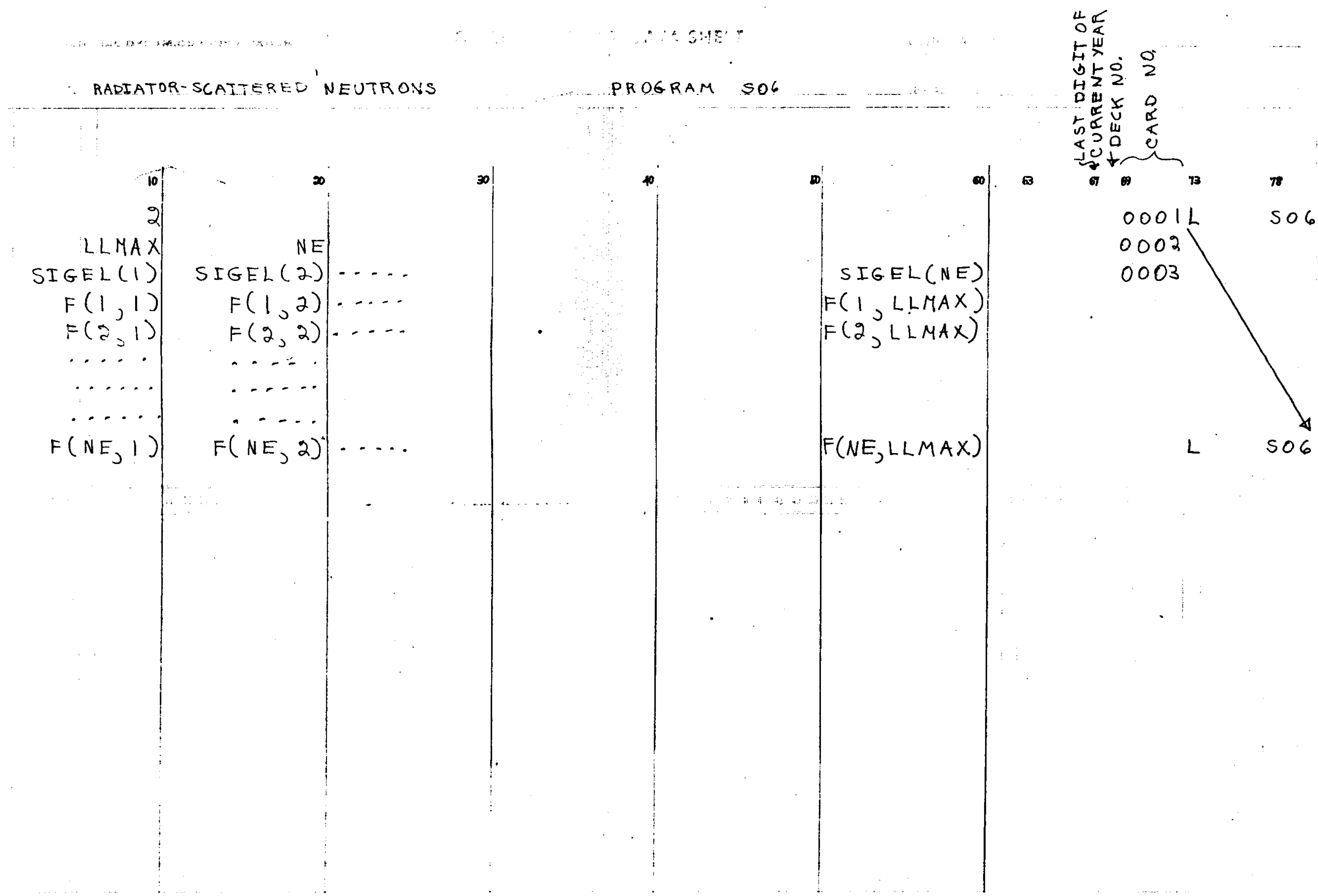



**Figure 5. Format for Cross-Section Library: Program S06**

1. Integers must end in the last column of a data field, i.e., Column 10, 20, 30, 40, 50, or 60.

2. A Decimal Number can end anywhere in the data field.

3. A Decimal Number with Exponent must end in the last column of a data field ($2.5 \times 10^6$ would be 2.5+06 or .25+07).

2.1.1.5 S06 Output Data

Output data from the program consists of the following:

1. Total flux at detector

2. Flux spectrum at detector

3. Flux from sub-areas

4. Fraction of total flux at detector from each sub-area

5. Flux spectrum at detector from each sub-area

With regard to the output data, the following should be noted:

1. If S(L,X,Y) is in units of n/cm$^2$-sec-Mev, then SIGEL(L) and F(L,LL) for each element are supplied for each energy E(L); Ø(L) is then the flux at the detector in units of n/cm$^2$-sec-Mev and output items 1, 3, and 4 have no meaning.

2. If S(L,X,Y) is in units of n/cm$^2$-sec in energy group L, then SIGEL(L) and F(L,LL) for each element consist of their average values over energy group L; Ø(L) then has units of n/cm$^2$-sec and all output items have meaning.

2.1.2 Gammas: IBM Procedure S14

A program, S14, has also been coded to calculate the radiator-scattered gamma flux. This program is described below. The FORTRAN statements are listed in Appendix C. Input and output for a sample problem are given in Appendix D. Machine operating instructions are given in Appendix E.

The geometry involved is the same as in the neutron program.

2.1.2.1 Derivation of Equation for Scattered Gamma Flux

In formulating the expression for the scattered gamma flux, the following assumptions were made:

1. Attenuation in the radiator can be neglected.

2. The gamma spectrum incident on the radiator can be represented by a number of discrete energy groups.

3. The scattered flux will consist of only single-scattered gammas.

4. An average energy can be assigned to each energy group, and this energy can be used in calculating the cross section for Compton scattering.

5. The radiation leaking from the reactor can be treated as if emitted from a point source.

With these assumptions, the scattered flux $\phi(L)$ in energy group L is given by

$$\phi(L) = t \iint_{\text{area}} \sum_{L'=1}^{L} \frac{S(L',X,Y)}{D^2} \Sigma(L',\Theta) F(\Theta, L' \longrightarrow L)\, dX\, dY, \qquad (8)$$

where $\phi(L)$ = scattered flux in energy group L in photons/cm$^2$-sec;

$t$ = thickness of radiator in cm;

$S(L',X,Y)$ = flux in energy group L' incident on the radiator at the point (X,Y) in photons/cm$^2$-sec;

$D$ = distance from scattering point to detector in cm;

$\Sigma(L',\Theta)$ = differential scattering cross section of radiator for group-L' photons in cm$^{-1}$/steradian;

$F(\Theta, L' \longrightarrow L)$ = "probability" that a group-L' photon which scatters through angle $\Theta$ will end up in group-L. This will always be either zero or unity, depending on $\Theta$, L', and L.

### 2.1.2.2 IBM Calculational Procedure

With the exception of $\Sigma(L',\theta)$ and $F(\theta,L' \longrightarrow L)$, which are discussed below, the quantities in Equation 8 are calculated in the same manner as in IBM Procedure S06.

Differential Scattering Cross Section. The cosine of the scattering angle, $\theta$, is calculated as in the neutron program (S06). The ratio of final to initial energy, $P(L)$, is then calculated by the equation

$$P(L) = 1\Big/\left[1+\gamma_0(L)(1-\cos\theta)\right], \tag{9}$$

where $\gamma_0(L) = EO(L)/0.51$, and

$EO(L)$ = average energy of group-L photons, in Mev.

The differential scattering cross section is then given by

$$\Sigma(L,\theta) = N_e\left(\frac{r_0^2}{2}\right)\ (P-P^2(1-\cos^2\theta)+P^3), \tag{10}$$

where $N_e$ = number of electrons per $cm^3$ in radiator,

$r_0$ = classical radius of electron, in cm.

Equations 9 and 10 are discussed in Reference 2.

$F(\theta,L' \longrightarrow L)$. This quantity is not actually calculated. Instead, the final energy, E1, is calculated by

$$E1(L) = EO(L)\ P(L).$$

E1 is then successively compared with the lower-energy limits $E(L)$ of the energy groups, beginning with $L = 1$, until the group in which E1 lies is found. The group-L flux scattered from the point in question is then assigned to that particular group.

### 2.1.2.3 S14 Input Data

Definition of Input Quantities. The program input for a single problem will consist of (1) the problem data and (2) one library of source data. The library data for a given sequence of problems must be read in before the problem decks are read in. Only one source library may be read in at a time. Therefore, if several problems are to be run in sequence, they must all use the same source library.

The input quantities comprising the problem and library data are listed and defined as follows:

Problem Data

| | |
|---|---|
| NA | Number of sub-areas (a positive integer). |
| NE | Number of energies (a positive integer). This must be the same in the problem data and source library. |
| SLOPE | Slope of the hypotenuses of all triangular sub-areas in a particular problem (a decimal number). |
| SEP | Source-detector separation distance, in cm (a decimal number). |
| YSLIB | Identification number of source library (a decimal number). Same digits as in Columns 63 through 68 of source library cards. |
| THICK | Thickness of radiator, in cm (a decimal number). |
| XNEL | Number of electrons per $cm^3$ in radiator (a decimal number with exponent). |
| NPX(K) | Number of points in X-mesh for sub-area K (a positive integer: NA values). |
| NPY(K) | Number of points in Y-mesh for sub-area K (a positive integer: NA values). |

Problem Data (cont'd)

| | |
|---|---|
| KT(K) | Denotes rectangular (KT = 0) or triangular (KT = 1) sub-area (NA values). |
| XO(K) | X-coordinate of lower left corner of sub-area K, in cm (a decimal number: NA values). |
| YO(K) | Y-coordinate of lower left corner of sub-area K, in cm (a decimal number: NA values). |
| DELX(K) | Interval between points in X-mesh of sub-area K, in cm (a decimal number: NA values). |
| DELY(K) | Interval between points in Y-mesh of sub-area K, in cm (a decimal number: NA values). |

Source Library

| | |
|---|---|
| NE | Defined under problem data. |
| MMAX | Number of values of R for which source points are defined (a positive integer). |
| NMAX | Number of values of $\alpha$ for which source points are defined (a positive integer). |
| R1(M) | Values of R in cm at which sources are defined (a decimal number: MMAX values in increasing order). |
| ALPHA1(N) | Values of $\alpha$ at which sources are defined; has units of degrees (a decimal number: NMAX values in increasing order). |
| EO(L) | Average energy in Mev of group-L photons (a decimal number with exponent: NE values). |
| E(L) | Lower energy bound of group L (a decimal number with exponent: NE values). It is important to note that E(L = NE) must always be zero, and the highest energy group must be Group 1. |
| S(L,M,N) | Source term (flux) for energy group L, radius R1(M), and angle ALPHA1(N) (a decimal number with exponent: NE · MMAX · NMAX values). |

Limits on Quantity of Input Data. The quantity of input data is limited by the following maximum values:

| Quantity Input | Maximum Value |
|---|---|
| NA | 20 |
| NE | 15 |
| NMAX | 20 |
| MMAX | 20 |
| NPX(K) | |
| Rectangular sub-area | 99 |
| Triangular sub-area | 49 |
| NPY(K) | 99 |

Input Data Formats. Formats for preparing input data are shown in Figures 6 and 7. The first card of the problem deck contains no data. The first card of a source library has a 1 in Column 10. The rules for entering input on data sheets are outlined in Section 2.1.1.

2.1.2.4 S14 Output Data

Output from the program consists of the following:

1. Total flux at detector.
2. Flux spectrum at detector.
3. Total flux and flux spectrum from each sub-area.
4. Fraction of total flux at the detector from each sub-area.

## 2.2 Calculations

Calculations have been carried out by use of the programs described above to determine the neutron and gamma fluxes scattered

RADIATOR-SCATTERED GAMMAS PROGRAM S14

| 10 | 20 | 30 | 40 | 50 | 60 | 63 JOB NO. | 67 PROBLEM NO. | 69 CARD NO. | 73 LAST DIGIT OF CURRENT YEAR | 78 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0001 | 2 | S14 |
| NA | NE | SLOPE | SEP | YSLIB | THICK | | | 0002 | | |
| XNEL | | | | | | | | 0003 | | |
| NPX(1) | NPX(2) ..... | | | | NPX(NA) | | | 0004 | | |
| NPY(1) | NPY(2) .... | | | | NPY(NA) | | | | | |
| KT(1) | KT(2) .... | | | | KT(NA) | | | | | |
| XO(1) | XO(2) .... | | | | XO(NA) | | | | | |
| YO(1) | YO(2) .... | | | | YO(NA) | | | | | |
| DELX(1) | DELX(2) .... | | | | DELX(NA) | | | | | |
| DELY(1) | DELY(2) ... | | | | DELY(NA) | | | | 2 | S14 |

**Figure 6. Format for Problem Data: Program S14**

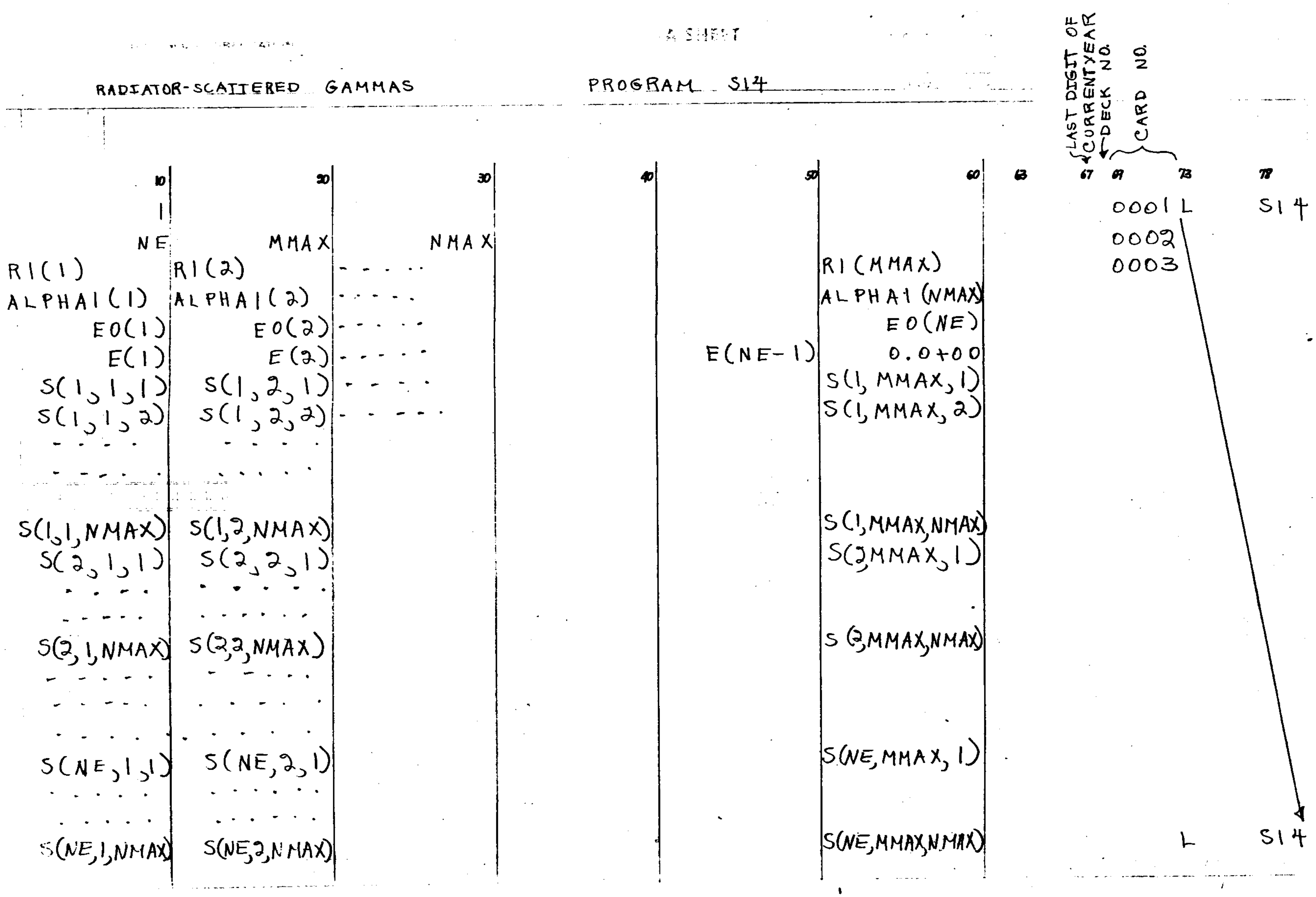



**Figure 7. Format for Source Library: Program S14**

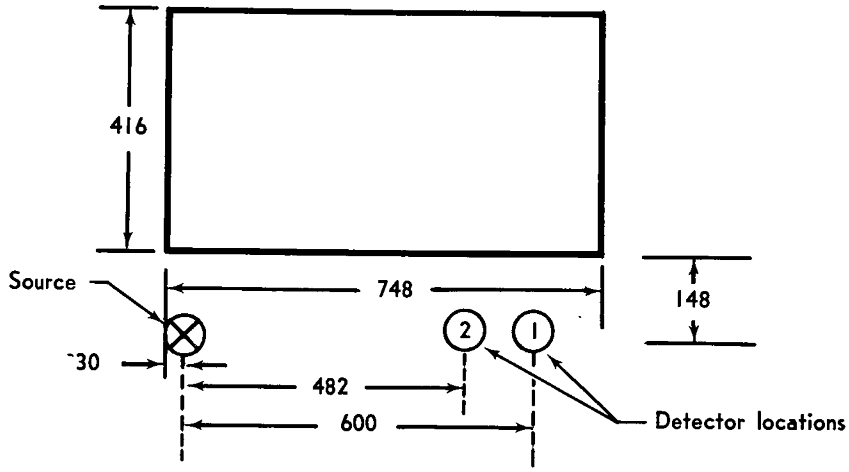
from the radiators of typical unshielded SNAP-8-powered spacecraft having rectangular- and triangular-shaped radiators. Results of these calculations are discussed in the subsections that follow.

### 2.2.1 Geometry of Radiator Systems

Two radiator configurations based on specifications given in Reference 1 were treated: the "flat" configuration shown on page 7 and the "Y" configuration shown on page 11. The flat configuration consists of two rectangular-shaped radiators lying opposite one another in the same plane, one on each side of the axis of the spacecraft. The Y configuration consists of three triangular-shaped radiators mounted radially about the spacecraft axis, each with the same axial position.

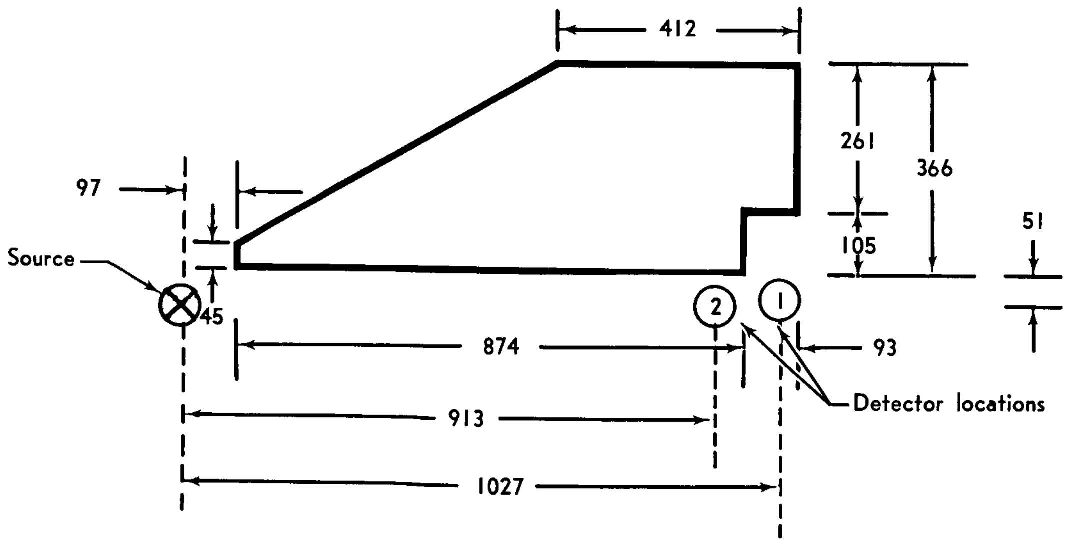
The geometries used in these calculations are shown in Figures 8a and 8b. Calculations were performed for a single radiator of each configuration, so that the total flux would then be twice the flux from a single radiator in the flat configuration and three times the flux from a single radiator in the Y configuration. The circled numbers in Figure 8 indicate the detector locations used in the calculations. Detector 1 coincides with the location of the scientific payload, Detector 2 with that of the ion-propulsion-system propellant tank.

For purposes of calculation, the radiators in both configurations were assumed to consist entirely of aluminum and to be 0.45-cm thick. (By the present method of calculation, the scattered flux is directly proportional to radiator thickness.)




(a) Flat Configuration

All dimensions in centimeters




(b) Y Configuration

**Figure 8. Radiator Geometries Used in Calculations**

### 2.2.2 Source Terms

#### 2.2.2.1 Method of Calculating

Both neutron and gamma source terms were obtained by use of the GD/FW shield penetration program, C-17 (Ref. 3). The reactor core was treated as a number of point sources. The output from this program consists of differential fluxes (particles/$cm^2$-sec-Mev-power unit) and dose rates. However, the radiator-scattered gamma calculation (S14) requires that the source terms consist of fluxes (particles/$cm^2$-sec-power unit) instead of differential fluxes. In order to use in the S14 program the gamma source data generated by the C-17 program, the following procedure was used:

1. The differential gamma spectrum at each radius and angle was normalized to the value at 0.25 Mev.

2. An average normalized spectrum was calculated from the normalized spectra obtained in Step 1. This was possible since the normalized spectra were all quite similar in shape.

3. The average normalized spectrum was then integrated over energy intervals to obtain relative group fluxes. The flux-weighted energy for each energy group was also calculated.

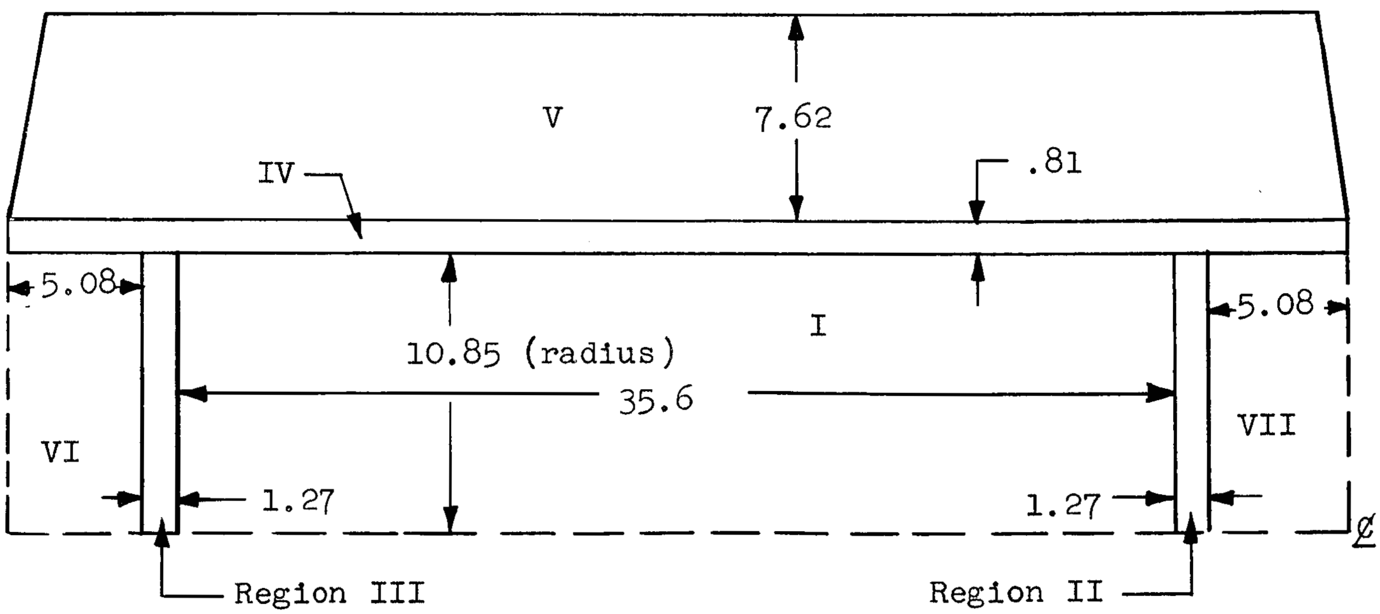
4. The group fluxes (photons/$cm^2$-sec-watt) at each angle and radius were then obtained by multiplying the differential flux at 0.25 Mev for each angle and radius by the relative group fluxes calculated in Step 3.

The source terms required by the S06 program for the neutron calculations are the differential fluxes calculated by the C-17 shield penetration program. Since results obtained from the radiator-scattered neutron program (S06) were the scattered differential fluxes at each detector, it was necessary to integrate these results over energy to obtain the total scattered fluxes.

The neutron and gamma source terms for an unshielded SNAP-8 reactor are given in Tables I and II.

2.2.2.2 Reactor Geometry and Composition

The composition and geometry of the unshielded SNAP-8 reactor, as used for input to the shield penetration program, were obtained from References 4 and 5 and are indicated below. Dimensions are in centimeters.



The Roman numerals indicate region numbers. The composition of each region is as follows:

| Region | Material | Density ($gm/cm^3$) |
|---|---|---|
| I (core) | NaK | 0.0705 |
| | H | 0.0898 |
| | Zr | 4.82 |
| | U-235 | 0.596 |
| | Hastelloy-N | 0.082 |
| II, III, IV | Fe | 8.0 |
| V | Be | 1.84 |
| VI, VII | Al | 0.74 |

## 2.3 Results

### 2.3.1 Flux and Dose

For an unshielded SNAP-8 reactor, the single scattered neutron and gamma spectra at the payload (Detector 1 in Figure 8) are given in Figures 9 and 11. For purposes of comparison, the unshielded direct-beam neutron and gamma spectra at the same detector positions are shown in Figures 10 and 12. The direct-beam spectra were obtained from the source data in Tables I and II. The integrated neutron fluxes and gamma dose rates are given in Tables III and IV. It should be pointed out that the unshielded dose rates and fluxes reported are those from a single radiator multiplied by 2 in the flat configuration and by 3 in the Y configuration. A reactor power of 600 kw thermal was assumed. The neutron elastic scattering cross sections and coefficients for the Legendre expansions for aluminum were taken from Reference 6.

TABLE I

NEUTRON SOURCE TERMS FOR UNSHIELDED SNAP-8 REACTOR
(neutrons/cm$^2$-sec-Mev-watt)

| α (deg) | R (cm) | Energy (Mev) .33 | 1.0 | 2.0 | 3.0 | 4.0 | 6.0 | 8.0 | 10.0 | 14.0 | 18.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 24 | 2.72(6) | 1.64(6) | 1.02(6) | 6.11(5) | 3.55(5) | 1.06(5) | 3.18(4) | 8.20(3) | 2.54(2) | 8.57(0) |
| | 180 | 2.18(4) | 1.32(4) | 8.34(3) | 5.12(3) | 3.04(3) | 9.43(2) | 3.69(2) | 1.14(2) | 2.41(0) | 7.48(-2) |
| | 305 | 7.24(3) | 4.38(3) | 2.77(3) | 1.71(3) | 1.01(3) | 3.16(2) | 1.27(2) | 4.00(1) | 8.15(-1) | 2.51(-2) |
| | 650 | 1.53(3) | 9.30(2) | 5.89(2) | 3.63(2) | 2.16(2) | 6.76(1) | 2.77(1) | 8.86(0) | 1.76(-1) | 5.36(-3) |
| | 7000 | 1.32(1) | 8.01(0) | 4.33(0) | 3.13(0) | 1.87(0) | 5.83(-1) | 2.37(-1) | 7.64(-2) | 1.51(-3) | 4.62(-5) |
| 30 | 24 | 8.97(6) | 2.57(6) | 1.33(6) | 2.76(5) | 1.19(5) | 2.82(4) | 6.28(3) | 1.35(3) | 5.82(1) | 1.92(0) |
| | 180 | 9.43(4) | 2.62(4) | 1.35(4) | 2.81(3) | 1.22(3) | 2.87(2) | 6.31(1) | 1.35(1) | 5.73(-1) | 1.86(-2) |
| | 305 | 3.27(4) | 9.08(3) | 4.68(3) | 9.69(2) | 4.19(2) | 9.87(1) | 2.17(1) | 4.62(0) | 1.94(-1) | 6.27(-3) |
| | 650 | 7.14(3) | 1.98(3) | 1.02(3) | 2.11(2) | 9.14(1) | 2.15(1) | 4.72(0) | 1.00(0) | 4.24(-2) | 1.37(-3) |
| | 7000 | 6.16(1) | 1.71(1) | 8.99(0) | 1.82(0) | 7.88(-1) | 1.85(-1) | 4.07(-2) | 8.62(-3) | 3.66(-4) | 1.18(-5) |
| 60 | 24 | 6.83(6) | 1.93(6) | 9.90(5) | 1.90(5) | 8.30(4) | 1.98(4) | 4.44(3) | 9.67(2) | 4.28(1) | 1.44(0) |
| | 180 | 1.11(5) | 3.15(4) | 1.62(4) | 3.06(3) | 1.34(3) | 3.22(2) | 7.26(1) | 1.59(1) | 7.06(-1) | 2.39(-2) |
| | 305 | 3.92(4) | 1.14(4) | 5.70(3) | 1.09(3) | 4.72(2) | 1.14(2) | 2.58(1) | 5.66(0) | 2.53(-1) | 8.57(-3) |
| | 650 | 8.65(3) | 2.45(3) | 1.26(3) | 2.41(2) | 1.06(2) | 2.54(1) | 5.73(0) | 1.26(0) | 5.64(-2) | 1.91(-3) |
| | 7000 | 7.46(1) | 2.11(1) | 1.09(1) | 2.08(0) | 9.14(-1) | 2.19(-1) | 4.94(-2) | 1.09(-2) | 4.83(-4) | 1.65(-5) |
| 90 | 24 | 7.53(6) | 2.20(6) | 1.14(6) | 2.27(5) | 9.87(4) | 2.38(4) | 5.41(3) | 1.19(3) | 5.31(1) | 1.81(0) |
| | 180 | 1.42(5) | 4.11(4) | 2.14(4) | 4.31(3) | 1.86(3) | 4.46(2) | 1.01(2) | 2.23(1) | 9.99(-1) | 3.42(-2) |
| | 305 | 4.92(4) | 1.43(4) | 7.41(3) | 1.49(3) | 6.44(2) | 1.54(2) | 3.50(1) | 7.70(0) | 3.45(-1) | 1.18(-2) |
| | 650 | 1.08(4) | 3.12(3) | 1.62(3) | 3.26(2) | 1.41(2) | 3.37(1) | 7.64(0) | 1.68(0) | 7.52(-2) | 2.57(-3) |
| | 7000 | 9.31(1) | 2.69(1) | 1.40(1) | 2.81(0) | 1.22(0) | 2.91(-1) | 6.59(-2) | 1.45(-2) | 6.48(-4) | 2.25(-5) |
| 120 | 24 | 6.83(6) | 1.93(6) | 9.90(5) | 1.90(5) | 8.30(4) | 1.98(4) | 4.44(3) | 9.67(2) | 4.28(1) | 1.44(0) |
| | 180 | 1.11(5) | 3.15(4) | 1.62(4) | 3.06(3) | 1.34(3) | 3.22(2) | 7.26(1) | 1.59(1) | 7.06(-1) | 2.39(-2) |
| | 305 | 3.92(4) | 1.14(4) | 5.70(3) | 1.09(3) | 4.72(2) | 1.14(2) | 2.58(1) | 5.66(0) | 2.53(-1) | 8.57(-3) |
| | 650 | 8.65(3) | 2.45(3) | 1.26(3) | 2.41(2) | 1.02(2) | 2.54(1) | 5.73(0) | 1.26(0) | 5.64(-2) | 1.91(-3) |
| | 7000 | 7.46(1) | 2.11(1) | 1.09(1) | 2.08(0) | 9.14(-1) | 2.19(-1) | 4.94(-2) | 1.09(-2) | 4.83(-4) | 1.65(-5) |

TABLE II

GAMMA SOURCE TERMS FOR UNSHIELDED SNAP-8 REACTOR
(photons/cm$^2$-sec-watt)

| α (deg) | R (cm) | Energy Range (Mev) 9-10 | 8-9 | 7-8 | 6-7 | 5-6 | 4-5 | 3-4 | 2-3 | 1.5-2.0 | 1.0-1.5 | .75-1.0 | .50-.75 | .25-.50 | 0-.25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 24 | 1.79(3) | 1.92(4) | 3.40(4) | 4.67(4) | 8.12(4) | 1.62(5) | 4.51(5) | 1.40(6) | 1.39(6) | 2.28(6) | 1.81(6) | 3.10(6) | 7.53(6) | 1.09(7) |
| | 180 | 1.40(1) | 1.50(2) | 2.65(2) | 3.65(2) | 6.33(2) | 1.27 3) | 3.52(3) | 1.09(4) | 1.09(4) | 1.78(4) | 1.41(4) | 2.42(4) | 5.89(4) | 8.50(4) |
| | 305 | 4.61(0) | 4.95(1) | 8.75(1) | 1.20(2) | 2.09(2) | 4.18(2) | 1.16(3) | 3.60(3) | 3.59(3) | 5.85(3) | 4.68(3) | 7.90(3) | 1.94(4) | 2.80(4) |
| | 650 | 9.81(-1) | 1.05(1) | 1.86(1) | 2.56(1) | 4.45(1) | 8.90(1) | 2.47(2) | 7.66(2) | 7.65(2) | 1.25(3) | 9.93(2) | 1.70(3) | 4.13(3) | 5.98(3) |
| | 7000 | 8.45(-3) | 9.10(-2) | 1.60(-1) | 2.21(-1) | 3.83(-1) | 7.67(-1) | 2.13(0) | 6.60(0) | 6.55(0) | 1.08(1) | 8.65(0) | 1.45(1) | 3.55(1) | 5.15(1) |
| 30 | 24 | 4.37(2) | 4.69(3) | 8.29(3) | 1.14(4) | 1.98(4) | 3.96(4) | 1.10(5) | 3.41(5) | 3.40(5) | 5.55(5) | 4.42(5) | 7.55(5) | 1.84(6) | 2.65(6) |
| | 180 | 8.36(0) | 8.97(1) | 1.59(2) | 2.18(2) | 3.79(2) | 7.59(2) | 2.11(3) | 6.53(3) | 6.50(3) | 1.07(4) | 8.48(3) | 1.45(4) | 3.53(4) | 5.10(4) |
| | 305 | 2.97(0) | 3.19(1) | 5.64(1) | 7.75(1) | 1.35(2) | 2.69(2) | 7.49(2) | 2.32(3) | 2.31(3) | 3.78(3) | 3.00(3) | 5.15(3) | 1.64(4) | 1.81(4) |
| | 650 | 6.60(-1) | 7.08(0) | 1.25(1) | 1.72(1) | 2.99(1) | 5.99(1) | 1.66(2) | 5.15(2) | 5.15(2) | 8.40(2) | 6.68(2) | 1.14(3) | 2.78(3) | 4.03(3) |
| | 7000 | 5.70(-3) | 6.11(-2) | 1.08(-1) | 1.49(-1) | 2.58(-1) | 5.17(-1) | 1.44(0) | 4.45(0) | 4.43(0) | 7.25(0) | 5.78(0) | 9.85(0) | 2.40(1) | 3.48(1) |
| 60 | 24 | 9.47(2) | 1.00(4) | 1.78(4) | 2.44(4) | 4.24(4) | 8.49(4) | 2.36(5) | 7.31(5) | 7.30(5) | 1.19(6) | 9.48(5) | 1.62(6) | 3.93(6) | 5.70(6) |
| | 180 | 1.47(1) | 1.58(2) | 2.80(2) | 3.85(2) | 6.68(2) | 1.34(3) | 3.72(3) | 1.15(4) | 1.15(4) | 1.88(4) | 1.49(4) | 2.55(4) | 6.20(4) | 8.98(4) |
| | 305 | 5.15(0) | 5.53(1) | 9.78(1) | 1.35(2) | 2.33(2) | 4.67(2) | 1.30(3) | 4.02(3) | 4.00(3) | 6.55(3) | 5.23(3) | 8.93(3) | 2.17(4) | 3.13(4) |
| | 650 | 1.13(0) | 1.21(1) | 2.15(1) | 2.95(1) | 5.13(1) | 1.03(2) | 2.85(2) | 8.83(2) | 8.80(2) | 1.44(3) | 1.15(3) | 1.96(3) | 4.75(3) | 6.88(3) |
| | 7000 | 9.76(-3) | 1.05(-1) | 1.85(-1) | 2.55(-1) | 4.43(-1) | 8.86(-1) | 2.46(0) | 7.62(0) | 7.60(0) | 1.24(1) | 9.88(0) | 1.69(1) | 4.10(1) | 5.95(1) |
| 90 | 24 | 1.03(3) | 1.09(4) | 1.93(4) | 2.66(4) | 4.61(4) | 9.23(4) | 2.57(5) | 7.94(5) | 7.94(5) | 1.30(6) | 1.03(6) | 1.76(6) | 4.28(6) | 6.20(6) |
| | 180 | 1.78(1) | 1.91(2) | 3.38(2) | 4.65(2) | 8.08(2) | 1.62(3) | 4.49(3) | 1.39(4) | 1.39(4) | 2.27(4) | 1.80(4) | 3.08(4) | 7.48(4) | 1.08(5) |
| | 305 | 6.15(0) | 6.60(1) | 1.17(2) | 1.60(2) | 2.79(2) | 5.58(2) | 1.55(3) | 4.80(3) | 4.80(3) | 7.80(3) | 6.23(3) | 1.07(4) | 2.58(4) | 3.75(4) |
| | 650 | 1.35(0) | 1.45(1) | 2.56(1) | 3.52(1) | 6.11(1) | 1.22(2) | 3.40(2) | 1.05(3) | 1.05(3) | 1.73(3) | 1.36(3) | 2.33(3) | 5.65(3) | 8.20(3) |
| | 7000 | 1.16(-2) | 1.25(-1) | 2.21(-1) | 3.03(-1) | 5.27(-1) | 1.05(0) | 2.93(0) | 9.07(0) | 9.07(0) | 1.48(1) | 1.18(1) | 2.01(1) | 4.89(1) | 7.08(1) |
| 120 | 24 | 9.47(2) | 1.00(4) | 1.78(4) | 2.44(4) | 4.24(4) | 8.49(4) | 2.36(5) | 7.31(5) | 6.30(5) | 1.19(6) | 9.48(5) | 1.62(6) | 3.93(6) | 5.70(6) |
| | 180 | 1.47(2) | 1.58(2) | 2.80(2) | 3.85(2) | 6.68(2) | 1.34(3) | 3.72(3) | 1.15(4) | 1.15(4) | 1.88(4) | 1.49(4) | 2.55(4) | 6.20(4) | 8.98(4) |
| | 305 | 5.15(0) | 5.53(1) | 9.78(1) | 1.35(2) | 2.33(2) | 4.67(2) | 1.30(3) | 4.02(3) | 4.00(3) | 6.55(3) | 5.23(3) | 8.93(3) | 2.17(4) | 3.13(4) |
| | 650 | 1.13(0) | 1.21(1) | 2.15(1) | 2.95(1) | 5.13(1) | 1.03(2) | 2.85(2) | 8.83(2) | 8.80(2) | 1.44(3) | 1.15(3) | 1.96(3) | 4.75(3) | 6.88(3) |
| | 7000 | 9.76(-3) | 1.05(-1) | 1.85(-1) | 2.55(-1) | 4.43(-1) | 8.86(-1) | 2.46(0) | 7.62(0) | 7.60(0) | 1.24(1) | 9.88(0) | 1.69(1) | 4.10(1) | 5.95(1) |

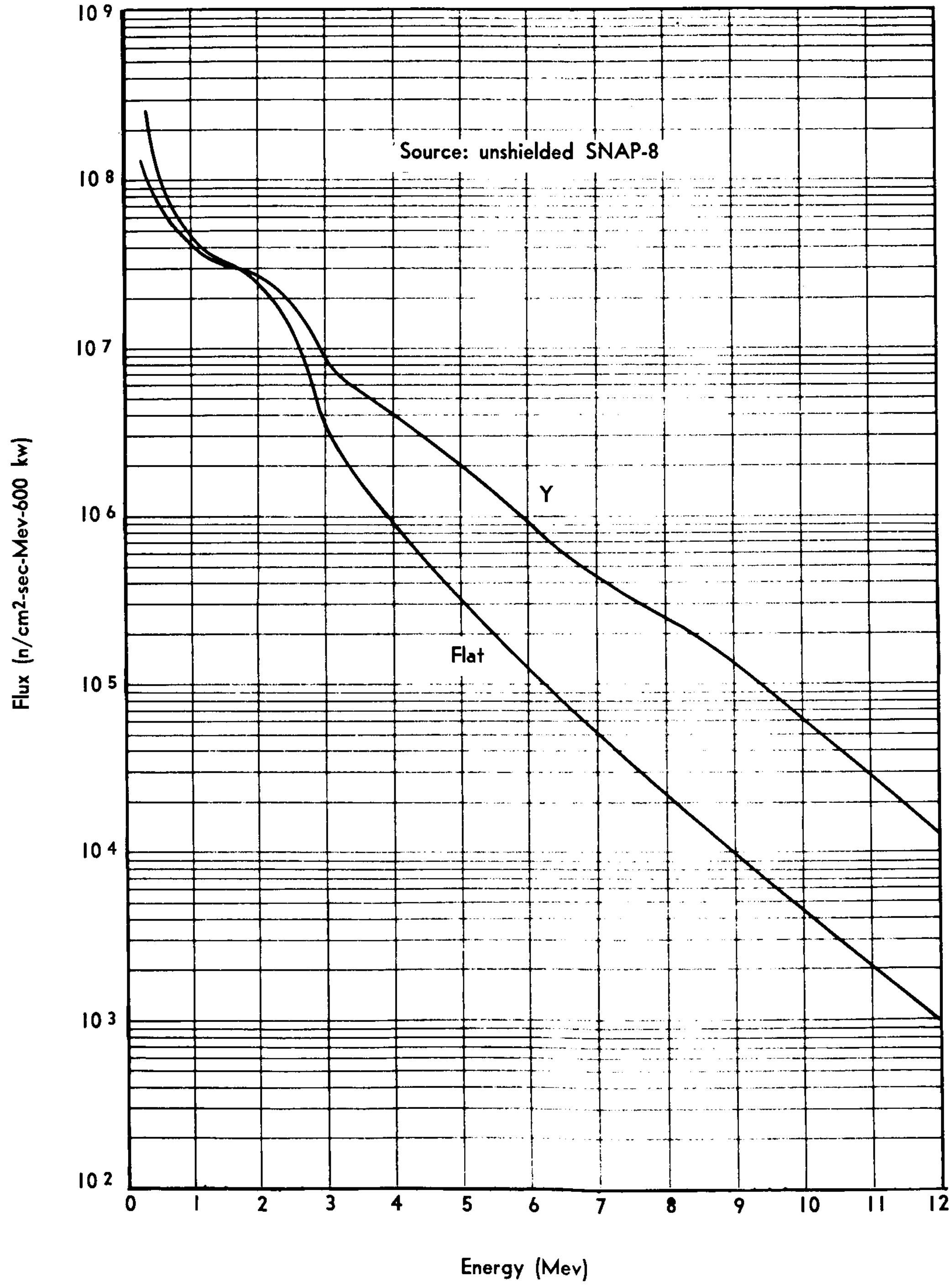



**Figure 9. Single-Scattered Neutron Spectra at Payload for Flat and Y Configurations**

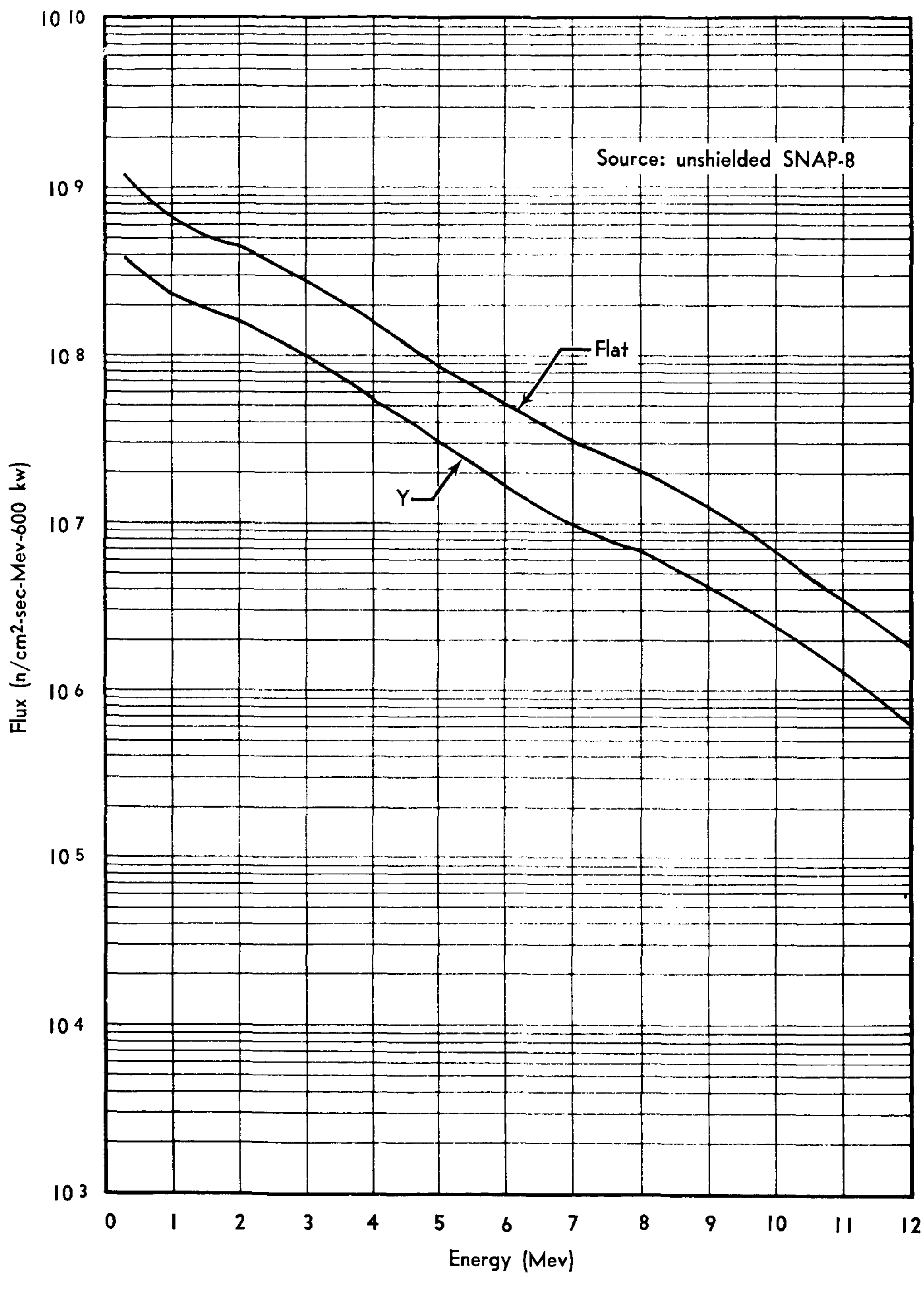



**Figure 10. Direct-Beam Neutron Spectra at Payload for Flat and Y Configurations**

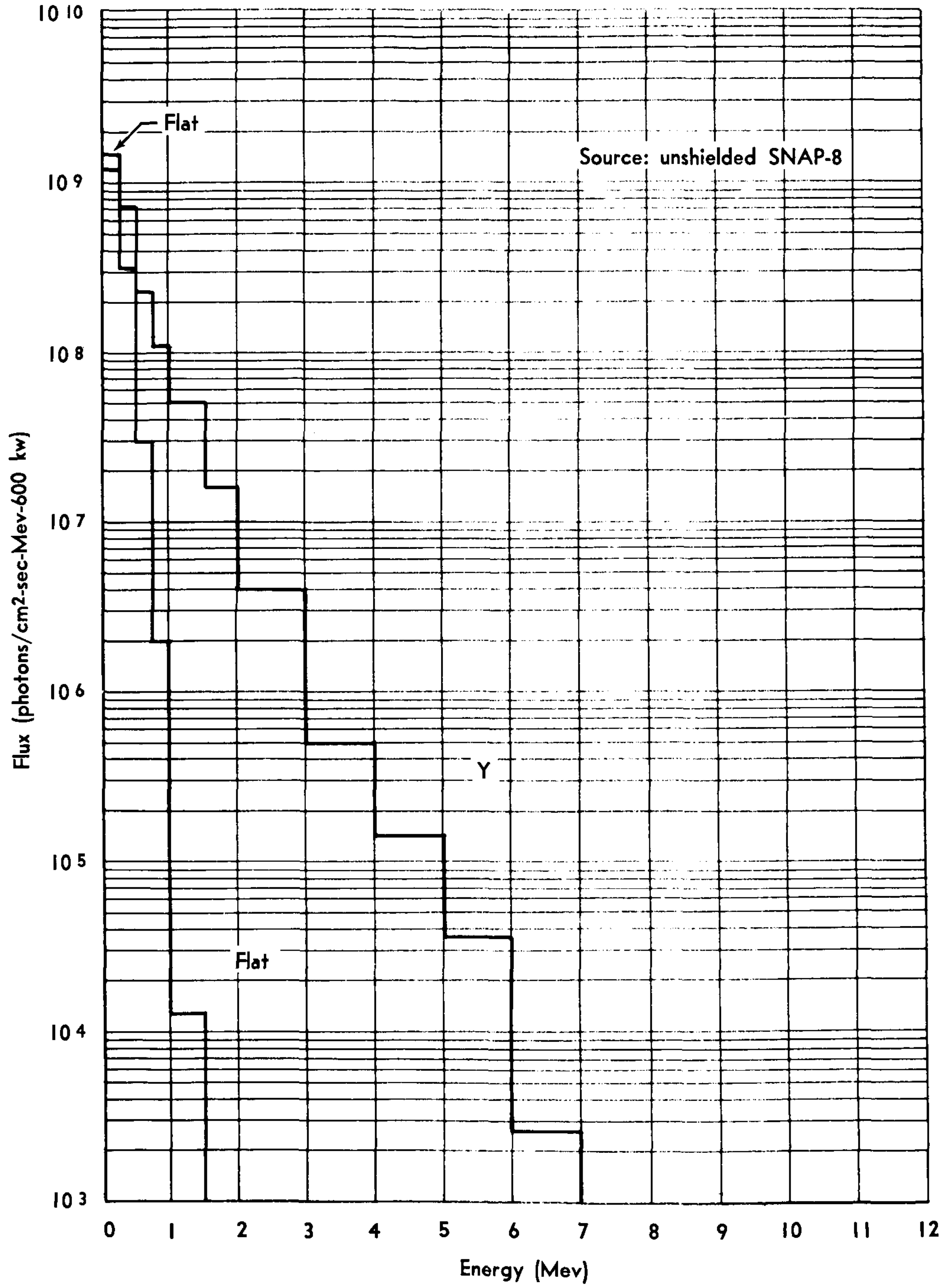



**Figure 11. Single-Scattered Gamma Spectra at Payload for Flat and Y Configurations**

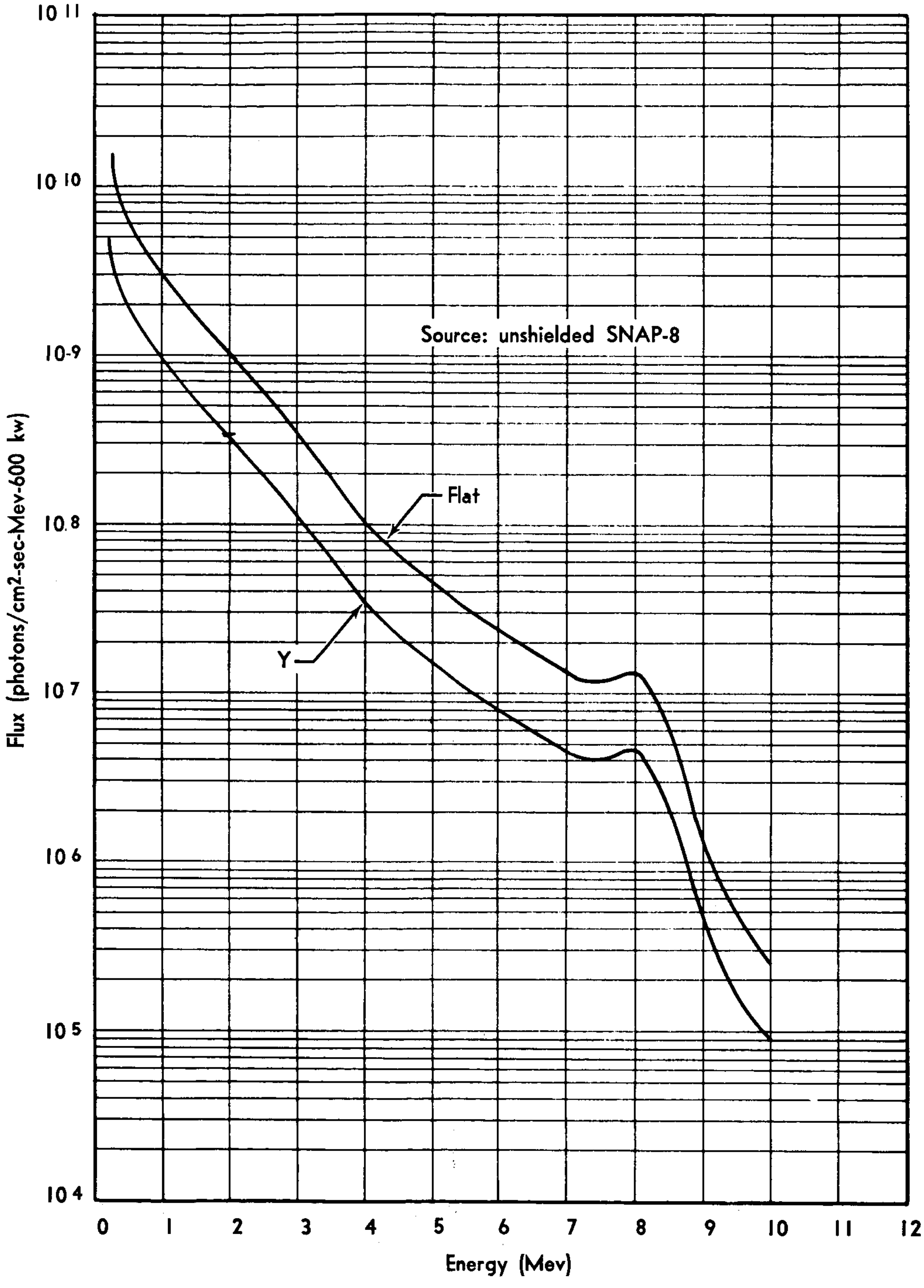



**Figure 12. Direct-Beam Gamma Spectra at Payload for Flat and Y Configurations**

TABLE III

TOTAL NEUTRON FLUX ABOVE 0.33 MEV
($neutrons/cm^2$-sec-600 kw)

| | Flat Configuration | Y Configuration |
|---|---|---|
| At Payload | | |
| Scattered | $1.2x10^8$ | $1.1x10^8$ |
| Direct Beam | $2.6x10^9$ | $8.9x10^8$ |
| At Propellant Tank | | |
| Scattered | $1.5x10^8$ | $1.7x10^8$ |
| Direct Beam | $4.0x10^9$ | $1.1x10^9$ |

TABLE IV

GAMMA DOSE RATES
(r/hr-600 kw)

| | Flat Configuration | Y Configuration |
|---|---|---|
| At Payload | | |
| Scattered | $1.5x10^2$ | $4.3x10^2$ |
| Direct Beam | $1.3x10^4$ | $4.3x10^3$ |
| At Propellant Tank | | |
| Scattered | $1.7x10^2$ | $5.4x10^2$ |
| Direct Beam | $2.0x10^4$ | $5.4x10^3$ |

The scattered gamma dose rates were obtained by the following expression:

$$\text{DOSE} = \sum_{i} f_i \, \phi_i,$$

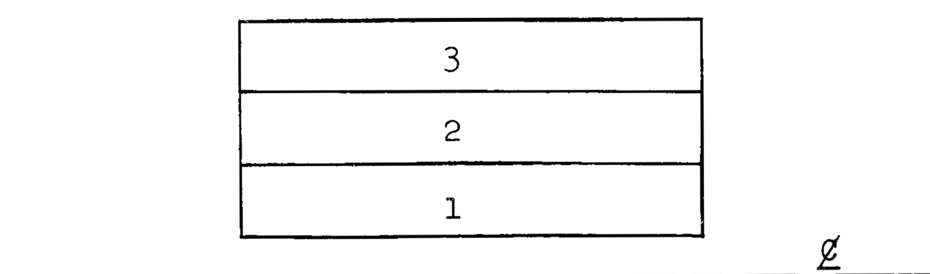
where $\phi_i$ = group i gamma flux,

$f_i$ = flux-to-dose conversion factor, approximated from the curve on page 19 of Reference 7.

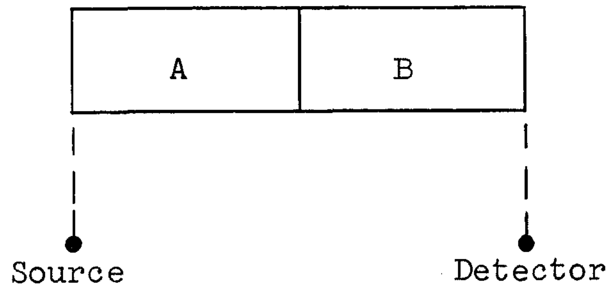
The direct-beam dose rates were obtained from the C-17 shield penetration program results.

2.3.2 Relative Importance of Radiator Regions

Of interest is the relative importance of various segments of the radiator with regard to scattering. With the flat configuration divided into three equal areas, as shown below, the percentage of total scattered neutron flux above 0.33 Mev contributed by each area is as follows: area 1, 70%; area 2, 20%; and area 3,10%. The percentage of scattered gamma dose rate contributed by each area is: for area 1, 73%; for area 2, 19%; and for area 3, 8%.



Next, consider the source-detector scattering surface arrangement shown below, where area A = area B.




For an angular-independent source term that varies as $1/r^2$, it can be shown that the scattered fluxes contributed by areas A and B are equal. This is true because, for a given scattering "point" in area A, there will be a "point" in area B for which the scattering angle and geometric attenuation from source to detector will be equal to the scattering angle and total geometric attenuation, respectively, for area A.

## 2.4 Discussion of Results

### 2.4.1 Limitations

The most important limitations on the radiator scattering calculations are:

1. Neglect of attenuation in the radiator.
2. Consideration only of single scattering.
3. Uncertainties in the source terms, particularly the neutron source term.

The errors introduced by the first two limitations compensate each other to some degree. It is not certain that the effects of either are significant.

Attenuation is neglected because accounting for it would require either that the reactor be treated as a number of source points or that a detailed knowledge of the angular distribution of the radiation leaving the reactor surface be obtained and an integration performed over the surface of the reactor. The latter approach would be the better of the two but, at present, methods are not available which would give the necessary angular distribution of leakage radiation. It should be pointed out that, while the reactor is assumed to be a point source as far as the geometry involved in the scattering calculations is concerned, the source terms used in the scattering calculations were obtained by treating the reactor core as a number of point sources.

In using the shield penetration program (C17, Ref. 3) for calculating neutron fluxes from systems which consist of both hydrogenous and nonhydrogenous materials, one is faced with certain basic limitations inherent in the application of moments method data to neutron penetration calculations. The most important of these are:

1. Difficulty in choosing the proper reference material.
2. Uncertainties due to boundary effects.

This points out the importance of more sophisticated methods for determining neutron source terms.

A reasonable estimate of the error introduced by the assumptions and uncertainties discussed above cannot be made.

### 2.4.2 General Observations

From Reference 1, page 5, the total allowed radiation doses in the payload area are $10^{13}$ n/cm$^2$ and $10^9$ ergs/gm(C) for neutrons and gammas, respectively. For a $10^4$-hour operating period, the maximum allowable neutron flux and gamma dose rate are then $2.8 \times 10^5$ n/cm$^2$-sec and $10^3$ r/hr, respectively. By comparing these numbers with those in Tables III and IV, one can see that, in the particular spacecraft treated in these calculations, it will be necessary to shield against both scattered and direct-beam neutrons. The gamma shielding required will depend on the gamma attenuation offered by the neutron shielding.

Since the scattering cross section for aluminum decreases with increasing neutron energy and its differential elastic scattering becomes highly anisotropic with increasing neutron energy, it is the low-energy neutrons leaking from the reactor that contribute most of the scattered flux. One can see this by comparing the shapes of the scattered and direct-beam neutron spectra, bearing in mind that energy loss due to scattering is negligible. This is fortunate, since it is easier to shield against low-energy neutrons than against those of high energy.

Conclusions and recommendations with regard to radiator scattering are discussed in Section 4.1 of this report.

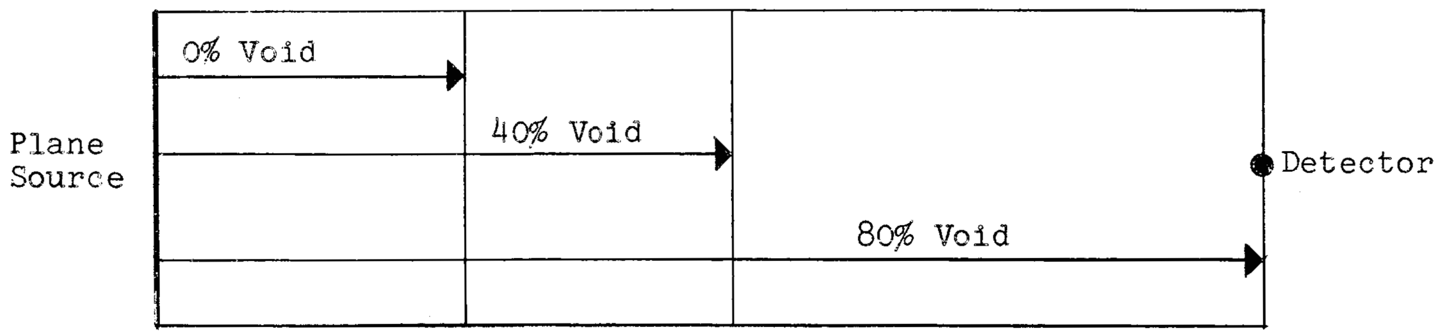
## III. DIRECT-BEAM SHIELDING

Shielding against direct-beam radiation has been studied from the standpoint of reducing the required shielding by either splitting or uniformly expanding the shield in order to increase the transverse leakage of radiation scattered within the shield. The effect of shield placement has also been considered. Results of Monte Carlo calculations performed at GD/FW to investigate shield expansion are presented, and the results of calculations performed by the Technical Research Group to study shield splitting are discussed. Thus far, the GD/FW study of direct-beam shielding has been confined to neutrons.

### 3.1 Expanded-Shield Studies

#### 3.1.1 Geometry

The geometry for the expanded-shield calculations is shown below.




The shield was assumed to be a right circular cylinder of polyethylene, 12 inches in diameter, which was uniformly expanded until 40% and 80% void fractions were achieved. Initial shield thicknesses of 9, 27, and 60 cm were considered. For each of these solid-shield thicknesses, the source-detector separation distance was assumed to be equal to the thickness of the shield when expanded to 80% void. The total mass of each shield was assumed to remain constant.

3.1.2 Source

The energy spectrum of the source was taken to be the same as that leaking from a typical nuclear rocket engine reactor. Although this spectrum differs considerably from that of the SNAP-8 reactor, the general conclusions drawn from this study should be applicable.

Two source angular distributions - isotropic and monodirectional - were treated.

3.1.3 Method of Calculation

IBM procedure K97, a Monte Carlo program, was used to make the calculations. A complete description of the calculational method is presented in Reference 8.

3.1.4 Results

Uncollided, scattered, and total dose rates per source neutron per second are presented in Figures 13 through 18 as a function of void percent for both source angular distributions and each initial shield thickness. The uncollided dose rates were calculated by conventional methods. The number of neutrons that leak from the side of the shield per source neutron as a function of void percent is shown in Figures 19 and 20 for a plane isotropic source and a plane monodirectional source, respectively.

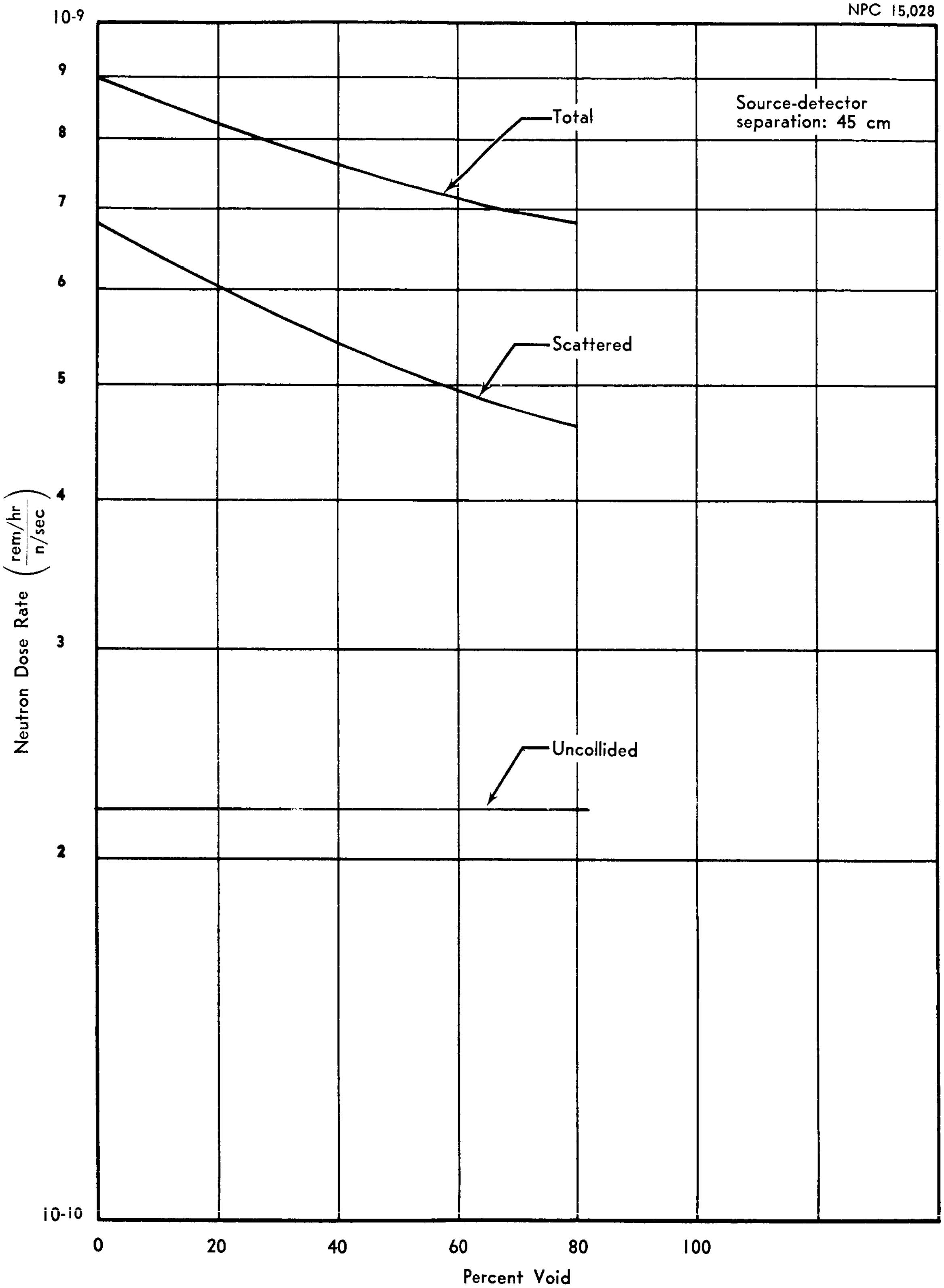



**Figure 13. Effect of Expanding 9-cm Polyethelene Shield: Plane Isotropic Source**

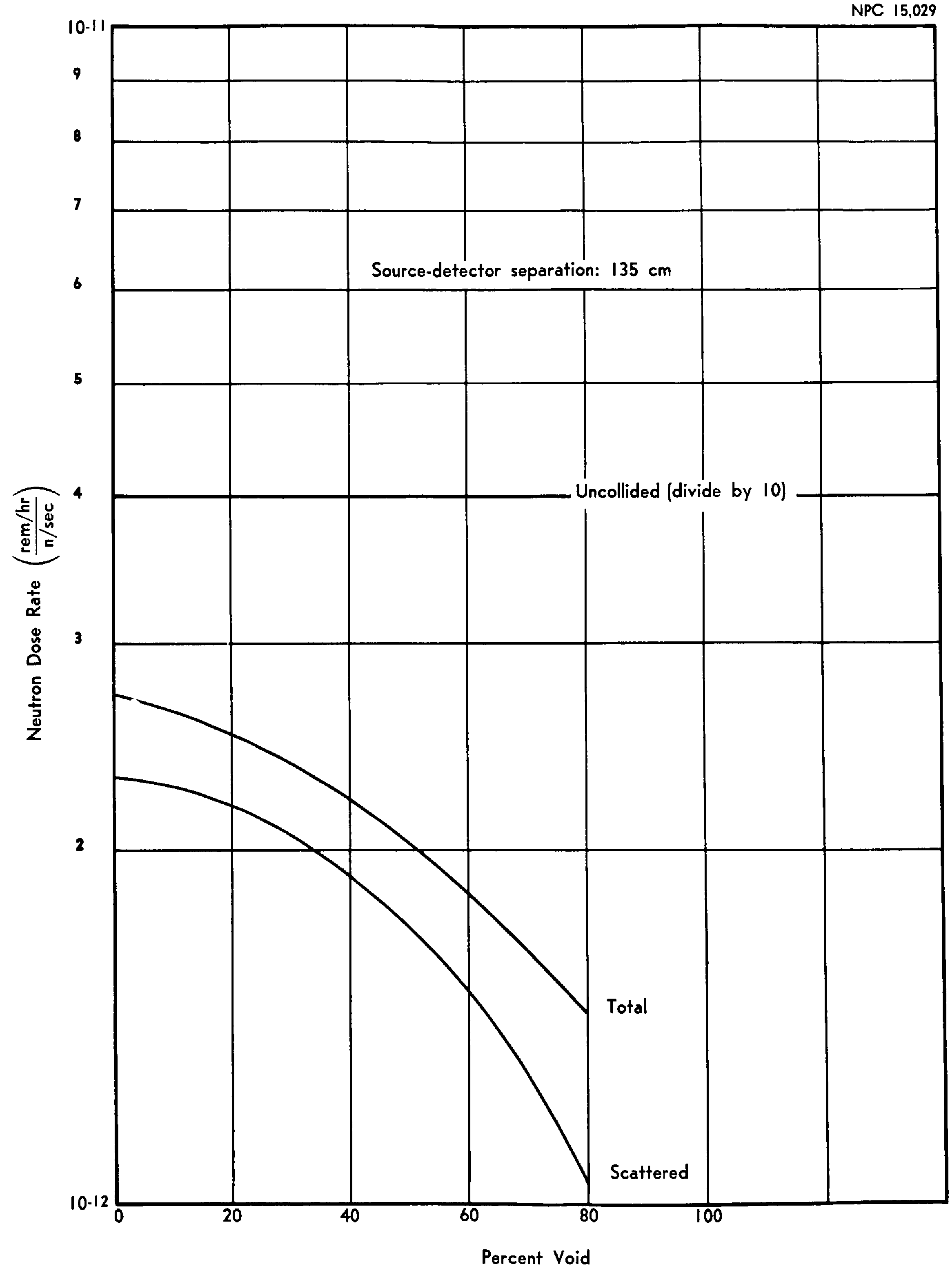



**Figure 14. Effect of Expanding 27-cm Polyethelene Shield: Plane Isotropic Source**

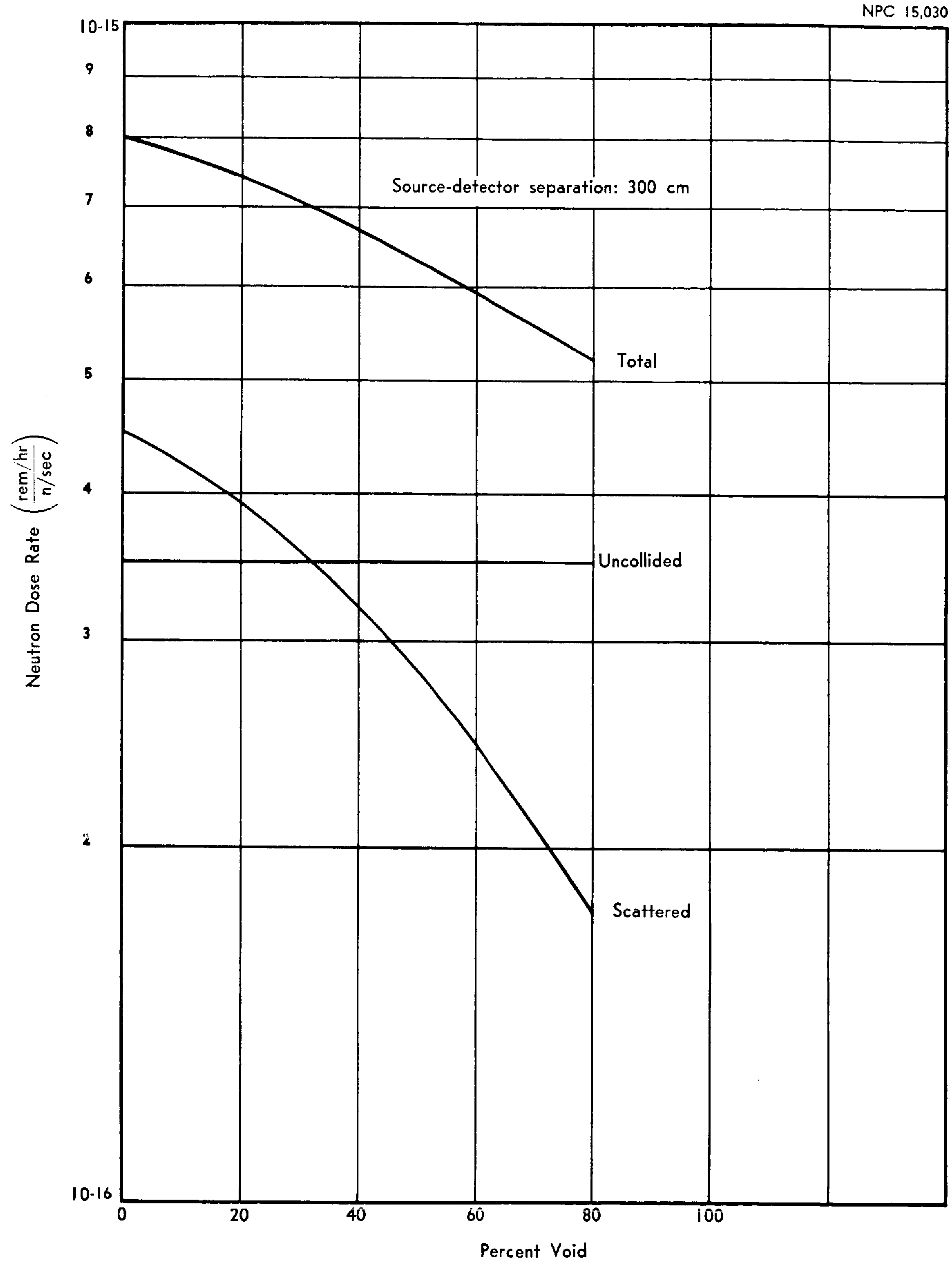



**Figure 15. Effect of Expanding 60-cm Polyethelene Shield: Plane Isotropic Source**

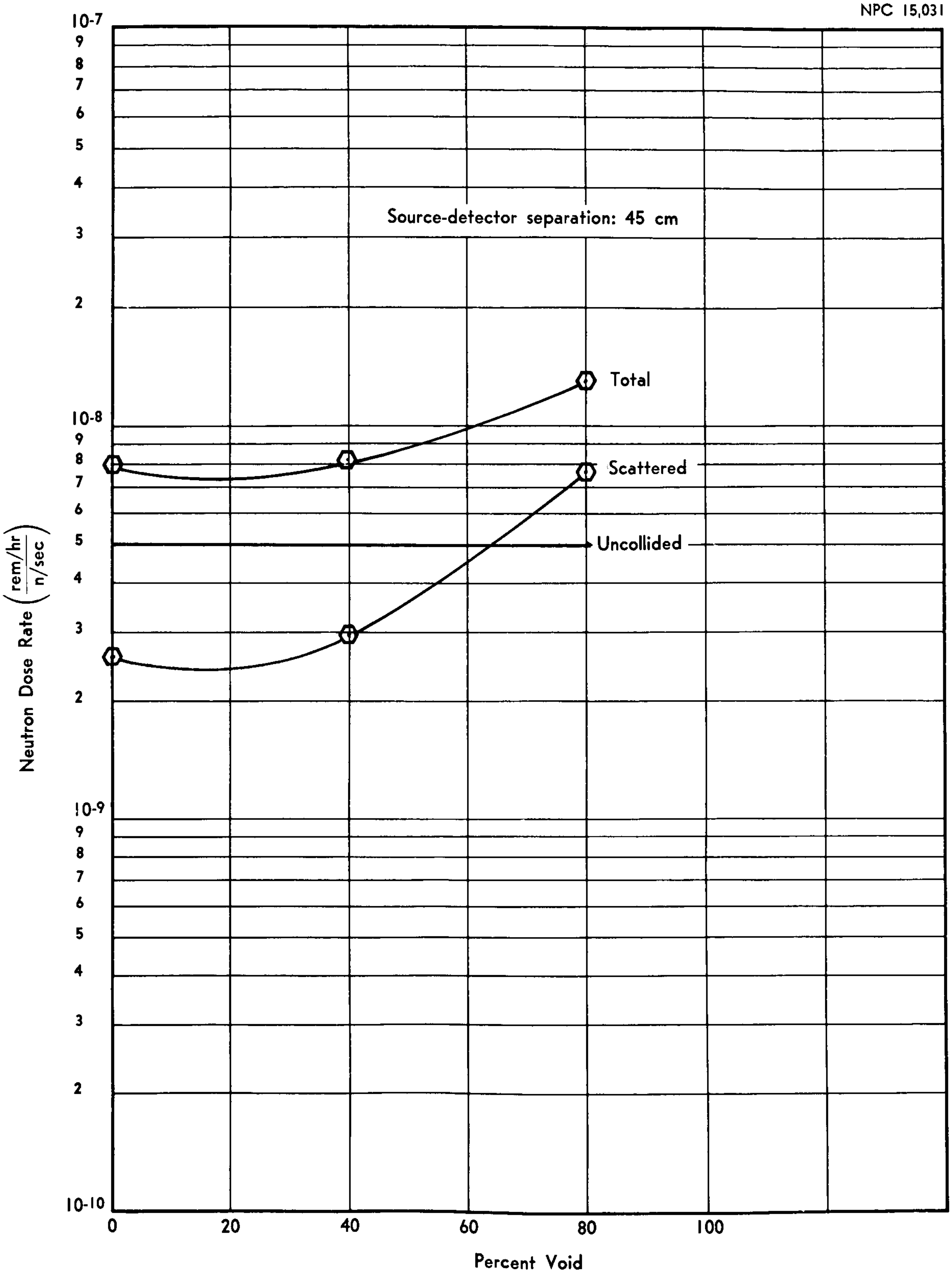



**Figure 16. Effect of Expanding 9-cm Polyethelene Shield: Plane Monodirectional Source**

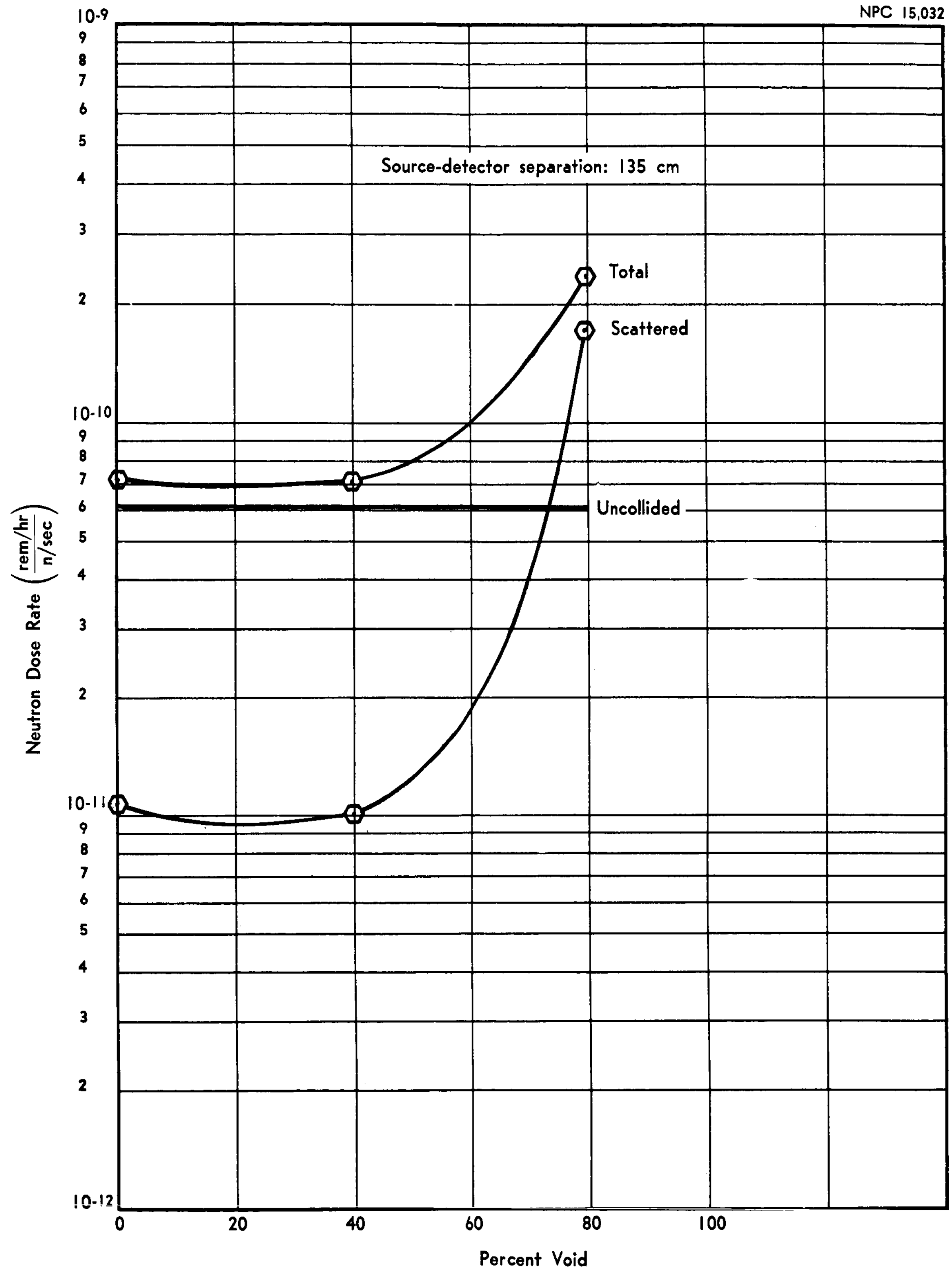



**Figure 17. Effect of Expanding 27-cm Polyethelene Shield: Plane Monodirectional Source**

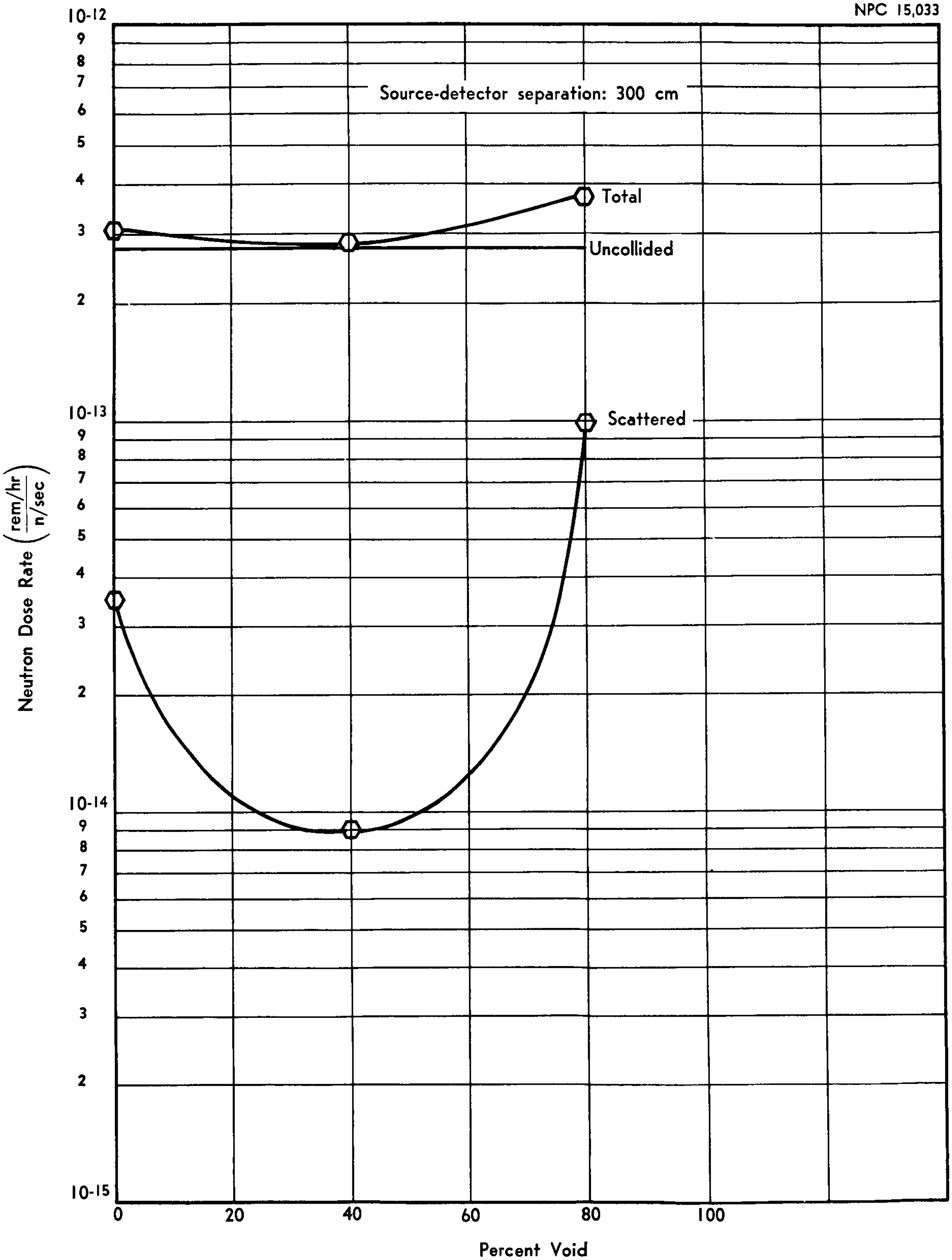



**Figure 18. Effect of Expanding 60-cm Polyethelene Shield: Plane Monodirectional Source**

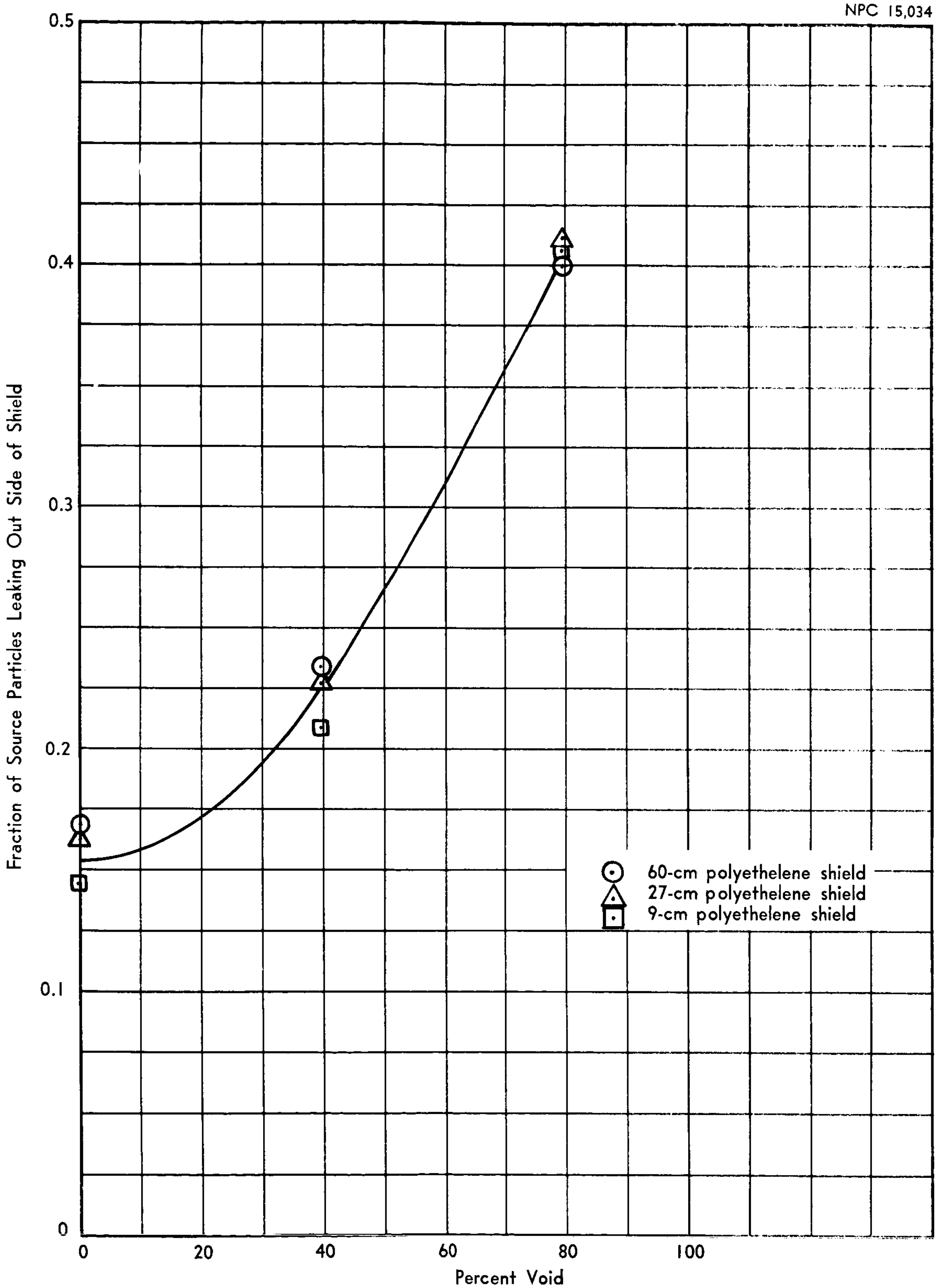



**Figure 19. Transverse Neutron Leakage for Plane Isotropic Source**

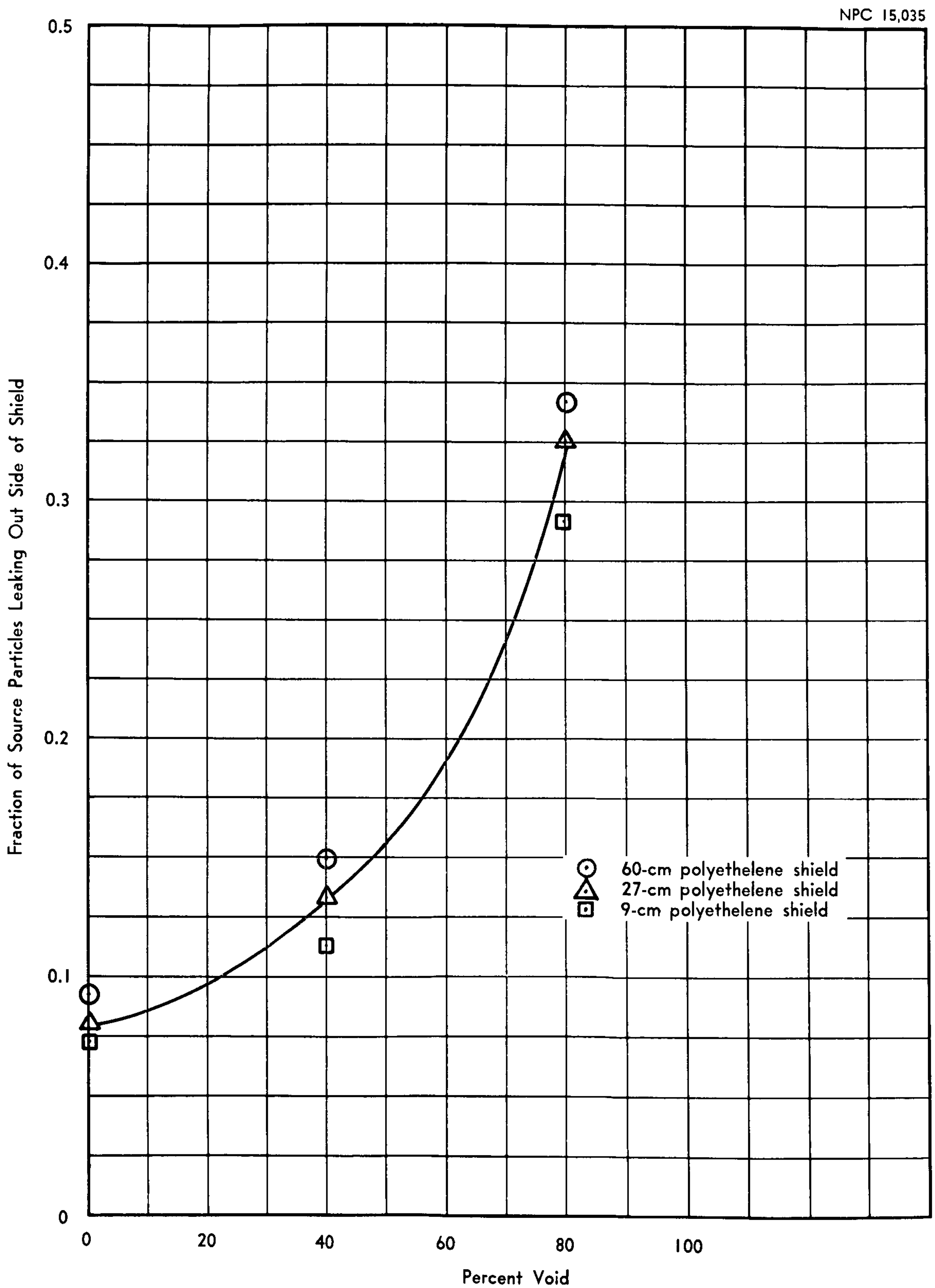



**Figure 20. Transverse Neutron Leakage for Plane Monodirectional Source**

Figures 13 through 15 indicate that the total dose rate from a plane isotropic source is reduced by expanding the shield. With an isotropic source the effectiveness of shield expansion is expected to be at a maximum when the source is located at the face of a hydrogenous material, since scattering is predominantly in the forward direction. If the source were located a large distance from the shield, the incident radiation would be more normal and the effect of expansion would be reduced.

The high magnitude of the uncollided dose rate relative to the total dose rate for the 60-cm case (Fig. 15) is felt to be caused by the source energy spectrum. For small thicknesses of polyethylene, the major contribution to the dose at the detector results from neutrons which originate at the source with energies of less than 5.0 Mev. A 40.0-cm thickness of polyethylene, however, removes most of those neutrons with energies below 5.0 Mev. Since the scattering cross section decreases as the energy increases, the uncollided dose rate becomes more important for polyethylene thicknesses greater than 40 cm. This latter effect would not be as noticeable for the SNAP-8 spectrum, since this spectrum is harder than that used in the calculation reported here.

Figures 16 and 17 indicate that, for shield thickness of 9 and 27 cm and for a monodirectional source, the effect of expanding the shield toward the detector is to increase the dose rate. This is because the effect of moving scattering points closer to the detector is greater than that of increasing the transverse leakage.

Figure 18 indicates that for a plain monodirectional source and a 60-cm shield thickness, the result of expanding the shield toward the detector is, first, to decrease and, then, to increase the scattered dose. This is probably due to the larger source-detector separation distance used in this case. With a 40% expansion, the fractional change in separation distance between scattering points closer to the source, where the scattering is highest, is less than that in the other cases which used shorter source-detector separation distances. The increase in transverse leakage due to a 40% expansion, therefore, compensates for the decrease in geometric attenuation, which results from moving scattering points closer to the source. With further expansion, the effect of moving the scattering points closer to the detector is greater than the increase in transverse leakage and the dose-rate increases. If the distance from shield to detector had been held constant and the shield expanded toward the source, the opposite effect would have been observed since the scattering points would be moving farther from the detector. This illustrates the importance of proper placement of the shield with respect to source and detector.

Figures 19 and 20 indicate that most of the increase in transverse leakage due to expansion is due to expansion of the first few mean free paths of the solid shield. This is especially true for the isotropic source, as can be noted by the fact that the data for the three shield thicknesses are quite close together.

Since those neutrons which leak from the side of the shield could reach the detector by scattering off radiators or other structure, it may be necessary to consider them in calculating the radiator-scattered dose rates for a composite shield configuration. The spectrum of neutrons leaking from the shield would be softer than the source spectrum, since neutrons from the shield would have undergone collisions in a moderating medium. The spectrum at the detector due to these neutrons would be even softer, as indicated by the discussion in Section 2.4.2.

The results just discussed indicate that it is possible to obtain significant reduction in neutron dose rate by expanding the direct-beam shield, but that the effect of expansion is dependent on several factors, the more important of which are angular distribution of source, initial (solid) shield thickness, and source-detector separation distance. The effect of expansion will also be dependent on other factors which were not specifically covered in this study. These would be shielding material, source energy spectrum, configurations of source and detector, ratio of source-detector separation distance to shield diameter, and shield placement. In actual design, one would consider the gamma dose rate and expansion in connection with splitting (i.e., breaking the shield into several sections and re-distributing these sections).

## 3.2 Split Shield Considerations

The results of a Monte Carlo study on the effect of splitting and placement of shadow shield configurations appropriate to manned nuclear rocket and ion-propelled vehicles has been reported by Aronson et al. in Reference 9. In that study, the geometry of the source-shield-detector configuration was axially symmetric and consisted of the source, a disc; the shield, a set of cylinders placed end-to-end; and the detector, a cylindrical cavity. The study considered both hydrogenous and nonhydrogenous shields. On pages 21, 22, and 23 of Reference 9 are listed ten tentative conclusions which Aronson et al. had obtained from their Monte Carlo results. The first three of these conclusions are (1) the neutron flux transmitted through a nonhydrogenous shield can be reduced appreciably by splitting the shield into two or more segments, (2) the dose reduction factor increases as the ratio of the source-detector separation distance to the shield radius increases until the ratio is so large that the unscattered flux predominates in the dose, and (3) the dose reduction due to splitting the shield increases with the thickness of the shield, up to some limiting thickness.

These conclusions are based mainly on their Monte Carlo results for a carbon shield in which the shield thickness was four feet and the disc source was emitting neutrons with energies in the fission spectrum and in directions defined by a cosine distribution. The source-detector separation distance used in the carbon-shield problems of interest in this discussion was 75 feet and the shield radius was five feet. These problems were run for cases where (1) the shield was located midway between the source and detector,

(2) the shield was split into two equal segments with one segment located one-third the way from the source to the detector and the other segment two-thirds of the way, and (3) the shield split into four equal segments, with a segment located at 1/5, 2/5, 3/5, and 4/5 of the distance between the source and detector. The configurations for these problems are denoted as (1/2), (1/3, 2/3), and (1/5, 2/5, 3/5, 4/5), respectively. The results for each configuration are shown in Table V.

TABLE V

NEUTRON FLUXES FOR VARIOUS SHIELD CONFIGURATIONS

| Configuration | Uncollided Flux ($n/cm^2$-sec) | Total Flux ($n/cm^2$-sec) |
|---|---|---|
| (1/2) | $2.5 \times 10^{-11}$ | $2.4 \times 10^{-10}$ |
| (1/3, 2/3) | $1.92 \times 10^{-11}$ | $9.6 \times 10^{-11}$ |
| (1/5, 2/5, 3/5, 4/5) | $2.4 \times 10^{-11}$ | $7.9 \times 10^{-11}$ |

The results shown for Configuration (1/3, 2/3) are the average of the results given in Table 6 of Reference 9 for problems 62 and 62A. These results show that splitting the shield into two segments reduces the flux in the detector cavity by 60% and that splitting it into four segments reduces the flux by 67%.

The uncollided flux should be the same for all three configurations. A hand calculation performed later in this study to determine the direct-beam component gave $2.88 \times 10^{-11}$ $n/cm^2$-sec as the uncollided flux, so that the uncollided fluxes in Table V appear to be underestimates, especially that for Configuration (1/3, 2/3).

An examination of the geometries shown in Figure 21 for Configurations (1/2) and (1/3, 2/3) reveals that none of the neutrons incident on the shield in Configuration (1/2) will enter the shield at an angle greater than 16 deg. Similarly, there will not be any neutrons entering the shield of Configuration (1/3, 2/3) at angles greater than 23 deg. It appears, then, that the results for the monodirectional source, as described in Section 3.1.4, can be used to examine these configurations. These results indicate that expansion of the shield toward the source reduces the flux at the detector, and that expansion of the shield toward the detector increases the detected flux. In expanding the shield toward the detector, it was noted that the effect of an increase in shield transverse leakage was less than the effect of moving the scattering centers closer to the detector.

Another thing to note about the two configurations illustrated in Figure 21 is that twice as many source neutrons will enter the shield in Configuration (1/3, 2/3) as will enter the shield in Configuration (1/2). It is not evident that the additional transverse leakage that might be expected in Configuration (1/3, 2/3) over that in Configuration (1/2) will be great enough to overcome the effect of adding more source particles into the shield system and the effect of moving the scattering points in the second section of Configuration (1/3, 2/3) toward the detector.

In order to settle some of the questions raised on the magnitude of each of the effects just discussed, problems using the geometries

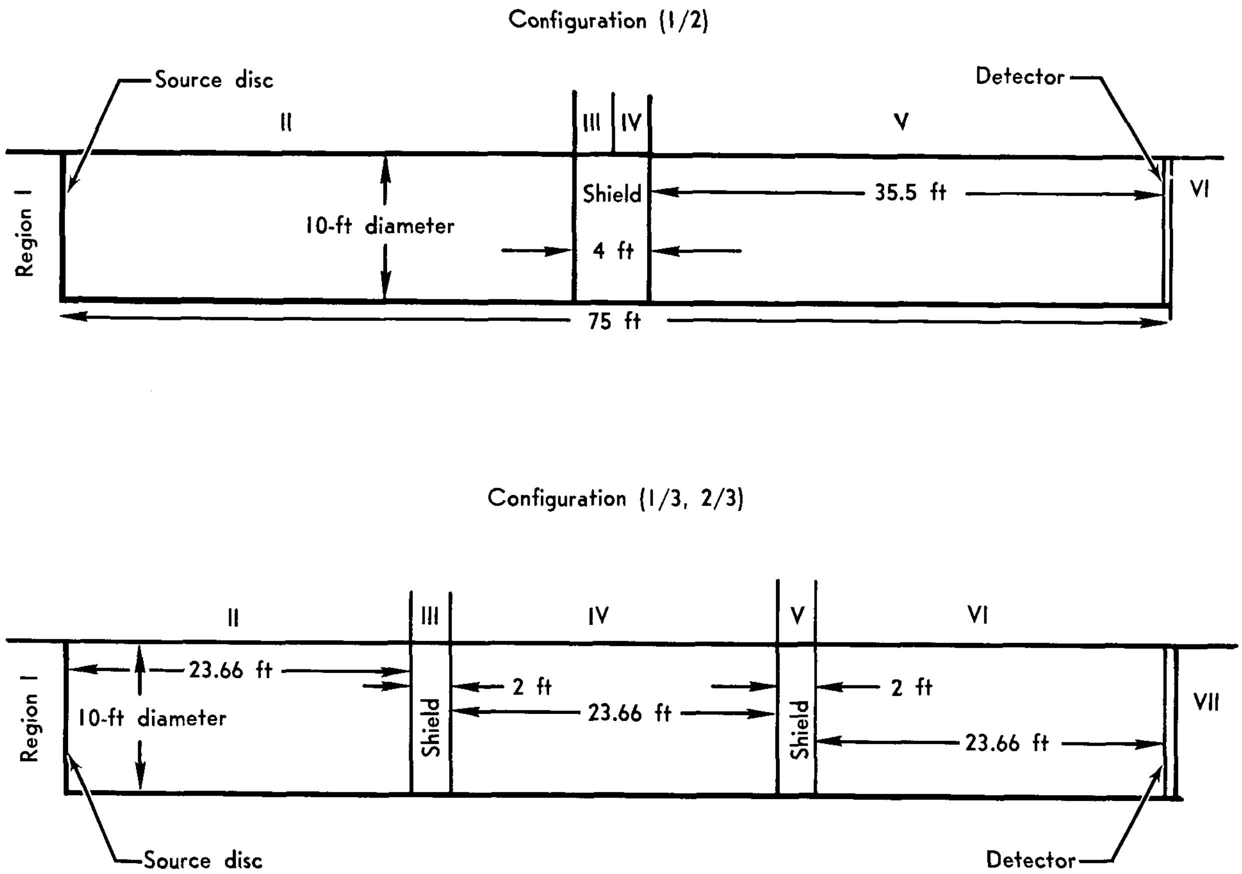



**Figure 21. Geometries for Configurations (1/2) and (1/3, 2/3)**

of Configurations (1/2) and (1/3, 2/3) were prepared and run on the General Electric Flexible Monte Carlo Code FMC-N (Ref. 10). The results of the FMC-N calculations gave $3.52 \times 10^{-9}$ n/cm$^2$-sec for Configuration (1/2) and $5.59 \times 10^{-9}$ n/cm$^2$-sec for Configuration (1/3, 2/3). It is to be noted that these fluxes are considerably higher than those given in Table V and that the flux in the detector cavity of Configuration (1/3, 2/3) is higher than that in the cavity of Configuration (1/2).

In addition to giving the total fluxes, the FMC-N code prints out the number current leaking out of the main geometry into outside regions. The flux estimator used in the FMC-N total flux calculations is based on the method of statistical estimation, whereas the current-leakage estimator is an analog estimator. These current-leakage results, normalized to one particle per second entering the shield, show that the leakage into Outside Regions III and IV of Configuration (1/2) is approximately the same as the leakage into Outside Regions III, IV, and V of Configuration (1/3, 2/3). The fraction of the neutron leakage into Outside Region VII of Configuration (1/3, 2/3) per neutron incident on the shield was about 80% of the leakage into Outside Region VI of Configuration (1/2).

Based on the fact that twice as many of the neutrons leaving the source will enter the first shield segment of Configuration (1/3, 2/3) as will enter the shield in Configuration (1/2), it was found that about 40% more neutrons will enter Outside Region VII of Configuration (1/3, 2/3) as will enter Outside Region VI of Configuration (1/2).

The ratio of the leakages into Outside Region VI of Configuration (1/2) and Outside Region VII of Configuration (1/3, 2/3) is approximately the same as the ratio obtained from the expectation fluxes in the detector cavities of both configurations.

The differences in the magnitudes of the fluxes computed by the use of FMC-N and those shown in Table V, as well as the fact that the FMC-N results do not support the conclusions given in Reference 9, are disturbing. Because of the importance of the problem of obtaining a minimum-weight reactor shield for spacecraft applications, it is recommended that further work be performed to investigate the concept of split shielding.

# IV. CONCLUSIONS AND RECOMMENDATIONS

## 4.1 Radiator Scattering

For the particular type of spacecraft geometries treated in Section 2.4.2 of this report, it will be necessary to shield against the scattered neutrons as well as the direct-beam neutrons and gammas. The scattered neutrons, due to low-energy radiation leaking from the reactor, will be somewhat easier to shield against than the direct-beam neutrons. As can be seen from the results in Section 2.3.2, it will not be necessary for the reactor shield to be such that all parts of the radiator are shielded to the same degree. Considerable savings in weight can therefore be made by properly shaping the shield. It may also be possible to obtain a minimum-weight shield by placing shielding around the payload.

Since the scattered neutron flux is a significant component, improvements in the methods for calculating this component should be developed in order to remove some of the uncertainties discussed in Section 2.4.1.

With regard to the study of radiator scattering of neutrons, the following recommendations are made.

1. The effect of shielding should be considered. In particular, the possibility of obtaining a minimum-weight shield by proper shaping and placement should be investigated.
2. The methods of analysis should be improved by determining the importance of attenuation in the scattering calculations; if found to important, a method of including attenuation in the scattering calculations should be provided.

3. The development and use of improved methods for calculating neutron source terms should be considered.

4. Calculations should be performed to determine the secondary gamma fluxes due to neutron activation of the radiator. Program S06 can be used in its present form to carry out these calculations for both prompt and decay gammas.

## 4.2 Direct-Beam Shielding

The following recommendations are made concerning the study of direct-beam shielding:

1. The effect of shield placement per se should be given further study.

2. The combined effects of splitting, expanding, and placement should be studied with realistic spacecraft geometries and SNAP reactor leakage spectra.

3. Direct-beam shielding should be considered in connection with radiator scattering, since the location of the direct-beam shielding could have a marked effect on the neutron flux incident on the radiators.

4. Effort should be directed toward resolving the apparent differences between TRG and GD/FW results for the split carbon shield discussed in Section 3.2. (This also points up the need for further study of shield-splitting, expansion, and placement.)

# APPENDIX A

## FORTRAN STATEMENTS FOR S06

## FORTRAN Statements for S06

```
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*     LIST8
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      DIMENSION
     1SOURCE(15)     ,PHIK(20)     ,PHIK2(20)    ,PHIL(15)    ,PHI(20,15)    ,
C
     2SUMLL(5)       ,P(10)        ,SX(100)      ,SY(100)     ,SIG(5)        ,
C
     3R1(20)         ,ALPHA1(20),F(25,15,10),X0(20)       ,Y0(20)        ,
C
     4DELX(20)       ,DELY   (20),ATOM(5)      ,SIGEL(15,25),S(15,20,20),
C
     5NPX(20)        ,NPY(20)      ,KT(20)       ,LLMAX(25)     ,YLIB(5)     ,
     6XLIB(25),LBRD(5)
      COMMON
     1SOURCE         ,PHIK         ,PHIK2        ,PHIL        ,PHI     ,
C
     2SUMLL          ,P            ,SX           ,SY          ,SIG     ,
C
     3R1             ,ALPHA1       ,F            ,X0          ,Y0      ,
C
     4DELX           ,DELY         ,ATOM         ,SIGEL         ,S     ,
C
     5NPX            ,NPY          ,KT           ,LLMAX         ,YLIB,
     6XLIB           ,L1           ,XLIBNO       ,LIBNO        ,XSLIB,
C
     7LB             ,YSLIB        ,LBRD         ,LBCK          ,NU    ,
C
     8L1             ,XID
C
      COMMON
     1NA    ,X1    ,Y1    ,DX    ,NX    ,NE    ,THICK,NX1    ,VI    ,X     ,
C
     2DY    ,NY    ,NYM   ,XNY   ,SLOPE,NY1   ,VJ    ,Y     ,ALPHA,RSQ   ,
C
     3R     ,DSQ   ,SEP   ,D     ,THETA,FMU   ,F1    ,PHIT  ,FNPX ,XM    ,
C
     4FNPY  ,YM    ,MMAX  ,NMAX  ,CON1  ,CON2  ,CON3  ,CON4  ,LLMAX1 ,XLL ,
C
     5NUMAX,SIGMA
C     READ IN LIBRARY DATA
C
C
C
      LB=0
      CALL LIB1(L1)
      GO TO (10 ,1000 ) ,L1
   10 CALL LIB    (3HS06    ,XLIBNO   )
C     READ  CONTROL  CARD
      READ  20,  LIBNO
   20 FORMAT (6I10)
      IF (LIBNO)   900 , 900   , 30
   30 GO TO  (35   ,200 )  ,        LIBNO
C
```

```
C       READ IN SOURCE LIBRARY (TYPE 1 LIBRARY )                   0055 S06
C                                                                  0056 S06
        READ 40 ,NE   ,MMAX , NMAX                                 0057 S06
     40 FORMAT    (3I10)                                           0058 S06
        READ 45 , (R1(M) , M=1 ,MMAX )                             0059 S06
        READ 45 , (ALPHA1 (N)   , N=1 ,NMAX )                      0060 S06
     45 FORMAT      (6F10.3)                                       0061 S06
C                                                                  0062 S06
        DO 50   L=1 , NE                                           0063 S06
        DO 50   N=1 , NMAX                                         0064 S06
        READ 60 ,       (  S(L,M,N)   , M = 1 , MMAX )             0065 S06
     60 FORMAT    (1P6E10.3)                                       0066 S06
     50 CONTINUE                                                   0067 S06
        XSLIB  = XLIBNO                                            0068 S06
        GO TO  10                                                  0069 S06
C                                                                  0070 S06
C       READ IN CROSS SECTION DATA  (TYPE 2  LIBRARIES )           0071 S06
    200 LB=LB+1                                                    0072 S06
C                                                                  0073 S06
        XLIB(LB) = XLIBNO                                          0074 S06
        READ 210, LLMAX(LB)   , NE                                 0075 S06
    210 FORMAT   (2I10)                                            0076 S06
        READ 220,         (  SIGEL(L,LB) , L=1, NE )               0077 S06
    220 FORMAT    ( 1P6E10.3)                                      0078 S06
C                                                                  0079 S06
        LLMAXX=LLMAX(LB)                                           0084 S06
        DO 230    L=1   , NE                                       0085 S06
        READ 225 , (F(LB , L , LL) , LL=1 , LLMAXX)                0086 S06
    225 FORMAT     ( 1P6E10.3)                                     0087 S06
    230 CONTINUE                                                   00871S06
        GO TO 10                                                   0088 S06
C                                                                  0089 S06
C                                                                  0090 S06
C                                                                  0091 S06
C                                                                  0092 S06
    900 PRINT  910                                                 0093 S06
    910 FORMAT (42H1 THE FOLLOWING LIBRARIES HAVE BEEN LOADED )    0094 S06
C                                                                  0095 S06
        PRINT 920   ,XSLIB   ,( XLIB(I) , I=1 , LB )               0096 S06
    920 FORMAT   (1H0 , 6F10.0)                                    0097 S06
C                                                                  0098 S06
C       READ IN AND TEST PROBLEM CONTROL NUMBERS                   0099 S06
C                                                                  0100 S06
        BACKSPACE 9                                                0101 S06
   1000 CALL SETUP   (3HS06 , XID )                                0102 S06
        READ 20 ,LIBNO                                             0103 S06
C                                                                  0104 S06
C                                                                  0105 S06
C                                                                  0106 S06
        READ 320 , NA ,     NUMAX ,LLMAX1 ,NE ,SLOPE               0107 S06
    320 FORMAT     (4I10,F10.0 )                                   0108 S06
C                                                                  0109 S06
        READ 330 , SEP , YSLIB ,THICK                              0110 S06
    330 FORMAT   ( E10.4 , E10.4 , F10.0 )                         0111 S06
C                                                                  0112 S06
        READ 340 , (NPX(K) ,K=1,NA)                                0113 S06
```

```
      READ 340 , (NPY(K) ,K=1,NA)                                          0114 S06
  340 FORMAT    (6I10)                                                     0115 S06
      READ 340  ,(KT(K) ,K=1 ,NA )                                         0116 S06
      READ 350  ,(XO(K) ,K=1 ,NA )                                         0117 S06
      READ 350  ,(YO(K) ,K=1 ,NA )                                         0118 S06
      READ 350  ,(DELX (K) ,K=1  ,NA )                                     0119 S06
      READ 350  ,(DELY (K) ,K=1  ,NA )                                     0120 S06
  350 FORMAT     (6F10.3 )                                                 0121 S06
      READ 360,(ATOM(NU) , NU=1, NUMAX )                                   0122 S06
  360 FORMAT   (6E10.4)                                                    0123 S06
      READ 370,        ( YLIB (NU)    ,NU=1 ,NUMAX )                       0124 S06
  370 FORMAT  (  6F10.3 )                                                  0126 S06
C                                                                          0127 S06
C                                                                          0128 S06
      IF (XSLIB - YSLIB )  9000 ,1100 ,9000                                0130 S06
 9000 PRINT 9010                                                           0131 S06
 9010 FORMAT  (17H1  WRONG LIBRARY )                                       0132 S06
      CALL END 9                                                           0134 S06
C                                                                          0135 S06
 1100 LBCK =0                                                              0136 S06
      DO 1160    I=1 , NUMAX                                               0137 S06
      DO 1150    J=1 , LB                                                  0138 S06
C                                                                          0139 S06
      IF (XLIB(J) -YLIB(I))      1150 ,1140 ,1150                          0140 S06
 1140 LBRD(I) = J                                                          0141 S06
      LBCK =LBCK + 1                                                       0142 S06
 1150 CONTINUE                                                             0143 S06
 1160 CONTINUE                                                             0144 S06
C                                                                          0145 S06
C                                                                          0146 S06
      IF  (LBCK -NUMAX)  9100 ,1200 ,9100                                  0147 S06
 9100 PRINT 9110                                                           0148 S06
 9110 FORMAT (52H1 LIBRARIES LOADED DO NOT AGREE WITH THOSE REQUESTED )    0149 S06
C                                                                          0150 S06
C                                                                          0151 S06
 1200 CALL SUB M                                                           0152 S06
      PRINT  9250,  PHIT  .                                                0153 S06
 9250 FORMAT (29H TOTAL FLUX AT DETECTOR IS    , 1P1E10.3 )                0154 S06
C                                                                          0155 S06
      PRINT  9260                                                          0156 S06
 9260 FORMAT(43H0 FLUX SPECTRUM AT DETECTOR BY INCREASING L)               0157 S06
      PRINT  9270,(PHIL(L) ,L=1, NE)                                       0158 S06
 9270 FORMAT (1H0,1P6E10.3)                                                0159 S06
C                                                                          0160 S06
      PRINT  9280                                                          0161 S06
 9280 FORMAT(43H0 TOTAL FLUX FROM SUB AREAS BY INCREASING K)               0162 S06
      PRINT  9290,(PHIK(K) ,K=1 ,NA)                                       0163 S06
 9290 FORMAT (1H0,1P6E10.3)                                                0164 S06
C                                                                          0165 S06
      PRINT  9300                                                          0166 S06
 9300 FORMAT(39H0 FRACTION OF TOTAL FLUX FROM SUB AREAS)                   0170 S06
      PRINT 9310 , (PHIK2(K) , K=1, NA )                                   0171 S06
 9310 FORMAT (1H0,1P6E10.3)                                                0172 S06
C                                                                          0173 S06
      DO  9311   K=1 , NA                                                  01731S06
      PRINT  9312 ,K                                                       01732S06
```

```
9312 FORMAT (36H0 FLUX BY INCREASING L FOR SUB AREA ,I2)              01733S06
     PRINT  9313, ( PHI (K,L) , L= 1, NE )                            01734S06
9313 FORMAT  (1H0,1P6E10.3)                                           01735S06
9311 CONTINUE                                                         01736S06
     IF (SENSE SWITCH 2 ).   9315 , 9375                              0174 S06
9315 PRINT 9320                                                       0178 S06
9320 FORMAT (48H0 COORDINATES OF LOWER LEFT CORNER OF SUB AREAS )     0179 S06
     PRINT 9330                                                       0180 S06
9330 FORMAT (37H0      K         X0(K)       Y0(K)         )          0181 S06
     PRINT 9340, (K ,X0(K) ,Y0(K)   ,K=1 ,NA)                         0182 S06
9340 FORMAT (1H0, I7 ,1F14.2 , 1F11.2)                                0183 S06
     PRINT 9370   , SEP                                               0192 S06
9370 FORMAT (42H0 SOURCE DETECTOR SEPARATION DISTANCE IS  ,1PE10.3 )  0193 S06
9375 GO TO  1000                                                      0198 S06
     END                                                              0199 S06
*    STRAP FORTRAN                                                    M001 S06
*    LIST8
CS06SBM          JACK GRIGSBY (E E JONES  2895)                       M002 S06
EZE  EZEC1 EZED2 EZED3 EOF   EZED5 EZEB1AEZEB3 EZEB4 EZEB1AEZEB5
     SUBROUTINE SUBM                                                  M003 S06
     DIMENSION                                                        0004 S06
    1SOURCE(15)    ,PHIK(20)    ,PHIK2(20)    ,PHIL(15)    ,PHI(20,15)   ,   0005 S06
C                                                                     0006 S06
    2SUMLL(5)      ,P(10)       ,SX(100)      ,SY(100)     ,SIG(5)       ,   0007 S06
C                                                                     0008 S06
    3R1(20)        ,ALPHA1(20),F(25,15,10),X0(20)       ,Y0(20)          ,   0009 S06
C                                                                     0010 S06
    4DELX(20)      ,DELY   (20),ATOM(5)       ,SIGEL(15,25),S(15,20,20), 0011 S06
C                                                                     0012 S06
    5NPX(20)       ,NPY(20)     ,KT(20)       ,LLMAX(25)    ,YLIB(5)     ,   0013 S06
    6XLIB(25),LBRD(5)                                                 0014 S06
     COMMON                                                           0015 S06
    1SOURCE        ,PHIK        ,PHIK2        ,PHIL        ,PHI    ,  0016 S06
C                                                                     0017 S06
    2SUMLL         ,P           ,SX           ,SY          ,SIG    ,  0018 S06
C                                                                     0019 S06
    3R1            ,ALPHA1      ,F            ,X0          ,Y0     ,  0020 S06
C                                                                     0021 S06
    4DELX          ,DELY        ,ATOM         ,SIGEL         ,S    ,  0022 S06
C                                                                     0023 S06
    5NPX           ,NPY         ,KT           ,LLMAX         ,YLIB,   0024 S06
    6XLIB          ,L1          ,XLIBNO       ,LIBNO        ,XSLIB,   0025 S06
C                                                                     0026 S06
    7LB            ,YSLIB       ,LBRD         ,LBCK          ,NU   ,  0027 S06
C                                                                     0028 S06
    8L1            ,XID                                               0029 S06
C                                                                     0030 S06
     COMMON                                                           0031 S06
    1NA    ,X1    ,Y1    ,DX    ,NX    ,NE    ,THICK,NX1   ,VI    ,X     ,   0032 S06
C                                                                     0033 S06
    2DY    ,NY    ,NYM   ,XNY   ,SLOPE,NY1    ,VJ    ,Y     ,ALPHA,RSQ   ,   0034 S06
C                                                                     0035 S06
    3R     ,DSQ   ,SEP   ,D     ,THETA,FMU    ,F1    ,PHIT  ,FNPX  ,XM    ,   0036 S06
C                                                                     0037 S06
    4FNPY  ,YM    ,MMAX  ,NMAX  ,CON1  ,CON2  ,CON3  ,CON4  ,LLMAX1 ,XLL  ,   0038 S06
C                                                                     0039 S06
```

```
     5NUMAX,SIGMA                                                       0040 S06
      DO 9000 K=1  , NA                                                 M042 S06
      X1=X0(K)                                                          M043 S06
      Y1=Y0(K)                                                          M044 S06
      DX=DELX(K)                                                        M045 S06
      NX=NPX(K)                                                         M046 S06
C                                                                       M047 S06
      DO 8100 L=1,NE                                                    M048 S06
      PHI(K,L)=0.0                                                      M049 S06
 8100 CONTINUE                                                          M050 S06
                                                                        M051 S06
C     CALCULATE SX FOR ALL I                                            M052 S06
C                                                                       M053 S06
      SX(1)= THICK     *DX/3.0                                          M054 S06
      SX(NX) =SX(1)                                                     M055 S06
      NX1=NX-1                                                          M056 S06
      DO 8200 I=2,NX1                                                   M057 S06
      VI=I                                                              M058 S06
      SX(I)=SX(1)*(MODF(2.0*(VI+1.0),4.0)+2.0)                          M059 S06
 8200 CONTINUE                                                          M060 S06
                                                                        M061 S06
C     DO LOOP FOR SUMMING OVER X                                        M062 S06
      NPXX=NPX(K)                                                       M063 S06
      DO 8000 I=1,NPXX                                                  M064 S06
      VI=I                                                              M065 S06
      X=X1+(VI-1.0)*DX                                                  M066 S06
C     GENERATE Y MESH                                                   M067 S06
      IF(KT(K)-1 )          7100 ,7200 ,7200                            M068 S06
 7100 DY=DELY(K)                                                        M069 S06
      NY=NPY(K)                                                         M070 S06
      GO TO 7300                                                        M071 S06
C                                                                       M072 S06
 7200 NY=3+(I-1)*2                                                      M073 S06
      NYM=NY-1                                                          M074 S06
      XNY=NYM                                                           M075 S06
      DY=SLOPE*(X-X1)/XNY                                               M076 S06
      NPY(K) = NY                                                       M0761S06
      GO TO 7300                                                        M077 S06
C     CALCULATE SY FOR ALL J                                            M082 S06
 7300 SY(1) =DY/3.0                                                     M083 S06
      SY(NY) = SY(1)                                                    M0831S06
      NY1=NY-1                                                          M084 S06
      DO   7400  J=2,NY1                                                M085 S06
      VJ =J                                                             M086 S06
      SY(J)  =  SY(1) * (MODF(2.0 * (VJ+1.0), 4.0) + 2.0)               M087 S06
 7400 CONTINUE                                                          M088 S06
      NPYY =  NPY(K)                                                    M090 S06
      DO 7000 J=1,NPYY                                                  M091 S06
      VJ=J                                                              M092 S06
      Y=Y1+(VJ-1.0)*DY                                                  M093 S06
C                                                                       M094 S06
      IF ( X )  7310, 7320 , 7330                                       M095 S06
 7310 ALPHA = 90.0 + ( ATANF (-X/Y ) ) * 57.296                         M0952S06
      GO TO 7311                                                        M0953S06
 7320 ALPHA =  90.0                                                     M0955S06
      GO TO 7311                                                        M0956S06
```

```
7330 ALPHA = ( ATANF (Y/X ). ) * 57.296                                M0958S06
     GO TO 7311                                                       M0959S06
                                                                      M096 S06
7311 RSQ          =X**2  +  Y**2                                      M097 S06
C                                                                     M098 S06
     R            =SQRTF(RSQ)                                         M099 S06
     CALL SUB1 (K,I,J)                                                M100 S06
     DSQ          =RSQ + SEP**2 -2.0*SEP*X                            M101 S06
C    SUB1 IS SOURCE CALCULATION                                       M102 S06
     D            =SQRTF(DSQ)                                         M103 S06
     FMU = ( SEP**2 - RSQ - DSQ ) / ( 2.0*R*D)                        M104 S06
     F1        = SX(I)* SY(J)/DSQ                                     M106 S06
C                                                                     M107 S06
     IF  (SENSE SWITCH 3 )  7430 , 6000                               M108 S06
7430 PRINT 7435 ,K ,I ,J                                              M109 S06
7435 FORMAT (44H0 X,Y,ALPHA,R,D,THETA,FMU, AND F1 FOR K I J ,I5,I5,I5 )M110 S06
     PRINT 7440 ,X,Y,ALPHA,R,D,THETA,FMU, F1                          M111 S06
7440 FORMAT (1H0,1P8E10.3)                                            M112 S06
6000 CALL SUB2 (K,I,J)                                                M114 S06
C    SUB2 IS NEUTRON CALCULATION  CONTAINS DO LOOP OVER ENERGY        M115 S06
7000 CONTINUE                                                         M121 S06
8000 CONTINUE                                                         M122 S06
9000 CONTINUE                                                         M123 S06
C                                                                     M124 S06
C                                                                     M125 S06
C    CALCULATE TOTAL AND FRACTIONAL FLUXES                            M126 S06
7425 PHIT =0.0                                                        M127 S06
     DO  9100   K=1 , NA                                              M128 S06
     PHIK(K)  =0.0                                                    M129 S06
C                                                                     M130 S06
     DO  9050   L=1 , NE                                              M131 S06
     PHIK(K)  =PHIK(K)  +PHI(K,L)                                     M132 S06
9050 CONTINUE                                                         M133 S06
C                                                                     M134 S06
     PHIT =PHIT + PHIK(K)                                             M135 S06
9100 CONTINUE                                                         M136 S06
C                                                                     M137 S06
     DO  9150   K=1 ,NA                                               M138 S06
C                                                                     M139 S06
     PHIK2(K) = PHIK(K)/PHIT                                          M140 S06
9150 CONTINUE                                                         M141 S06
     DO 9200   L=1 ,NE                                                M148 S06
C                                                                     M149 S06
     PHIL(L) =0.0                                                     M150 S06
C                                                                     M151 S06
     DO 9175   K=1 , NA                                               M152 S06
C                                                                     M153 S06
     PHIL(L) = PHIL(L)+ PHI(K,L)                                      M154 S06
9175 CONTINUE                                                         M155 S06
9200 CONTINUE                                                         M156 S06
9207 RETURN                                                           M176 S06
     END                                                              M177 S06
*    STRAP FORTRAN                                                    1001 S06
*    LIST8
CS06SB1         JACK GRIGSBY   ,E E JONES  2895)                      1002 S06
EZE  EZEC1 EZED2 EZED3 EOF   EZED5 EZFB1AEZEB3 EZEB4 EZEB1AEZEB5
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      SUBROUTINE SUB1(K,I,J)                                                2003 S06
      DIMENSION                                                             0004 S06
     1SOURCE(15)    ,PHIK(20)    ,PHIK2(20)    ,PHIL(15)    ,PHI(20,15)    ,  0005 S06
C                                                                           0006 S06
     2SUMLL(5)      ,P(10)       ,SX(100)      ,SY(100)     ,SIG(5)        ,  0007 S06
C                                                                           0008 S06
     3R1(20)        ,ALPHA1(20),F(25,15,10),X0(20)      ,Y0(20)           ,  0009 S06
C                                                                           0010 S06
     4DELX(20)      ,DELY  (20),ATOM(5)     ,SIGEL(15,25),S(15,20,20),      0011 S06
C                                                                           0012 S06
     5NPX(20)       ,NPY(20)     ,KT(20)       ,LLMAX(25)    ,YLIB(5)      ,  0013 S06
     6XLIB(25),LBRD(5)                                                      0014 S06
      COMMON                                                                0015 S06
     1SOURCE        ,PHIK        ,PHIK2        ,PHIL        ,PHI    ,       0016 S06
C                                                                           0017 S06
     2SUMLL         ,P           ,SX           ,SY          ,SIG    ,       0018 S06
C                                                                           0019 S06
     3R1            ,ALPHA1      ,F            ,X0          ,Y0     ,       0020 S06
C                                                                           0021 S06
     4DELX          ,DELY        ,ATOM         ,SIGEL         ,S    ,       0022 S06
C                                                                           0023 S06
     5NPX           ,NPY         ,KT           ,LLMAX         ,YLIB,        0024 S06
     6XLIB          ,L1          ,XLIBNO       ,LIBNO         ,XSLIB,       0025 S06
C                                                                           0026 S06
     7LB            ,YSLIB       ,LBRD         ,LBCK          ,NU    ,      0027 S06
C                                                                           0028 S06
     8L1            ,XID                                                    0029 S06
C                                                                           0030 S06
      COMMON                                                                0031 S06
     1NA    ,X1    ,Y1    ,DX    ,NX    ,NE    ,THICK,NX1   ,VI    ,X      ,  0032 S06
C                                                                           0033 S06
     2DY    ,NY    ,NYM   ,XNY   ,SLOPE,NY1   ,VJ    ,Y     ,ALPHA,RSQ    ,  0034 S06
C                                                                           0035 S06
     3R     ,DSQ   ,SEP   ,D     ,THETA,FMU   ,F1    ,PHIT  ,FNPX ,XM     ,  0036 S06
C                                                                           0037 S06
     4FNPY  ,YM    ,MMAX  ,NMAX  ,CON1  ,CON2  ,CON3  ,CON4  ,LLMAX1  ,XLL ,  0038 S06
C                                                                           0039 S06
     5NUMAX,SIGMA                                                           0040 S06
      IF (R-R1(1)) 20, 2 ,2                                                 1042 S06
    2 IF (ALPHA -ALPHA1(1))  20,5,5                                         1043 S06
C                                                                           1044 S06
    5 DO 10  M=1 ,MMAX                                                      1045 S06
      IF (R1(M)-R )   10 ,40 ,40                                            1046 S06
   10 CONTINUE                                                              1047 S06
   20 PRINT 30                                                              1048 S06
   30 FORMAT ( 48H A VALUE OF R1 OR ALPHA1 CALLS FOR EXTRAPOLATION)         1049 S06
      PRINT 31,K,L,I,J                                                      10491S06
   31 FORMAT (31H0  X,Y,R,ALPHA FOR K,L,I,J OF  4I5 )                       10492S06
      PRINT 32,  X,Y,R,ALPHA                                                10493S06
   32 FORMAT (1H0 ,1P4E10.3 )                                               10494S06
      PRINT 33                                                              10495S06
   33 FORMAT (33H0  MIN AND MAX INPUT R AND ALPHA )                         10496S06
      PRINT 34, (R1(1),R1(MMAX),ALPHA1(1),ALPHA1(NMAX) )                    10497S06
   34 FORMAT (1H0 ,1P4E10.3)                                                10498S06
      CALL AUTO                                                             1050 S06
   40 DO 50    N=1 , NMAX                                                   1051 S06
```

```
      IF (ALPHA1(N)  -ALPHA)      50 ,60 ,60                            1052 S06
   50 CONTINUE                                                          1053 S06
      GO TO 20                                                          1054 S06
   60 CON1 =(ALPHA-ALPHA1(N-1))/(ALPHA1(N)-ALPHA1(N-1))                 1055 S06
C                                                                       1056 S06
      DO 100 L=1 ,NE                                                    1060 S06
      CON3=S(L,M-1,N-1) +CON1*(S(L,M-1,N)-S(L,M-1,N-1))                 1061 S06
C                                                                       1062 S06
      CON4=S(L,M,N-1)   +CON1*(S(L,M,N)-S(L,M,N-1))                     1063 S06
C                                                                       1064 S06
      SOURCE(L)=(CON3 * R1(M-1)**2+CON4 *R1(M)**2 ) / (2.0*R**2)        1065 S06
C                                                                       1066 S06
  100 CONTINUE                                                          10661S06
      IF (SENSE SWITCH 4 )      65   ,110                               1067 S06
C                                                                       1068 S06
   65 PRINT  70  , K , I , J                                            1069 S06
   70 FORMAT (37H0 SOURCES FOR ALL L FOR  K I AND J OF,I5 ,I5 ,I5 )     1070 S06
      PRINT 75 , ( SOURCE(L), L=1 , NE )                                1071 S06
   75 FORMAT    ( 1P6E10.3)                                             1072 S06
C                                                                       1073 S06
  110 RETURN                                                            1075 S06
      END                                                               1076 S06
*     STRAP FORTRAN                                                     2001 S06
*     LIST8
CS06SB2           JACK GRIGSBY (E E JONES  2895)                        2002 S06
EZE   EZEC1 EZED2 EZED3 EOF   EZED5 EZEB1AEZEB3 EZEB4 EZEB1AEZEB5
      SUBROUTINE SUB2 (K,I,J)                                           2003 S06
      DIMENSION                                                         0004 S06
     1SOURCE(15)    ,PHIK(20)    ,PHIK2(20)    ,PHIL(15)    ,PHI(20,15)   ,  0005 S06
C                                                                       0006 S06
     2SUMLL(5)      ,P(10)       ,SX(100)      ,SY(100)     ,SIG(5)       ,  0007 S06
C                                                                       0008 S06
     3R1(20)        ,ALPHA1(20),F(25,15,10),X0(20)     ,Y0(20)        ,  0009 S06
C                                                                       0010 S06
     4DELX(20)      ,DELY  (20),ATOM(5)        ,SIGEL(15,25),S(15,20,20),  0011 S06
C                                                                       0012 S06
     5NPX(20)       ,NPY(20)     ,KT(20)       ,LLMAX(25)     ,YLIB(5)    ,  0013 S06
     6XLIB(25),LBRD(5)                                                  0014 S06
      COMMON                                                            0015 S06
     1SOURCE        ,PHIK        ,PHIK2        ,PHIL        ,PHI    ,   0016 S06
C                                                                       0017 S06
     2SUMLL         ,P           ,SX           ,SY          ,SIG    ,   0018 S06
C                                                                       0019 S06
     3R1            ,ALPHA1      ,F            ,X0          ,Y0     ,   0020 S06
C                                                                       0021 S06
     4DELX          ,DELY        ,ATOM         ,SIGEL         ,S    ,   0022 S06
C                                                                       0023 S06
     5NPX           ,NPY         ,KT           ,LLMAX         ,YLIB,    0024 S06
     6XLIB          ,L1          ,XLIBNO       ,LIBNO        ,XSLIB,    0025 S06
C                                                                       0026 S06
     7LB            ,YSLIB       ,LBRD         ,LBCK          ,NU   ,   0027 S06
C                                                                       0028 S06
     8L1            ,XID                                                0029 S06
C                                                                       0030 S06
      COMMON                                                            0031 S06
     1NA    ,X1    ,Y1    ,DX    ,NX    ,NE    ,THICK,NX1   ,VI    ,X      ,  0032 S06
```

```
C                                                                        0033 S06
     2DY    ,NY    ,NYM   ,XNY   ,SLOPE,NY1   ,VJ    ,Y     ,ALPHA,RSQ   ,  0034 S06
C                                                                        0035 S06
     3R     ,DSQ   ,SEP   ,D     ,THETA,FMU   ,F1    ,PHIT  ,FNPX  ,XM    ,  0036 S06
C                                                                        0037 S06
     4FNPY  ,YM    ,MMAX  ,NMAX  ,CON1  ,CON2  ,CON3  ,CON4  ,LLMAX1 ,XLL  ,  0038 S06
C                                                                        0039 S06
     5NUMAX,SIGMA                                                        0040 S06
C     DIMENSION AND COMMON GO HERE                                       2041 S06
C                                                                        2042 S06
C     CALCULATE LEGENDRE COEFICIENTS FOR CROSS SECTION CALCULATION      2043 S06
      P(1)=1.0                                                           2045 S06
      P(2)=FMU                                                           2047 S06
C                                                                        2048 S06
      IF (LLMAX1 -2)    100 ,100 ,60                                     2049 S06
   60 DO 70  LL= 3 ,LLMAX1                                               2050 S06
      XLL=LL                                                             2051 S06
C                                                                        2052 S06
      P(LL) =(     (2.0*XLL-3.0) *  FMU * P(LL-1) -(XLL-2.0)*P(LL-2))/   2053 S06
     1             (XLL-1.0)                                             2054 S06
C                                                                        2055 S06
   70 CONTINUE                                                           2056 S06
C     DO LOOP OVER ENERGY                                                2060 S06
  100 DO 900  L=1 , NE                                                   2061 S06
C                                                                        2062 S06
C     CALCULATE MICROSCOPIC CROSS SECTIONS    SIG  (NU)                  2063 S06
C                                                                        2064 S06
      DO 800  NUP=1 ,NUMAX                                               2065 S06
      NU = LBRD(NUP)                                                     2066 S06
C                                                                        2067 S06
      SUMLL(NUP)=0.0                                                     2068 S06
C                                                                        2069 S06
      LLM= LLMAX(NU)                                                     2070 S06
      DO  790  LL=1 ,LLM                                                 2071 S06
      XLL=LL                                                             2072 S06
C                                                                        2073 S06
      SUMLL(NUP)=SUMLL(NUP)+(2.0*XLL-1.0)*F(NU,L,LL)*P(LL)/12.5664       2074 S06
  790 CONTINUE                                                           2075 S06
      SIG(NUP)= SIGEL(L,NU)* SUMLL(NUP)                                  2076 S06
  800 CONTINUE                                                           2082 S06
C     CALCULATE MACROSCOPIC CROSS SECTIONS                               2083 S06
  803 SIGMA =0.0                                                         2084 S06
C                                                                        2085 S06
      DO  810  NU=1 , NUMAX                                              2086 S06
      SIGMA = SIGMA + ATOM(NU) * SIG(NU)                                 2088 S06
C                                                                        2092 S06
  810 CONTINUE                                                           2093 S06
      PHI(K,L) = PHI(K,L)+SOURCE(L)*SIGMA *F1                            2094 S06
C                                                                        2095 S06
      IF (SENSE SWITCH 6 )  801   ,    900                               2089 S06
  801 PRINT          802   , K ,I ,J ,L   ,SIGMA                         2090 S06
  802 FORMAT (26H0  K   I   J   L   AND SIGMA  ,I5,I5,I5,I5,1P1E10.3)    2091 S06
      PRINT 815                                                          20961S06
  815 FORMAT (29H0 PHI(K,L)  SOURCE(L) AND F1  )                         20962S06
      PRINT 820    ,PHI(K,L), SOURCE(L) , F1                             20963S06
  820 FORMAT (1P3E10.3)                                                  20964S06
```

## APPENDIX B

## INPUT AND OUTPUT FOR S06 SAMPLE PROBLEM

## Problem Data for S06

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | 53890100012 | S06 |
| 6 | 1 | 9 | 10 | 0.58 | | 53890100022 | S06 |
| 913.0 | 509321.0 | 0.45 | | | | 53890100032 | S06 |
| 79 | 15 | 61 | 49 | 55 | 45 | 53890100042 | S06 |
| 9 | 0 | 9 | 0 | 35 | 15 | 53890100052 | S06 |
| 0 | 1 | 0 | 1 | 0 | 0 | 53890100062 | S06 |
| 97.540 | 97.54 | 198.700 | 198.700 | 650.700 | 650.70 | 53890100072 | S06 |
| 50.59 | 92.05 | 92.05 | 155.40 | 155.40 | 50.59 | 53890100082 | S06 |
| 7.092 | 7.229 | 7.533 | 9.417 | 7.620 | 7.239 | 53890100092 | S06 |
| 5.181 | 0.0 | 7.925 | 0.0 | 7.676 | 7.493 | 53890100102 | S06 |
| .0602+00 | | | | | | 53890100112 | S06 |
| 511223.0 | | | | | | 53890100122 | S06 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | | | | | 5093210001L | S06 |
| 10 | 5 | 5 | | | 5093210002L | S06 |
| 24.0 | 180.0 | 305.0 | 650.0 | 7000.0 | 5093210003L | S06 |
| 0.0 | 30.0 | 60.0 | 90.0 | 120.0 | 5093210004L | S06 |
| 2.72+06 | 2.18+04 | 7.24+03 | 1.53+03 | 1.32+01 | 5093210005L | S06 |
| 8.97+06 | 9.43+04 | 3.27+04 | 7.14+03 | 6.16+01 | 5093210006L | S06 |
| 6.83+06 | 1.11+05 | 3.92+04 | 8.65+03 | 7.46+01 | 5093210007L | S06 |
| 7.53+06 | 1.42+05 | 4.92+04 | 1.08+04 | 9.31+01 | 5093210008L | S06 |
| 6.83+06 | 1.11+05 | 3.92+04 | 8.65+03 | 7.46+01 | 5093210009L | S06 |
| 1.64+06 | 1.32+04 | 4.38+03 | 9.30+02 | 8.01+00 | 5093210010L | S06 |
| 2.57+06 | 2.62+04 | 9.08+03 | 1.98+03 | 1.71+01 | 5093210011L | S06 |
| 1.93+06 | 3.15+04 | 1.11+04 | 2.45+03 | 2.11+01 | 5093210012L | S06 |
| 2.20+06 | 4.11+04 | 1.43+04 | 3.12+03 | 2.69+01 | 5093210013L | S06 |
| 1.93+06 | 3.15+04 | 1.11+04 | 2.45+03 | 2.11+01 | 5093210014L | S06 |
| 1.02+06 | 8.34+03 | 2.77+03 | 5.89+02 | 4.33+00 | 5093210015L | S06 |
| 1.33+06 | 1.35+04 | 4.68+03 | 1.02+03 | 8.79+00 | 5093210016L | S06 |
| 9.90+05 | 1.62+04 | 5.70+03 | 1.26+03 | 1.09+01 | 5093210017L | S06 |
| 1.14+06 | 2.14+04 | 7.41+03 | 1.62+03 | 1.40+01 | 5093210018L | S06 |
| 9.90+05 | 1.62+04 | 5.70+03 | 1.26+03 | 1.09+01 | 5093210019L | S06 |
| 6.11+05 | 5.12+03 | 1.71+03 | 3.63+02 | 3.13+00 | 5093210020L | S06 |
| 2.76+05 | 2.81+03 | 9.69+02 | 2.11+02 | 1.82+00 | 5093210021L | S06 |
| 1.90+05 | 3.06+03 | 1.09+03 | 2.41+02 | 2.08+00 | 5093210022L | S06 |
| 2.27+05 | 4.31+03 | 1.49+03 | 3.26+02 | 2.81+00 | 5093210023L | S06 |
| 1.90+05 | 3.06+03 | 1.09+03 | 2.41+02 | 2.08+00 | 5093210024L | S06 |
| 3.55+05 | 3.04+03 | 1.01+03 | 2.16+02 | 1.87+00 | 5093210025L | S06 |
| 1.19+05 | 1.22+03 | 4.19+02 | 9.14+01 | 7.88-01 | 5093210026L | S06 |
| 8.30+04 | 1.34+03 | 4.72+02 | 1.06+02 | 9.14-01 | 5093210027L | S06 |
| 9.87+04 | 1.86+03 | 6.44+02 | 1.41+02 | 1.22+00 | 5093210028L | S06 |
| 8.30+04 | 1.34+03 | 4.72+02 | 1.06+02 | 9.14-01 | 5093210029L | S06 |
| 1.06+05 | 9.43+02 | 3.16+02 | 6.76+01 | 5.83-01 | 5093210030L | S06 |
| 2.82+04 | 2.87+02 | 9.87+01 | 2.15+01 | 1.85-01 | 5093210031L | S06 |
| 1.98+04 | 3.22+02 | 1.14+02 | 2.54+01 | 2.19-01 | 5093210032L | S06 |
| 2.38+04 | 4.46+02 | 1.54+02 | 3.37+01 | 2.91-01 | 5093210033L | S06 |
| 1.98+04 | 3.22+02 | 1.14+02 | 2.54+01 | 2.19-01 | 5093210034L | S06 |
| 3.18+04 | 3.69+02 | 1.27+02 | 2.77+01 | 2.39-01 | 5093210035L | S06 |
| 6.28+03 | 6.31+01 | 2.17+01 | 4.72+00 | 4.07-02 | 5093210036L | S06 |
| 4.44+03 | 7.26+01 | 2.58+01 | 5.73+00 | 4.94-02 | 5093210037L | S06 |
| 5.41+03 | 1.01+02 | 3.50+01 | 7.64+00 | 6.59-02 | 5093210038L | S06 |
| 4.44+03 | 7.26+01 | 2.58+01 | 5.73+00 | 4.94-02 | 5093210039L | S06 |
| 8.20+03 | 1.14+02 | 4.00+01 | 8.86+00 | 7.64-02 | 5093210040L | S06 |
| 1.35+03 | 1.35+01 | 4.62+00 | 1.00+00 | 8.62-03 | 5093210041L | S06 |
| 9.67+02 | 1.59+01 | 5.66+00 | 1.26+00 | 1.09-02 | 5093210042L | S06 |
| 1.19+03 | 2.23+01 | 7.70+00 | 1.68+00 | 1.45-02 | 5093210043L | S06 |
| 9.67+02 | 1.59+01 | 5.66+00 | 1.26+00 | 1.09-02 | 5093210044L | S06 |
| 2.54+02 | 2.41+00 | 8.15-01 | 1.76-01 | 1.51-03 | 5093210045L | S06 |
| 5.82+01 | 5.73-01 | 1.94-01 | 4.24-02 | 3.66-04 | 5093210046L | S06 |
| 4.28+01 | 7.06-01 | 2.54-01 | 5.63-02 | 4.85-04 | 5093210047L | S06 |
| 5.31+01 | 9.99-01 | 3.45-01 | 7.52-02 | 6.48-04 | 5093210048L | S06 |
| 4.28+01 | 7.06-01 | 2.53-01 | 5.63-02 | 4.85-04 | 5093210049L | S06 |
| 8.57+00 | 7.48-02 | 2.51-02 | 5.36-03 | 4.62-05 | 5093210050L | S06 |
| 1.92+00 | 1.86-02 | 6.27-03 | 1.37-03 | 1.18-05 | 5093210051L | S06 |
| 1.44+00 | 2.39-02 | 8.57-03 | 1.91-03 | 1.65-05 | 5093210052L | S06 |
| 1.81+00 | 3.42-02 | 1.18-02 | 2.57-03 | 2.22-05 | 5093210053L | S06 |
| 1.44+00 | 2.39-02 | 8.57-03 | 1.91-03 | 1.65-05 | 5093210054L | S06 |
| | | | | | 00054 | |

## Cross-Section Library for S06

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2 | | | | | | 5112230001L | S06 |
| 9 | 10 | | | | | 5112230002L | S06 |
| 3.6+00 | 2.7+00 | 3.03+00 | 2.29+00 | 1.85+00 | 1.24+00 | 5112230003L | S06 |
| 0.86+00 | 0.67+00 | 0.69+00 | 0.85+00 | | | 5112230004L | S06 |
| 1.0+00 | .082+00 | .004+00 | 0.0+00 | 0.0+00 | 0.0+00 | 5112230005L | S06 |
| 0.0+00 | 0.0+00 | 0.0+00 | | | | 5112230006L | S06 |
| 1.0+00 | .256+00 | .072+00 | .004+00 | 0.0+00 | 0.0+00 | 5112230007L | S06 |
| 0.0+00 | 0.0+00 | 0.0+00 | | | | 5112230008L | S06 |
| 1.0+00 | .321+00 | .115+00 | .015+00 | .004+00 | 0.0+00 | 5112230009L | S06 |
| 0.0+00 | 0.0+00 | 0.0+00 | | | | 5112230010L | S06 |
| 1.0+00 | .390+00 | .175+00 | .030+00 | .015+00 | .003+00 | 5112230011L | S06 |
| 0.0+00 | 0.0+00 | 0.0+00 | | | | 5112230012L | S06 |
| 1.0+00 | .449+00 | .250+00 | .049+00 | .036+00 | .013+00 | 5112230013L | S06 |
| .003+00 | 0.0+00 | 0.0+00 | | | | 5112230014L | S06 |
| 1.0+00 | .530+00 | .410+00 | .182+00 | .147+00 | .062+00 | 5112230015L | S06 |
| .022+00 | .003+00 | 0.0+00 | | | | 5112230016L | S06 |
| 1.0+00 | .590+00 | .482+00 | .307+00 | .242+00 | .146+00 | 5112230017L | S06 |
| .067+00 | .016+00 | 0.0+00 | | | | 5112230018L | S06 |
| 1.0+00 | .622+00 | .502+00 | .365+00 | .292+00 | .208+00 | 5112230019L | S06 |
| .112+00 | .031+00 | .006+00 | | | | 5112230020L | S06 |
| 1.0+00 | .680+00 | .514+00 | .422+00 | .350+00 | .288+00 | 5112230021L | S06 |
| .201+00 | .105+00 | .036+00 | | | | 5112230022L | S06 |
| 1.0+00 | .709+00 | .509+00 | .432+00 | .375+00 | .305+00 | 5112230023L | S06 |
| .237+00 | .162+00 | .077+00 | | | | 5112230024L | S06 |
| | | | | | | 00024 | |

## Output for S06

GENERAL DYNAMICS/FORT WORTH S06 PROB 538901 DATE 8-27-62 PAGE 1

TOTAL FLUX AT DETECTOR IS 1.682+02

FLUX SPECTRUM AT DETECTOR BY INCREASING L

| | | | | | |
|---|---|---|---|---|---|
| 1.047+02 | 3.240+01 | 2.114+01 | 6.270+00 | 2.867+00 | 6.070-01 |
| 1.601-01 | 3.822-02 | 8.353-04 | 3.080-05 | | |

TOTAL FLUX FROM SUB AREAS BY INCREASING K

| | | | | | |
|---|---|---|---|---|---|
| 2.983+01 | 6.429+00 | 2.286+01 | 3.097+01 | 3.365+01 | 4.444+01 |

FRACTION OF TOTAL FLUX FROM SUB AREAS

| | | | | | |
|---|---|---|---|---|---|
| 1.774-01 | 3.823-02 | 1.359-01 | 1.841-01 | 2.001-01 | 2.643-01 |

FLUX BY INCREASING L FOR SUB AREA 1

| | | | | | |
|---|---|---|---|---|---|
| 1.639+01 | 6.335+00 | 4.624+00 | 1.438+00 | 7.393-01 | 2.152-01 |
| 6.789-02 | 1.763-02 | 4.380-04 | 1.674-05 | | |

FLUX BY INCREASING L FOR SUB AREA 2

| | | | | | |
|---|---|---|---|---|---|
| 4.196+00 | 1.240+00 | 7.973-01 | 1.367-01 | 5.075-02 | 6.988-03 |
| 7.371-04 | 8.219-05 | 1.122-06 | 4.058-08 | | |

FLUX BY INCREASING L FOR SUB AREA 3

| | | | | | |
|---|---|---|---|---|---|
| 1.318+01 | 4.763+00 | 3.363+00 | 9.595-01 | 4.581-01 | 1.056-01 |
| 2.620-02 | 5.727-03 | 1.007-04 | 2.981-06 | | |

FLUX BY INCREASING L FOR SUB AREA 4

| | | | | | |
|---|---|---|---|---|---|
| 2.075+01 | 5.672+00 | 3.526+00 | 7.056-01 | 2.747-01 | 3.544-02 |
| 4.572-03 | 6.658-04 | 1.700-05 | 8.611-07 | | |

FLUX BY INCREASING L FOR SUB AREA 5

| | | | | | |
|---|---|---|---|---|---|
| 2.457+01 | 5.242+00 | 2.886+00 | 6.687-01 | 2.419-01 | 3.184-02 |
| 6.982-03 | 1.689-03 | 4.209-05 | 1.650-06 | | |

FLUX BY INCREASING L FOR SUB AREA 6

| | | | | | |
|---|---|---|---|---|---|
| 2.561+01 | 9.145+00 | 5.942+00 | 2.362+00 | 1.102+00 | 2.120-01 |
| 5.376-02 | 1.243-02 | 2.363-04 | 8.523-06 | | |

# APPENDIX C

## FORTRAN STATEMENTS FOR S14

## FORTRAN Statements for S14

```
*JOB    9247    86 JACK GRIGSBY (E E JONES 2895)    S.N. 801184          0001 S14
*       STRAP FORTRAN                                                    0002 S14
*       LIST8                                                                 S14
CS14              JACK GRIGSBY (E E JONES 2895)                          0003 S14
EZE     EZEC1 EZED2 EZED3 EOF   EZED5 EZEB1AEZEB3 EZEB4 EZEB1AEZEB5           S14
        DIMENSION                                                        0004 S14
       1SOURCE(15), PHIK(20), PHIK2(20) , PHIL(15), PHI(20,15),SX(100),  0005 S14
C                                                                        0006 S14
       2SY(100)   , R1(20)   , ALPHA1(20),X0(20)  , Y0(20)   , DELX(20), 0007 S14
C                                                                        0008 S14
       3DELY(20)  , S(15,20,20),NPX(20) ,NPY(20) , KT(20)    , E0(15)  , 0009 S14
C                                                                        0010 S14
       4E(15)                                                            0011 S14
        COMMON                                                           0015 S14
       1SOURCE ,PHIK ,PHIK2 ,PHIL ,PHI ,SX ,SY ,R1 ,ALPHA1 ,X0, Y0,      0016 S14
C                                                                        0017 S14
       2DELX    ,DELY ,S      ,NPX ,NPY   ,KT ,XLIB ,L1 ,XLIBNO ,LIBNO,  0018 S14
C                                                                        0019 S14
       3XSLIB   ,LB    ,XID    ,NA   ,X1 ,Y1 ,DX ,NX ,NE ,THICK   ,NX1,  0020 S14
C                                                                        0021 S14
       4VI   ,X   ,DY ,NY ,NYM ,XNY ,SLOPE ,NY1,VJ ,Y ,ALPHA ,RSQ ,      0022 S14
C                                                                        0023 S14
       5R  ,DSQ ,SEP,D ,FMU ,F1 ,PHIT ,FNPX ,FNPY , MMAX ,NMAX ,CON1 ,   0024 S14
C                                                                        0025 S14
       6CON2 ,CON3 ,CON4 ,CON5 ,CON6 ,CON7 ,CON8 , CON9 ,R0 ,CON10  ,    0026 S14
       7SIGMA   ,E1 ,E0 ,E   ,XNEL                                       0027 S14
C       READ IN LIBRARY DATA                                             0041 S14
C                                                                        0044 S14
        LB=0                                                             0045 S14
        CALL LIB1(L1)                                                    0046 S14
        GO TO (10 ,1000 ) ,L1                                            0047 S14
   10   CALL LIB   (3HS14   ,XLIBNO   )                                  0048 S14
C       READ  CONTROL  CARD                                              0049 S14
        READ  20,  LIBNO                                                 0050 S14
   20   FORMAT (6I10)                                                    0051 S14
        IF (LIBNO) 900,900,35                                            0052 S14
C                                                                        0054 S14
C       READ IN SOURCE LIBRARY (TYPE 1 LIBRARY )                         0055 S14
C                                                                        0056 S14
   35   READ 40 ,NE   ,MMAX , NMAX                                       0057 S14
   40   FORMAT   (3I10)                                                  0058 S14
        READ 45 , (R1(M) , M=1 ,MMAX )                                   0059 S14
        READ 45 , (ALPHA1 (N)   , N=1 ,NMAX )                            0060 S14
   45   FORMAT     (6F10.3)                                              0061 S14
        READ 360 ,(E0(L), L=1,NE)                                        0122 S14
  360   FORMAT     (6E10.4)                                              0123 S14
        READ 370 ,(E(L) ,L=1 ,NE)                                        0124 S14
  370   FORMAT     (6E10.4)                                              0126 S14
C                                                                        0062 S14
        DO 50    L=1 , NE                                                0063 S14
        DO 50    N=1 , NMAX                                              0064 S14
        READ 60 ,         (  S(L,M,N)   , M = 1 , MMAX )                 0065 S14
   60   FORMAT   (1P6E10.3)                                              0066 S14
   50   CONTINUE                                                         0067 S14
```

```
      XSLIB  = XLIBNO                                                   0068 S14
      GO TO  10                                                         0069 S14
  900 PRINT  910                                                        0093 S14
  910 FORMAT (42H1 THE FOLLOWING LIBRARIES HAVE BEEN LOADED )           0094 S14
C                                                                       0095 S14
      PRINT 920  ,XSLIB  ,( XLIB(I) , I=1 , LB )                        0096 S14
  920 FORMAT  (1H0 , 6F10.0)                                            0097 S14
C                                                                       0098 S14
C     READ IN AND TEST PROBLEM CONTROL NUMBERS                          0099 S14
C                                                                       0100 S14
      BACKSPACE 9                                                       0101 S14
 1000 CALL SETUP  (3HS14 , XID )                                        0102 S14
      READ 20 ,LIBNO                                                    0103 S14
C                                                                       0104 S14
C                                                                       0105 S14
C                                                                       0106 S14
      READ 320 ,NA,NE,SLOPE,SEP,YSLIB,THICK                             0107 S14
  320 FORMAT  (2I10,4F10.0)                                             0108 S14
C                                                                       0109 S14
      READ 330 ,XNEL                                                    0110 S14
  330 FORMAT  ( 1P1E10.3)                                               0111 S14
C                                                                       0112 S14
      READ 340 , (NPX(K) ,K=1,NA)                                       0113 S14
      READ 340 , (NPY(K) ,K=1,NA)                                       0114 S14
  340 FORMAT    (6I10)                                                  0115 S14
      READ 340  ,(KT(K) ,K=1 ,NA )                                      0116 S14
      READ 350  ,(XO(K) ,K=1 ,NA )                                      0117 S14
      READ 350  ,(YO(K) ,K=1 ,NA )                                      0118 S14
      READ 350  ,(DELX (K) ,K=1   ,NA )                                 0119 S14
      READ 350  ,(DELY (K) ,K=1   ,NA )                                 0120 S14
  350 FORMAT     (6F10.3 )                                              0121 S14
C                                                                       0127 S14
      RO  =.0000000000000000000000079524 *XNEL                          0151 S14
C                                                                       0128 S14
      IF (XSLIB-YSLIB) 9000 ,1200 ,9000                                 0130 S14
 9000 PRINT 9010                                                        0131 S14
 9010 FORMAT  (17H1  WRONG LIBRARY )                                    0132 S14
      CALL END 9                                                        0134 S14
 1200 CALL SUB M                                                        0152 S14
      PRINT  9250,  PHIT                                                0153 S14
 9250 FORMAT (29H TOTAL FLUX AT DETECTOR IS    , 1P1E10.3 )             0154 S14
C                                                                       0155 S14
      PRINT  9260                                                       0156 S14
 9260 FORMAT(43H0 FLUX SPECTRUM AT DETECTOR BY INCREASING L)            0157 S14
      PRINT  9270,(PHIL(L) ,L=1, NE)                                    0158 S14
 9270 FORMAT (1H0,1P6E10.3)                                             0159 S14
C                                                                       0160 S14
      PRINT  9280                                                       0161 S14
 9280 FORMAT(43H0 TOTAL FLUX FROM SUB AREAS BY INCREASING K)            0162 S14
      PRINT  9290,(PHIK(K) ,K=1 ,NA)                                    0163 S14
 9290 FORMAT (1H0,1P6E10.3)                                             0164 S14
C                                                                       0165 S14
      PRINT  9300                                                       0166 S14
 9300 FORMAT(39H0 FRACTION OF TOTAL FLUX FROM SUB AREAS)                0170 S14
```

```
      PRINT 9310 , (PHIK2(K) , K=1, NA )                                0171 S14
 9310 FORMAT (1H0,1P6E10.3)                                             0172 S14
C                                                                       0173 S14
      DO  9311    K=1 , NA                                              01731S14
      PRINT 9312 , K                                                    01732S14
 9312 FORMAT (36H0 FLUX BY INCREASING L FOR SUB AREA ,I2)               01733S14
      PRINT  9313, ( PHI (K,L) , L= 1, NE )                             01734S14
 9313 FORMAT  (1H0,1P6E10.3)                                            01735S14
 9311 CONTINUE                                                          01736S14
      IF (SENSE SWITCH 2 )   9315 , 9375                                0174 S14
 9315 PRINT 9320                                                        0178 S14
 9320 FORMAT (48H0 COORDINATES OF LOWER LEFT CORNER OF SUB AREAS )      0179 S14
      PRINT 9330                                                        0180 S14
 9330 FORMAT (37H0      K        XO(K)       YO(K)        )             0181 S14
      PRINT 9340, (K ,XO(K) ,YO(K)  ,K=1 ,NA)                           0182 S14
 9340 FORMAT (1H0, I7 ,1F14.2 , 1F11.2)                                 0183 S14
      PRINT 9370  , SEP                                                 0192 S14
 9370 FORMAT (42H0 SOURCE DETECTOR SEPARATION DISTANCE IS  ,1PE10.3 )   0193 S14
 9375 GO TO  1000                                                       0198 S14
      END                                                               0199 S14
*     STRAP FORTRAN                                                     M001 S14
*     LIST8                                                                  S14
CS14SBM          JACK GRIGSBY (E E JONES  2895)                         M002 S14
EZE   EZEC1 EZED2 EZED3 EOF   EZED5 EZEB1AEZEB3 EZEB4 EZEB1AEZEB5            S14
      SUBROUTINE SUBM                                                   M003 S14
      DIMENSION                                                         0004 S14
     1SOURCE(15), PHIK(20), PHIK2(20) , PHIL(15), PHI(20,15),SX(100),   0005 S14
C                                                                       0006 S14
     2SY(100)    , R1(20)   , ALPHA1(20),XO(20)   , YO(20)    , DELX(20),  0007 S14
C                                                                       0008 S14
     3DELY(20)   , S(15,20,20),NPX(20) ,NPY(20) , KT(20)    , EO(15)  ,  0009 S14
C                                                                       0010 S14
     4E(15)                                                             0011 S14
      COMMON                                                            0015 S14
     1SOURCE ,PHIK ,PHIK2 ,PHIL ,PHI ,SX ,SY ,R1 ,ALPHA1 ,XO, YO,       0016 S14
C                                                                       0017 S14
     2DELX   ,DELY ,S     ,NPX ,NPY  ,KT ,XLIB ,L1 ,XLIBNO ,LIBNO,      0018 S14
C                                                                       0019 S14
     3XSLIB  ,LB   ,XID   ,NA  ,X1 ,Y1 ,DX ,NX ,NE ,THICK  ,NX1,        0020 S14
C                                                                       0021 S14
     4VI   ,X   ,DY ,NY ,NYM ,XNY ,SLOPE ,NY1,VJ ,Y ,ALPHA ,RSQ ,       0022 S14
C                                                                       0023 S14
     5R  ,DSQ ,SEP,D ,FMU ,F1 ,PHIT ,FNPX ,FNPY ,  MMAX ,NMAX ,CON1 ,   0024 S14
C                                                                       0025 S14
     6CON2 ,CON3 ,CON4 ,CON5 ,CON6 ,CON7 ,CON8 , CON9 ,RO ,CON10  ,     0026 S14
     7SIGMA  ,E1 ,EO ,E   ,XNEL                                         0027 S14
      DO 9000 K=1 , NA                                                  M042 S14
      X1=XO(K)                                                          M043 S14
      Y1=YO(K)                                                          M044 S14
      DX=DELX(K)                                                        M045 S14
      NX=NPX(K)                                                         M046 S14
C                                                                       M047 S14
      DO 8100 L=1,NE                                                    M048 S14
      PHI(K,L)=0.0                                                      M049 S14
```

```
 8100 CONTINUE                                                          M050 S14
C      CALCULATE SX FOR ALL I                                           M052 S14
C                                                                       M053 S14
      SX(1)= THICK     *DX/3.0                                          M054 S14
      SX(NX) =SX(1)                                                     M055 S14
      NX1=NX-1                                                          M056 S14
      DO 8200 I=2,NX1                                                   M057 S14
      VI=I                                                              M058 S14
      SX(I)=SX(1)*(MODF(2.0*(VI+1.0),4.0)+2.0)                          M059 S14
 8200 CONTINUE                                                          M060 S14
                                                                        M061 S14
C      DO LOOP FOR SUMMING OVER X                                       M062 S14
      NPXX=NPX(K)                                                       M063 S14
      DO 8000 I=1,NPXX                                                  M064 S14
      VI=I                                                              M065 S14
      X=X1+(VI-1.0)*DX                                                  M066 S14
C      GENERATE Y MESH                                                  M067 S14
      IF(KI(K)-1 )          7100 ,7200 ,7200                            M068 S14
 7100 DY=DELY(K)                                                        M069 S14
      NY=NPY(K)                                                         M070 S14
      GO TO 7300                                                        M071 S14
C                                                                       M072 S14
 7200 NY=3+(I-1)*2                                                      M073 S14
      NYM=NY-1                                                          M074 S14
      XNY=NYM                                                           M075 S14
      DY=SLOPE*(X-X1)/XNY                                               M076 S14
      NPY(K) = NY                                                       M0761S14
      GO TO 7300                                                        M077 S14
C      CALCULATE SY FOR ALL J                                           M082 S14
 7300 SY(1) =DY/3.0                                                     M083 S14
      SY(NY) = SY(1)                                                    M0831S14
      NY1=NY-1                                                          M084 S14
      DO  7400  J=2,NY1                                                 M085 S14
      VJ =J                                                             M086 S14
      SY(J)  =  SY(1) * (MODF(2.0 * (VJ+1.0), 4.0) + 2.0)               M087 S14
 7400 CONTINUE                                                          M088 S14
      NPYY =  NPY(K)                                                    M090 S14
      DO 7000 J=1,NPYY                                                  M091 S14
      VJ=J                                                              M092 S14
      Y=Y1+(VJ-1.0)*DY                                                  M093 S14
C                                                                       M094 S14
      IF ( X )  7310, 7320 , 7330                                       M095 S14
 7310 ALPHA = 90.0 + ( ATANF (-X/Y ) ) * 57.296                         M0952S14
      GO TO 7311                                                        M0953S14
 7320 ALPHA =  90.0                                                     M0955S14
      GO TO 7311                                                        M0956S14
 7330 ALPHA = ( ATANF (Y/X ) ) * 57.296                                 M0958S14
      GO TO 7311                                                        M0959S14
C                                                                       M096 S14
 7311 RSQ          =X**2  +  Y**2                                       M097 S14
C                                                                       M098 S14
      R            =SQRTF(RSQ)                                          M099 S14
      CALL SUB1 (K,I,J)                                                 M100 S14
      DSQ          =RSQ + SEP**2 -2.0*SEP*X                             M101 S14
```

```
C     SUB1 IS SOURCE CALCULATION                                          M102 S14
      D            =SQRTF(DSQ)                                            M103 S14
      FMU = ( SEP**2 - RSQ - DSQ ) / ( 2.0*R*D)                           M104 S14
      F1       = SX(I)* SY(J)/DSQ                                         M106 S14
C                                                                         M107 S14
      IF  (SENSE SWITCH 3 )  7430 , 6000                                  M108 S14
 7430 PRINT 7435 ,K ,I ,J                                                 M109 S14
 7435 FORMAT (44H0 X,Y,ALPHA,R,D,THETA,FMU, AND F1 FOR K I J ,I5,I5,I5 )M110 S14
      PRINT 7440 ,X,Y,ALPHA,R,D,THETA,FMU, F1                             M111 S14
 7440 FORMAT (1H0,1P8E10.3)                                               M112 S14
 6000 CALL SUB2 (K,I,J)                                                   M114 S14
C     SUB2 IS GAMMA CALCULATION CONTAINS DO LOOP OVER ENERGY              M115 S14
 7000 CONTINUE                                                            M121 S14
 8000 CONTINUE                                                            M122 S14
 9000 CONTINUE                                                            M123 S14
C                                                                         M124 S14
C                                                                         M125 S14
C     CALCULATE TOTAL AND FRACTIONAL FLUXES                               M126 S14
 7425 PHIT =0.0                                                           M127 S14
      DO  9100    K=1 , NA                                                M128 S14
      PHIK(K)   =0.0                                                      M129 S14
C                                                                         M130 S14
      DO  9050    L=1 , NE                                                M131 S14
      PHIK(K)   =PHIK(K)   +PHI(K,L)                                      M132 S14
 9050 CONTINUE                                                            M133 S14
C                                                                         M134 S14
      PHIT =PHIT + PHIK(K)                                                M135 S14
 9100 CONTINUE                                                            M136 S14
C                                                                         M137 S14
      DO  9150    K=1 ,NA                                                 M138 S14
C                                                                         M139 S14
      PHIK2(K) = PHIK(K)/PHIT                                             M140 S14
 9150 CONTINUE                                                            M141 S14
      DO 9200    L=1 ,NE                                                  M148 S14
C                                                                         M149 S14
      PHIL(L) =0.0                                                        M150 S14
C                                                                         M151 S14
      DO 9175    K=1 , NA                                                 M152 S14
C                                                                         M153 S14
      PHIL(L) = PHIL(L)+ PHI(K,L)                                         M154 S14
 9175 CONTINUE                                                            M155 S14
 9200 CONTINUE                                                            M156 S14
 9207 RETURN                                                              M176 S14
      END                                                                 M177 S14
*     STRAP FORTRAN                                                       1001 S14
*     LIST8                                                                    S14
CS14SB1          JACK GRIGSBY  ,E E JONES  2895)                          1002 S14
EZE   EZEC1 EZED2 EZED3 EOF   EZED5 EZEB1AEZEB3 EZEB4 EZEB1AEZEB5              S14
      SUBROUTINE SUB1(K,I,J)                                              2003 S14
      DIMENSION                                                           0004 S14
     1SOURCE(15), PHIK(20), PHIK2(20) , PHIL(15), PHI(20,15),SX(100),     0005 S14
C                                                                         0006 S14
     2SY(100)    , R1(20)   , ALPHA1(20),X0(20)   , Y0(20)    , DELX(20), 0007 S14
C                                                                         0008 S14
```

```
     3DELY(20)   , S(15,20,20),NPX(20) ,NPY(20) , KT(20)    , EO(15)   ,    0009 S14
C                                                                           0010 S14
     4E(15)                                                                 0011 S14
      COMMON                                                                0015 S14
     1SOURCE ,PHIK ,PHIK2 ,PHIL ,PHI ,SX ,SY ,R1 ,ALPHA1 ,XO, YO,           0016 S14
C                                                                           0017 S14
     2DELX   ,DELY ,S     ,NPX ,NPY  ,KT ,XLIB ,L1 ,XLIBNO ,LIBNO,          0018 S14
C                                                                           0019 S14
     3XSLIB  ,LB   ,XID   ,NA  ,X1 ,Y1 ,DX ,NX ,NE ,THICK  ,NX1,            0020 S14
C                                                                           0021 S14
     4VI   ,X   ,DY ,NY ,NYM ,XNY ,SLOPE ,NY1,VJ ,Y ,ALPHA ,RSQ ,           0022 S14
C                                                                           0023 S14
     5R   ,DSQ ,SEP,D ,FMU ,F1 ,PHIT ,FNPX ,FNPY , MMAX ,NMAX ,CON1 ,        0024 S14
C                                                                           0025 S14
     6CON2 ,CON3 ,CON4 ,CON5 ,CON6 ,CON7 ,CON8 , CON9 ,RO ,CON10  ,         0026 S14
     7SIGMA  ,E1 ,EO ,E   ,XNEL                                             0027 S14
      IF (R-R1(1)) 20, 2 ,2                                                 1042 S14
    2 IF (ALPHA -ALPHA1(1))  20,5,5                                         1043 S14
C                                                                           1044 S14
    5 DO 10  M=1 ,MMAX                                                      1045 S14
      IF (R1(M)-R )   10 ,40 ,40                                            1046 S14
   10 CONTINUE                                                              1047 S14
   20 PRINT 30                                                              1048 S14
   30 FORMAT ( 48H A VALUE OF R1 OR ALPHA1 CALLS FOR EXTRAPOLATION)         1049 S14
      PRINT 31,K,L,I,J                                                      10491S14
   31 FORMAT (31H0  X,Y,R,ALPHA FOR K,L,I,J OF  4I5 )                       10492S14
      PRINT 32,   X,Y,R,ALPHA                                               10493S14
   32 FORMAT (1H0 ,1P4E10.3 )                                               10494S14
      PRINT 33                                                              10495S14
   33 FORMAT   (33H0  MIN AND MAX INPUT R AND ALPHA )                       10496S14
      PRINT 34, (R1(1),R1(MMAX),ALPHA1(1),ALPHA1(NMAX) )                    10497S14
   34 FORMAT (1H0 ,1P4E10.3)                                                10498S14
      CALL AUTO                                                             1050 S14
   40 DO 50     N=1 , NMAX                                                  1051 S14
      IF (ALPHA1(N)  -ALPHA)      50 ,60 ,60                                1052 S14
   50 CONTINUE                                                              1053 S14
      GO TO 20                                                              1054 S14
   60 CON1 =(ALPHA-ALPHA1(N-1))/(ALPHA1(N)-ALPHA1(N-1))                     1055 S14
C                                                                           1056 S14
      DO 100 L=1 ,NE                                                        1060 S14
      CON3=S(L,M-1,N-1) +CON1*(S(L,M-1,N)-S(L,M-1,N-1))                     1061 S14
C                                                                           1062 S14
      CON4=S(L,M,N-1)    +CON1*(S(L,M,N)-S(L,M,N-1))                        1063 S14
C                                                                           1064 S14
      SOURCE(L)=(CON3 * R1(M-1)**2+CON4 *R1(M)**2 ) / (2.0*R**2)            1065 S14
C                                                                           1066 S14
  100 CONTINUE                                                              10661S14
      IF (SENSE SWITCH 4 )      65    ,110                                  1067 S14
C                                                                           1068 S14
   65 PRINT   70   , K , I , J                                              1069 S14
   70 FORMAT (37H0 SOURCES FOR ALL L FOR  K I AND J OF,I5 ,I5 ,I5 )         1070 S14
      PRINT 75 , ( SOURCE(L), L=1 , NE )                                    1071 S14
   75 FORMAT     ( 1P6E10.3)                                                1072 S14
C                                                                           1073 S14
```

## FORTRAN Statements for S14 (Cont'd)

```
  110 RETURN                                                            1075 S14
      END                                                               1076 S14
*     STRAP FORTRAN                                                     2002 S14
*     LIST8                                                                  S14
CS14SB2          JACK GRIGSBY (E E JONES   2896)                        2003 S14
EZE   EZEC1 EZED2 EZED3 EOF   EZED5 EZEB1AEZEB3 EZEB4 EZEB1AEZEB5            S14
      SUBROUTINE SUB2 (K,I,J)                                           2004 S14
      DIMENSION                                                         00041S14
     1SOURCE(15), PHIK(20), PHIK2(20) , PHIL(15), PHI(20,15),SX(100),   0005 S14
C                                                                       0006 S14
     2SY(100)    , R1(20)   , ALPHA1(20),XO(20)  , YO(20)    , DELX(20),  0007 S14
C                                                                       0008 S14
     3DELY(20)   , S(15,20,20),NPX(20) ,NPY(20) , KT(20)    , EO(15)   ,  0009 S14
C                                                                       0010 S14
     4E(15)                                                             0011 S14
      COMMON                                                            0015 S14
     1SOURCE ,PHIK ,PHIK2 ,PHIL ,PHI ,SX ,SY ,R1 ,ALPHA1 ,XO, YO,       0016 S14
C                                                                       0017 S14
     2DELX   ,DELY ,S      ,NPX ,NPY  ,KT ,XLIB ,L1 ,XLIBNO ,LIBNO,     0018 S14
C                                                                       0019 S14
     3XSLIB  ,LB   ,XID   ,NA  ,X1 ,Y1 ,DX ,NX ,NE ,THICK  ,NX1,        0020 S14
C                                                                       0021 S14
     4VI   ,X   ,DY ,NY ,NYM ,XNY ,SLOPE ,NY1,VJ ,Y ,ALPHA ,RSQ ,        0022 S14
C                                                                       0023 S14
     5R   ,DSQ ,SEP,D ,FMU ,F1 ,PHIT ,FNPX ,FNPY , MMAX ,NMAX ,CON1 ,    0024 S14
C                                                                       0025 S14
     6CON2 ,CON3 ,CON4 ,CON5 ,CON6 ,CON7 ,CON8 , CON9 ,RO ,CON10  ,     0026 S14
     7SIGMA   ,E1 ,EO ,E   ,XNEL                                        0027 S14
C     DO LOOP OVER ENERGY                                               2029 S14
C                                                                       2030 S14
      DO 600      L=1   ,NE                                             2031 S14
C                                                                       2032 S14
C     CALCULATE SIGMA                                                   2033 S14
      CON7 = EO(L)/0.51                                                 2035 S14
      CON6 = 1.0 / (1.0 + CON7*(    1.0 - FMU) )                        2036 S14
      SIGMA = RO * ( CON6 - ( CON6**2)*(1.0-FMU**2) + CON6**3 ) / 2.0   2038 S14
C     CALCULATE FINAL ENERGY                                            2040 S14
      E1 = CON7*CON6 * 0.51                                             2042 S14
C                                                                       2054 S14
C     DETERMINE WHICH GROUP E1 LIES IN  AND CALCULATE PHI               2055 S14
C                                                                       2056 S14
      DO  610    LF= 1,  NE                                             2057 S14
C                                                                       2058 S14
      IF  ( E(LF)-E1 )      620 , 620 ,  610                            2059 S14
  610 CONTINUE                                                          2060 S14
C                                                                       2061 S14
C                                                                       2062 S14
  620 PHI (K,LF)= PHI (K,LF)+ SOURCE(L) * SIGMA    * F1                 2063 S14
      IF (SENSE SWITCH 6)  630,600                                      20631S14
 630  PRINT 635                                                         20632S14
 635  FORMAT (30H0 K I J L E1 SIGMA AND SOURCE )                        20633S14
      PRINT 640 ,K,I,J,L,E1,SIGMA,SOURCE(L)                             20634S14
 640  FORMAT ( 4I5,1P3E10.3)                                            20635S14
C                                                                       2064 S14
```

FORTRAN Statements for S14 (Cont'd)

```
                                                    2065 S14
600 CONTINUE                                        2066 S14
    RETURN                                          2067 S14
    END                                        00381
```

# APPENDIX D

## INPUT AND OUTPUT FOR S14 SAMPLE PROBLEM

## Problem Data for S14

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | 56430300012 | S14 |
| 6 | 14 | 0.58 | 913.0 | 529621.0 | 0.45 | 56430300022 | S14 |
| 0.782+24 | | | | | | 56430300032 | S14 |
| 79 | 15 | 61 | 49 | 55 | 45 | 56430300042 | S14 |
| 9 | 0 | 9 | 0 | 35 | 15 | 56430300052 | S14 |
| 0 | 1 | 0 | 1 | 0 | 0 | 56430300062 | S14 |
| 97.54 | 97.54 | 198.70 | 198.700 | 650.7 | 650.700 | 56430300072 | S14 |
| 50.59 | 92.05 | 92.05 | 155.40 | 155.4 | 50.590 | 56430300082 | S14 |
| 7.092 | 7.229 | 7.533 | 9.417 | 7.620 | 7.2390 | 56430300092 | S14 |
| 5.181 | 0.0 | 7.925 | 0.0 | 7.676 | 7.4930 | 56430300102 | S14 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | 5296210001L | S14 |
| 14 | 5 | 5 | | | | 5296210002L | S14 |
| 24.0 | 180.0 | 305.0 | 650.0 | 7000.0 | | 5296210003L | S14 |
| 0.0 | 30.0 | 60.0 | 90.0 | 120.0 | | 5296210004L | S14 |
| 9.34+00 | 8.25+00 | 7.51+00 | 6.43+00 | 5.43+00 | 4.39+00 | 5296210005L | S14 |
| 3.36+00 | 2.37+00 | 1.72+00 | 1.20+00 | 8.59-01 | 6.09-01 | 5296210006L | S14 |
| 3.45-01 | 1.17-01 | | | | | 5296210007L | S14 |
| 9.00+00 | 8.00+00 | 7.00+00 | 6.00+00 | 5.00+00 | 4.00+00 | 5296210008L | S14 |
| 3.00+00 | 2.00+00 | 1.50+00 | 1.00+00 | 7.50-01 | 5.00-01 | 5296210009L | S14 |
| 2.50-01 | 0.00+00 | | | | | 5296210010L | S14 |
| 1.79+03 | 1.40+01 | 4.60+00 | 9.81-01 | 8.45-03 | | 5296210011L | S14 |
| 4.37+02 | 8.36+00 | 2.97+00 | 6.60-01 | 5.70-03 | | 5296210012L | S14 |
| 9.36+02 | 1.47+01 | 5.15+00 | 1.13+00 | 9.76-03 | | 5296210013L | S14 |
| 1.03+03 | 1.78+01 | 6.15+00 | 1.35+00 | 1.16-02 | | 5296210014L | S14 |
| 9.36+02 | 1.47+01 | 5.15+00 | 1.13+00 | 9.76-03 | | 5296210015L | S14 |
| 1.92+04 | 1.50+02 | 4.95+01 | 1.05+01 | 9.10-02 | | 5296210016L | S14 |
| 4.69+03 | 8.97+01 | 3.19+01 | 7.08+00 | 6.11-02 | | 5296210017L | S14 |
| 1.00+04 | 1.58+02 | 5.53+01 | 1.21+01 | 1.05-01 | | 5296210018L | S14 |
| 1.09+04 | 1.91+02 | 6.60+01 | 1.45+01 | 1.25-01 | | 5296210019L | S14 |
| 1.00+04 | 1.58+02 | 5.53+01 | 1.21+01 | 1.05-01 | | 5296210020L | S14 |
| 3.40+04 | 2.65+02 | 8.75+01 | 1.86+01 | 1.60-01 | | 5296210021L | S14 |
| 8.29+03 | 1.59+02 | 5.64+01 | 1.25+01 | 1.08-01 | | 5296210022L | S14 |
| 1.78+04 | 2.80+02 | 9.78+01 | 2.15+01 | 1.85-01 | | 5296210023L | S14 |
| 1.93+04 | 3.38+02 | 1.17+02 | 2.56+01 | 2.21-01 | | 5296210024L | S14 |
| 1.78+04 | 2.80+02 | 9.78+01 | 2.15+01 | 1.85-01 | | 5296210025L | S14 |
| 4.67+04 | 3.65+02 | 1.20+02 | 2.56+01 | 2.21-01 | | 5296210026L | S14 |
| 1.14+04 | 2.18+02 | 7.75+01 | 1.72+01 | 1.49-01 | | 5296210027L | S14 |
| 2.44+04 | 3.85+02 | 1.35+02 | 2.95+01 | 2.55-01 | | 5296210028L | S14 |
| 2.66+04 | 4.65+02 | 1.60+02 | 3.52+01 | 3.03-01 | | 5296210029L | S14 |
| 2.44+04 | 3.85+02 | 1.35+02 | 2.95+01 | 2.55-01 | | 5296210030L | S14 |
| 8.12+04 | 6.33+02 | 2.09+02 | 4.45+01 | 3.83-01 | | 5296210031L | S14 |
| 1.98+04 | 3.79+02 | 1.35+02 | 2.99+01 | 2.58-01 | | 5296210032L | S14 |
| 4.24+04 | 6.68+02 | 2.33+02 | 5.13+01 | 4.43-01 | | 5296210033L | S14 |
| 4.61+04 | 8.08+02 | 2.79+02 | 6.11+01 | 5.27-01 | | 5296210034L | S14 |
| 4.24+04 | 6.68+02 | 2.33+02 | 5.13+01 | 4.43-01 | | 5296210035L | S14 |
| 1.62+05 | 1.27+03 | 4.18+02 | 8.90+01 | 7.67-01 | | 5296210036L | S14 |
| 3.96+04 | 7.59+02 | 2.69+02 | 5.99+01 | 5.17-01 | | 5296210037L | S14 |
| 8.49+04 | 1.34+03 | 4.67+02 | 1.03+02 | 8.86-01 | | 5296210038L | S14 |
| 9.24+04 | 1.62+03 | 5.58+02 | 1.22+02 | 1.05+00 | | 5296210039L | S14 |
| 8.49+04 | 1.34+03 | 4.67+02 | 1.03+02 | 8.86-01 | | 5296210040L | S14 |
| 4.51+05 | 3.52+03 | 1.16+03 | 2.47+02 | 2.13+00 | | 5296210041L | S14 |
| 1.10+05 | 2.11+03 | 7.49+02 | 1.66+02 | 1.44+00 | | 5296210042L | S14 |
| 2.36+05 | 3.72+03 | 1.30+03 | 2.85+02 | 2.46+00 | | 5296210043L | S14 |
| 2.57+05 | 4.49+03 | 1.55+03 | 3.40+02 | 2.93+00 | | 5296210044L | S14 |
| 2.36+05 | 3.72+03 | 1.30+03 | 2.85+02 | 2.46+00 | | 5296210045L | S14 |
| 1.40+06 | 1.09+04 | 3.60+03 | 7.66+02 | 6.60+00 | | 5296210046L | S14 |
| 3.41+05 | 6.53+03 | 2.32+03 | 5.15+02 | 4.45+00 | | 5296210047L | S14 |
| 7.31+05 | 1.15+04 | 4.02+03 | 8.83+02 | 7.62+00 | | 5296210048L | S14 |
| 7.94+05 | 1.39+04 | 4.80+03 | 1.05+03 | 9.07+00 | | 5296210049L | S14 |
| 7.31+05 | 1.15+04 | 4.02+03 | 8.83+02 | 7.62+00 | | 5296210050L | S14 |
| 1.39+06 | 1.09+04 | 3.59+03 | 7.65+02 | 6.55+00 | | 5296210051L | S14 |
| 3.40+05 | 6.50+03 | 2.31+03 | 5.15+02 | 4.43+00 | | 5296210052L | S14 |
| 7.30+05 | 1.15+04 | 4.00+03 | 8.80+02 | 7.60+00 | | 5296210053L | S14 |
| 7.94+05 | 1.39+04 | 4.80+03 | 1.05+03 | 9.07+00 | | 5296210054L | S14 |

## Source Library for S14 (Cont'd)

| | | | | | | |
|---|---|---|---|---|---|---|
| 7.30+05 | 1.15+04 | 4.00+03 | 8.80+02 | 7.60+00 | 5296210055L | S14 |
| 2.28+06 | 1.78+04 | 5.85+03 | 1.25+03 | 1.08+01 | 5296210056L | S14 |
| 5.55+05 | 1.07+04 | 3.78+03 | 8.40+02 | 7.25+00 | 5296210057L | S14 |
| 1.19+06 | 1.88+04 | 6.55+03 | 1.44+03 | 1.24+01 | 5296210058L | S14 |
| 1.30+06 | 2.27+04 | 7.80+03 | 1.73+03 | 1.48+01 | 5296210059L | S14 |
| 1.19+06 | 1.88+04 | 6.55+03 | 1.44+03 | 1.24+01 | 5296210060L | S14 |
| 1.81+06 | 1.41+04 | 4.68+03 | 9.93+02 | 8.55+00 | 5296210061L | S14 |
| 4.42+05 | 8.48+03 | 3.00+03 | 6.68+02 | 5.78+00 | 5296210062L | S14 |
| 9.48+05 | 1.49+04 | 5.23+03 | 1.15+03 | 9.88+00 | 5296210063L | S14 |
| 1.03+06 | 1.80+04 | 6.23+03 | 1.36+03 | 1.18+01 | 5296210064L | S14 |
| 9.48+05 | 1.49+04 | 5.23+03 | 1.15+03 | 9.88+00 | 5296210065L | S14 |
| 3.10+06 | 2.42+04 | 7.90+03 | 1.70+03 | 1.46+01 | 5296210066L | S14 |
| 7.55+05 | 1.45+04 | 5.15+03 | 1.14+03 | 9.85+00 | 5296210067L | S14 |
| 1.62+06 | 2.55+04 | 8.93+03 | 1.96+03 | 1.69+01 | 5296210068L | S14 |
| 1.76+06 | 3.08+04 | 1.07+04 | 2.33+03 | 2.01+01 | 5296210069L | S14 |
| 1.62+06 | 2.55+04 | 8.93+03 | 1.96+03 | 1.69+01 | 5296210070L | S14 |
| 7.53+06 | 5.89+04 | 1.94+04 | 4.13+03 | 3.55+01 | 5296210071L | S14 |
| 1.84+06 | 3.53+04 | 1.64+04 | 2.78+03 | 2.40+01 | 5296210072L | S14 |
| 3.93+06 | 6.20+04 | 2.17+04 | 4.75+03 | 4.10+01 | 5296210073L | S14 |
| 4.28+06 | 7.48+04 | 2.58+04 | 5.65+03 | 4.89+01 | 5296210074L | S14 |
| 3.93+06 | 6.20+04 | 2.17+04 | 4.75+03 | 4.10+01 | 5296210075L | S14 |
| 1.09+07 | 8.50+04 | 2.80+04 | 5.98+03 | 5.15+01 | 5296210076L | S14 |
| 2.65+06 | 5.10+04 | 1.81+04 | 4.03+03 | 3.48+01 | 5296210077L | S14 |
| 5.70+06 | 8.98+04 | 3.13+04 | 6.88+03 | 5.95+01 | 5296210078L | S14 |
| 6.20+06 | 1.08+05 | 3.75+04 | 8.20+03 | 7.08+01 | 5296210079L | S14 |
| 5.70+06 | 8.98+04 | 3.13+04 | 6.88+03 | 5.95+01 | 5296210080L | S14 |
| | | | | | 00080 | |

**Output for S14**

```
GENERAL DYNAMICS/FORT WORTH S14 PROB     564303 DATE  8-29-62 PAGE    1

TOTAL FLUX AT DETECTOR IS     4.798+02
 FLUX SPECTRUM AT DETECTOR BY INCREASING L
  0.         0.         0.         1.510-04  1.165-02  6.799-02
  2.737-01  2.011+00  5.183+00  1.520+01  1.736+01  3.834+01
  1.329+02  2.685+02
 TOTAL FLUX FROM SUB AREAS BY INCREASING K
  9.832+01  1.024+01  6.852+01  5.376+01  6.740+01  1.816+02
 FRACTION OF TOTAL FLUX FROM SUB AREAS
  2.049-01  2.135-02  1.428-01  1.120-01  1.405-01  3.785-01
 FLUX BY INCREASING L FOR SUB AREA  1
  0.         0.         0.         1.510-04  1.151-02  6.374-02
  2.300-01  1.511+00  3.173+00  7.489+00  5.808+00  1.115+01
  2.800+01  4.089+01
 FLUX BY INCREASING L FOR SUB AREA  2
  0.         0.         0.         0.         0.         0.
  0.         4.261-04  1.256-02  2.464-01  4.631-01  8.175-01
  3.874+00  4.830+00
 FLUX BY INCREASING L FOR SUB AREA  3
  0.         0.         0.         0.         0.         0.
  6.780-03  2.125-01  9.454-01  3.059+00  3.980+00  8.274+00
  2.175+01  3.030+01
 FLUX BY INCREASING L FOR SUB AREA  4
  0.         0.         0.         0.         0.         0.
  0.         0.         1.169-02  5.019-01  1.612+00  4.126+00
  1.908+01  2.843+01
 FLUX BY INCREASING L FOR SUB AREA  5
```

**Output for S14 (Cont'd)**

GENERAL DYNAMICS/FORT WORTH S14 PROB 564303 DATE 8-29-62 PAGE 2

| | | | | | |
|---|---|---|---|---|---|
| 0. | 0. | 0. | 0. | 0. | 0. |
| 0. | 0. | 1.190-07 | 1.726-02 | 2.261-01 | 1.551+00 |
| 1.209+01 | 5.351+01 | | | | |

FLUX BY INCREASING L FOR SUB AREA 6

| | | | | | |
|---|---|---|---|---|---|
| 0. | 0. | 0. | 0. | 1.377-04 | 4.251-03 |
| 3.699-02 | 2.868-01 | 1.040+00 | 3.886+00 | 5.270+00 | 1.242+01 |
| 4.810+01 | 1.106+02 | | | | |

# APPENDIX E

## MACHINE OPERATING INSTRUCTIONS FOR PROCEDURES S06 AND S14

## APPENDIX E

## MACHINE OPERATING INSTRUCTIONS FOR PROCEDURES S06 and S14

The computer codes S06 and S14 (procedures) are designed to run in STRAP, the GD/FW operating system for the IBM-7090. In the modified version of the 709/7090 FORTRAN System used at GD/FW, the STRAP System is read from the system tape and control transferred to it whenever a STRAP control card is encountered by either SIGNON or SCAN. At the end of a STRAP job, the FORTRAN Common I-O Package is stored and control returned to SIGNON.

A method by which computing installations other than GD/FW may run a computer code designed for use with STRAP as a standard execute job in the 709/7090 FORTRAN System has been developed. The job deck for running in this mode is composed of the following parts in the order listed:

1. DATE card and/or I.D. card compatible with the version of the 709/7090 FORTRAN System used by the installation running the job.

2. Any FORTRAN Monitor comment or PAUSE cards needed by the individual computing installation.

3. The STRAP control deck, which is numbered consecutively in Columns 73-75, beginning with 001, and has STRP2 in Columns 76-80 of each card. Card 001 is an EXQ control card.

4. The program binary deck for the computer code in question. This deck is numbered consecutively in Columns 73-76, beginning at 0001, and has the computer code identification in Columns 78-80 of each card.

5. Problem-data decks and library-data decks.

The following statements should convey to anyone familiar with the basic 709/7090 FORTRAN System all the information needed to run a STRAP job:

1. The job deck is written as a file on the input tape. When the FORTRAN Monitor reaches this file, control is transferred to the STRAP Monitor via the XEQ card, and the STRAP Monitor in turn transfers control to the specific computer code being run.

2. Tapes A1, A2, and A3 are the system, input, and output tapes in STRAP, just as in the FORTRAN system. B4 is written on by the FORTRAN Monitor and hence must not be filed protected.

3. Tape B1 is used as an intermediate tape.

4. The memory locations between $(3)_8$ and $(143)_8$ permanently reserved for the use of the FORTRAN Monitor are not used by STRAP procedures.

5. Programmed stops in STRAP procedures are preceded by a comment on the on-line printer.

6. The output added to tape A3 by STRAP jobs will <u>not</u> be followed by an end-of-file.

7. Upon completion of a STRAP run, the system tape on A1 is rewound, the FORTRAN Common I-O Package is read in, two Monitor records (DUMP and C-to-tape) are skipped on A1, and (LOAD) is called to bring in SIGNON.

8. Tapes are assigned in STRAP jobs according to the following table:

| Logical No. or Tape Function | Actual 7090 Tape Assignment |
|---|---|
| 1 | B1 |
| 2 | B2 |
| 3 | B3 |
| 4 | B4 |
| 5 | B5 |
| 6 | B6 |
| 7 | A4 |
| 8 | A5 |
| 9, READ | A2 |
| 10, PRINT | A3 |
| 11 | A6 |
| 12 | A5 |
| SYSTEM | A1 |

The actual 7090 tape assignment corresponding to logical tape numbers 1, 2, 3, 4, 5, 6, 7, 11, or 12 may be altered by the using installation. The choice of tape units must, however, be limited to channels A, B, or C. The following is an octal listing of the STRAP tape unit table.

| | | |
|---|---|---|
| 77643 | 000000000024 | |
| 44 | 2201 | LOGICAL TAPE 1 |
| 45 | 2202 | 2 |
| 46 | 2203 | 3 |
| 47 | 2204 | 4 |
| 50 | 2205 | 5 |
| 51 | 2206 | 6 |
| 52 | 1204 | 7 |
| 53 | 1205 | 8 |
| 54 | 1202 | 9 |
| 55 | 1203 | 10 |
| 56 | 1206 | 11 |
| 57 | 1205 | 12 |
| 60 | 0000 | 13 |
| 61 | 0000 | 14 |
| 62 | 0000 | 15 |
| 63 | 0000 | 16 |
| 64 | 0000 | 17 |
| 65 | 0000 | 18 |
| 66 | 0000 | 19 |
| 77667 | 000000001201 | 20 |

The format of this table is identical to the FORTRAN unit table (IOU) in the FORTRAN library. It is assumed that anyone attempting to change the table will be familiar with standard FORTRAN usage of table (IOU). This table appears on a separate absolute binary card in both the STRP2 and STRPR2 near the end of the decks. Changes may be made by using installation on this card or by binary corrections inserted just before the last card of each deck. The 22 word/card standard binary format is used in each deck---columnar binary in STRP2 and row binary in STRPR2. The check-sum on the cards in both decks must be either correct or zero.

As an example, suppose it is desired to change the actual 7090 tape assignment of logical tape 3 from B3 to C1. Location 77746 would be changed from 2203 to 3201 in both the STRP2 and STRPR2 decks.

9. Recovery is initiated on STRAP procedures by loading from the on-line card reader the STRAP Recovery Deck (numbered consecutively in Columns 73-74 beginning at 01 with STRPR2 in Columns 75-80 of each card).

10. Whenever it appears that a problem on a STRAP procedure is unable to reach completion, or whenever it is desired for any reason to terminate the problem (not the job), then the following steps should be taken:

    a. Place the computer in manual and wait until operation stops.

    b. Place the machine in automatic.

    c. Depress sense switch 1.

    d. Load the STRAP Recovery Deck from the on-line card reader.

11. If it becomes necessary to interrupt a job being run, the operator should depress sense switch 1. Within 10 minutes of this step, the procedure should indicate by an on-line comment what action has been taken, and what steps must be taken to restart the procedure. In many procedures, the takedown action will consist of nothing more than skipping the problems not yet completed. If the latter alternative is taken, then the problems not processed should merely be rescheduled at a later time.

The following restrictions apply to the running of procedures S06 and S14 by the method outlined in this section:

1. Subroutine DATE (in the STRAP Control Deck) assumes that the current date is stored in cell $(142)_8$ in standard FORTRAN format. If local changes to the FORTRAN system have altered this standard, then subroutine DATE should be replaced by a subroutine which does the following:

    a. Stores the current date in absolute cell $(77777)_8$ as an integer of the form:

    (MONTH) · 10000 + (DAY OF MONTH) · 100 + (LAST TWO DIGITS OF YEAR).

    b. Returns control to 1,4.

Subroutine DATE is on standard relocatable binary instruction cards near the beginning of the STRAP Control Deck.

2. Whenever a recovery or termination of a problem is executed, the following items should be noted:

   a. The correct date may not appear on the remaining output of the job on which recovery was made.

   b. Information retained between jobs in locations $(3)_8$ - $(143)_8$ will probably be lost.

   c. When the job is complete, an on-line comment will be given directing the operator to reload the START card to begin the next job on the input tape.

Both procedures, S06 and S14, will give error prints in the event that one of the following situations exists:

1. The wrong source library has been loaded. This will cause the machine to stop after printing WRONG LIBRARY.

2. A calculated value of R or ALPHA does not fall within the range of input values of R1 or ALPHA1. This will cause the machine to go to the next problem after printing A VALUE OF R1 OR ALPHA1 CALLS FOR EXTRAPOLATION; the values of K, L, I, J, X, Y, R, ALPHA involved; and the maximum and minimum values of R1 and ALPHA1. K, L, I, and J are subscripts on sub-area, energy, mesh point in X mesh, and mesh point in Y mesh, respectively.

When the cross-section libraries loaded in procedure S06 do not agree with those called for in the problem deck, the following print out will be given: LIBRARIES LOADED DO NOT AGREE WITH THOSE REQUESTED.

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