VARIED: A Computer Program for Variational Neutronics Calculations

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Abstract

A computer program to perform variational neutronics calculations is described. The inputs are direct and adjoint fluxes and the basic multigroup data. The program has been written to couple with output from ANISN calculations. A sample problem is included.

1. Theory

Variational methods[1] coupled with discrete ordinates transport calculations[2] have recently been applied[3,4,5] to the problem of estimating a functional, $G[\phi]$, of the neutron-photon flux ϕ, which is the solution of the linear equation

$$L\phi = S. \tag{1}$$

Here L is the neutron-photon transport operator and S is external source. Suppose we have solved for a reference flux ϕ_o in some particular (reference) system (represented by the transport operator L_o) and the associated adjoint flux ϕ_o^* for the same system. ϕ_o^* is the solution of the adjoint equation

$$L_o^* \phi_o = G'[\phi_o], \tag{2}$$

L_o^* is the corresponding adjoint transport operator and $G'[\phi_o]$ is the functional derivative of G with respect to ϕ[1]. An estimate of the functional $G[\phi]$ in a perturbed or altered system can be obtained variationally without performing additional and costly transport calculations. Two variational principles which can be used to provide such estimates[1,4] are the Roussopoulos variational principle

$$I_R[\phi_o^*,\phi_o] = G[\phi_o] + \langle\phi_o^*, S - L\phi_o\rangle \tag{3}$$

or Schwinger variational principle

$$I_S[\phi_o^*,\phi_o] = G\left[\frac{\langle\phi_o, S\rangle\phi_o}{\langle\phi_o^*, L\phi_o\rangle}\right] . \tag{4}$$

Here, $G[\phi]$ is the estimate of the functional in the perturbed system L. If the reference functions ϕ_o,ϕ_o^* differ from the exact solutions ϕ and ϕ^*

by first order errors, then the variational results I_R and I_S will estimate $G[\phi]$ within second-order errors with respect to the exact answer.

Let $L = L_o + \Delta L$, where ΔL is in practice a relatively small change to the reference system, L_o. ΔL is often the change due to the variation of some material already in the system or newly put into the system. Equation (3) becomes

$$I_R[\phi_o^*,\phi_o] = G[\phi_o] - \langle\phi_o^*,\Delta L\phi_o\rangle \tag{5}$$

and (4) becomes

$$I_S[\phi_o^*,\phi_o] = G\left[\frac{\langle\phi_o^*,S\rangle\phi_o}{\langle\phi_o^*,S\rangle + \langle\phi_o^*,\Delta L\phi_o\rangle}\right] \tag{6}$$

since

$$L_o\phi_o = S \tag{7}$$

Here $G[\phi_o]$ is the ordinary 0-th-order perturbation estimate and $\langle\phi_o^*,\Delta L\phi_o\rangle$ is the variational compensation of the functional due to the flux change. The term, $\langle\phi_o^*, \Delta L\phi_o\rangle$, is called the sensitivity term[3], in accordance with its effect on the estimate of the functional.

The computer program, VARIED, has been written mainly to calculate the sensitivity term, $\langle\phi_o^*,\Delta L\phi_o\rangle$, when the fluxes ϕ_o and ϕ_o^* are calculated from discrete ordinate transport codes, in particular, the transport code ANISN[6].

The multigroup discrete ordinates form of the transport operator, L, and its adjoint L^*, are

$$L_{DO} = \mu_j \frac{\partial}{\partial x} + \Sigma_T^g(x) - \sum_{g'\leq g}^{G} \sum_{j'=1}^{N} \sum_{\ell=0}^{L} \Sigma_{s\ell}^{g'\to g}(x) P_\ell(\mu_j) W_{j'} P_\ell(\mu_{j'}) \tag{8}$$

$$L^*_{DO} = -\mu_j \frac{\partial}{\partial x} + \Sigma_T^g (x) - \sum_{g' \geq g}^{G} \sum_{j'=1}^{N} \sum_{\ell=0}^{L} \Sigma_{s\ell}^{g \to g'} (x) P_\ell(\mu_j) W_{j'} P_\ell(\mu_{j'}) \tag{9}$$

where j is the index of the angular ordinate, W_j is the angular weight, μ_j the angular root, N is the order of the discrete ordinate expansion, g is the energy group number, G is the total number of energy groups used in this transport problem, P_ℓ is ℓ-th Legendre polynominal, and L is the order of scattering anisotropy[2]. Note here the ℓ-th moment of the scattering cross section $\Sigma_{s\ell}^{g \to g'}$ is already multiplied by $2\ell + 1$ as generally used[6].

From Equation (8) we get

$$\Delta L = \Delta\Sigma_T^g (x) - \sum_{g' \leq g}^{G} \sum_{j'=1}^{N} \sum_{\ell=0}^{L} \Delta\Sigma_{s\ell}^{g' \to g} (x) P_\ell(\mu_j) W_{j'} P(\mu_{j'}) \tag{10}$$

where

$$\Delta\Sigma_T^g (x) = \Sigma_{T,\text{perturbed}}^g (x) - \Sigma_{T,\text{reference}}^g (x) \tag{11}$$

$$\Delta\Sigma_{s\ell}^{g' \to g} (x) = \Sigma_{s\ell,\text{perturbed}} (x) - \Sigma_{s\ell,\text{reference}}^{g' \to g} (x) \tag{12}$$

and both are always due to the change of concentration of some materials already in the reference system or newly put in from the reference system to the perturbed system. When the differences are due to changes in the nuclear data, as in the problem of nuclear cross section sensitivity studies[7], we treat the different nuclear data sets for the same nuclide as different materials. From Equations (10), (11) and (12), the sensitivity term becomes

$$\langle \phi_o^*, \Delta L \phi_o \rangle = \sum_{i=1}^{I} \Delta X_i \sum_{g=1}^{G} \sum_{j=1} W_j \phi_{o,j,i}^{*,g} \Big[-\Delta \Sigma_{T,i}^{g} \phi_{o,j,i}^{g}$$

$$+ \sum_{g' \leq g}^{G} \sum_{j'=1}^{N} \sum_{\ell=0}^{L} \Delta \Sigma_{s\ell,i}^{g' \to g} \phi_{o,j',i}^{g'} W_{j'} P_\ell(\mu_j) P_\ell(\mu_{j'}) \Big] \qquad (13)$$

The sensitivity term is calculated in some zone defined by homogenizing the materials contained in this particular region. In this zone, $\Delta\Sigma_T^g$ and $\Delta\Sigma_{s\ell}^{g' \to g}$ should be the same in each of the intervals making up a particular zone. Thus ΔX_i is the width for the i-th interval. I is the total number of intervals in this zone and $\phi_{o,j,i}^{*g}$ and $\phi_{o,j,i}^{g}$ are the adjoint and forward flux for the reference system in the g-th group j-th angular ordinate and i-th interval respectively.

References

1. G. C. Pomraning, "A Derivation of Variational Principles for Inhomogeneous Equations," Nucl. Sci. Eng. 29, 220-236(1967).

2. G. I. Bell, S. Gladstone, Nuclear Reactor Theory, Von Nostrand Reinhold Co. (1970).

3. D. E. Bartine et al., "Cross-Section Sensitivity of Breeding Ratio in a Fusion-Reactor Blanket," Trans. Am. Nucl. Soc. 16, 8 (1973).

4. Robert Conn and W. M. Stacey, Jr., "Variational Methods for Controlled Thermonuclear Reactor Blanket Studies" Nuclear Fusion 13, 185 (1973).

5. Robert Conn, "Perturbation Theory for Neutron and Photon Transport Calculations in Controlled Fusion Blankets and Shields," Trans. Am. Nucl. Soc. 16, 343 (1973).

6. W. W. Engle, Jr., "A Users Manual for ANISN" K-1693, Oak Ridge Gaseous Diffusion Plant, March 1967.

7. D. E. Bartine et al., "Cross-Section Sensitivity Analysis for Discrete Ordinates Calculations," Trans. Am. Nucl. Soc. 16, 345 (1973).

2. Input Description

The description here uses standard FORTRAN conventions to describe the data formats.

Card No. 1 (20A4)

Title Card

Card No. 2 (7I6)

Item	Cols.	Name	Description
1	1-6	IMA	number of materials to be changed
2	7-12	IGM	number of energy groups
3	13-18	ISCT	order of scattering anisotropy
4	19-24	IHM	length of cross section table
5	25-30	IHT	position of total cross section in the cross section table
6	31-36	IHS	position of inner scattering cross section
7	37-42	ISN	order of discrete ordinates

Card No. 3 (4I6)

1	1-6	ITA	number of intervals
2	7-12	NPRINT	= 0 Print input cross section sets
			= 1 do not print input cross section sets
			= 2 also do not print varied cross section set
3	13-18	NXSEC	= 0 using new cross section sets as input
			= 1 using that of the previous problem
4	19-24	INDEP	file name for the cross section sets, if not equal to zero

If NXSEC = 0, Cards No. 4, No. 5, No. 6, No. 7, No. 8, and No. 9 are used.

Card No. 4 (ANISN FORMAT)

Cross section sets in ANISN FORMAT

Material 1,	Po	group 1, group 2, ..., group G
	P1	group 1, group 2, ..., group G
	⋮	
	Pn	group 1, group 2, ..., group G
Material 2, . . .		

Card No. 5 (6E12.5)

Item	Cols.	Name	Description
1	1-12	DEN(1)	old concentration of material 1
2	13-24	DEN(2)	old concentration of material 2
⋮	⋮	⋮	
IMA		DEN(IMT)	old concentration of material IMA

Card No. 6 (6E12.5)

1	1-12	VARIA(1)	new concentration of material 1
2	13-24	VARIA(2)	new concentration of material 2
⋮	⋮	⋮	
IMA		VARIA(IMA)	new concentration of material IMA

Card No. 7 (12I6)

1	1-6	IACT(1)	position of the response to
2	7-12	IACT(2)	calculate the 0-th order perturbation term for
⋮	⋮		
IMA		IACT(IMA)	material 1, 2, ..., IMA. If not used, assign each IACT(I) as zero.

Card No. 8 (6E12.5)

1	1-12	TMU(1)	Roots of the discrete ordinate
2	13-24	TMU(2)	μ_j where j = 1,2, . . ., ISN+1
⋮	⋮	⋮	
ISN+1		TMU(ISN+1)	

Card No. 9 (6E12.5)

Item	Cols.	Name	Description
1	1-12	W(1)	angular weights for the
2	13-24	W(2)	discrete ordinates W_j,
⋮	⋮	⋮	where j = 1,2, . . ., ISN+1
ISN+1		W(ISN+1)	

Card No. 10 (6E12.5)

1	1-12	SS(1)	interval boundary for each
2	13-24	SS(2)	mesh points SS(I), I = 1,2, . . .,
⋮	⋮	⋮	ITA+1
ITA+1		SS(ITA+1)	

Card No. 11 (5I6)

1	1-6	ITAPE	= 0 Read the angular fluxes from cards = 1 read the angular fluxes from tapes (or files)
2	7-12	IMIN	≠ 0 for ITAPE = 1 only, number of interval to start reading in
3	13-24	IMAX	≠ 0 for ITAPE = 1 only, total number of intervals in this zone or system
4	25-36	NFO	≠ 0 for ITAPE = 1 only, tape (or file) number for forward fluxes, ϕ_o
5	37-48	NAD	≠ 0 for ITAPE = 1 only, tape (or file) number for adjoint fluxes, ϕ_o^*

If ITAPE = 0, Card No. 12 and No. 13 are used.

Card No. 12 (6E12.5)

1	1-12	FOFLUX(1,1,1)	Forward fluxes FOFLUX(I,J,K) I is the mesh point, J is energy group, K is the angular ordinate, the input order is mesh point (ITA+1) x energy group (IGM) x angular ordinates (ISN)
2	13-24	FOFLUX(1,1,2)	
⋮			
ISN		FOFLUX(1,1,ISN)	
ISN+1		FOFLUX(1,2,1)	
⋮			

Card No. 12 (6E12.5) con't.

⋮	
ISN x IGM	FOFLUX(1,IGM,ISN)
ISN x IGM +1	FOFLUX(2,1,1)
⋮	
ISN x IGM x (ITA +1)	FOFLUX(ITA+1,IGM,ISN)

Card No. 13 (6E12.5) Adjoint fluxes ADFLUX(I,J,K). The description is the same as Card No. 12.

Note: If adjoint fluxes are input in cards. The orders of energy groups should be rearranged from the output of ANISN code.

3. Output Description

The output of the program VARIED is described as follows.

Title.

If NXSEC = 1. The input cross-section data sets will be listed. If NPRINT = 1, print out the varied cross section sets, if NPRINT = 0, also print out the cross section data for each material.

Interval boundaries

If IWRITE = 1. The forward fluxes are printed out and then the adjoint fluxes also are printed out.

If IACT(I) ≠ 0. The total fluxes will be listed in the order of energy group x interval number. The functional estimated by the reference fluxes for the particular zone $G[\phi_0]$ is given.

Intervalwise summation for the sensitivity term

Result of the sensitivity term or the total estimated function for the particular zone, if $G[\phi_0]$ is given.

4. Sample Problem

The sample problem applied here is from Reference (4). It is to estimate the helium production rate in a Controlled Thermal-Nuclear Reactor blanket system. The reference blanket system has a 0.5 cm niobium first wall followed by a 3 cm homogenized zone of Natural Lithium and 6% niobium structural material coolant and breeding, another 0.5 cm niobium second wall, a 60 cm natural lithium and Nb zone, a 30 cm graphite reflector and another 6 cm homogenized coolant and breeding zone. The helium production rate in the first and second walls is 10.6833×10^{-4}. The transport calculations are performed with 6 group, P1 cross section, slab geometry, and an S_4 discrete ordinates approximation using the ANISN Code. The first wall is divided into six intervals and is designated as the first zone. The second wall is divided into two intervals and designated the third zone. The test problem is to determine the helium production rate in these walls when the walls are replaced by vanadium. We proceed using the variational method. Knowing the forward flux ϕ_o and the response-corresponding adjoint flux ϕ_o^*, we can estimate the 0-th order perturbation value and sensitivity term by VARIED.

The input and output are listed in the following. When the niobium walls are replaced by vanadium walls, the helium production rate in these walls is the sum of the results shown in the output, which is

$$\begin{aligned} I_R[\phi_o^*, \phi_o] &= 20.8848 \times 10^{-4} + 11.7996 \times 10^{-4} \\ &= 32.6844 \times 10^{-4} \end{aligned}$$

The helium production rate in lowest order perturbation theory is

$$\begin{aligned} G[\phi_o] &= 20.5621 \times 10^{-4} + 11.2657 \times 10^{-4} \\ &= 31.2878 \times 10^{-4} \end{aligned}$$

The exact solution calculated from ANISN is 32.7548×10^{-4}.

4.1 LIST OF SAMPLE PROBLEM INPUT

```
(CARD NO. 1)
****SAMPLE PROBLEM OF V-A-R-I-E-D, NB-V ZONE 1 ****
(CARD NO. 2)
    2     6         1       10       4       5       4
(CARD NO. 3)
    6     0         0        0
(CARD NO. 4)
   9.22    -3
    39612- 6               0.      39757- 4     19269- 4 5R         0.
    8.03   -3
    36969- 6               0.      40973- 4     20443- 4     50001- 6 4R         0.
   6.38    -3
    33017- 6               0.      41905- 4     21305- 4     54621- 6     47287- 8
 3R        0.
   4.91    -3
    28400- 6               0.      42581- 4     21903- 4     61129- 6     85392- 8
    97701- 8 2R            0.
   3.62    -3
    23298- 6               0.      42921- 4     22412- 4     69712- 6     14651- 7
    16870- 7      18496- 7              0.
   2.58    -3
    18724- 6               0.      42831- 4     21885- 4     80200- 6     25381- 7
    27737- 7      30667- 7     32350- 7
 4R        0.     52215- 4 5R           0.
 4R        0.     55307- 4     31950- 6 4R          0.
 4R        0.     57268- 4     40674- 6 4R          0.
 4R        0.     58244- 4     48593- 6 4R          0.
 4R        0.     57978- 4     54069- 6 4R          0.
 4R        0.     56190- 4     55854- 6 4R          0.
   2.2     -02    5.7465-02
   0.0            2.3106       1.0924      5R 0.0
   1.4000-02      4.6955-02
    0.0           2.4357       1.2254       1.2309-01 4R 0.0
   8.0000-03      3.7531-02
   0.0            2.5714       1.3519       1.2882-01    2.0072-03 3R 0.0
   3.8000-03      3.0618-02
    0.0           2.7349       1.4648       1.3401-01    4.5303-03    3.1371-03
 2R 0.0
   2.0000-03      2.4960-02
    0.0           2.8858       1.5622       1.4004-01    7.9092-03    6.8620-03
   4.6119-03       0.0
   1.0000-03      2.0305-02
    0.0           3.0460       1.6654       1.4937-01    1.0908-02    1.1628-02
   9.8059-03      6.4145-03
 4R 0.0           2.7261     5R 0.0
 4R 0.0           3.0865       -85409-07 4R 0.0
 4R 0.0           3.4343       1.1882-02 4R 0.0
 4R 0.0           3.7410       3.2205-02 4R 0.0
 4R 0.0           3.9975       4.7823-02 4R 0.0
 4R 0.0           4.2537       5.8979-02 4R 0.0
  T
(CARD NO. 5)
      0.0555          0.0
```

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(CARD NO. 6)
       0.0        0.0722
(CARD NO. 7)
    1     1
(CARD NO. 8)
-1.0           -8.81917E-01-3.33333E-01 3.33333E-01 8.81917E-01
(CARD NO. 9)
 0.0            1.66667E-01 3.33333E-01 3.33333E-01 1.66667E-01
(CARD NO. 10)
 0.0            8.33333E-02 1.66667E-01 2.50000E-01 3.33333E-01 4.16667E-01
 5.00000E-01
(CARD NO. 11)
    0     0     0     0     0     0
(CARD NO. 12)
   .91826E+00   .11063E+01   .33643E+01   .33643E+01   .11063E+01
   .47977E-01   .79560E-01   .28915E+00   .28915E+00   .79560E-01
   .41027E-01   .50216E-01   .95433E-01   .95433E-01   .50216E-01
   .72143E-01   .78667E-01   .10946E+00   .10946E+00   .78667E-01
   .64498E-01   .68394E-01   .84843E-01   .84843E-01   .68394E-01
   .54618E-01   .57200E-01   .67530E-01   .67530E-01   .57200E-01
  -.85374E-01  -.30716E-01   .41104E+00   .61820E+01   .22433E+01
   .40284E-01   .71494E-01   .27947E+00   .29855E+00   .87711E-01
   .40454E-01   .49770E-01   .96944E-01   .94004E-01   .50647E-01
   .72329E-01   .79027E-01   .11232E+00   .10674E+00   .78295E-01
   .64675E-01   .68685E-01   .86646E-01   .83131E-01   .68097E-01
   .54791E-01   .57456E-01   .68860E-01   .66267E-01   .56940E-01
  -.86160E-01  -.33581E-01   .38893E+00  0.59384E+01   .22452E+01
   .32803E-01   .63635E-01   .26993E-00   .30711E+00   .95677E-01
   .39866E-01   .49310E-01   .98541E-01   .92650E-01   .51065E-01
   .72499E-01   .79375E-01   .11533E+00   .10416E+00   .77912E-01
   .64842E-01   .68968E-01   .88547E-01   .81506E-01   .67795E-01
   .54958E-01   .57708E-01   .70263E-01   .65066E-01   .56677E-01
  -.86751E-01  -.36194E-01   .36737E+00   .57051E+01   .22457E+01
   .25511E-01   .55970E-01   .26065E+00   .31464E+00   .10332E+00
   .39262E-01   .48836E-01   .10023E+00   .91368E-01   .51469E-01
   .72650E-01   .79709E-01   .11851E+00   .10171E+00   .77521E-01
   .64998E-01   .69244E-01   .90547E-01   .79965E-01   .67487E-01
   .55119E-01   .57956E-01   .71743E-01   .63925E-01   .56409E-01
  -.87154E-01  -.38562E-01   .34634E+00   .54816E+01   .22448E+01
   .18402E-01   .48491E-01   .25160E+00   .32121E+00   .11066E+00
   .38643E-01   .48347E-01   .10202E+00   .90152E-01   .51859E-01
   .72782E-01   .80027E-01   .12184E+00   .99400E-01   .77122E-01
   .65143E-01   .69511E-01   .92651E-01   .78506E-01   .67175E-01
   .55273E-01   .58200E-01   .73301E-01   .62842E-01   .56138E-01
  -.87375E-01  -.40695E-01   .32578E+00   .52674E+01   .22426E+01
   .11469E-01   .41190E-01   .24278E+00   .32688E+00   .11770E+00
   .38007E-01   .47844E-01   .10391E+00   .88998E-01   .52234E-01
   .72892E-01   .80327E-01   .12535E+00   .97210E-01   .76716E-01
   .65274E-01   .69768E-01   .94863E-01   .77126E-01   .66860E-01
   .55419E-01   .58438E-01   .74942E-01   .61816E-01   .55866E-01
  -.87420E-01  -.42599E-01   .30566E+00   .50623E+01   .22392E+01
   .47039E-02   .34060E-01   .23418E+00   .33172E+00   .12443E+00
   .37354E-01   .47325E-01   .10591E+00   .87902E-01   .52596E-01
   .72979E-01   .80609E-01   .12903E+00   .95141E-01   .76306E-01
   .65391E-01   .70012E-01   .97185E-01   .75825E-01   .66544E-01
   .55556E-01   .58669E-01   .76666E-01   .60845E-01   .55591E-01
(CARD NO. 13)
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```
 .26514E-03  .10362E-03  .10362E-03  .79328E-03  .31011E-03
 .22745E-03  .89055E-04  .89055E-04  .68249E-03  .26596E-03
 .17836E-03  .69996E-04  .69996E-04  .53706E-03  .20856E-03
 .13469E-03  .53038E-04  .53038E-04  .40769E-03  .15747E-03
 .98706E-04  .38762E-04  .38762E-04  .29782E-03  .11518E-03
 .69047E-04  .26660E-04  .26660E-04  .20396E-03  .79890E-04
 .22071E-03  .15189E-03  .23258E-03  .69179E-03  .26090E-03
 .18866E-03  .13105E-03  .20133E-03  .59442E-03  .22301E-03
 .14747E-03  .10337E-03  .15924E-03  .46724E-03  .17437E-03
 .11090E-03  .78732E-04  .12172E-03  .35395E-03  .13113E-03
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 .55815E-04  .39970E-04  .62157E-04  .17596E-03  .66330E-04
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 .87170E-04  .10448E-03  .18715E-03  .29739E-03  .10473E-03
 .63721E-04  .76682E-04  .13756E-03  .21652E-03  .76345E-04
 .44614E-04  .53288E-04  .95940E-04  .14649E-03  .52728E-04
 .13212E-03  .24854E-03  .47344E-03  .47361E-03  .16209E-03
 .11137E-03  .21522E-03  .41068E-03  .40475E-03  .13682E-03
 .85957E-04  .17029E-03  .32541E-03  .31664E-03  .10577E-03
 .63526E-04  .13025E-03  .24946E-03  .23792E-03  .78286E-04
 .46309E-04  .95673E-04  .18341E-03  .17264E-03  .56865E-04
 .32445E-04  .66603E-04  .12807E-03  .11548E-03  .39095E-04
 .88034E-04  .29682E-03  .58572E-03  .35660E-03  .11256E-03
 .72955E-04  .25731E-03  .50809E-03  .30285E-03  .93655E-04
 .55398E-04  .20376E-03  .40261E-03  .23561E-03  .71427E-04
 .39995E-04  .15603E-03  .30874E-03  .17542E-03  .51831E-04
 .28976E-04  .11465E-03  .22702E-03  .12652E-03  .37372E-04
 .20323E-04  .79902E-04  .15863E-03  .82874E-04  .25444E-04
 .44149E-04  .34503E-03  .69280E-03  .23407E-03  .63020E-04
 .34742E-04  .29934E-03  .60088E-03  .19603E-03  .50496E-04
 .25015E-04  .23720E-03  .47608E-03  .15059E-03  .37100E-04
 .16605E-04  .18177E-03  .36509E-03  .10979E-03  .25391E-04
 .11742E-04  .13361E-03  .26846E-03  .78057E-04  .17885E-04
 .82601E-05  .93173E-04  .18765E-03  .48603E-04  .11787E-04
 .50851E-06  .39310E-03  .79484E-03  .10584E-03  .13503E-04
-.32246E-05  .34128E-03  .68919E-03  .84106E-04  .73880E-05
-.51556E-05  .27056E-03  .54592E-03  .61435E-04  .28270E-05
-.66176E-05  .20745E-03  .41863E-03  .40925E-04 -.10055E-05
-.53709E-05  .15251E-03  .30780E-03  .27178E-04 -.15741E-05
-.37316E-05  .10640E-03  .21521E-03  .12601E-04 -.18643E-05
(CARD NO. 1)
****SAMPLE PROBLEM OF V-A-R-I-E-D, NB-V ZONE 3 ****
(CARD NO. 2)
    2     6     1    10     4     5     4
(CARD NO. 3)
    2     0     1     0
(CARD NO. 10)
        0.0        0.25        0.50
(CARD NO. 11)
    0     0     0     0     0     1
(CARD NO. 12)
-8.64235E-02 2.01684E-00 2.96703E-00 2.07288E-01-5.34736E-02          1-1
-2.18799E-02 1.85470E-01 3.17190E-01 1.09828E-01-3.32159E-03          1-2
 1.76856E-02 7.01303E-02 1.02944E-01 5.78910E-02 2.46028E-02          1-3
 4.38988E-02 9.39126E-02 1.25053E-01 7.37448E-02 4.90829E-02          1-4
```

4.34030E-02	6.82929E-02	8.39315E-02	5.93244E-02	4.65252E-02	1-5
3.84581E-02	5.45948E-02	6.47048E-02	4.80123E-02	4.04951E-02	1-6
-8.36921E-02	1.97503E-00	2.65123E-00	1.75681E-01	-5.40590E-02	2-1
-2.48247E-02	1.84019E-01	2.86780E-01	1.15983E-01	-6.00172E-03	2-2
1.74297E-02	6.88832E-02	9.32057E-02	6.28193E-02	2.46607E-02	2-3
4.46299E-02	9.17514E-02	1.13193E-01	7.99085E-02	5.01498E-02	2-4
4.42360E-02	6.66365E-02	7.65813E-02	6.41997E-02	4.76344E-02	2-5
3.92639E-02	5.32129E-02	5.91937E-02	5.18961E-02	4.15191E-02	2-6
-8.02926E-02	1.92980E-00	2.37266E-00	1.45738E-01	-5.37458E-02	3-1
-2.79427E-02	1.82024E-01	2.60019E-01	1.23950E-01	-8.81754E-03	3-2
1.70596E-02	6.75204E-02	8.47591E-02	6.86927E-02	2.46300E-02	3-3
4.52540E-02	8.94794E-02	1.02936E-01	8.72253E-02	5.11459E-02	3-4
4.49969E-02	6.49236E-02	7.02396E-02	6.99523E-02	4.87006E-02	3-5
4.00235E-02	5.17955E-02	5.44355E-02	5.64766E-02	4.25211E-02	3-6
(CARD NO. 13)					
2.41263E-04	8.55708E-04	1.19655E-03	9.11635E-04	3.04632E-04	1-1
2.03392E-04	2.56395E-04	7.74176E-04	9.91471E-04	7.23546E-04	1-2
1.56577E-04	5.59112E-04	7.51281E-04	6.01497E-04	1.97169E-04	1-3
1.15717E-04	4.12804E-04	5.43954E-04	4.49071E-04	1.45691E-04	1-4
8.52921E-05	2.96557E-04	3.84170E-04	3.25249E-04	1.06496E-04	1-5
6.26018E-05	1.91899E-04	2.39297E-04	2.19124E-04	7.57605E-05	1-6
1.10873E-04	9.82614E-04	1.44606E-03	5.91793E-04	1.56658E-04	2-1
8.95050E-05	8.34657E-04	1.21280E-03	4.94385E-04	1.28806E-04	2-2
6.58351E-05	6.47668E-04	9.30207E-04	3.78355E-04	9.54558E-05	2-3
4.57009E-05	4.81190E-04	6.84776E-04	2.76337E-04	6.71838E-05	2-4
3.35675E-05	3.47065E-04	4.89836E-04	1.97148E-04	4.84644E-05	2-5
2.62095E-05	2.27737E-04	3.17480E-04	1.27574E-04	3.48718E-05	2-6
-1.79994E-05	1.10796E-03	1.66139E-03	2.26089E-04	1.23575E-05	3-1
-2.27713E-05	9.44557E-04	1.40308E-03	1.73395E-04	1.16430E-06	3-2
-2.34879E-05	7.35334E-04	1.08356E-03	1.21637E-04	-6.20115E-06	3-3
-2.31567E-05	5.48919E-04	8.05178E-04	7.71416E-05	-1.12534E-05	3-4
-1.73337E-05	3.97062E-04	5.80019E-04	4.92014E-05	-9.54389E-06	3-5
-9.67751E-06	2.63202E-04	3.84227E-04	2.16607E-05	-6.08225E-06	3-6

4.2 List of Sample Problem Output

****SAMPLE PROBLEM OF V-A-R-I-E-D, NB-V ZONE 1 ****

X-SECTION 240 ENTRIES READ

THE INPUT X-SECTIONS OF MATERIAL 1 ARE

P 0 X-SECTION

POS.	ENERGY GROUP FROM 1 TO 6					
1	9.22000-03	8.03000-03	6.38000-03	4.91000-03	3.62000-03	2.58000-03
2	3.96120-02	3.69690-02	3.30170-02	2.84000-02	2.32980-02	1.87240-02
3	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	3.97570+00	4.09730+00	4.19050+00	4.25810+00	4.29210+00	4.28310+00
5	1.92690+00	2.04430+00	2.13050+00	2.19030+00	2.24120+00	2.18850+00
6	0.00000	5.00010-02	5.46210-02	6.11290-02	6.97120-02	8.02000-02
7	0.00000	0.00000	4.72870-04	8.53920-04	1.46510-03	2.53810-03
8	0.00000	0.00000	0.00000	9.77010-04	1.68700-03	2.77370-03
9	0.00000	0.00000	0.00000	0.00000	1.84960-03	3.06670-03
10	0.00000	0.00000	0.00000	0.00000	0.00000	3.23500-03

P 1 X-SECTION

POS.	ENERGY GROUP FROM 1 TO 6					
1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
3	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5	5.22150+00	5.53070+00	5.72680+00	5.82440+00	5.79780+00	5.61900+00
6	0.00000	3.19500-02	4.06740-02	4.85930-02	5.40690-02	5.58540-02
7	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
9	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

THE INPUT X-SECTIONS OF MATERIAL 2 ARE

P 0 X-SECTION

POS.	ENERGY GROUP FROM 1 TO 6					
1	2.20000-02	1.40000-02	8.00000-03	3.80000-03	2.00000-03	1.00000-03
2	5.74650-02	4.69550-02	3.75310-02	3.06180-02	2.49600-02	2.03050-02
3	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	2.31060+00	2.43570+00	2.57140+00	2.73490+00	2.88580+00	3.04600+00
5	1.09240+00	1.22540+00	1.35190+00	1.46480+00	1.56220+00	1.66540+00
6	0.00000	1.23090-01	1.28820-01	1.34010-01	1.40040-01	1.49370-01
7	0.00000	0.00000	2.00720-03	4.53030-03	7.90920-03	1.09080-02
8	0.00000	0.00000	0.00000	3.13710-03	6.86200-03	1.16280-02
9	0.00000	0.00000	0.00000	0.00000	4.61190-03	9.80590-03
10	0.00000	0.00000	0.00000	0.00000	0.00000	6.41450-03

P 1 X-SECTION

POS.	ENERGY GROUP FROM 1 TO 6					
1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
3	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5	2.72610+00	3.08650+00	3.43430+00	3.74100+00	3.99750+00	4.25370+00
6	0.00000	-8.54090-03	1.18820-02	3.22050-02	4.78230-02	5.89790-02
7	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
9	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

THE VARIED CROSS SECTION READY FOR INPUT IS AS FOLLOWS

P 0 X-SECTION

POS.	ENERGY GROUP FROM 1 TO 6					
1	1.07669-03	5.65135-04	2.23510-04	1.85500-06	-5.65100-05	-7.09900-05
2	1.95051-03	1.33837-03	8.77295-04	6.34420-04	5.09073-04	4.26839-04
3	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	-5.38260-02	-5.15426-02	-4.69177-02	-3.88648-02	-2.98568-02	-1.77909-02
5	-2.80717-02	-2.49848-02	-2.06356-02	-1.58031-02	-1.15958-02	-1.21987-03
6	0.00000	6.11204-03	6.26934-03	6.28286-03	6.24187-03	6.33341-03
7	0.00000	0.00000	1.18676-04	2.79695-04	4.89731-04	6.46693-04
8	0.00000	0.00000	0.00000	1.72275-04	4.01808-04	6.85601-04
9	0.00000	0.00000	0.00000	0.00000	2.30326-04	5.37784-04
10	0.00000	0.00000	0.00000	0.00000	0.00000	2.83584-04

P 1 X-SECTION

POS.	ENERGY GROUP FROM 1 TO 6					
1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
3	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5	-9.29688-02	-8.41086-02	-6.98809-02	-5.31540-02	-3.31584-02	-4.73736-03
6	0.00000	-2.38988-03	-1.39953-03	-3.71711-04	4.51991-04	1.15839-03
7	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
9	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

```
        INTERVAL BOUNDARIES ARE

   POINT  1       0.00000    POINT  2     8.33333-02 POINT  3     1.66667-01 POINT  4     2.50000-01
   POINT  5       3.33333-01 POINT  6     4.16667-01 POINT  7     5.00000-01 POINT


  TOTAL FLUX
2.58904+00  2.52208+00  2.43506+00  2.35138+00  2.27086+00  2.19340+00  2.19247-01  2.19053-01  2.18605-01
2.17887-01  2.16915-01  2.15708-01  8.03731-02  8.04225-02  8.05215-02  8.06709-02  8.08703-02  8.11199-02
9.92180-02  9.93091-02  9.94947-02  9.97749-02  1.00149-01  1.00618-01  7.93747-02  7.94337-02  7.95520-02
7.97296-02  7.99672-02  8.02652-02  6.40975-02  6.41411-02  6.42287-02  6.43604-02  6.45370-02  6.47585-02

  THE REACT RATE FROM REFERENCE FLUX IS      2.05621-03


       INTERVALWISE SUMMATION IS

  1     -8.66262-05   2     -8.88235-05   3     -7.42889-05   4     -5.99281-05   5     -4.57505-05

  6     -3.17644-05

       *************************************
       *                                   *
       * THE RESULT IS EQUAL TO:  2.08848-03 *
       *                                   *
       *************************************
```

****SAMPLE PROBLEM OF V-A-R-I-E-D, NB-V ZONE 3 ****

INTERVAL BOUNDARIES ARE

POINT 1 0.00000 POINT 2 2.50000-01 POINT 3 5.00000-01 POINT

FORWARD FLUX INPUT
NOTE: AVERAGE FROM TH E ADJACENT MESH POINTS

INTERVAL 1

ENERGY GROUP 1 ANGLE FROM 1 TO 5
-8.50578-02 1.99593+00 2.80913+00 1.91484-01 -5.37663-02

ENERGY GROUP 2 ANGLE FROM 1 TO 5
-2.33523-02 1.84744-01 3.01985-01 1.12905-01 -4.66165-03

ENERGY GROUP 3 ANGLE FROM 1 TO 5
1.75576-02 6.95067-02 9.80748-02 6.03551-02 2.46317-02

ENERGY GROUP 4 ANGLE FROM 1 TO 5
4.42643-02 9.28320-02 1.19123-01 7.68266-02 4.96163-02

ENERGY GROUP 5 ANGLE FROM 1 TO 5
4.38195-02 6.74647-02 8.02564-02 6.17620-02 4.70798-02

ENERGY GROUP 6 ANGLE FROM 1 TO 5
3.88610-02 5.39038-02 6.19492-02 4.99542-02 4.10071-02

INTERVAL 2

ENERGY GROUP 1 ANGLE FROM 1 TO 5
-8.19923-02 1.95241+00 2.51194+00 1.60709-01 -5.39024-02

ENERGY GROUP 2 ANGLE FROM 1 TO 5
-2.63837-02 1.83021-01 2.73399-01 1.19966-01 -7.40963-03

ENERGY GROUP 3 ANGLE FROM 1 TO 5
1.72446-02 6.82018-02 8.89824-02 6.57560-02 2.46453-02

ENERGY GROUP 4 ANGLE FROM 1 TO 5
4.49419-02 9.06154-02 1.08064-01 8.35669-02 5.06478-02

ENERGY GROUP 5 ANGLE FROM 1 TO 5
4.46164-02 6.57800-02 7.34104-02 6.70760-02 4.81675-02

ENERGY GROUP 6 ANGLE FROM 1 TO 5

3.96437-02	5.25042-02	5.68146-02	5.41863-02	4.20201-02

8.26600-06	2.45469-04	3.50853-04	7.46173-05	1.43948-05	

TOTAL FLUX

1.32390+00	1.20730+00	1.68311-01	1.60391-01	6.84997-02	6.70540-02
8.90579-02	8.74210-02	6.64302-02	6.58201-02	5.31196-02	5.27544-02

THE REACT RATE FROM REFERENCE FLUX IS 1.12657-03

ADJOINT FLUX INPUT
NOTE: AVERAGE FROM TH E ADJACENT MESH POINTS

INTERVAL 1

ENERGY GROUP 1 ANGLE FROM 1 TO 5
1.76068-04 9.19161-04 1.32130-03 7.51714-04 2.30645-04

ENERGY GROUP 2 ANGLE FROM 1 TO 5
1.46448-04 5.45526-04 9.93488-04 7.42928-04 4.26176-04

ENERGY GROUP 3 ANGLE FROM 1 TO 5
1.11206-04 6.03390-04 8.40744-04 4.89926-04 1.46312-04

ENERGY GROUP 4 ANGLE FROM 1 TO 5
8.07089-05 4.46997-04 6.14365-04 3.62704-04 1.06437-04

ENERGY GROUP 5 ANGLE FROM 1 TO 5
5.94298-05 3.21811-04 4.37003-04 2.61198-04 7.74802-05

ENERGY GROUP 6 ANGLE FROM 1 TO 5
4.44056-05 2.09818-04 2.78388-04 1.73349-04 5.53161-05

INTERVAL 2

ENERGY GROUP 1 ANGLE FROM 1 TO 5
4.64368-05 1.04529-03 1.55372-03 4.08941-04 8.45077-05

ENERGY GROUP 2 ANGLE FROM 1 TO 5
3.33668-05 8.89607-04 1.30794-03 3.33890-04 6.49851-05

ENERGY GROUP 3 ANGLE FROM 1 TO 5
2.11736-05 6.91501-04 1.00688-03 2.49996-04 4.46273-05

ENERGY GROUP 4 ANGLE FROM 1 TO 5
1.12721-05 5.15054-04 7.44977-04 1.76739-04 2.79652-05

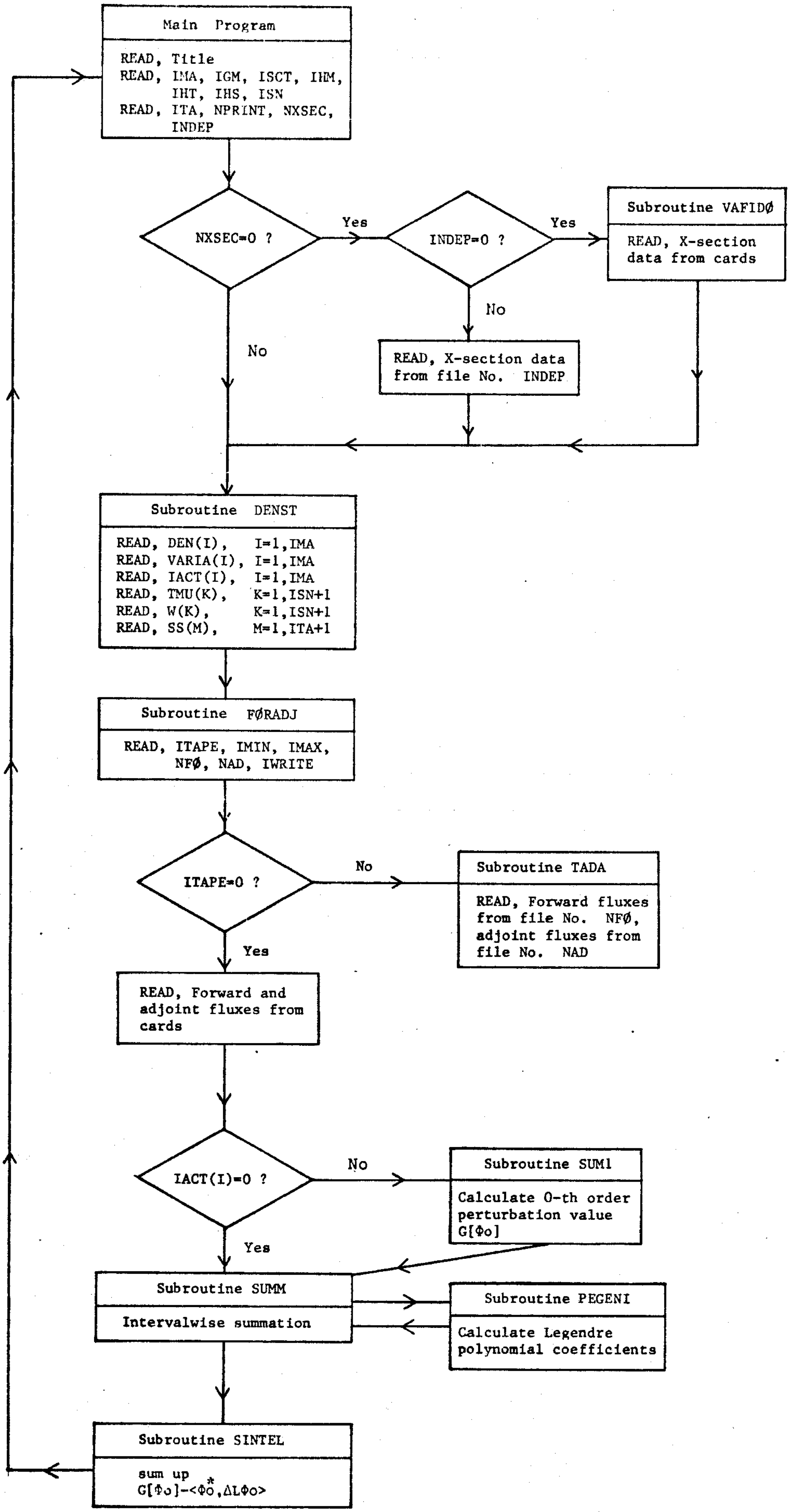
ENERGY GROUP 5 ANGLE FROM 1 TO 5
8.11590-06 3.72063-04 5.34927-04 1.23175-04 1.94603-05

ENERGY GROUP 6 ANGLE FROM 1 TO 5

INTERVALWISE SUMMATION IS

1 -1.04979-04 2 -1.08603-04

```
****************************************
*                                      *
* THE RESULT IS EQUAL TO:  1.17996-03 *
*                                      *
****************************************
```



5-] Diagram of the program VARIED

5.2 Program VARIED List

```
C THIS IS A VARITIONAL PROGRAM TO CALXULATE (S*,W) AND (W*,*LW), WHERE W AND W*
C ARE THE REFERENCE FORWORD ANGULAR FLUX AND ADJOINT ANGULAR FLUX OBTAINED FROM
C THE RELATIONS LW=S, AND L*W*=S*, WHERE L IS THE TRANSPORT OPERATOR.
      DIMENSION T(20)
      COMMON D(23920),IMA,IGM,ISCT,IHM,IHT,IHS,ITA,ISN,TMU(5),W(5),
     *SS(60),REACT,NPRINT,NXSEC,CXH(50,46,4),INDEP
    1 NIN=5
      NON=6
      READ(5,20)(T(I),I=1,20)
      WRITE(6,30)T
C ****READ IMA,IGM,ISCT,IHM,IHT,IHS,
C IMA IS THE NUMBER OF MATERIALS
C IGM IS THE NUMBER OF ENERGY GROUPS
C ISCT IS THE ORDER OF ANGULAR QUARDRATURE
C IHM IS THE LENGTH OF CROSS SECTION TABLE
C IHT IS THE POSITION OF TOTAL CROSS SECTION
C IHS IS THE POSITION OF INNER SCATTERING SCATTERING CROSS SECTION
C ISN IS THE ORDER OF DISCRETE ORDINATE
      READ(NIN,10)IMA,IGM,ISCT,IHM,IHT,IHS,ISN
C ****READ ITA,NPRINT,NXSEC,INDEP
C ITA IS THE NUMBER OF INTERVALS IN THIS ZONE
C NPRINT DETERMINES WHETHER TO PRINT THE CROSS SECTION DATA AND FLUXES OR NOT
C NXSEC IS 0 OR 1 DETERMINES USING NEW CROSS SECTION DATA OR USING THAT OF THE P
C PREVIOUS PROBLEM.
C INDEP IS THE NUMBER OF THECROSS SECTION FILE, IF USED.
      READ(NIN,10)ITA,NPRINT,NXSEC,INDEP
      ISCT=ISCT+1
      ISN=ISN+1
      JJ=IMA*IGM*IHM*ISCT
      IF(NXSEC.NE.0)GO TO 2
      IF(INDEP.EQ.0)CALL VAFIDO(NIN,NON,JJ)
    2 CALL DENST(NIN,NON)
      GO TO 1
   10 FORMAT(12I6)
   20 FORMAT(20A4)
   30 FORMAT(1H1,10X,20A4)
      END
```

```
C THIS IS TO READ THE CROSS SECTION DATA IN A-N-I-S-N FORMAT, STOLEN FROM THE
C PROGRAM SUBROUTINE F-I-D-O IN A-N-I-S-N.
      SUBROUTINE VAFIDO(N5,N6,JJ)
      DIMENSION IN(6),K(6),V(6)
      COMMON D(1)
      DATA LR,LT,LPL,LMI/1HR,1HT,1H+,1H-/
      J=0
    1 READ(N5,10)(IN(I),K(I),V(I),I=1,6)
   10 FORMAT(6(I2,A1,F9.0))
      DO 27 I=1,6
      IF(K(I).NE.LPL.AND.K(I).NE.LMI)GO TO 27
C ****EXPONENTIATION
      L=IN(I)
      IF(L.EQ.0)GO TO 27
      E=10.0**L
      IF(K(I).EQ.LMI)GO TO 28
      V(I)=V(I)*E
      GO TO 27
   28 V(I)=V(I)/E
   27 CONTINUE
      DO 2 I=1,6
      IF(K(I).EQ.LR)GO TO 7
      IF(K(I).EQ.LT)GO TO 9
      GO TO 14
C ****TERMINATION
    9 WRITE(N6,100)JJ
  100 FORMAT(1H0,10H X-SECTION,I7,13H ENTRIES READ)
      IF(J.EQ.JJ)RETURN
      WRITE(N6,200)J
  200 FORMAT(1X,13H ERROR***NOW ,I7,14H  ENTRIES READ)
      STOP
    7 L=IN(I)
      DO 18 II=1,L
      J=J+1
   18 D(J)=V(I)
      GO TO 2
C ****REGULAR INPUT
   14 IF(V(I).NE.0.0)GO TO 17
      IF(SIGN(1.0,V(I)).LT.0.0)GO TO 2
   17 J=J+1
      D(J)=V(I)
    2 CONTINUE
      GO TO 1
      END
```

```
      SUBROUTINE FORADJ
C ****SUBROUTINE FORADJ
      COMMON FOFLUX(52,46,5),ADFLUX(52,46,5),IMA,IGM,ISCT,IHM,IHT,IHS,
     *ITA,ISN,TMU(5),W(5),SS(60),REACT,NPRINT,NXSEC,CXH(50,46,4),INDEP
C ****READ THE FORWARD FLUX
      IA=ITA+1
C READ ITAPE, IMIN, IMAX, NFO, NAD, IWRITE
C ** ITAPE=0, READ THE ANGULAR FLUXES FROM CARDS
C ** ITAPE=1, READ THE ANGULAR FLUXES FROM TAPES
C ** ITAPE=1, IMIN= NUMBER OF INTERVAL TO START READING IN
C ** ITAPE=1, IMAX= TOTAL INTERVALS IN THIS SYSTEM
C ** ITAPE=1, NFO= FORWARD FLUX TAPE NUMBER
C ** ITAPE=1, NAD= ADJOINT FLUX TAPE NUMBER
C ** IWRITE IS 1 OR 0 DETERMINES WHETHER TO PRINT THE FLUXES OR NOT
      READ(5,350)ITAPE,IMIN,IMAX,NFO,NAD,IWRITE
  350 FORMAT(6I6)
      IF(ITAPE.EQ.0)GO TO 5
      IAF=1
      NIN=NFO
      CALL TADA(NIN,IMIN,IMAX,IAF)
      IAF=2
      NIN=NAD
      CALL TADA(NIN,IMIN,IMAX,IAF)
      GO TO 6
C *****************************************************************************
    5 DO 10 II=1,IA
      DO 10 J=1,IGM
      READ(5,50)(FOFLUX(II,J,K),K=1,ISN)
   10 CONTINUE
C ****READ THE ADJOINT FLUXES
      DO 20 II=1,IA
      DO 20 J=1,IGM
      READ(5,50)(ADFLUX(II,J,K),K=1,ISN)
   20 CONTINUE
C******************************************************************************
CALCULATE THE AVERAGE ANGULAR FLUX FIRST..................
    6 DO 15 J=1,IGM
      DO 15 K=1,ISN
      DO 15 II=2,IA
      IM=II-1
      FOFLUX(IM,J,K)=(FOFLUX(IM,J,K)+FOFLUX(II,J,K))/2.
      ADFLUX(IM,J,K)=(ADFLUX(IM,J,K)+ADFLUX(II,J,K))/2.
   15 CONTINUE
      IF(IWRITE.EQ.0)RETURN
      WRITE(6,100)
      DO 30 I=1,ITA
      WRITE(6,150)I
      DO 30 J=1,IGM
      WRITE(6,200)J,ISN
      WRITE(6,250)(FOFLUX(I,J,K),K=1,ISN)
   30 CONTINUE
      WRITE(6,300)
      DO 40 I=1,ITA
      WRITE(6,150)I
      DO 40 J=1,IGM
      WRITE(6,200)J,ISN
```

```
      WRITE(6,250)(ADFLUX(I,J,K),K=1,ISN)
   40 CONTINUE
   50 FORMAT(6E12.5)
  100 FORMAT(1H1,10X,18HFORWARD FLUX INPUT/10X,53HNOTE' AVERAGE FROM TH
     1E ADJACENT MESH POINTS            )
  150 FORMAT(///10X,10H  INTERVAL,I4)
  200 FORMAT(//10X,13H ENERGY GROUP,I4,18H   ANGLE FROM 1 TO I4)
  250 FORMAT(5X,6(1PE12.5))
  300 FORMAT(1H1,10X,18HADJOINT FLUX INPUT/10X,53HNOTE' AVERAGE FROM TH
     1E ADJACENT MESH POINTS            )
      RETURN
      END
```

```
      SUBROUTINE SUMM
      DIMENSION SOCXSN(60),PLEG(4,5)
      COMMON FOFLUX(52,46,5),ADFLUX(52,46,5),IMA,IGM,ISCT,IHM,IHT,IHS,
     *ITA,ISN,TMU(5),W(5),SS(60),REACT,NPRINT,NXSEC,CXH(50,46,4),INDEP
      IA=ITA
      DO 99 I=1,IA
   99 SOCXSN(I)=0.0
      CALL PEGENL(ISCT,ISN,TMU,PLEG)
      DO 200 NX=1,IA
      DO 200 IG=1,IGM
      DO 200 JN=1,ISN
      S1=0.0
      DO 100 IG1=1,IG
      IGS=IHS+(IG-IG1)
      DO 100 JN1=1,ISN
      DO 100 IL=1,ISCT
      IF(CXH(IGS,IG,IL).GT.1.0E-20)GO TO 50
      S=0.0
      GO TO 100
   50 S=CXH(IGS,IG,IL)*FOFLUX(NX,IG1,JN1)*W(JN1)*PLEG(IL,JN1)*
     1PLEG(IL,JN)
  100 S1=S1+S
      S2=CXH(IHT,IG,1)*FOFLUX(NX,IG,JN)-S1
      S3=W(JN)*ADFLUX(NX,IG,JN)*S2
  200 SOCXSN(NX)=SOCXSN(NX)+S3
      WRITE(6,20)(I,SOCXSN(I),I=1,IA)
   20 FORMAT(1H1,10X,25HINTERVALWISE SUMMATION IS//6(I4,4X,1PE12.5))
      CALL SINTEL(SOCXSN)
      RETURN
      END
```

```
      SUBROUTINE PEGENL(LS,NDISC,TMU,PLEG)
      DIMENSION TMU(5),PLEG(4,5)
      DO 10 I=1,NDISC
   10 PLEG(1,I)=1.0
      IF(LS-1)1,1,2
    1 RETURN
    2 DO 20 I=1,NDISC
   20 PLEG(2,I)=TMU(I)
      IF(LS-2)1,1,3
    3 DO 30 I=1,NDISC
      DO 30 J=3,LS
      G=TMU(I)*PLEG(J-1,I)
   30 PLEG(J,I)=G-PLEG(J-2,I)+G-(G-PLEG(J-2,I))/FLOAT(J-1)
      RETURN
      END
```

```
      SUBROUTINE SINTEL(SOCXSN)
      DIMENSION SOCXSN(60)
      COMMON FOFLUX(52,46,5),ADFLUX(52,46,5),IMA,IGM,ISCT,IHM,IHT,IHS,
     *ITA,ISN,TMU(5),W(5),SS(60),REACT,NPRINT,NXSEC,CXH(50,46,4),INDEP
      SUM=0.0
      DO 1 I=1,ITA
      II=I+1
    1 SUM=SUM+(SS(II)-SS(I))*SOCXSN(I)
      SUM=REACT-SUM
      WRITE(6,10)SUM
   10 FORMAT(1H ////10X,40H****************************************/10X,
     11H*,38X,1H*/10X,1H*,1X,23HTHE RESULT IS EQUAL TO'1PE12.5,2H */10X,
     21H*,38X,1H*/10X,40H****************************************)
      RETURN
      END
```

```
      SUBROUTINE SUM1(XACT)
      DIMENSION TOF(52,46),XACT(46)
      COMMON FOFLUX(52,46,5),ADFLUX(52,46,5),IMA,IGM,ISCT,IHM,IHT,IHS,
     *ITA,ISN,TMU(5),W(5),SS(60),REACT,NPRINT,NXSEC,CXH(50,46,4),INDEP
      DO 10 I=1,ITA
      DO 10 J=1,IGM
   10 TOF(I,J)=0.0
C ****CALCULATION OF TOTAL FLUX
      DO 20 I=1,ITA
      DO 20 J=1,IGM
      DO 20 K=1,ISN
   20 TOF(I,J)=W(K)*FOFLUX(I,J,K)+TOF(I,J)
      WRITE(6,100)((TOF(I,J),I=1,ITA),J=1,IGM)
  100 FORMAT(1H //10X,10HTOTAL FLUX/(5X,9(1PE12.5)))
      REACT=0.0
      DO 30 I=1,ITA
      II=I+1
      TEM=0.0
      DO 40 J=1,IGM
   40 TEM=TEM+XACT(J)*TOF(I,J)
   30 REACT=REACT+TEM*(SS(II)-SS(I))
      WRITE(6,200)REACT
  200 FORMAT(1H //10X,40HTHE REACT RATE FROM REFERENCE FLUX IS    ,1PE12.
     15)
      RETURN
      END
```

```
      SUBROUTINE TADA(NIN,IMIN,IMAX,IAF)
      DIMENSION FLUX(92,5)
      COMMON FOFLUX(52,46,5),ADFLUX(52,46,5),IMA,IGM,ISC1,IHM,IHT,IHS,
     *ITA,ISN,TMU(5),W(5),SS(60),REACT,NPRINT,NXSEC,CXH(50,46,4),INDEP
      IA=IMAX+1
      IIA=ITA+1
      IF(IAF.EQ.2)GO TO 50
      DO 10 K=1,IGM
      READ(NIN)((FLUX(I,J),I=1,IA),J=1,ISN)
      DO 10 L=1,ISN
      II=IMIN-1
      DO 10 M=1,IIA
      II=II+1
      FOFLUX(M,K,L)=FLUX(II,L)
   10 CONTINUE
      REWIND NIN
      RETURN
   50 DO 15 K=1,IGM
      READ(NIN)((FLUX(I,J),I=1,IA),J=1,ISN)
      DO 15 L=1,ISN
      II=IMIN-1
      DO 15 M=1,IIA
      II=II+1
      ADFLUX(M,K,L)=FLUX(II,L)
   15 CONTINUE
      IIG=IGM/2
      K=IGM+1
      DO 55 I=1,IIG
      K=K-1
      DO 55 J=1,ISN
      DO 55 M=1,IIA
      AD1=ADFLUX(M,I,J)
      ADFLUX(M,I,J)=ADFLUX(M,K,J)
      ADFLUX(M,K,J)=AD1
   55 CONTINUE
      ISN1=ISN/2
      IDIF=ISN-2*ISN1
      JMAX=ISN+1
      IF(IDIF)1,1,2
    1 JJ=0
      GO TO 3
    2 JJ=1
    3 DO 60 J=1,ISN1
      JJ=JJ+1
      JMAX=JMAX-1
      DO 60 I=1,IGM
      DO 60 M=1,IIA
      AD2=ADFLUX(M,I,JJ)
      ADFLUX(M,I,JJ)=ADFLUX(M,I,JMAX)
      ADFLUX(M,I,JMAX)=AD2
   60 CONTINUE
      REWIND NIN
      RETURN
      END
```