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WANL-TME-1378
FEBRUARY 1966

Westinghouse Astronuclear Laboratory

BETALS:

A FORTRAN II Program for Calculating
Beta-effective (β_{eff}) and Prompt Neutron
Lifetime (ℓ_p) for a Reactor With Given
Flux (ϕ) and Adjoint (ϕ^+) Solutions

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INFORMATION CATEGORY

WANL-TME-1378
FEBRUARY 1966

DW Drawbaugh
unclassified 2/15/66
Authorized Classifier - Date

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BETALS:

A FORTRAN II Program for Calculating
Beta-effective (β_{eff}) and Prompt Neutron
Lifetime (ℓ_p) for a Reactor With Given
Flux (ϕ) and Adjoint (ϕ^+) Solutions

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INTRODUCTION

This program calculates beta-effective (β_{eff}) and prompt neutron lifetime (ℓ_p) for a reactor with (two dimensional) multigroup flux (ϕ_j) and adjoint (ϕ_j^+) solutions. The code accepts the ϕ_j and ϕ_j^+ as punched by the VARI-QUIR⁽¹⁾ program, and requires various other group constants, some of which are available from the GAM-TNS-RC⁽²⁾ program. This program was designed specifically for use in conjunction with the two above mentioned codes.*

The BETALS (and FAVELA**) programs will be added to VARI-QUIR at a later date; this version is intended to provide a convenient way of calculating β_{eff} and ℓ_p until then. The program listing includes many explanatory comments, for those who may wish to modify it to suit their own purposes.

*Be sure to request microscopic cross sections when GAM-TNS-RC output is intended to be used as BETALS input.

**Described in the appendix, page 46.

DEFINITIONS: Input and Calculated Quantities;

The code calculates seven integrals, $D_1, \dots, D_7$ defined as follows⁽³⁾:

$$(1) \quad D_1 = \int_V \sum_{i=1}^G (\nu \sigma_f)_i^{25} \phi_i \, dV$$

$$(2) \quad D_2 = \int_V \left[\sum_{i=1}^G (\nu \sigma_f)_i^{25} \phi_i \right] \left[\sum_{j=1}^G (\chi D)_j^{25} \phi_j^+ \right] dV$$

$$(3) \quad D_3 = \int_V \left[\sum_{i=1}^G (\nu \sigma_f)_i^{25} \phi_i \right] \left[\sum_{j=1}^G \chi_j \phi_j^+ \right] dV$$

$$(4) \quad D_4 = \int_V \sum_{i=1}^G (\nu \sigma_f)_i^{28} \phi_i \, dV$$

$$(5) \quad D_5 = \int_V \left[\sum_{i=1}^G (\nu \sigma_f)_i^{28} \phi_i \right] \left[\sum_{j=1}^G (\chi D)_j^{28} \phi_j^+ \right] dV$$

$$(6) \quad D_6 = \int_V \left[\sum_{i=1}^G (\nu \sigma_f)_i^{28} \phi_i \right] \left[\sum_{j=1}^G \chi_j \phi_j^+ \right] dV$$

$$(7) \quad D_7 = \int_V \sum_{i=1}^G \frac{\phi_i \phi_i^+}{v_i} \, dV$$

Where dV is taken over the entire reactor volume and may be in cylindrical ($dV = 2\pi r dr dz$), or slab ($dV = z dy dx$) geometry in the code, depending on an input key, and where:

(8) G = number of energy groups,

(9) $(\nu \sigma_f)_i^{25}$ = nu-sigma-fission of U^{235} from energy group i ; $(\nu \sigma_f)_i^{28}$ is similarly defined for U^{238} ,

(10) $(\chi_D)_j^{25}$ = the fraction of delayed neutrons emitted into energy group j from U^{235} ; $(\chi_D)_j^{28}$ is similarly defined for U^{238} ,

(11) χ_j = the fraction of fission neutrons emitted into energy group j (fission spectrum),

(12) v_i = the velocity of the neutrons in group i .

The quantities described in (8), (9), and (11) are available directly from the output of GAM-TNS-RC, those in (10) may be had from the data of KEEPIN⁽⁴⁾, et.al. and from ANL-5800⁽⁵⁾ (see table VI of reference 3 for a fairly useful selection of these numbers). (12) is available through use of the FAVELA code.

Defining:

$$(13) D = \frac{D_1 \cdot D_2 \left(\frac{1}{v} \right)^{25} \left(\frac{n}{F} \right)^{25}}{D_3} + \frac{D_1 \cdot D_5 \left(\frac{1}{v} \right)^{28} \left(\frac{n}{F} \right)^{28}}{D_3}$$

$$(14) \quad P = \frac{D_1 \cdot \left(\bar{\nu}^{25} - \left(\frac{\eta}{\beta} \right)^{25} \right)}{\bar{\nu}^{25}} + \frac{D_1 D_6 \left(\bar{\nu}^{28} - \left(\frac{\eta}{\beta} \right)^{28} \right)}{\bar{\nu}^{28} D_3}$$

Where:

(15) $\bar{\nu}^{25}$ = average number of neutrons per U^{235} fission; $\bar{\nu}^{28}$ is similarly defined for U^{238} ,

(16) $\left(\frac{\eta}{\beta} \right)^{25}$ = average number of delayed neutrons per U^{235} fission; $\left(\frac{\eta}{\beta} \right)^{28}$ is similarly defined for U^{238} .

Quantities in (15) and (16) are also found in reference 5 and table VI of reference 3.

The expressions (13) and (14) are then used to calculate β_{eff} :

$$(17) \quad \beta_{\text{eff}} = \frac{D}{D + P} \quad .$$

ℓ_p is given by

$$(18) \quad \ell_p = \frac{D_7}{D_3 + D_6} \quad .$$

DESCRIPTION OF THE NUMERICAL PROCEDURE

The integrations $D_1, \dots, D_7$ are carried out using a double, piecewise application of Simpson's rule. In any region, R_{ij} (i = region index relative to the abscissa, j = region index relative to the ordinate), there are nine points, numbered 1-9 (see figure 1), for which VARI-QUIR calculates a flux and an adjoint. Let (a_i, b_j) be

Figure 1

the coordinates of the lower left-hand corner of region R_{ij} ; let $2g_i$ and $2h_j$ be its length along the abscissa and ordinate respectively. Let γ_{ijk} be some group constant in R_{ij} of energy group k . Let $\phi_k(a_i, b_j)$ be the flux from energy

group k , at the point (a_i, b_i) , with a similar notation for the fluxes at the other eight points of the region.

For the first application of Simpson's rule, intermediate integrals $f_i(a_i)$, $f_i(a_i + g_i)$ and $f(a_i + 2g_i)$ are calculated:

$$(19) \quad f_i(a_i) = C(a_i) \sum_{j=1}^J \left\{ \sum_{k=1}^G \left[\gamma_{ijk} \phi_k(a_i, b_j) \right. \right. \\ \left. \left. + 4 \gamma_{ijk} \phi_k(a_i, b_{j+h_j}) \right. \right. \\ \left. \left. + \gamma_{ijk} \phi_k(a_i, b_{j+2h_j}) \right] \right\}$$

where J is the number of regions along the ordinate and $C = 1$ for slab geometry and $C = a_i$ for cylindrical geometry. Similarly:

$$(20) \quad f_i(a_i + g_i) = C(a_i + g_i) \sum_{j=1}^J \left\{ \sum_{k=1}^G \left[\gamma_{ijk} \phi_k(a_i + g_i, b_j) + 4 \gamma_{ijk} \phi_k(a_i + g_i, b_{j+h_j}) \right. \right. \\ \left. \left. + \gamma_{ijk} \phi_k(a_i + g_i, b_{j+2h_j}) \right] \right\}$$

$$\begin{aligned}
 (21) \quad f_i(a_i+2g_i) = & C(a_i+2g_i) \sum_{j=1}^J \left\{ \sum_{k=1}^G \left[\gamma_{ijk} \phi_k(a_i+2g_i, b_j) \right. \right. \\
 & + 4\gamma_{ijk} \phi_k(a_i+2g_i, b_j+h_j) \\
 & \left. \left. + \gamma_{ijk} \phi_k(a_i+2g_i, b_j+2h_j) \right] \right\}.
 \end{aligned}$$

Where C is 1 for slab geometry and is equal to its argument for cylindrical geometry.

A second application of Simpson's rule yields the final result:

$$(22) \quad D = F \cdot \sum_{i=1}^I \left[f_i(a_i) + 4f_i(a_i+g_i) + f(a_i+2g_i) \right].$$

Where: F is the third dimension for slab geometry and F is 2π for cylindrical geometry, and where I is the number of regions along the abscissa.

Since Simpson's rule yields exact results when the function integrated is a polynomial of degree 2 or less, this procedure does not introduce a lower level of approximation than is inherent in the VARI-QUIR code.

INPUT INSTRUCTIONS

<u>Cards</u>	<u>Format</u>	<u>Card Columns</u>	<u>Variable Name</u>	
1	A	1-80	HDG	Arbitrary title card.
2	6I4	1-4, 5-8, etc..., R.A.*	NGR NRG NZG NOMATS IGEOM INOUT	Number of energy groups (G). Number of regions along r axis (x-axis for a slab geometry problem). Number of regions along Z axis (y-axis for a slab problem). Number of different materials present. Geometry type: 0 for cylindrical and 1 for slab. Output suppressor: 0 for no effect, 1 suppresses all output except for final result. Restrictions: $NGR \leq 20$ $NRG \leq 10$ $NZG \leq 10$ $NOMATS \leq 100$
3	20I4	1-4, 5-8, etc. R.A.	IM	Material identification for each region; there must be $NRG \times NZG$ entries, 20 per card (see page 12).
4	5E15.8	1-15, 16-30, etc.	DR(or DX for slab geometry)	Length in cm. of each region along the r-axis (or x-axis); there must be NRG entries, 5 per card.
5	5E15.8	1-15, 16-30, etc.	DZ(or DY for slab geometry)	Length in cm. of each region along the z-axis (or y-axis); there must be NZG entries, 5 per card.

*R.A., Right Adjusted.

<u>Card</u>	<u>Format</u>	<u>Card Columns</u>	<u>Variable Name</u>	
6	5E15.8	1-15, 16-30, etc.	PHI	VARI-QUIR flux output: A set of cards for each energy group, starting with the highest energy, and with $(2NRG+1)(2NZG+1)$ entries per set, 5 per card.
7	5E15.8	1-15, 16-30, etc.	ADJ	VARI-QUIR adjoint output, arranged the same as card 6; the punched $\emptyset$ and $\emptyset^+$ output from VARI-QUIR runs may be entered directly, with no alteration or rearranging.
8	2A6	1-6, 7-12	SP1 SP2	Alphameric label for species 1 and species 2, usually: SP1 = U-235b (b = blank) SP2 = U-238b
9	5E15.8	1-15, 16-30, etc.	GNUSF1	$(\nu\sigma_f)_{ij}^{25}$, a set of cards for each material, with one entry within the set for each energy group, starting with the highest energy; sets are stacked in ascending order of material number: $\{[(\nu\sigma_f)_{ij}^{25}, i=1, G] j=1, M\}$, (equation 9), G = no. of groups, M = no. of materials.
10	5E15.8	1-15, 16-30, etc.	GNUSF2	$(\nu\sigma_f)_{ij}^{28}$, entered in the same way as $(\nu\sigma_f)_{ij}^{25}$, on card 9 (equation 9).
11	5E15.8	1-15, 16-30, etc.	CHID1	$(\chi_D)_{ij}^{25}$, entered in the same way as card 9 (equation 10).
12	5E15.8	1-15, 16-30, etc.	CHID2	$(\chi_D)_{ij}^{28}$, entered in same way as card 9 (equation 10).

<u>Card</u>	<u>Format</u>	<u>Card Columns</u>	<u>Variable Name</u>	
13	5E15.8	1-15, 16-30, etc.	CHI	χ_{ij} , entered in same way as card 9 (equation 11).
14	5E15.8	1-15, 16-30, etc.	V	v_{ij} , entered in same way as card 9 (equation 12). In cards 9-14, j ranges over the materials.
15	5E15.8	1-15, 16-30, etc.	ENOF1 ENOF2 GNU1 GNU2 THIRD	$(n/F)^{25}$, (equation 15), $(n/F)^{28}$, (equation 15), $(\bar{\nu})^{25}$, (equation 14), $(\bar{\nu})^{28}$, (equation 14), Third dimension (Z) in slab geometry; for cylindrical geometry, THIRD is automatically set to 2π , regardless of what is entered.

Cases may be stacked by repeating the
input, cards 1-15.

Sample Problem

Configuration of Reactor Used in Sample Problem

Westinghouse Electric Corporation

CODING FORM FOR IBM TYPE 7090 COMPUTER
FORTRAN - FAP

P. GT
V. Sande

METALS

ANALYST
W. GRAY

PHONE
579

DATE
1-12-66

PROGRAM NO.	DECK NO.

L. S. NO.	67126

SHEET
1 OF 2

[illegible]

JAN 16	U	W.	11 56

2
SHEET

14

* XEQ
* LIST

BEGIN LOAD TIME 11.189

ENTRY POINTS TO SUBROUTINES REQUESTED FROM LIST BY,
(FPT) (TSHM) (RTN) (SVN) (FIL)

SUBROUTINE ENTRY POINTS AND STARTING LOCATIONS 11.184 11.184 11.184 11.184

15

	ENTRY START		ENTRY START		ENTRY START		ENTRY START
MAIN-P	00152 00144	GHOST	00440 00427		00440 00427		00440 00427
SBKER	05632	OVFLW	05625		05625		05625
EPMDL	05605	(SVN)	05170		05170		05170
ERROR	0532	ERTRP	05044		05044		05044
(TSH)	05074	(BLUK)	05354 05755		05354 05755		05354 05755
(STH)	05748	(WTC)	05477 05475		05477 05475		05477 05475
(RER)	05524	(RTN)	7423 05572		7423 05572		7423 05572
(TCO)	1000 10477	(TEF)	10000		10000		10000
(REW)	10002	(WFF)	10001		10001		10001
(RDS)	10576	(ICS)	10502		10502		10502
(LCH)	10610	(CHF)	10615		10615		10615
(SDL)	10612	(SOF)	10611		10611		10611
(ICU)	10644 10641	(FT)	10670 10652		10670 10652		10670 10652
EXIT	11621 11617	(TES)	11653 11653		11653 11653		11653 11653

EXECUTION TIME 11.192

SAMPLE PROBLEM

SPECIES 1 = U-235 , SPECIES 2 =U-238

NO. OF R-COORDINATES = 13

```

I      R(I)
1 0.
2 0.750000000E 01
3 0.150000000E 02
4 0.224999999E 02
5 0.300000000E 02
6 0.349999999E 02
7 0.400000000E 02
8 0.425000000E 02
9 0.450000000E 02
10 0.474999999E 02
11 0.500000000E 02
12 0.575000000E 02
13 0.650000000E 02

```

```

15 I      DR(I)
1 0.150000000E 02
2 0.150000000E 02
3 0.099999999E 02
4 0.500000000E 01
5 0.500000000E 01
6 0.150000000E 02

```

```

I      DZ(I)
1 0.400000000E 02
2 0.300000000E 02
3 0.099999999E 02
4 0.700000000E 02

```

```

NO. OF REGIONS ALONG R-AXIS = 6
NO. OF REGIONS ALONG Z-AXIS = 4
TOTAL NO. OF REGIONS      = 24
NO. OF ENERGY GROUPS     = 4
NO. OF MATERIALS          = 6

```

GNU-SIGMA FISSION, SPECIES 1, FOR MATERIALS 1-6

GROUP

1	0.20276400E-02 0.	0.20276400E-02 0.11487520E-01	0.19134300E-02 0.	0.17135590E-02 0.
2	0.23276600E-02 0.	0.25345700E-02 0.74559400E-02	0.14745700E-02 0.	0.14806700E-02 0.
3	0.19648650E-01 0.	0.10212080E-01 0.	0.12105520E-01 0.	0.11815090E-01 0.
4	0.91472999E-01 0.	0.91316599E-01 0.	0.92425590E-01 0.	0.92235400E-01 0.

GNU-SIGMA FISSION, SPECIES 2
GROUP

1	0.39509999F-04 0.	0.39529999F-04 0.	0.19590000E-04	0.19709999E-04
2	0. 0.	0. 0.	0.	0.
3	0. 0.	0. 0.	0.	0.
4	0. 0.	0. 0.	0.	0.

DELAYED NEUTRON FRACTIONS, SPECIES 1
GROUP

1	0. 0.	0. 0.	0.	0.
2	0.09999999F 01 0.	0.09999999E 01 0.	0.09999999E 01	0.09999999E 01
3	0. 0.	0. 0.	0.	0.
4	0. 0.	0. 0.	0.	0.

DELAYED NEUTRON FRACTIONS, SPECIES 2
GROUP

1	0. 0.	0. 0.	0.	0.
2	0.09999999E 01 0.	0.09999999E 01 0.	0.09999999E 01	0.09999999E 01
3	0. 0.	0. 0.	0.	0.
4	0. 0.	0. 0.	0.	0.

FISSION SPECTRUM
GROUP

1	0.75356218E-00 0.	0.75356218E-00 0.	0.75356218E-00 0.	0.75356218E-00 0.
2	0.24643214E-00 0.	0.24643214E-00 0.	0.24643214E-00 0.	0.24643214E-00 0.
3	0. 0.	0. 0.	0. 0.	-0. 0.
4	0. 0.	0. 0.	0. 0.	-0. 0.

AVERAGE NEUTRON VELOCITIES
GROUP

1	0.27660999E 10 0.26983999E 10	0.27664000E 10 0.26981999E 10	0.27345999E 10	0.27350000E 10
2	0.65772000E 09 0.62170999E 09	0.65724000E 09 0.67150999E 09	0.64127000E 09	0.64148000E 09
3	0.59204999E 08 0.17876000E 08	0.59227999E 08 0.21341000E 08	0.53150000E 08	0.53121000E 08
4	0.62442999E 06 0.14211000E 07	0.62125000E 06 0.14204000E 07	0.10061000E 07	0.10240000E 07

AVERAGE NO. OF DELAYED NEUTRONS
SPECIES 1 SPECIES 2

0.16500000E-01 0.41150999E-01

AVERAGE NU
SPECIES 1 SPECIES 2

2 0.25600000E 01 0.26199999E 01

REGION.....MATERIAL

1.....	1
2.....	2
3.....	2
4.....	2
5.....	1
6.....	2
7.....	2
8.....	2
9.....	1
10.....	2
11.....	2
12.....	2
13.....	3
14.....	4
15.....	4
16.....	4
17.....	5
18.....	5
19.....	5
20.....	5
21.....	6
22.....	6
23.....	6
24.....	6

23

R, Z GEOMETRY SPECIFIED, THICK = 0.2852

INTEGRAL CALCULATION RESULTS

D(1) = 0.15858102E 13
D(2) = 0.29892006E 18
D(3) = 0.26668981E 18
D(4) = 0.10151535E 10
D(5) = 0.24860676E 15
D(6) = 0.22133054E 15
D(7) = 0.57041810E 13

BETA-EFFECTIVE = 0.72272673E-02
L-SUB-P = 0.21371086E-04

EOF ON INPUT TAPE

159 LINES OUTPUT THIS JOB.

OFF AT 11.198

REFERENCES

- (1) G. Collier and J. W. Riese, "VARI-QUIR-III: A Two-Dimensional Steady State Multi-Group Diffusion Code", WANL-TNR-189, December 1964.
- (2) G. Gibson, M. Melnick, and W. Gray, "Changes in the GAM-TNS Program and Cross Section Library", WANL-TME-1228, August 1965.
- (3) D. Meneghetti, "Recent Advances and Problems in Theoretical Analyses of ZPR-III Fast Critical Assemblies", Physics of Fast and Intermediate Reactors, Vol. 1, Proceedings of the Seminar on the Physics of Fast and Intermediate Reactors sponsored by International Atomic Energy Agency, August 3-11, 1961.
- (4) G. R. Keepin, T.F. Wimett, and R. K. Ziegler, LA-2118 (1957).
- (5) Reactor Physics Constants, ANL-5800, 24, (1958).

APPENDIX I

Listing of BETALS Program

Main Program

C	BETALS	BETALS 1
C	CA PROGRAM TO CALCULATE BETA-EFFECTIVE AND PROMPT NEUTRON LIFETIME USING	BETALS 2
C	C VARI-QUIR FLUX AND ADJOINT SOLUTIONS AND GAM-TNS MULTIGROUP CONSTANTS	BETALS 3
C		BETALS 4
C	*****	
C		
C	C MOST OF THE VARIABLES APPEARING BELOW ARE EXPLAINED IN THE COMMENTS TO	BETALS 5
C	C THE GHOST AND BANQUO SUBROUTINES.	BETALS 6
C		BETALS 7
C	C FOR SLAB (X,Y) GEOMETRY PROBLEMS-	BETALS 8
C		BETALS 9
C	C THE R-AXIS BECOMES THE X-AXIS	BETALS10
C	C THE Z-AXIS BECOMES THE Y-AXIS	BETALS11
C	C THE THIRD DIMENSION BECOMES Z(INPUT).	BETALS12
C		
C	*****	
C		BETALS13
	COMMON NRG,NZG,NGR,IM,NOMATS,NRP,NZP, IGEOM, INOUT	BETALS14
	COMMON R,Z,DR,DZ	BETALS15
	COMMON GNUSF1,GNUSF2,CHID1,CHID2,CHI	BETALS16
	COMMON PHI,ADJ	BETALS17
	COMMON ENOF1,ENOF2,GNU1,GNU2	BETALS18
	COMMON EGY,D,A	BETALS19
	DIMENSION IM(144)	BETALS20
	DIMENSION R(21),Z(21),DR(10),DZ(10)	BETALS21
	DIMENSION GNUSF1(20,20),GNUSF2(20,20),CHID1(20,20),CHID2(20,20),	BETALS22
	1CHI(20,20)	BETALS23
	DIMENSION PHI(20,450),ADJ(20,450)	BETALS24
	DIMENSION EGY(20),D(7), HDG(14)	BETALS25
1000	FORMAT(20I4)	BETALS26
1100	FORMAT(5E15.8)	BETALS27
1200	FORMAT(13A6,A2)	BETALS28
1300	FORMAT(1H1, 13A6,A2)	BETALS29
10	RIPT 5, 1200, (HDG(I), I=1,14)	BETALS30
	WOT6,1300,(HDG(I),I=1,14)	BETALS31
	RIPT 5,1000, NGR,NRG,NZG,NOMATS, IGEOM, INOUT	BETALS32
	NREG = NRG*NZG	BETALS33
	NRP=2*NRG+1	BETALS34
	NZP=2*NZG+1	BETALS35
	RIPT 5,1000, (IM(I),I=1,NREG)	BETALS36
	RIPT 5, 1100, (DR(I), I=1, NRG)	BETALS37
	RIPT 5, 1100, (DZ(I), I=1, NZG)	BETALS38
	NPTS = NRP*NZP	BETALS39
	DO 20 I=1, NGR	BETALS40
20	KIPT 5, 1100, (PHI(I, IPT), IPT=1, NPTS)	BETALS41
	DO 30 I=1, NGR	BETALS42
30	RIPT 5, 1100, (ADJ(I, IPT), IPT=1, NPTS)	BETALS43

CALL GHOST
GO TO 10
END

BETALS44
BETALS45
BETALS46

Subroutine GHOST

```

SUBROUTINE GHOST
C SUBPROGRAM TO CALCULATE BETA EFFECTIVE AND L-P FROM FLUXES AND ADJOINTS
C FROM VARI-QUIR
C
COMMON NRG,NZG,NGR,IM,NOMATS,NRP,NZP, IGEOM, INOUT
COMMON R,Z,DR,DZ
COMMON GNUSF1,GNUSF2,CHID1,CHID2,CHI
COMMON PHI,ADJ
COMMON ENOF1,ENOF2,GNU1,GNU2
COMMON D,A
DIMENSION IM(144)
DIMENSION R(21),Z(21),DR(10),DZ(10)
DIMENSION GNUSF1(20,20),GNUSF2(20,20),CHID1(20,20),CHID2(20,20),
1CHI(20,20)
DIMENSION PHI(20,450),ADJ(20,450)
DIMENSION EGY(20),D(7),FDG(14)
DIMENSION V(20,20)
RIPT 5, 1000, SP1, SP2
1000 FORMAT(2A6)
C
C *****
C
C IM(I) = MATERIAL NUMBER FOR REGION NUMBER I
C NOMATS = NUMBER OF DIFFERENT KINDS OF MATERIALS
C NRG=NUMBER OF REGIONS ALONG R-AXIS, IR=R-REGION INDEX.
C NZG=NUMBER OF REGIONS ALONG Z-AXIS, IZ=Z-REGION INDEX.
C NRP=2*NRG+1=NO. OF POINTS ALONG R AXIS.
C NZP=2*NZG+1=NO. OF POINTS ALONG Z AXIS.
C NGR=NO. OF ENERGY GROUPS.
C
C INITIALLY THE FLUXES AND ADJOINTS ARE STORED IN A TWO DIMENSIONAL
C ARRAY BY POINT AND BY GROUP (SEE FIG.2-B), ARRAY SIZE=NGR*(NRP*NZP)
C
C THE GROUP CONSTANTS ARE STORED IN A SIMILAR MANNER, EXCEPT THAT
C ARRAY SIZE=NGR*(NRG*NZG).
C
C DR(I)=INCREMENT IN R FOR R-REGION I.
C DZ(I)=INCREMENT IN Z FOR Z-REGION I.
C R(I)=THE R-COORDINATE OF POINT I, THERE ARE 2*NRG+1 R(I)'S.
C Z(I)=THE Z-COORDINATE OF POINT I, THERE ARE 2*NZG+1 Z(I)'S.
C
C
C
C
C FIG. 1, VARI-QUIR NUMBERING SYSTEM FOR REGIONS, POINTS, GROUP CONSTANTS, FLUX
C- THE REACTOR-

```

```

GHOST 1
GHOST 2
GHOST 3
GHOST 4
GHOST 5
GHOST 6
GHOST 7
GHOST 8
GHOST 9
GHOST 10
GHOST 11
GHOST 12
GHOST 13
GHOST 14
GHOST 15
GHOST 16
GHOST 17
GHOST 18
GHOST 19
GHOST 20
GHOST 21
GHOST 22
GHOST 23
GHOST 24
GHOST 25
GHOST 26
GHOST 27
GHOST 28
GHOST 29
GHOST 30
GHOST 31
GHOST 32
GHOST 33
GHOST 34
GHOST 35
GHOST 36
GHOST 37
GHOST 38

```

C		
C	*****	
C	READ IN LOWER BOUNDARY GROUP ENERGIES, GROUP 1 HAS HIGHEST ENERGY	GHOST 39
C	UPPER ENERGY BOUND IS 10MEV	GHOST 40
	N=NGR+1	GHOST 41
C	READ THE GROUP CONSTANTS AND STORE ACCORDING GROUP AND REGION NUMBER,	GHOST 42
C	SEF FIG. 2-A FOR STORAGE ALLOCATION.	GHOST 43
	NREG=NRG*NZG	GHOST 44
	NRP=2*NRG+1	GHOST 45
	NZP=2*NZG+1	GHOST 46
	NPTS=NRP*NZP	GHOST 47
C	NREG=NO. OF REGIONS	GHOST 48
C		GHOST 49
	10 DO 20 J = 1,NOMATS	GHOST 50
	20 RIPT 5,3100,(GNUSF1(I,J),I=1,NGR)	GHOST 51
	DO 30 J=1,NOMATS	GHOST 52
	30 RIPT 5,3100,(GNUSF2(I,J),I=1,NGR)	GHOST 53
	DO 40 J=1,NOMATS	GHOST 54
	40 RIPT 5,3100,(CHID1(I,J),I=1,NGR)	GHOST 55
	DO 50 J=1,NOMATS	GHOST 56
	50 RIPT 5,3100,(CHID2(I,J),I=1,NGR)	GHOST 57
	DO 60 J=1,NOMATS	GHOST 58
	60 RIPT 5,3100,(CHI(I,J),I=1,NGR)	GHOST 59
C	CHID1(I),CHID2(I),FRACTION OF DELAYED NEUTRONS FROM SPECIES 1 OR 2	GHOST 60
	DO 70 J = 1,NOMATS	GHOST 61
	70 RIPT 5, 3100, (V(I,J),I=1,NGR)	GHOST 62
C	EMITTED INTO GROUP 1.	GHOST 63
C	GNUSF1(I), GNUSF2(I), NU-SIGMA FISSION FOR SPECIES 1 OR 2 FOR GROUP 1.	GHOST 64
C	CHI = FISSION SPECTRUM.	GHOST 65
C		GHOST 66
C	READ THE NON-ENERGY DEPENDENT, NON REGION DEPENDENT QUANTITIES.	GHOST 67
	RIPT 5,3100 ,ENOF1,ENOF2,GNU1,GNU2	GHOST 68
C	ENOF1,ENOF2 =NUMBER OF DELAYED NEUTRONS PER FISSION(AVERAGE).	GHOST 69
C	GNU1,GNU2 = NU-SIGMA FISSION(AVERAGE)	GHOST 70
C		GHOST 71
C	CALCULATE THE NRP R-COORDINATES	GHOST 72
	IF(IGEOM)80,100,80	GHOST 73
	80 DO 90 JIM =1,NRG	GHOST 74
	90 R(I) = 1.	GHOST 75
	GO TO 120	GHOST 76
	100 CONTINUE	GHOST 77
	THIRD = 6.2831853	GHOST 78
	M=2	GHOST 79
	R(1)=0.	GHOST 80
	DO 110 I=1,NRG	GHOST 81
	I=1	GHOST 82
	K1=2*I-1	GHOST 83

```

      *---*---*---*---* / / *---*---*
      I I J I I I I KI
      . A9. . . . . . .
      I-1I N1 I 2N1 I 3N1I I M I
      *---*---*---*---* / / *---*---*
      I-2I A8 I I I I I
      / / / / / /

      / I / / / /
      7*---*---*---*---* / / *---*---*
      I A7 I I I I I
      6. A6. I . . . . .
      I 3 I P3 I Q3 I I R3 I
      5*---*---*---*---* / / *---*---*
      I A5 I I I I I
      4. A4. . . . . .
      I 2 I P2 I Q2 I I R2 I
      3*---*---*---*---* / / *---*---*
      I A3 I I I I I
      I I I I I I I
      2. A2. . . . . .
      I I I I I I I
      I 1 I P1 I Q1 I I R1 I
      1*---*---*---*---* / / *---*---*
      A1

```

```

      *
      ***
      *
      * ***** R (OR X)
      *
      *
      Z (OR Y)

```

KEY- * = A REGION CORNER POINT
 . = A REGION INTERPOLANT POINT
 SO THAT EACH REGION LOOKS LIKE-

```

      *---*---*
      L31 L6 L91
      1 1
      . L5. .
      L21 L81
      1 N 1
      *---*---*
      L1 L4 L7

```

N = REGION NUMBER
 L1-L9 = PCINT NUMBERS

REGION NUMBERING

N1= NZG
 P1= N1+1
 P2= N1+2
 ETC...,

 Q1= 2N1+1
 Q2= 2N2+2
 ETC...
 M= NRG*NZG

POINT NUMBERING

I= 2NZG+1
 A1= I+1
 A2= I+2
 ETC...
 A8=2I-2
 A9=2I-1
 J= 2I
 ETC...
 .
 .
 .
 K=(2NRG+1)(2NZG+1)

GROUP CONSTANTS ARE
 INDEXED BY MATERIAL
 NO., AND EACH MATER
 IAL NO. IS INDEXED
 BY REGION.

FLUXES AND ADJOINTS
 ARE INDEXED BY POINT
 NO.

K2=2*I	GHOST 84
DEL=DR(I)/2.	GHOST 85
R(M)= R(K1)+DEL	GHOST 86
R(M+1)=R(K2)+DEL	GHOST 87
110 M = M + 2	GHOST 88
120 CONTINUE	GHOST 89
IF(INOUI)270,130,270	GHOST 90
130 CONTINUE	GHOST 91
C	GHOST 92
C WRITE THE INPUT	GHOST 93
WOT 6, 1100, SP1, SP2	GHOST 94
1100 FORMAT (13H0SPECIES 1 = A6, 13H, SPECIES 2 = A6)	GHOST 95
WOT 6,1200, NRP	GHOST 96
DO 140 I=1,NRP	GHOST 97
I=I	GHOST 98
140 WOT 6,1400, I, R(I)	GHOST 99
1200 FORMAT(23H0NU. OF R-COORDINATES = 13 /	GHOST 100
1 23H0 I R(I))	GHOST 101
WOT 6,1300	GHOST 102
DO 150 I=1,NRG	GHOST 103
I=I	GHOST 104
150 WOT 6,1400, I, DR(I)	GHOST 105
WOT 6,1500	GHOST 106
DO 160 I=1,NZG	GHOST 107
I=I	GHOST 108
160 WOT 6,1400, I, DZ(I)	GHOST 109
1300 FORMAT(12H0 I DR(I))	GHOST 110
1400 FORMAT(13, E15.8)	GHOST 111
1500 FORMAT(12H0 I DZ(I))	GHOST 112
WOT 6, 1600, NRG,NZG,NREG,NGR,NOMATS	GHOST 113
1600 FORMAT(30H0NU. OF REGIONS ALONG R-AXIS = 13 /	GHOST 114
1 30H NO. OF REGIONS ALONG Z-AXIS = 13 /	GHOST 115
2 30H TOTAL NU. OF REGIONS = 13 /	GHOST 116
3 30H NO. OF ENERGY GROUPS = 13 /	GHOST 117
4 30H NO. OF MATERIALS = 13 /)	GHOST 118
WOT 6, 1700, NOMATS	GHOST 119
1700 FORMAT(45H1GNO-SIGMA FISSION, SPECIES 1, FOR MAT'LS 1-, 12 //	GHOST 120
1 6H GROUP	) GHOST 121
DO 170 I=1,NGR	GHOST 122
170 WOT 6,1800, I, (GNUSF1(I,J),J=1,NOMATS)	GHOST 123
1800 FORMAT(1H0, 14, 4E20.8 / (5H ,4E20.8))	GHOST 124
WOT 6, 1900	GHOST 125
1900 FORMAT(29H1GNO-SIGMA FISSION, SPECIES 2/	GHOST 126
1 6H GROUP	) GHOST 127
DO 180 I=1,NGR	GHOST 128
180 WOT 6,1800, I, (GNUSF2(I,J),J=1,NOMATS)	GHOST 129
WOT 6,2000	GHOST 130

2000	FORMAT(37H1DELAYED NEUTRON FRACTIONS, SPECIES 1 / 6H GROUP	)	GHOST131
	DO 190 I=1,NGR		GHOST132
190	WOT 6,1800, I, (CHID1(I,J),J=1,NOMATS)		GHOST133
	WOT 6,2100		GHOST134
2100	FORMAT(37H1DELAYED NEUTRON FRACTIONS, SPECIES 2 / 6H GROUP	)	GHOST135
	DO 200 I=1,NGR		GHOST136
200	WOT 6,1800, I, (CHID1(I,J),J=1,NOMATS)		GHOST137
	WOT 6, 2200		GHOST138
2200	FORMAT(17H1FISSION SPECTRUM /6H GROUP)		GHOST139
	DO 210 I=1,NGR		GHOST140
210	WOT 6,1800, I, (CHI(I,J), J=1,NOMATS)		GHOST141
	WOT 6,2300		GHOST142
2300	FORMAT(27H1AVERAGE NEUTRON VELOCITIES /		GHOST143
	1 6H GROUP)		GHOST144
	DO 220 I=1,NGR		GHOST145
220	WOT 6, 1800, I, (V(I,J), J=1,NOMATS)		GHOST146
	WOT 6,2400,ENOF1,ENOF2, GNU1, GNU2		GHOST147
2400	FORMAT(32H0AVERAGE NO. OF DELAYED NEUTRONS/		GHOST148
	1 35H SPECIES 1 SPECIES 2 //		GHOST149
	2 2E20.8 , /		GHOST150
	3 11H0AVERAGE NU /		GHOST151
	4 35H SPECIES 1 SPECIES 2 //		GHOST152
	5 2E20.8)		GHOST153
	WOT6, 2500		GHOST154
2500	FORMAT(19H1REGION....MATERIAL)		GHOST155
	DO 230 I=1,NREG		GHOST156
	I=I		GHOST157
230	WOT 6, 2600, I, IM(I)		GHOST158
2600	FORMAT(5X12, 10H.....12)		GHOST159
	IF(IGEQM)240,250,240		GHOST160
240	CRUD = 6H SLAB		GHOST161
	GO TO 260		GHOST162
250	CRUD = 6H R, Z		GHOST163
260	CONTINUE		GHOST164
	WOT 6, 2700, CRUD,THIRD		GHOST165
2700	FORMAT(1H0, A6,28HGEOMETRY SPECIFIED, THIRD = F9.4)		GHOST166
C			GHOST167
C	PHI(I,J)= FLUX FOR GROUP I, POINT J.		GHOST168
C	ADJ(I,J)= ADJOINT FOR GROUP I, POINT J.		GHOST169
C	FLUXES AND ADJOINTS ARE GIVEN AS IN FIG. 2-A.		GHOST170
C			GHOST171
C	CALCULATE THE INTEGRALS D(1) AND D(2)		GHOST172
	270 CONTINUE		GHOST173
	DO 280 I=1,2		GHOST174
	I=I		GHOST175
	CALL BANQUO(I,ARG,NZG,NGR,R,GNUSF1,CHID1,OR,DZ,PHI,ADJ,S,A,IM,		GHOST176
	1THIRD)		GHOST177

280 D(1)=A	GH0ST178
C CALCULATE THE INTEGRAL D(3)	GH0ST179
I=2	GH0ST180
CALL BANQUO(I,NRG,NZG,NGR,R,GNUSF1,CHI ,DR,DZ ,PHI,ADJ,S,A,IM,	GH0ST181
1THIRD)	GH0ST182
D(3)=A	GH0ST183
C CALCULATE THE INTEGRALS D(4) AND D(5)	GH0ST184
DO 290 I=1,2	GH0ST185
I=1	GH0ST186
CALL BANQUO(I,NRG,NZG,NGR,R,GNUSF2,CHID2,DR,DZ,PHI,ADJ,S,A,IM,	GH0ST187
1THIRD)	GH0ST188
290 D(I+3)=A	GH0ST189
C CALCULATE THE INTEGRAL D(6)	GH0ST190
I=2	GH0ST191
CALL BANQUO(I,NRG,NZG,NGR,R,GNUSF2,CHI,DR,DZ,PHI,ADJ,S,A,IM,THIRD)	GH0ST192
D(6)=A	GH0ST193
C CALCULATE THE INTEGRAL D(7) AS A TYPE 1 PROBLEM	GH0ST194
DO 300 I=1,NGR	GH0ST195
DO 300 J=1,NPTS	GH0ST196
300 PHI(I,J) = PHI(I,J)*ADJ(I,J)	GH0ST197
DO 310 I=1,NGR	GH0ST198
DO 310 J = 1, NOMATS	GH0ST199
310 CHID1(I,J) = 1./V(I,J)	GH0ST200
I=1	GH0ST201
CALL BANQUO(I,NRG,NZG,NGR,R,CHID1,CHID2,DR,DZ,PHI,ADJ,S,A,IM,	GH0ST202
1THIRD)	GH0ST203
D(7)=A	GH0ST204
C WRITE ALL RESULTS	GH0ST205
WOT 6,2800	GH0ST206
2800 FORMAT(29H1INTEGRAL CALCULATION RESULTS//)	GH0ST207
DO 320 I=1,7	GH0ST208
320 WOT 6,2900, I, D(I)	GH0ST209
2900 FORMAT(3H D(,I1,5H) = E15.8)	GH0ST210
C CALCULATE BETA EFFECTIVE AND L-SUB-P.	GH0ST211
ONU1=1./GNU1	GH0ST212
ONU2=1./GNU2	GH0ST213
DD = (D(1)* (D(2)*ONU1*ENOF1 + D(5)*ONU2*ENOF2))/D(3)	GH0ST214
ONU1=GNU1-ENOF1	GH0ST215
ONU2=GNU2-ENOF2	GH0ST216
PP = D(1)* (ONU1/GNU1 + D(6)*ONU2/(D(3)*GNU2))	GH0ST217
C	GH0ST218
BETEFF = DD/(DD+PP)	GH0ST219
ELSUBP = D(7)/(D(3)+D(6))	GH0ST220
C	GH0ST221
WOT 6, 3000, BETEFF, ELSUBP	GH0ST222
3000 FORMAT(17HOBETA-EFFECTIVE = E15.8 /	GH0ST223
1 17H L-SUB-P = E15.8)	GH0ST224

3100 FORMAT(5E15.8)
RETURN
END

GHOST225
GHOST226
GHOST227

Subroutine BANQUO

```

      SUBROUTINE BANQUO(ITYP,NRG,NZG,NGR,R,GC1,GC2,DR,DZ,F1,F2,S,A,IMAT,BANQUO 1
      1THIRD) BANQUO 2
C SUBPROGRAM TO CALCULATE INTEGRALS FOR GHOST. BANQUO 3
C*****
C BANQUO 4
C   NRG=NO. OF REGIONS ALONG R-AXIS. BANQUO 5
C   NZG=NO. OF REGIONS ALONG Z-AXIS. BANQUO 6
C   NGR=NO. OF ENERGY GROUPS. BANQUO 7
C   R(I)=R COORDINATE OF R-POINT I. BANQUO 8
C BANQUO 9
C   GC1(I,J),GC2(I,J)=GROUP CONSTANTS, GROUP I, REGION J. BANQUO10
C   DR(IR)=WIDTH OF REGION IR, DZ(IZ)=WIDTH OF REGION IZ. BANQUO11
C   F1(I,J),F2(I,J)=FUNCTIONS TO BE INTEGRATED OVER. BANQUO12
C BANQUO13
C   ITYP=TYPE OF PROBLEM, BANQUO14
C BANQUO15
C   ITYP=1, ONE FUNCTION TO BE INTEGRATED OVER, SUCH AS INTEGRAL D BANQUO16
C   ITYP=2, TWO FUNCTIONS, SUCH AS INTEGRAL D(2). BANQUO17
C BANQUO18
C*****
C CALCULATE NO.OF POINTS ALONG R AND Z AXES, (NRP, NRZ). BANQUO19
C
C*****
C   DIMENSION DR(1),DZ(1),R(1),Z(1),GC1(20,1),F1(20,1), BANQUO20
C   1GC2(20,1),F2(20,1) , IMAT(1) BANQUO21
C   DIMENSION SL(30), SM(30), SR(30) BANQUO22
C   NRP = 2*NRG+1 BANQUO23
C   NZP = 2*NZG+1 BANQUO24
C*****
C CALCULATE TOTAL NO. OF REGIONS (NREG) AND POINTS(NPTS). BANQUO25
C
C*****
C   NREG = NRG*NZG BANQUO26
C   10 NPTS = NRP*NZP BANQUO27
C*****
C   INITIALIZE MAIN INTEGRAL BANQUO28
C
C*****
C   S=0. BANQUO29
C*****
C   INITIALIZATION OF ABSOLUTE REGION NO. BANQUO30
C
C*****

```

IRGNO = 1	BANQU031
DO 90 IRG = 1, NRG	BANQU032
IRG = IRG	BANQU033
IRT = 2*IRG+1	BANQU034
IMD = IRT -1	BANQU035
ILF = IMD -1	BANQU036
C*****	
C	
C IRG = REGION NO. INDEX ALONG R AXIS	BANQU037
C IRT = POINT NO. INDEX ALONG R AXIS FOR RIGHT HAND POINT OF IRG	BANQU038
C IMD = POINT NO. INDEX ALONG R AXIS FOR MIDDLE POINT OF IRG	BANQU039
C ILF = POINT NO. INDEX ALONG R AXIS FOR LEFT HAND POINT OF IRG	BANQU040
C	
C*****	
IPNOL = (ILF -1)*NZP + 1	BANQU041
IPNOM = (IMD -1)*NZP + 1	BANQU042
20 IPNOR = (IRT -1)*NZP + 1	BANQU043
C*****	
C	
C INITIALIZATION OF ABSOLUTE POINT NO.	BANQU044
C IPNOL = LEFTMOST POINT NO. OF IRG	BANQU045
C IPNOM = MIDDLE POINT NO. OF IRG	BANQU046
C IPNOR = RIGHTMOST POINT NO. OF IRG	BANQU047
C	
C*****	
SL(IRG) = 0.	BANQU048
SM(IRG) = 0.	BANQU049
SR(IRG) = 0.	BANQU050
DO 80 IZG = 1, NZG	BANQU051
IUP = 2*IZG + 1	BANQU052
ICT = IUP-1	BANQU053
ILO = ICT-1	BANQU054
C*****	
C	
C IZG = REGION NO. INDEX ALONG Z AXIS	BANQU055
C IUP = POINT NO. INDEX ALONG Z AXIS FOR UPPER POINT OF IZG	BANQU056
C ICT = POINT NO. INDEX ALONG Z AXIS FOR CENTER POINT OF IZG	BANQU057
C ILO = POINT NO. INDEX ALONG Z AXIS FOR LOWER POINT OF IZG	BANQU058
C	
C*****	
30 IZG = IZG	BANQU059
C*****	
C	
C IRGNO = ABSOLUTE REGION NO.	BANQU060
C	
C*****	
STL1 = 0.	BANQU061

```

      STL2 = 0.
      STL3 = 0.
      STM1 = 0.
      STM2 = 0.
      STM3 = 0.
      STR1 = 0.
      STR2 = 0.
      STR3 = 0.
      DO 40 IGR = 1, NGR
      IGR = IGR
      IMNO = IMAT(IGRNO)
      FMP = GC1(IGR,IMNO)
C IGR = ENERGY GROUP NO. INDEX
      STL1 = STL1 + FMP*F1(IGR,IPNOL)
      STL2 = STL2 + FMP*F1(IGR,IPNOL+ 1)
      STL3 = STL3 + FMP*F1(IGR,IPNOL+ 2)
C
      STM1 = STM1 + FMP*F1(IGR,IPNOM)
      STM2 = STM2 + FMP*F1(IGR,IPNOM+ 1)
      STM3 = STM3 + FMP*F1(IGR,IPNOM+ 2)
C
      STR1 = STR1 + FMP*F1(IGR,IPNOR)
      STR2 = STR2 + FMP*F1(IGR,IPNOR+1)
      STR3 = STR3 + FMP*F1(IGR,IPNOR+2)
40 CONTINUE
C
C
      IF(ITYP - 1) 70, 70, 50
50 CONTINUE
      TTL1 = 0.
      TTL2 = 0.
      TTL3 = 0.
C
      TTM1 = 0.
      TTM2 = 0.
      TTM3 = 0.
C
      TTR1 = 0.
      TTR2 = 0.
      TTR3 = 0.
      DO 60 IGR = 1, NGR
      IMNO = IMAT(IGRNO)
      FMP = GC2(IGR, IMNO )
C
      TTL1 = TTL1 + FMP*F2(IGR,IPNOL)
      TTL2 = TTL2 + FMP*F2(IGR,IPNOL +1)
      TTL3 = TTL3 + FMP*F2(IGR,IPNOL +2)

```

```

BANQU062
BANQU063
BANQU064
BANQU065
BANQU066
BANQU067
BANQU068
BANQU069
BANQU070
BANQU071
BANQU072
BANQU073
BANQU074
BANQU075
BANQU076
BANQU077
BANQU078
BANQU079
BANQU080
BANQU081
BANQU082
BANQU083
BANQU084
BANQU085
BANQU086
BANQU087
BANQU088
BANQU089
BANQU090
BANQU091
BANQU092
BANQU093
BANQU094
BANQU095
BANQU096
BANQU097
BANQU098
BANQU099
BANQU000
BANQU001
BANQU002
BANQU003
BANQU004
BANQU005
BANQU006
BANQU007
BANQU008

```

C	TTM1 = TTM1 + FMP*F2(IGR,IPNOM)	BANQU009
	TTM2 = TTM2 + FMP*F2(IGR,IPNOM +1)	BANQU010
	TTM3 = TTM3 + FMP*F2(IGR,IPNOM +2)	BANQU011
C		BANQU012
	TTR1 = TTR1 + FMP*F2(IGR,IPNOR)	BANQU013
	TTR2 = TTR2 + FMP*F2(IGR,IPNOR+1)	BANQU014
	TTR3 = TTR3 + FMP*F2(IGR,IPNOR+2)	BANQU015
60	CONTINUE	BANQU016
	STL1 = STL1*TTL1	BANQU017
	STL2 = STL2*TTL2	BANQU018
	STL3 = STL3*TTL3	BANQU019
	STM1 = STM1*TTM1	BANQU020
	STM2 = STM2*TTM2	BANQU021
	STM3 = STM3*TTM3	BANQU022
	STR1 = STR1*TTR1	BANQU023
	STR2 = STR2*TTR2	BANQU024
	STR3 = STR3*TTR3	BANQU025
70	CONTINUE	BANQU026
	IRGNO = IRGNO + 1	BANQU027
	IPNOL = IPNOL + 2	BANQU028
	IPNOM = IPNOM + 2	BANQU029
	IPNOR = IPNOR + 2	BANQU030
C	*****	BANQU031
C		
C	UPDATED ABSOLUTE INDICES, IRGNO, IPNOL, IPNOM, IPNOR	BANQU032
C		
C	*****	
	H = DZ(IZG)/6.	BANQU033
	SL(IGR) = R(ILF)*SL(IGR)	BANQU034
	SM(IGR) = R(IMD)*SM(IGR)	BANQU035
	SR(IGR) = R(IRT)*SR(IGR)	BANQU036
	SL(IGR) = SL(IGR) + (STL1 + 4.*STL2 + STL3)*H	BANQU037
	SM(IGR) = SM(IGR) + (STM1 + 4.*STM2 + STM3)*H	BANQU038
	SR(IGR) = SR(IGR) + (STR1 + 4.*STR2 + STR3)*H	BANQU039
80	CONTINUE	BANQU040
C	*****	
C		
C	CALCULATE MAIN INTEGRAL	BANQU041
C		
C	*****	
	H = DR(IGR)/6.	BANQU042
	S = S + (SL(IGR) + 4.*SM(IGR) + SR(IGR))*H	BANQU043
90	CONTINUE	BANQU044
	A = THIRD*S	BANQU045
	RETURN	BANQU046
	END	BANQU047

APPENDIX II

The FAVELA Program

FAVELA Program

The FAVELA Code calculates the average neutron velocity of each broad group by averaging the velocity over the GAM-TNS flux spectrum:

$$(1) \quad \bar{v}_j = \frac{\int_{E_{2j}}^{E_{1j}} v \phi(v) dv}{\int_{E_{2j}}^{E_{1j}} \phi(v) dv}$$

where:

(2) $\bar{v}_j$ = average neutron velocity of group j,

(3) E_{1j} , E_{2j} are the upper and lower boundary energies, respectively, of group j.

The program integrates by trapezoids over the GAM and TNS fine group structure, utilizing 62 GAM fluxes (out of 68, all but the last card of the GAM punched flux output) which run from 10 MeV to 1.86 eV, and 93 TNS fluxes (all of the TNS punched flux output, if 93 energy points are requested), which run from 1.86 eV to .001 eV.

*The value of ℓ_p is extremely sensitive to $\bar{v}_j$; a simple arithmetic mean is inadequate. If one wants a hand calculation, a $\frac{1}{E} \phi$ spectrum may be assumed, then the result is

$$\bar{v}_j = \frac{v_{1j} v_{2j} \ln(v_{1j}/v_{2j})}{(v_{1j} - v_{2j})}$$

where v_{1j} and v_{2j} are the neutron velocities corresponding to E_{1j} and E_{2j} .

The program punches the velocities; this output can be entered directly into the BETALS program.

INPUT INSTRUCTIONS

Card Set	Variable Names(s)	Variable	Type	Precision	Fortran Format	Card Columns	Description and Remarks
1	T		A		13A6,A2	1-80	Arbitrary title card.
2	NGF		I		I4	1-4	No. of GAM fluxes to be read in (62).
	NTF		I		I4	5-8	No. of TNS fluxes to be read in (93).
	NGR		I		I4	9-12	No. of energy groups.
	NGMATS		I		I4	13-16	No. of different materials NGF + NTF = 155.
3	EGY	D	R	S	6E12.5	1-12, 13-24, etc...	Energy points (ev) from 2 to NGR-1 starting with highest energy, EGY(1) = 10MeV; usually EGY(NGR+1) = .001 eV.
4	FLUX	D	R	S	6E12.5		GAM fluxes, enter NOMATS sets of fluxes, each set containing NGF entries (can be entered directly from GAM-TNS output).
5	TFLUX	D	R	S	6E12.5		TNS fluxes, enter NOMATS sets of fluxes, each set containing NTF entries (can be entered directly from GAM-TNS output).
Stack problems by repeating the input.							

Listing of FAVELA Program
and Sample Problem

CFAVELA, PROGRAM TO FLUX AVERAGE THE VELOCITIES AND PUNCH

```
C
  DIMENSION T(14), EGY(20), FLUX(20,200),V(20,20)
  10 RIPT 5,1000,(T(I),I=1,14)
  1000 FORMAT(13A6,A2)
  WOT 6, 1050,(T(I), I=1,14)
  1050 FORMAT(1H1, 13A6, A2)
C
C READ THE PROBLEM SPECS.
  RIPT 5,1100, NGF, NTF, NGR, NOMATS
  1100 FORMAT(18I4)
C
C READ THE EMERGY BREAK PCINTS
  EGY(1) = 10.E+6
  NGRP1 = NGR + 1
  RIPT 5,1200, (EGY(I),I=2,NGRP1)
C
C READ THE GAM FLUXES
  DO 20 I = 1,NOMATS
  RIPT 5,1200, (FLUX(I,J), J=1,NGF)
  20 CONTINUE
C
C READ THE TNS FLUXES
  N1 = NGF + 1
  N2 = NGF + NTF
  1200 FORMAT( 6E12.5)
  DO 30 I = 1, NOMATS
  RIPT 5,1200, (FLUX(I,J),J = N1, N2)
  30 CONTINUE
C
C REORDER THE TNS FLUXES
  DO 50 I = 1, NOMATS
  DO 40 J = N1,N2
  K = N2 - J +1
  BUCKET = FLUX(I,K)
  TUFFET = FLUX(I,J)
  FLUX(I,K) = TUFFET
  FLUX(I,J) = BUCKET
  40 CONTINUE
  50 CONTINUE
C
C CALCULATE THE FLUX AVERAGED CROSS SECTIONS
  CALL FAVELA(FLUX,EGY,FGAM,NOMATS,NGR,V)
C
C PUNCH OUT THE VELOCITIES FOR THE BETALS PROGRAM
  DO 60 J = 1,NOMATS
  WOT 7,1300, (V(I,J),I = 1,NGR)
```

```
FAVMNP 1
FAVMNP 2
FAVMNP 3
FAVMNP 4
FAVMNP 5
FAVCHG 1

FAVMNP 6
FAVMNP 7
FAVMNP 8
FAVMNP 9
FAVMNP10
FAVMNP11
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FAVMNP37
FAVMNP38
FAVMNP39
FAVMNP40
FAVMNP41
FAVMNP42
FAVMNP43
FAVMNP44
FAVMNP45
```

1300 FORMAT(5E15.8)
60 CONTINUE
GO TO 10
END

FAVMNP46
FAVMNP47
FAVMNP48
FAVMNP49

SUBROUTINE FAVELA(FLUX,EGY,FGAM,NOMATS,NGR,V)
 CFLUXAV-PROGRAM TO FLUX AVERAGE NEUTRON VELOCITIES FOR BETALS
 DIMENSION FLUX(20,1),V(20,1),EGY(1),VEL(155),ID(20),FGAM(1)
 CVELOCITY TABLE

VEL(1) = 0.437730CE 10
 VEL(2) = 0.3862954E 10
 VEL(3) = 0.3409045E 10
 VEL(4) = 0.3008471E 10
 VEL(5) = 0.2654967E 10
 VEL(6) = 0.234300CE 10
 VEL(7) = 0.2067690E 10
 VEL(8) = 0.1824730E 10
 VEL(9) = 0.1610319E 10
 VEL(10) = 0.1421101E 10
 VEL(11) = 0.1254117E 10
 VEL(12) = 0.1106755E 10
 VEL(13) = 0.9767077E 09
 VEL(14) = 0.8619415E 09
 VEL(15) = 0.7606607E 09
 VEL(16) = 0.6712807E 09
 VEL(17) = 0.5924032E 09
 VEL(18) = 0.5227939E 09
 VEL(19) = 0.4613640E 09
 VEL(20) = 0.4071523E 09
 VEL(21) = 0.3593107E 09
 VEL(22) = 0.3170905E 09
 VEL(23) = 0.2798314E 09
 VEL(24) = 0.2469504E 09
 VEL(25) = 0.2179329E 09
 VEL(26) = 0.1923251E 09
 VEL(27) = 0.1697263E 09
 VEL(28) = 0.1497830E 09
 VEL(29) = 0.1321830E 09
 VEL(30) = 0.1166511E 09
 VEL(31) = 0.1029442E 09
 VEL(32) = 0.9084796E 08
 VEL(33) = 0.8017305E 08
 VEL(34) = 0.7075246E 08
 VEL(35) = 0.6243883E 08
 VEL(36) = 0.5510208E 08
 VEL(37) = 0.4862741E 08
 VEL(38) = 0.4291354E 08
 VEL(39) = 0.3787107E 08
 VEL(40) = 0.3342110E 08
 VEL(41) = 0.2949402E 08
 VEL(42) = 0.2602838E 08
 VEL(43) = 0.2296996E 08

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VEL(44) = 0.2027092E 08
VEL(45) = 0.1788902E 08
VEL(46) = 0.1578701E 08
VEL(47) = 0.1393199E 08
VEL(48) = 0.1229493E 08
VEL(49) = 0.1085024E 08
VEL(50) = 0.9575305E 07
VEL(51) = 0.8450177E 07
VEL(52) = 0.7457255E 07
VEL(53) = 0.6581004E 07
VEL(54) = 0.5807716E 07
VEL(55) = 0.5125291E 07
VEL(56) = 0.4523054E 07
VEL(57) = 0.3991581E 07
VEL(58) = 0.3522558E 07
VEL(59) = 0.3108646E 07
VEL(60) = 0.2743371E 07
VEL(61) = 0.2421016E 07
VEL(62) = 0.2136539E 07
VEL(63) = 0.1887830E 07
VEL(64) = 0.1818029E 07
VEL(65) = 0.1750920E 07
VEL(66) = 0.1695321E 07
VEL(67) = 0.1661069E 07
VEL(68) = 0.1637836E 07
VEL(69) = 0.1608323E 07
VEL(70) = 0.1578258E 07
VEL(71) = 0.1547609E 07
VEL(72) = 0.1516341E 07
VEL(73) = 0.1468191E 07
VEL(74) = 0.1451786E 07
VEL(75) = 0.1418407E 07
VEL(76) = 0.1384224E 07
VEL(77) = 0.1366110E 07
VEL(78) = 0.1349175E 07
VEL(79) = 0.1331304E 07
VEL(80) = 0.1313190E 07
VEL(81) = 0.1295562E 07
VEL(82) = 0.1276191E 07
VEL(83) = 0.1264881E 07
VEL(84) = 0.1238087E 07
VEL(85) = 0.1218589E 07
VEL(86) = 0.1198773E 07
VEL(87) = 0.1178624E 07
VEL(88) = 0.1158125E 07
VEL(89) = 0.1143975E 07
VEL(90) = 0.1115997E 07

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VEL(91) = 0.1094325E 07
VEL(92) = 0.1072215E 07
VEL(93) = 0.1049640E 07
VEL(94) = 0.1026568E 07
VEL(95) = 0.1009630E 07
VEL(96) = 0.9787941E 06
VEL(97) = 0.9540105E 06
VEL(98) = 0.9076963E 06
VEL(99) = 0.8906488E 06
VEL(100) = 0.8754600E 06
VEL(101) = 0.8588883E 06
VEL(102) = 0.8476605E 06
VEL(103) = 0.8189179E 06
VEL(104) = 0.7891290E 06
VEL(105) = 0.7581706E 06
VEL(106) = 0.7454274E 06
VEL(107) = 0.7324624E 06
VEL(108) = 0.7192638E 06
VEL(109) = 0.7058184E 06
VEL(110) = 0.6921119E 06
VEL(111) = 0.6781284E 06
VEL(112) = 0.6638504E 06
VEL(113) = 0.6492585E 06
VEL(114) = 0.6343310E 06
VEL(115) = 0.6190437E 06
VEL(116) = 0.6033692E 06
VEL(117) = 0.5872764E 06
VEL(118) = 0.5707301E 06
VEL(119) = 0.5536895E 06
VEL(120) = 0.5361076E 06
VEL(121) = 0.5179291E 06
VEL(122) = 0.4990890E 06
VEL(123) = 0.4795092E 06
VEL(124) = 0.4590951E 06
VEL(125) = 0.4377300E 06
VEL(126) = 0.4266464E 06
VEL(127) = 0.4152672E 06
VEL(128) = 0.4035671E 06
VEL(129) = 0.3915176E 06
VEL(130) = 0.3790853E 06
VEL(131) = 0.3662312E 06
VEL(132) = 0.3529092E 06
VEL(133) = 0.3390642E 06
VEL(134) = 0.3246293E 06
VEL(135) = 0.3095219E 06
VEL(136) = 0.2936382E 06
VEL(137) = 0.2768448E 06

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VEL(138) = 0.2589646E 06	FAVELA42
VEL(139) = 0.2397546E 06	FAVELA43
VEL(140) = 0.2188650E 06	FAVELA44
VEL(141) = 0.1957588E 06	FAVELA45
VEL(142) = 0.1857131E 06	FAVELA46
VEL(143) = 0.1750920E 06	FAVELA47
VEL(144) = 0.1637836E 06	FAVELA48
VEL(145) = 0.1516341E 06	FAVELA49
VEL(146) = 0.1384224E 06	FAVELA50
VEL(147) = 0.1313190E 06	FAVELA51
VEL(148) = 0.1238087E 06	FAVELA52
VEL(149) = 0.1158125E 06	FAVELA53
VEL(150) = 0.1072215E 06	FAVELA54
VEL(151) = 0.9787940E 05	FAVELA55
VEL(152) = 0.8754600E 05	FAVELA56
VEL(153) = 0.7581706E 05	FAVELA57
VEL(154) = 0.6190437E 05	FAVELA58
VEL(155) = 0.4377300E 05	FAVELA59
C	FAVELA60
CDETERMINE THE VELOCITY BREAK POINTS BY,	FAVELA61
C**1ST , CONVERT ENERGY BREAK POINTS TO VELOCITIES IN CGS UNITS	FAVELA62
JBRK = 63	FAVELA63
N = NGR + 1	FAVELA64
DO 10 I=1,N	FAVELA65
EGY(I) = EGY(I)*1.60207E-12	FAVELA66
EGY(I) = SQRTF(EGY(I)*1.196E+24)	FAVELA67
10 CONTINUE	FAVELA68
C**2ND, COMPARE THE ABOVE VELOCITIES WITH THE VELOCITY TABLE TO DETERMIN	FAVELA69
C**BREAK POINT INDICES.	FAVELA70
LORE = 1	FAVELA71
LEI = 155	FAVELA72
DO 150 J =1,N	FAVELA73
JDX=J	FAVELA74
20 DO 60 I =LORE,LEI	FAVELA75
IF(EGY(J) - VEL(I))60, 30, 40	FAVELA76
30 IEQ = 1	FAVELA77
ISV = I + 1	FAVELA78
GO TO 50	FAVELA79
40 IEQ = 0	FAVELA80
ISV = I	FAVELA81
50 CONTINUE	FAVELA82
IDX = I	FAVELA83
GO TO 70	FAVELA84
60 CONTINUE	FAVELA85
70 CONTINUE	FAVELA86
LORE = ISV	FAVELA87
IF(IEQ) 80,90,80	FAVELA88

80 ID(J) = IDX	FAVELA89
GO TO 140	FAVELA90
90 CONTINUE	FAVELA91
DEL1 = EGY(J) - VEL(IDX)	FAVELA92
IDXM1 = IDX - 1	FAVELA93
IF(IDXM1)80,80,100	FAVELA94
100 CONTINUE	FAVELA95
DEL2 = VEL(IDXM1) - EGY(J)	FAVELA96
IF(DEL1)230,240,110	FAVELA97
110 IF(DEL2)250,260,120	FAVELA98
120 CONTINUE	FAVELA99
IF(DEL1 - DEL2)80,80,130	FAVELA00
130 ID(J) = IDXM1	FAVELA01
140 CONTINUE	FAVELA02
150 CONTINUE	FAVELA03
C**THE ID ARRAY NOW CONTAINS THE BREAK POINT INDICES FROM 10MEV TO .001E	FAVELA04
C** ID(1-N), WRITE OUT THESE POINTS.	FAVELA05
WOT 6,1000	FAVELA06
1000 FORMAT(42HOBREAK BREAK VEL. VEL. /	FAVELA07
1 42H POINT POINT TABLE FROM /	FAVELA08
2 42H VELOCITY INDEX TABLE)	FAVELA09
DO 160 I = 1,N	FAVELA10
IDX = ID(I)	FAVELA11
WOT 6, 1100, I, EGY(I), IDX, VEL(IDX)	FAVELA12
160 CONTINUE	FAVELA13
1100 FORMAT(16, 5XE12.5, 3X15, 5XE12.5)	FAVELA14
C*CONTINUE WITH INTEGRATION	FAVELA15
C	FAVELA16
DO 220 J = 1,NOMATS	FAVELA17
DO 210 I = 1,NGR	FAVELA18
C**DETERMINE THE LIMITS OF INTEGRATION FOR THIS GROUP	FAVELA19
IUPLIM = ID(I+1)	FAVELA20
ILOLIM = ID(I)	FAVELA21
WOT 6,1200, I,J, IUPLIM, ILOLIM	FAVELA22
1200 FORMAT(12HOGROUP NO. = I3/12H MAT'L NO. = I3/12H UP. LIM. = I3/12	FAVELA23
1H LO. LIM. = I3 /)	FAVELA24
C**INITIALIZE THE INTEGRALS	FAVELA25
FNUM = 0.	FAVELA26
FDEN = 0.	FAVELA27
KUP = IUPLIM - 1	FAVELA28
DO 200 K = ILOLIM, KUP	FAVELA29
DV = VEL(K) - VEL(K+ 1)	FAVELA30
IF(K-JBRK)180,170,180	FAVELA31
170 F = FGAM(J)	FAVELA32
GO TO 190	FAVELA33
180 F = FLUX(J,K)	FAVELA34
190 DF = FLUX(J,K+1) - F	FAVELA35

```

      FDEN = FDEN + (F*DV + DF*DV*.5)
      F = F*VEL(K)
      DF = FLUX(J,K+1)*VEL(K+1) - F
      FNUM = FNUM + (F*DV + DF*DV*.5)
200  CONTINUE
      V(I,J) = FNUM/FDEN
      WOT 6,1300, V(I,J)
1300  FORMAT(37H AV. VEL. FOR THIS GROUP AND MATERIAL/
1      5H V = E12.5 )
210  CONTINUE
220  CONTINUE
      GO TO 280
230  WOT 6,1400, IDX,JDX
1400  FORMAT(18H DEL1 NEG., I,J = 13,2H, 13 )
      GO TO 270
240  WOT 6,1500, IDX,JDX
1500  FORMAT(18H DEL1 = 0., I,J = 13,2H, 13 )
      GO TO 270
250  WOT 6,1600, IDX,JDX
1600  FORMAT(18H DEL2 NEG., I,J = 13,2H, 13 )
      GO TO 270
260  WOT 6,1700, IDX,JDX
1700  FORMAT(18H DEL2 = 0 , I,J = 13,2H, 13 )
270  CALL EXIT
280  RETURN
      END

```

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FAVELA36
FAVELA37
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FAVELA56
FAVELA57
FAVELA58
FAVELA59
FAVELA60
FAVELA61

```

FAVELA CODE SAMPLE PROFILE

BREAK POINT	BREAK POINT VELOCITY	VEL. TABLE INDEX	VEL. FROM TABLE
1	0.+3773E 10	1	0.+3773E 10
2	0.12542E 10	11	0.12541E 10
3	0.10294E 09	31	0.10294E 09
4	0.18378E 07	63	0.18378E 07
5	0.+3773E 05	155	0.43773E 05

GROUP NO. = 1
 MAT'L NO. = 1
 UP. LIM. = 11
 LO. LIM. = 1
 AV. VEL. FOR THIS GROUP AND MATERIAL
 V = 0.27561E 10

GROUP NO. = 2
 MAT'L NO. = 1
 UP. LIM. = 31
 LO. LIM. = 11
 AV. VEL. FOR THIS GROUP AND MATERIAL
 V = 0.65772E 09

GROUP NO. = 3
 MAT'L NO. = 1
 UP. LIM. = 63
 LO. LIM. = 31
 AV. VEL. FOR THIS GROUP AND MATERIAL
 V = 0.59205E 08

GROUP NO. = 4
 MAT'L NO. = 1
 UP. LIM. = 155
 LO. LIM. = 63
 AV. VEL. FOR THIS GROUP AND MATERIAL
 V = 0.+2+43E 06

GROUP NO. = 1
 MAT'L NO. = 2
 UP. LIM. = 11
 LO. LIM. = 1
 AV. VEL. FOR THIS GROUP AND MATERIAL
 V = 0.704E 10

GROUP NO. = 1

MAT'L NO. = 2
UP. LIM. = 31
LO. LIM. = 11
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.5578E 09

GROUP NO. = 3
MAT'L NO. = 2
UP. LIM. = 63
LO. LIM. = 31
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.59228E 09

GROUP NO. = 4
MAT'L NO. = 2
UP. LIM. = 155
LO. LIM. = 63
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.62125E 09

GROUP NO. = 1
MAT'L NO. = 3
UP. LIM. = 11
LO. LIM. = 1
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.27346E 10

GROUP NO. = 2
MAT'L NO. = 3
UP. LIM. = 31
LO. LIM. = 11
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.64127E 09

GROUP NO. = 3
MAT'L NO. = 3
UP. LIM. = 63
LO. LIM. = 31
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.5315E 09

GROUP NO. = 4
MAT'L NO. = 3
UP. LIM. = 155
LO. LIM. = 63
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.6117E 09

GROUP NO. = 1
MAT'L NO. = 4
UP. LIM. = 11
LO. LIM. = 1
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.27359E 10

GROUP NO. = 2
MAT'L NO. = 4
UP. LIM. = 31
LO. LIM. = 11
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.64148E 09

GROUP NO. = 3
MAT'L NO. = 4
UP. LIM. = 63
LO. LIM. = 31
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.53192E 08

GROUP NO. = 4
MAT'L NO. = 4
UP. LIM. = 155
LO. LIM. = 63
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.10024E 07

GROUP NO. = 1
MAT'L NO. = 5
UP. LIM. = 11
LO. LIM. = 1
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.26984E 10

GROUP NO. = 2
MAT'L NO. = 5
UP. LIM. = 31
LO. LIM. = 11
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.62171E 09

GROUP NO. = 3
MAT'L NO. = 5
UP. LIM. = 63
LO. LIM. = 31
AV. VEL. FOR THIS GROUP AND MATERIAL

V = 0.17876E 08

GROUP NO. = 4
MAT'L NO. = 5
UP. LIM. = 155
LO. LIM. = 63
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.14211E 07

GROUP NO. = 1
MAT'L NO. = 6
UP. LIM. = 11
LO. LIM. = 1
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.26962E 10

GROUP NO. = 2
MAT'L NO. = 6
UP. LIM. = 31
LO. LIM. = 11
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.62181E 09

GROUP NO. = 3
MAT'L NO. = 6
UP. LIM. = 63
LO. LIM. = 31
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.21341E 08

GROUP NO. = 4
MAT'L NO. = 6
UP. LIM. = 155
LO. LIM. = 63
AV. VEL. FOR THIS GROUP AND MATERIAL
V = 0.14204E 07