DKRDOSE and DKRCONVERT: A Dose Rate Calculation Code and an Auxiliary Data Handling Code for the DKR and DKR-1100 Radioactivity Codes

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Abstract

DKRDOSE and DKRCONVERT are two auxiliary data handling programs that are used to calculate dose rates from the decay gamma-ray sources computed by the DKR and DKR-1100 radioactivity codes. DKRCONVERT takes the binary decay gamma-ray source file produced by DKR (DKR-1100) and converts it into a fido formatted decay gamma-ray source file. This decay gamma-ray source file is used to compute dose rates within DKRDOSE either by direct multiplication with the tissue kerma adjoint field or by use as decay gamma-ray sources for a photon transport calculation with the computed gamma-ray flux being multiplied by gamma-ray flux-to-dose rate factors.

1. Introduction

Along with the calculation of radioactivity, afterheat and bhp, the calculation of dose rate is another quantity of importance and concern in a fusion reactor design. Particularly the determination of the radioactivity and dose rate play a major role in determining the first wall material, blanket structure, environmental impact and maintenance procedures of the fusion reactor.

The radioactivity, afterheat and bhp are calculated by the DKR(1) and DKR-1100(2) radioactivity codes. The decay gamma-ray source computed by DKR (DKR-1100) is used by the DKRDOSE code to calculate either spatially dependent dose rates at a specific time, t, after shutdown or time dependent dose rates at a specific position, r. The DKRCONVERT program is an intermediate data handling program used to rewrite and transfer gamma-ray source data from DKR (DKR-1100) to DKRDOSE or ANISN.

Section 2 contains a brief outline of the calculational procedure used and the tissue kerma data employed in the computation of dose rates. A description of the input data required for the DKRDOSE and DKRCONVERT programs is given in Section 3. The Appendix contains sample problems and program listings of both codes.

2. Calculational Procedure and Data

2.1 Calculational Procedure

Two calculational schemes are used to compute dose rates at various positions within the Target Development Facility. The separate computational steps involved are shown in the flowchart diagrams of Fig. 1 for the forward scheme and in Fig. 2 for the adjoint scheme.

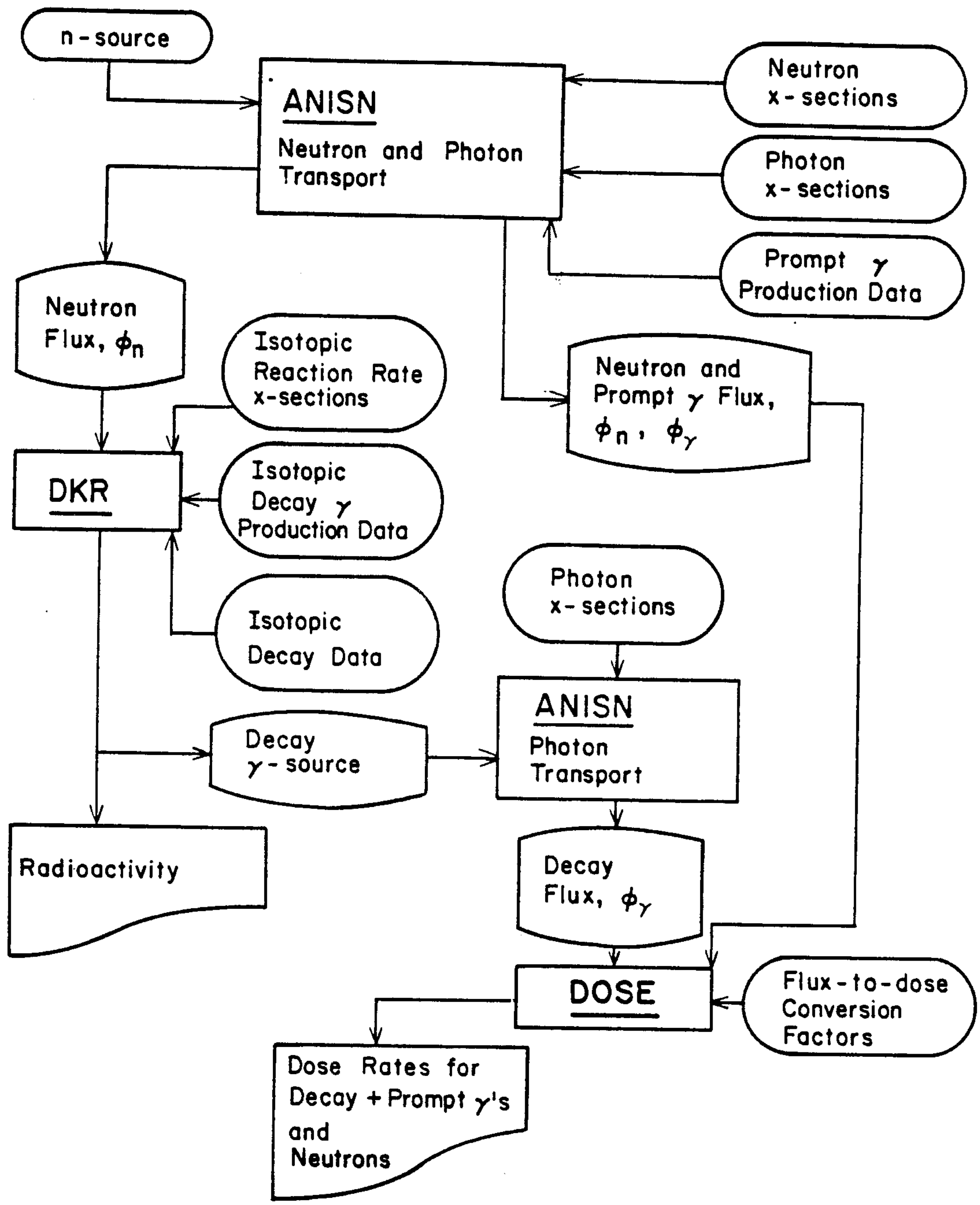

Fig. 1. Flowchart for the calculation of dose rates using the forward scheme.

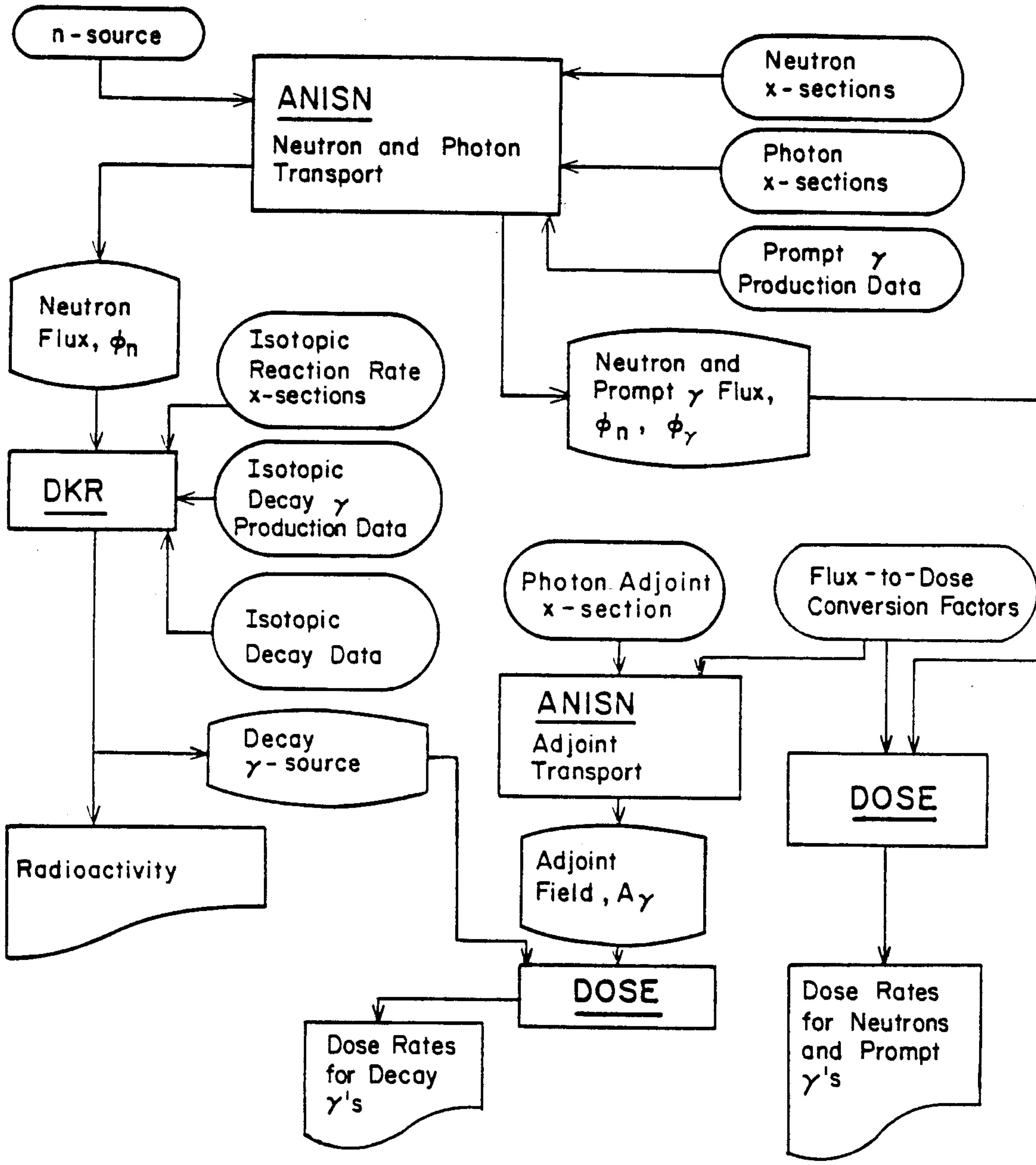

Fig. 2. Flowchart for the calculation of dose rates using the adjoint scheme.

The forward scheme is composed of four separate steps to compute decay gamma dose rates. The first step is the determination of the steady state neutron flux throughout the reactor using the one-dimensional transport code ANISN.[3] The input to ANISN consists of neutron sources and neutron cross-sections. Gamma photon cross-sections and prompt gamma production data are required as additional input if the prompt gamma dose is of interest. The second step involves the use of the DKR code to compute material activation resulting from neutron transmutation reactions and the computation of the decay gamma source. Determination of the decay gamma source involves multiplying the disintegrations per second of an isotope by its gamma spectrum per decay and summing over all isotopes. The input to DKR consists of the neutron flux, isotopic reaction rate cross-sections, isotopic decay gamma production data, and isotopic decay data (decay constant, mode of decay). The third step is the calculation of the steady state gamma flux throughout the facility using the decay gamma sources and the ANISN transport code. Input for the gamma flux calculations consists of the decay gamma sources computed by the DKR code and the gamma photon cross-sections. The input to the ANISN code is prepared by the auxiliary data handling program, DKRCONVERT (not shown on the flowchart of Fig. 1) which rewrites the binary gamma-ray source file into a fido formatted gamma-ray source file required for ANISN input. The fourth and final step is the multiplication of the gamma flux at a position, r, by the tissue flux-to-dose conversion factors to obtain the dose rate at the position, r. This operation is performed by the auxiliary code DOSE. If there is interest in the neutron and prompt gamma dose rates, they can be computed directly from the step 1 ANISN neutron and prompt gamma fluxes by use of DOSE and the tissue flux-to-dose conversion factors (see Fig. 1). Note, the prompt neutron and gamma photon dose is not required for an after shutdown decay gamma dose calculation.

The adjoint scheme also uses four separate computational steps for the determination of decay gamma dose rates. Steps one and two are identical to those of the forward scheme. Step three is the determination of the adjoint dose field throughout the facility using the ANISN transport code. The input consists of the flux-to-dose conversion factors at the position, r, and the gamma photon adjoint cross-sections. The fourth and final step is the multiplication of the adjoint field by the gamma decay sources, which have been written into fido format by the DKRCONVERT auxiliary data handling program from the DKR (DKR-1100) computed gamma-ray sources in step two, to obtain the dose rate at the position, r.

The forward scheme is used if it is of interest to obtain the dose rate as a function of position throughout the facility at a specific time after shutdown. The adjoint scheme is employed if the dose rate at a given position, but for various times after shutdown of the facility, is required. Thus, depending on the nature and particular requirements of the problem, the forward or adjoint scheme is chosen. If the dose rate at one position, r', and at one time after shutdown, t', is required, then usually it is more advantageous to use the forward scheme as it provides additional dose rate information at other positions.

2.2 Data Libraries

The data required for a dose rate calculation are the flux-to-dose rate conversion factors taken from the American National Standard 6.11.[4] The gamma-ray data given in the standard has been collapsed to the 21 gamma-ray energy group structure required by the DKR (DKR-1100) activation codes and the photon cross section library used in the ANISN transport calculations.[5] Also, the neutron flux-to-dose rate conversion factors given in the standard have been collapsed to the 25 neutron group structure of the neutron cross section library. Therefore, the dose rate due to decay gamma-rays and that due to prompt neutrons and gamma-rays can be computed with the DKRDOSE program. Table 2.1 presents the gamma-ray and neutron flux-to-dose rate conversion factors used in DKRDOSE. The dose rates computed have the units mrem/hr.

3. Description of Input

3.1 Input Data for the DKRDOSE Program

Card No. 1 (A72)

Title Card

Card No. 2 (8I6,F12.3)

LID	1-6	Identification number
LTH	7-12	Program execution option 1: Calculate spatially dependent dose rates with forward flux 2: Calculate time dependent dose rates with adjoint field
LGE	13-18	Geometry 1: slab 2: cylinder 3: sphere 4: torus
NGRP	19-24	Number of energy groups in the problem 21: gamma-ray energy group structure 25: neutron energy group structure
NAS	25-30	Number of after shutdown times
IZN	31-36	Number of zones
INTVAL	37-42	Number of mesh cells (intervals)

Table 2.1. Gamma-Ray and Neutron Flux-to-Dose-Rate Factor

Units [mrem/hr]

Energy Group	Gamma-Ray Factors	Neutron-Factors
1	1.180E-02	2.081E-01
2	1.030E-02	1.908E-01
3	8.776E-03	1.720E-01
4	7.845E-03	1.551E-01
5	7.477E-03	1.471E-01
6	7.110E-03	1.471E-01
7	6.740E-03	1.471E-01
8	6.371E-03	1.473E-01
9	6.003E-03	1.495E-01
10	5.604E-03	1.522E-01
11	5.226E-03	1.543E-01
12	4.828E-03	1.464E-01
13	4.407E-03	1.372E-01
14	3.960E-03	1.287E-01
15	3.467E-03	1.270E-01
16	2.925E-03	1.271E-01
17	2.310E-03	9.815E-02
18	1.508E-03	5.596E-02
19	7.533E-04	2.167E-02
20	3.833E-04	5.695E-03
21	5.741E-04	3.692E-03
22		4.081E-03
23		4.472E-03
24		4.524E-03
25		3.973E-03

IPOS	43-48	Interval number for which dose rate is computed 0: dose rate is calculated for all intervals (only used in the forward case) n: interval number for which dose rate is computed
RTORUS	49-60	Radius of the torus (tokamak, stellarator, etc.)

Card No. 3 (6E12.3)

Radius(1)	1-12	Inner radius of first zone
Radius(2)	13-24	Outer radius of first zone
Radius(3)	25-36	Outer radius of second zone
.		
.		
.		
Radius(IZN+1)		Outer radius of last zone

Card No. 4 (12I6)

NINT(1)	1-6	Number of intervals in the first zone
NINT(2)	7-12	Number of intervals in the second zone
.		
.		
.		
NINT(IZN)		Number of intervals in the last zone

Card No. 5 (12A4)

BAS(1)	1-4	Alphanumeric characters for the first after shutdown time
BAS(2)	5-8	Alphanumeric characters for the second after shutdown time
.		
.		
.		
BAS(NAS)		Alphanumeric characters for the last after shutdown time

Table 3.1. DKRDOSE Dimensions

NGRP	Number of energy groups (21 gamma ray or 25 neutron)
NAS	Number of after shutdown times ($<$ 12)
IZN	Number of material zones ($<$ 100)
INTVAL	Number of mesh intervals ($<$ 400)

Table 3.2. DKRDOSE I/O Units

N5(5)	Standard input unit from which the basic data cards are read
N6(6)	Standard output unit for printing
N8(18)	Gamma-ray source file (only used in the adjoint case)
N9(19)	Forward gamma-ray or neutron flux file (used in the forward case) Gamma or neutron tissue kerma adjoint field file (used in the adjoint case)

3.2 Input for the DKRCONVERT Program

Card No. 1 (2I6)

NF	1-6	Number of binary files gamma-ray data is read from
ISRT	7-12	Number of additional gamma-ray source values inserted into the file

Card No. 2 (10I6)

NT(1)	1-6	Binary file of first gamma-ray source file
INTR(1)	7-12	Number of the last mesh cell on first source file
NT(2)	13-18	Binary file of second gamma-ray source file
INTR(2)	19-24	Number of the last mesh cell on the second source file
.		
.		
.		
NT(NF)		Binary file of last gamma-ray source file
INTR(NF)		Number of the last mesh cell on the last source file

Card No. 3 (2I6)

LAS	1-6	Number of the after shutdown time to which additional gamma-ray sources are inserted 0: a gamma-ray value of zero is inserted at position, IPOS, for all after shutdown times n: the gamma-ray sources given in Card No. 4 are inserted at the time after shutdown, LAS. All other times receive the value zero
IPOS	7-12	Position at which the additional gamma-ray sources are added

Card No. 4 (6E12.3) (only required if LAS > 0)

Value(1)	1-12	The group 1 gamma-ray source to be added
Value(2)	13-24	The group 2 gamma-ray source to be added
.		
.		
.		
Value(21)		The group 21 gamma-ray source to be added

Cards 3 and 4 are repeated ISRT times (i.e., for each position for which additional gamma-ray sources are inserted).

Notes

The question naturally arises, why insert extra gamma-ray sources or extra mesh cells. There are several reasons for doing so. First, as is mentioned in the DKR-1100 manual, when the radioactivity is computed for a reactor which contains a central vacuum or void, the mesh cells placed in the void for the neutron transport calculation are removed via the LCLPS parameter in the activation calculation. Thus if the dose rate within the void is required, then these deleted void mesh cells must be replaced. This is done via the ISRT parameter (ISRT=0) in DKRCONVERT. Second, if the dose rate external to the reactor (the outer edge of the reactor) is required, the extra mesh cell external to the reactor can be inserted by using the ISRT parameter. Third, in ICF reactors, the condensable target debris is plated onto the inner surface of the first wall structure. Thus, to properly take the debris decay gamma-ray sources into account, a mesh cell containing the target debris gamma-ray sources must be added prior to the first wall structure. Again this can be done via the ISRT parameter.

Table 3.3. DKRCONVERT Dimensions

NF	Number of binary gamma-ray source files from which data is read (< 5)
INTR	Number of final mesh intervals (< 150)
NAS	Number of after shutdown times (< 12)
NGRP	Number of energy groups (< 21)

Table 3.4. DKRCONVERT I/O Units

N5(5)	Standard input unit from which the basic data cards are read
N6(6)	Standard output unit for printing
NT12(12)	Fido formatted gamma-ray source output unit
NT(1)	Input unit of first gamma-ray source file
NT(2)	Input unit of second gamma-ray source file
.	
.	
.	
NT(NF)	Input unit of last gamma-ray source file

References

1. T.Y. Sung and W.F. Vogelsang, "DKR: A Radioactivity Calculation Code for Fusion Reactors," University of Wisconsin Fusion Technology Institute Report UWFDM-170 (September 1976).

2. D.L. Henderson, "DKR-1100: A Univac 1100 Version of the DKR Radioactivity Code," University of Wisconsin Fusion Technology Institute Report UWFDM-671 (February 1986).

3. W. Engles, "A User's Manual for ANISN," RSIC Code Package CCC-254, Radiation Shielding and Information Center, Oak Ridge National Laboratory, Oak Ridge, TN.

4. American National Standard Neutron and Gamma-Ray Flux-to-Dose-Rate Factors, ANSI/ANS-6.1.1-1977 (N666), published by the American Nuclear Society, 555 North Kensington Avenue, LaGrange Park, IL 60525.

5. R.T. Perry and G.A. Moses, "A Combined P3, VITAMIC-C, MACKLIB-IV, Coupled 25 Neutron-21 Gamma Group Cross Section Library - The UW Cross Section Library," University of Wisconsin Fusion Technology Institute Report UWFDM-390 (December 1980).

Appendix

A. Sample Problems for DKRDOSE

A.1 Sample Problem #1

The dose rate for an aluminum first wall, 16.2 cm thick, followed by a 300 cm thick borated water shield is computed using the forward (direct) option. Since the IPOS parameter equals zero, the dose rate for all positions is computed.

Table A-1 Input for Sample Problem #1

```
*  *  *  *  *  *  SPERRY 1180 TIME/SHARING EXEC --- MULTI-PROCESSOR SYSTEM --- VER.  MACC 38.33  SITE *  MACC      *  *  *  *  *  *
RUNID: Y53378         PROJECT: 12902         USER: 1125297216          CREATED ON JAN 27, 1986 AT 08:32:32   INPUT DEVICE: U03076
             FILE NAME: NEAT$LIST$                PART NUMBER: 00      PRINTED ON JAN 27, 1986 AT 08:32:35   OUTPUT DEVICE: NAPR2


Key listing of 1125297216*DKRDOSE1.PRNT2
1    |C  --  BELOW IS THE INPUT FOR THE FORWARD (DIRECT) CASE
2    |TDF F.W. --> ALUMINUM (3.0M WTR BRN shield):FRWD: MESH79
3    |    10     1     3    21     1     4    79     0          0.00
4    | 290.000E+00 300.000E+00 316.200E+00 336.200E+00 616.200E+00
5    |     5     8    10    56
6    | 0 m




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```

Table A-2 Output for Sample Problem #1

```
TDF F.W. --> ALUMINUM (3.0M WTR BRN shield):FRWD: MESH79

IDENTIFICATION NUMBER - "LID"                                      10
EXECUTION OPTION - "LTH" 1/2; FORWARD/ADJOINT                       1
GEOMETRY OPTION - "LGE" 1/2/3/4; SLAB/CYLINDER/SPHERE/TORUS         3
NUMBER OF ENERGY GROUPS - "NGRP" 21/25; GAMMA/NEUTRON               21
NUMBER OF AFTER SHUTDOWN TIMES - "NAS"                              1
NUMBER OF MATERIALS ZONES - "IZN"                                   4
NUMBER OF MESH INTERVALS - "INTVAL"                                79
INTERVAL NUMBER OF TISSUE - "IPUS" 0/NMBR; ALL/INTERVAL             0
RADIUS OF TORUS - "RTORUS"                                       .000

RADIUS(I)
   290.0+000   300.0+000   316.2+000   336.2+000   616.2+000

INT(I)
     5      8     10     56

BAS(I)
  0 m

ANISN FORWARD CASE SCALAR FLUX FILE READ:   TDF ALUMINUM FIRST WALL + WATER + BORON
```

Table A-2 Continued

FORWARD CASE DOSE RATE CALCULATION AT 0 m AFTER SHUTDOWN

INTERVAL NO.	RADIUS [cm]	VOLUME [cm**3]	DOSE RATE [mrem/hr]
1	291.0000	2.12827+006	6.29760-009
2	293.0000	2.15763+006	6.37972-009
3	295.0000	2.18719+006	6.42468-009
4	297.0000	2.21694+006	6.47387-009
5	299.0000	2.24690+006	6.52801-009
6	301.0125	2.30571+006	6.51251-009
7	303.0375	2.33684+006	6.32322-009
8	305.0625	2.36817+006	5.99172-009
9	307.0875	2.39972+006	5.60026-009
10	309.1125	2.43148+006	5.18524-009
11	311.1375	2.46343+006	4.76577-009
12	313.1625	2.49561+006	4.35223-009
13	315.1875	2.52799+006	4.00750-009
14	317.2000	2.52876+006	3.84967-009
15	319.2000	2.56075+006	3.70452-009
16	321.2000	2.59294+006	3.44716-009
17	323.2000	2.62533+006	3.13722-009
18	325.2000	2.65792+006	2.82798-009
19	327.2000	2.69072+006	2.54540-009
20	329.2000	2.72371+006	2.29450-009
21	331.2000	2.75691+006	2.07291-009
22	333.2000	2.79030+006	1.87644-009
23	335.2000	2.82390+006	1.70131-009
24	338.7000	7.20806+006	1.44566-009
25	343.7000	7.42244+006	1.13856-009
26	348.7000	7.63996+006	8.99643-010
27	353.7000	7.86065+006	7.12525-010
28	358.7000	8.08443+006	5.65649-010
29	363.7000	8.31136+006	4.50434-010
30	368.7000	8.54147+006	3.59815-010
31	373.7000	8.77471+006	2.88183-010
32	378.7000	9.01108+006	2.31570-010
33	383.7000	9.25059+006	1.86779-010
34	388.7000	9.49325+006	1.51170-010
35	393.7000	9.73905+006	1.22831-010
36	398.7000	9.98799+006	1.00150-010
37	403.7000	1.02401+007	8.19524-011
38	408.7000	1.04953+007	6.72983-011
39	413.7000	1.07537+007	5.54450-011
40	418.7000	1.10152+007	4.58206-011
41	423.7000	1.12798+007	3.79864-011
42	428.7000	1.15476+007	3.15750-011
43	433.7000	1.18185+007	2.63190-011
44	438.7000	1.20926+007	2.19935-011
45	443.7000	1.23698+007	1.84224-011
46	448.7000	1.26502+007	1.54664-011
47	453.7000	1.29337+007	1.30122-011
48	458.7000	1.32203+007	1.09684-011
49	463.7000	1.35101+007	9.26289-012
50	468.7000	1.38030+007	7.83615-012
51	473.7000	1.40991+007	6.63984-012
52	478.7000	1.43983+007	5.63475-012
53	483.7000	1.47006+007	4.78865-012
54	488.7000	1.50061+007	4.07505-012

Table A-2 Continued

55	493.7000	1.53147+007	3.47219-012
56	498.7000	1.56265+007	2.96202-012
57	503.7000	1.59414+007	2.52964-012
58	508.7000	1.62595+007	2.16268-012
59	513.7000	1.65807+007	1.85080-012
60	518.7000	1.69050+007	1.58539-012
61	523.7000	1.72325+007	1.35927-012
62	528.7000	1.75631+007	1.16638-012
63	533.7000	1.78969+007	1.00168-012
64	538.7000	1.82338+007	8.60906-013
65	543.7000	1.85738+007	7.40451-013
66	548.7000	1.89170+007	6.37291-013
67	553.7000	1.92634+007	5.48859-013
68	558.7000	1.96128+007	4.72983-013
69	563.7000	1.99654+007	4.07824-013
70	568.7000	2.03212+007	3.51808-013
71	573.7000	2.06801+007	3.03610-013
72	578.7000	2.10421+007	2.62090-013
73	583.7000	2.14073+007	2.26262-013
74	588.7000	2.17756+007	1.95293-013
75	593.7000	2.21471+007	1.68453-013
76	598.7000	2.25217+007	1.45069-013
77	603.7000	2.28994+007	1.24506-013
78	608.7000	2.32803+007	1.06321-013
79	613.7000	2.36643+007	8.86750-014

A.2 Sample Problem #2

The dose rate for an aluminum first wall, 4 cm thick, is computed for the mesh cell #15 by using the adjoint option. The aluminum wall is preceded by a carbon ISSEC, 10 cm thick, and a Boral sheet, 1 cm thick. A Boral sheet, 1 cm thick, and a 300 cm thick borated water shield follow the first wall. The dose rate is computed for 12 after shutdown times.

Table A-3 Input for Sample Problem #2

```
*  *  *  *  *  *  SPERRY 1180 TIME/SHARING EXEC --- MULTI-PROCESSOR SYSTEM --- VER.  MACC 38.33  SITE *  MACC      *  *  *  *  *  *
RUNID: Y53378        PROJECT: 12902        USER: 1125297216         CREATED ON JAN 27, 1986 AT 08:25:10   INPUT DEVICE: U03076
             FILE NAME: NEAT$LIST$               PART NUMBER: 00         PRINTED ON JAN 27, 1986 AT 08:25:12  OUTPUT DEVICE: NAPR2


Key listing of 1125297216*DKRDOSE1.PRNT2
1    |C  --   BELOW IS THE INPUT FOR THE ADJOINT CASE
2    |TDF ALUMINUM: CARBON+ BORAL+ F.W.+ BORAL+ WATER+ BORON: ADJT: MESH 15
3    |    10      2      3     21     12      8     81     15          0.00
4    | 288.000E+00 289.000E+00 299.000E+00 300.000E+00 304.000E+00 305.000E+00
5    | 325.000E+00 605.000E+00 606.000E+00
6    |     1      5      2      4      2     10     56      1
7    | 0 m 1 m10 m1 hr6 hr1 dy1 wk1 mo1 yr10 y100y1 ky


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```

Table A-4 Output for Sample Problem #2

```
TDF ALUMINUM: CARBON+ BORAL+ F.A.+ BORAL+ WATER+ BORON: ADJT: MESH 15

IDENTIFICATION NUMBER - "LID"                                              10
EXECUTION OPTION - "LTH" 1/2; FORWARD/ADJOINT                               2
GEOMETRY OPTION - "LGE" 1/2/3/4; SLAB/CYLINDER/SPHERE/TORUS                 3
NUMBER OF ENERGY GROUPS - "NGRP" 21/25; GAMMA/NEUTRON                      21
NUMBER OF AFTER SHUTDOWN TIMES - "NAS"                                     12
NUMBER OF MATERIALS ZONES - "IZN"                                           8
NUMBER OF MESH INTERVALS - "INTVAL"                                        81
INTERVAL NUMBER OF TISSUE - "IPOS" 0/NMBR; ALL/INTERVAL                    15
RADIUS OF TORUS - "RTORUS"                                               .000

RADIUS(I)
   283.0+000   289.0+000   299.0+000   300.0+000   304.0+000   305.0+000   325.0+000   605.0+000   606.0+000

INT(I)
     1     5     2     4     2    10    56     1

BAS(I)
   0 m   1 m   10 m   1 hr   8 hr   1 dy   1 wk   1 mo   1 yr   10 y   100y   1 ky

ANISN ADJOINT FLUX FILE READ: TDF ADJNTRON:MSH17 CARBON+BORAL+ALM+BORAL+SHIELD

GAMMA SOURCE FILE READ FOR   1 AFTER SHUTDOWN TIME

GAMMA SOURCE FILE READ FOR   2 AFTER SHUTDOWN TIME

GAMMA SOURCE FILE READ FOR   3 AFTER SHUTDOWN TIME

GAMMA SOURCE FILE READ FOR   4 AFTER SHUTDOWN TIME

GAMMA SOURCE FILE READ FOR   5 AFTER SHUTDOWN TIME

GAMMA SOURCE FILE READ FOR   6 AFTER SHUTDOWN TIME

GAMMA SOURCE FILE READ FOR   7 AFTER SHUTDOWN TIME

GAMMA SOURCE FILE READ FOR   8 AFTER SHUTDOWN TIME

GAMMA SOURCE FILE READ FOR   9 AFTER SHUTDOWN TIME

GAMMA SOURCE FILE READ FOR  10 AFTER SHUTDOWN TIME

GAMMA SOURCE FILE READ FOR  11 AFTER SHUTDOWN TIME

GAMMA SOURCE FILE READ FOR  12 AFTER SHUTDOWN TIME
```

Table A-4 Continued

ADJOINT CASE DOSE RATE CALCULATION

INTERVAL NO.	RADIUS [cm]	VOLUME [cm**3]	INTERVAL NO.	RADIUS [cm]	VOLUME [cm**3]
1	288.5000	1.04593+006	42	412.5000	1.06914+007
2	290.0000	2.11367+006	43	417.5000	1.09521+007
3	292.0000	2.14293+006	44	422.5000	1.12160+007
4	294.0000	2.17238+006	45	427.5000	1.14830+007
5	296.0000	2.20204+006	46	432.5000	1.17532+007
6	298.0000	2.23190+006	47	437.5000	1.20265+007
7	299.2500	5.62663+005	48	442.5000	1.23030+007
8	299.7500	5.64545+005	49	447.5000	1.25826+007
9	300.5000	1.13475+006	50	452.5000	1.28653+007
10	301.5000	1.14231+006	51	457.5000	1.31512+007
11	302.5000	1.14990+006	52	462.5000	1.34403+007
12	303.5000	1.15752+006	53	467.5000	1.37324+007
13	304.2500	5.81622+005	54	472.5000	1.40277+007
14	304.7500	5.83536+005	55	477.5000	1.43262+007
15	306.0000	2.35334+006	56	482.5000	1.46278+007
16	308.0000	2.38420+006	57	487.5000	1.49325+007
17	310.0000	2.41526+006	58	492.5000	1.52404+007
18	312.0000	2.44553+006	59	497.5000	1.55514+007
19	314.0000	2.47600+006	60	502.5000	1.58656+007
20	316.0000	2.50466+006	61	507.5000	1.61829+007
21	318.0000	2.54153+006	62	512.5000	1.65033+007
22	320.0000	2.57360+006	63	517.5000	1.68269+007
23	322.0000	2.60567+006	64	522.5000	1.71536+007
24	324.0000	2.63834+006	65	527.5000	1.74835+007
25	327.5000	5.73924+006	66	532.5000	1.78165+007
26	332.5000	5.94655+006	67	537.5000	1.81526+007
27	337.5000	7.15707+006	68	542.5000	1.84919+007
28	342.5000	7.37070+006	69	547.5000	1.88344+007
29	347.5000	7.58747+006	70	552.5000	1.91799+007
30	352.5000	7.80738+006	71	557.5000	1.95287+007
31	357.5000	8.03043+006	72	562.5000	1.98805+007
32	362.5000	8.25663+006	73	567.5000	2.02355+007
33	367.5000	8.48597+006	74	572.5000	2.05937+007
34	372.5000	8.71644+006	75	577.5000	2.09549+007
35	377.5000	8.95406+006	76	582.5000	2.13194+007
36	382.5000	9.19282+006	77	587.5000	2.16869+007
37	387.5000	9.43473+006	78	592.5000	2.20576+007
38	392.5000	9.67977+006	79	597.5000	2.24315+007
39	397.5000	9.92796+006	80	602.5000	2.28085+007
40	402.5000	1.01793+007	81	605.5000	4.60721+006
41	407.5000	1.04338+007			

Table A-4 Continued

```
THE DOSE RATES AT INTERVAL   15, RADIUS    306.000 cm FOR   12 TIMES AFTER SHUTDOWN ARE:
THE DOSE RATE  0 m AFTER SHUTDOWN IS  9.83510+005 mrem/hr
THE DOSE RATE  1 m AFTER SHUTDOWN IS  8.01087+005 mrem/hr
THE DOSE RATE 10 m AFTER SHUTDOWN IS  7.11962+005 mrem/hr
THE DOSE RATE 1 hr AFTER SHUTDOWN IS  5.18534+005 mrem/hr
THE DOSE RATE 5 hr AFTER SHUTDOWN IS  4.89253+005 mrem/hr
THE DOSE RATE 1 dy AFTER SHUTDOWN IS  2.12345+005 mrem/hr
THE DOSE RATE 1 wk AFTER SHUTDOWN IS  5.99611+002 mrem/hr
THE DOSE RATE 1 mo AFTER SHUTDOWN IS  2.92489+002 mrem/hr
THE DOSE RATE 1 yr AFTER SHUTDOWN IS  1.23471+002 mrem/hr
THE DOSE RATE 10 y AFTER SHUTDOWN IS  3.15231+000 mrem/hr
THE DOSE RATE 100y AFTER SHUTDOWN IS  5.83153-002 mrem/hr
THE DOSE RATE 1 ky AFTER SHUTDOWN IS  5.82405-002 mrem/hr
```

B. Sample Problem for DKRCONVERT

The sample problem consists of combining two binary gamma-ray source files and inserting two additional mesh cells, one at the inner edge (beginning) and one at the outer edge (end). The binary files are read from units 2 and 3. The inserted mesh cells are for positions 1 and 81.

Note

The output file created has the following format (I2,A1,E9.3). Thus, the output looks like the following examples 12R_.xxx+xxx or _0_.xxx+xxx. If the input to ANISN is read format free, the 0 on the second example must be removed or one will obtain an error for the ANISN source read. The 0 can be removed by an editor using a global _0_ change to ___ command.

Table B-1 Input for Sample Problem for DKRCONVERT

```
*  *  *  *  *  *  SPERRY 1180 TIME/SHARING EXEC --- MULTI-PROCESSOR SYSTEM --- VER.  MACC 38.33  SITE *  MACC        *  *  *  *  *  *
RUNID: Y53264        PROJECT: 12902          USER: 1125297216           CREATED ON JAN 26, 1986 AT 18:23:54   INPUT DEVICE: U03076
             FILE NAME: NEAT$LIST$                 PART NUMBER: 00       PRINTED ON JAN 26, 1986 AT 18:23:55  OUTPUT DEVICE: NAPR2


Key listing of 1125297216*DKRCONVRT.PRNT2
 1    |C  --  GIVEN BELOW IS A SAMPLE OF THE INPUT
 2    |      2     2
 3    |      2    79      3     13
 4    |      0     1
 5    |      0    81




***EOF***        1 PAGES COST      $0.10    PROJ BALANCE    $1762.61 USER BALANCE     $179.92
```

Table B-2 Output for Sample Problem for DKRCONVERT

```
----- INPUT VALUES -----

NUMBER OF BINARY FILES TO BE READ - "NF"            2
NUMBER OF VALUES TO BE INSERTED - "ISRT"            2

FILE NUMBER UNITS - "NT(I)"
       2       3

LAST INTERVAL TO BE READ ON FILES - "INTR(I)"
      79      13

READING OF BINARY FILE  2 COMPLETED

READING OF BINARY FILE  3 COMPLETED

INSERT VALUES FOR AFTER SHUTDOWN NO.  0 AND POSITION  1

INSERT VALUES FOR AFTER SHUTDOWN NO.  0 AND POSITION 81
```

Table B-2 Continued

1	81R	.000										
2	81R	.000										
3	81R	.000										
4	81R	.000										
5	14R	.000	0	.122+006	0	.103+006	0	.871+005	0	.736+005	0	.622+005
6	0	.525+005	0	.443+005	0	.374+005	0	.315+005	0	.265+005	0	.200+005
7	0	.129+005	0	.831+004	0	.534+004	0	.343+004	0	.220+004	0	.141+004
8	0	.900+003	0	.575+003	0	.367+003	0	.234+003	0	.149+003	0	.953+002
9	0	.607+002	0	.387+002	0	.247+002	0	.157+002	0	.100+002	0	.637+001
10	0	.406+001	0	.255+001	0	.164+001	0	.105+001	0	.665+000	0	.424+000
11	0	.270+000	0	.172+000	0	.109+000	0	.694-001	0	.442-001	0	.281-001
12	0	.179-001	0	.114-001	0	.724-002	0	.461-002	0	.293-002	0	.186-002
13	0	.119-002	0	.755-003	0	.480-003	0	.305-003	0	.194-003	0	.124-003
14	0	.787-004	0	.500-004	0	.318-004	0	.203-004	0	.129-004	0	.820-005
15	0	.522-005	0	.332-005	0	.211-005	0	.134-005	0	.855-006	0	.543-006
16	0	.342-006	0	.000								
17	81R	.000										
18	14R	.000	0	.169+007	0	.142+007	0	.120+007	0	.102+007	0	.858+006
19	0	.724+006	0	.611+006	0	.516+006	0	.435+006	0	.366+006	0	.276+006
20	0	.178+006	0	.115+006	0	.737+005	0	.473+005	0	.303+005	0	.194+005
21	0	.124+005	0	.793+004	0	.507+004	0	.323+004	0	.206+004	0	.132+004
22	0	.838+003	0	.534+003	0	.340+003	0	.217+003	0	.138+003	0	.879+002
23	0	.560+002	0	.356+002	0	.227+002	0	.144+002	0	.919+001	0	.585+001
24	0	.372+001	0	.237+001	0	.151+001	0	.958+000	0	.610+000	0	.388+000
25	0	.247+000	0	.157+000	0	.999-001	0	.636-001	0	.404-001	0	.257-001
26	0	.164-001	0	.104-001	0	.665-002	0	.422-002	0	.268-002	0	.171-002
27	0	.109-002	0	.691-003	0	.439-003	0	.280-003	0	.178-003	0	.113-003
28	0	.720-004	0	.458-004	0	.292-004	0	.186-004	0	.118-004	0	.749-005
29	0	.471-005	0	.000								
30	81R	.000										
31	81R	.000										
32	81R	.000										
33	81R	.000										
34	0	.000	0	.489+001	0	.405+001	0	.344+001	0	.292+001	0	.248+001
35	2R	.000	0	.150+004	0	.138+004	0	.127+004	0	.117+00469R		.000
36	81R	.000										
37	0	.000	0	.111+003	0	.972+002	0	.857+002	0	.750+002	0	.648+002
38	0	.212+008	0	.203+008	0	.249+008	0	.226+008	0	.208+008	0	.191+008
39	0	.157+008	0	.131+008	0	.245+005	0	.206+005	0	.174+005	0	.147+005
40	0	.124+005	0	.105+005	0	.888+004	0	.747+004	0	.630+004	0	.531+004
41	0	.400+004	0	.253+004	0	.168+004	0	.107+004	0	.686+003	0	.439+003
42	0	.281+003	0	.180+003	0	.115+003	0	.734+002	0	.469+002	0	.299+002
43	0	.191+002	0	.121+002	0	.774+001	0	.493+001	0	.314+001	0	.200+001
44	0	.127+001	0	.811+000	0	.516+000	0	.329+000	0	.209+000	0	.133+000
45	0	.847-001	0	.539-001	0	.343-001	0	.218-001	0	.139-001	0	.884-002
46	0	.562-002	0	.358-002	0	.228-002	0	.145-002	0	.921-003	0	.586-003
47	0	.375-003	0	.237-003	0	.151-003	0	.960-004	0	.611-004	0	.389-004
48	0	.247-004	0	.157-004	0	.100-004	0	.637-005	0	.405-005	0	.258-005
49	0	.164-005	0	.104-005	0	.664-006	0	.423-006	0	.269-006	0	.171-006
50	0	.109-006	0	.683-007	0	.000						
51	0	.000	0	.123+002	0	.104+002	0	.895+001	0	.769+001	0	.656+001
52	2R	.000	0	.359+005	0	.346+005	0	.330+005	0	.310+00569R		.000

Time step 1

AT SHUT Down

Table B-2 Continued

53	0	.000	0	.121+004	0	.109+004	0	.971+003	0	.651+003	0	.725+003
54	0	.193+007	0	.135+007	0	.225+007	0	.214+007	0	.201+007	0	.187+007
55	0	.103+007	0	.174+007	67R	.000						
56	0	.000	0	.248+003	0	.222+003	0	.194+003	0	.162+003	0	.126+003
57	0	.268+008	0	.257+008	0	.314+008	0	.287+008	0	.263+008	0	.241+008
58	0	.173+008	0	.155+008	67R	.000						
59	0	.000	0	.950+002	0	.839+002	0	.743+002	0	.651+002	0	.562+002
60	0	.130+008	0	.124+005	0	.153+008	0	.140+008	0	.128+008	0	.117+008
61	0	.331+007	0	.794+007	67R	.000						
62	0	.000	0	.911+001	0	.796+001	0	.701+001	0	.612+001	0	.527+001
63	2R	.000	0	.606+004	0	.561+004	0	.517+004	0	.475+004	69R	.000
64	0	.000	0	.253+001	0	.229+001	0	.201+001	0	.175+001	0	.151+001
65	2R	.000	0	.457+004	0	.429+004	0	.393+004	0	.360+004	69R	.000
66	8R	.000	0	.144+003	0	.133+003	0	.122+003	0	.112+003	69R	.000

C. DKRDOSE Program Listing

Key listing of 1125297216*DKRDOSE1.PRINT

```
C  ---------------------- PROGRAM DKRDOSE ------------------------------
C
C  THIS PROGRAM IS DESIGNED TO CALCULATE THE DOSE RATE OF A CERTAIN
C  REACTOR DUE TO NEUTRONS OR GAMMAS BY USING THE COMBINATION OF EITHER
C  AN ADJOINT FIELD AND A NEUTRON OR GAMMA SOURCE DISTRIBUTION OR THE
C  ANISN FORWARD SCALAR FLUX AND NEUTRON OR GAMMA FLUX-TO-DOSE CONVER-
C  SION FACTORS.  THIS PROGRAM IS SETUP FOR 25 NEUTRON GROUPS OR 21
C  GAMMA GROUPS.  THE LIMIT ON ARRAY SIZES ARE 400 MESH INTERVALS, 100
C  MATERIAL ZONES, AND 12 AFTER SHUTDOWN TIMES.
C
      DIMENSION NINT(100), RADIUS(101), VOL(400), AVRAD(400), RATE(400),
     >          AJRATE(12)
      CHARACTER TITLE*72, BAS(12)*4
C
C  ASSIGNING INPUT AND OUTPUT UNITS
C
      N5 = 5
      N6 = 6
      N8 = 18
      N9 = 19
C
C  READ INPUT DATA
C
      CALL RDINPT( N5, N6, LID, LTH, LGE, NGRP, NAS, IZN, INTVAL, IPOS,
     >             NINT, RADIUS, RTORUS, BAS, TITLE )
C
C  COMPUTE AVERAGE RADIUS AND VOLUME OF EACH MESH INTERVAL
C
      CALL CLCV( N6, LGE, IZN, NINT, RADIUS, RTORUS, VOL, AVRAD )
C
C  NOW TO COMPUTE THE DOSE RATES FOR THE FORWARD OR ADJOINT CASES
C
      IF( LTH .EQ. 1 ) THEN
         CALL FORWD( N6, N9, INTVAL, NGRP, IPOS, RATE )
         WRITE(N6,200) BAS(NAS)
         WRITE(N6,205)
         IF( IPOS .EQ. 0 ) THEN
            DO 10 I=1,INTVAL
               WRITE(N6,210) I,AVRAD(I),VOL(I),RATE(I)
   10       CONTINUE
         ELSE
            WRITE(N6,210) IPOS,AVRAD(IPOS),VOL(IPOS),RATE(IPOS)
         ENDIF
      ELSE IF( LTH .EQ. 2 ) THEN
         CALL ADJNT( N6, N8, N9, INTVAL, NGRP, IPOS, NAS, IZN, NINT,
     >               VOL, AJRATE )
         WRITE(N6,215)
         WRITE(N6,220)
         INT = INTVAL / 2
         INT1 = INT + 1
         IF( 2 * INT  .NE.  INTVAL ) THEN
            DO 20 I=1,INT
```

```
                II = INT1 + I
                WRITE(N6,225) I,AVRAD(I),VOL(I),II,AVRAD(II),VOL(II)
   20        CONTINUE
             WRITE(N6,225) INT1,AVRAD(INT1),VOL(INT1)
          ELSE
             DO 30 I=1,INT
                II = INT + I
                WRITE(N6,225) I,AVRAD(I),VOL(I),II,AVRAD(II),VOL(II)
   30        CONTINUE
          ENDIF
          WRITE(N6,230) IPOS,AVRAD(IPOS),NAS
          WRITE(N6,235) (BAS(I),AJRATE(I),I=1,NAS)
       ELSE
          WRITE(N6,240) LTH
          STOP
       ENDIF
C
  200 FORMAT('1',5X,'FORWARD CASE DOSE RATE CALCULATION AT ',A4,
     >               ' AFTER SHUTDOWN')
  205 FORMAT('0',5X,'INTERVAL NO.',5X,'RADIUS [CM]',5X,'VOLUME [CM**3]',
     >          5X,'DOSE RATE [MREM/HR]')
  210 FORMAT(' ',9X,I4,9X,F11.4,6X,1PE12.5,10X,1PE12.5)
  215 FORMAT('1',5X,'ADJOINT CASE DOSE RATE CALCULATION')
  220 FORMAT('0',5X,'INTERVAL NO.',5X,'RADIUS [CM]',5X,'VOLUME [CM**3]'
     >        ,15X,'INTERVAL NO.',5X,'RADIUS [CM]',5X,'VOLUME [CM**3]')
  225 FORMAT(' ',9X,I4,8X,F11.4,7X,1P1E12.5,
     >         20X,I4,8X,0PF11.4,7X,1P1E12.5)
  230 FORMAT('1',5X,'THE DOSE RATES AT INTERVAL ',I4,', RADIUS ',F10.3,
     >               ' CM FOR ',I4,' TIMES AFTER SHUTDOWN ARE:')
  235 FORMAT('0',5X,'THE DOSE RATE ',A4,' AFTER SHUTDOWN IS ',1PE12.5,
     >               ' MREM/HR')
  240 FORMAT('0','ERROR ----> IN "LTH" INPUT.  READ AS ',I4)
      STOP
      END
C  ---------------------- SUBROUTINE RDINPT --------------------------
C
C THIS SUBROUTINE READS AND PRINTS THE INPUT DATA FOR THE DKRDOSE CODE
C
      SUBROUTINE RDINPT(
     1 N5,N6,
     2
     3 LID, LTH, LGE, NGRP, NAS, IZN, INTVAL, IPOS, NINT, RADIUS,
     3 RTORUS, BAS, TITLE )
C
      DIMENSION NINT(100), RADIUS(101)
      CHARACTER TITLE*72, BAS(12)*4
C
C  READ TITLE
C
      READ(N5,100) TITLE
C
C  READ ID NUMBER "LID", EXECUTION OPTION "LTH", GEOMETRY OPTION "LGE",
C       NUMBER OF ENERGY GROUPS "NGRP", NUMBER OF AFTER SHUTDOWN TIMES
C       "NAS", NUMBER OF MATERIAL ZONES "IZN", NUMBER OF MESH INTERVALS
C       "INTVAL", INTERVAL NUMBER OF TISSUE "IPOS", RADIUS OF TORUS
C       "RTORUS".
C
```

```
      READ(N5,105) LID, LTH, LGE, NGRP, NAS, IZN, INTVAL, IPOS, RTORUS
C
C  READ THE ZONE RADII POSITIONS (RADII POSITIONS = ZONES + 1)
C
      READ(N5,110) (RADIUS(I),I=1,IZN+1)
C
C  READ THE NUMBER OF MESH INTERVALS PER ZONE
C
      READ(N5,115) (NINT(I),I=1,IZN)
C
C  READ THE AFTER SHUTDOWN TIMES
C
      READ(N5,120) (BAS(I),I=1,NAS)
C
  100 FORMAT(A72)
  105 FORMAT(8I6,F12.3)
  110 FORMAT(6E12.3)
  115 FORMAT(12I6)
  120 FORMAT(12A4)
C
C  IN THIS SECTION ALL OF THE INPUT PARAMETERS ARE PRINTED
C
C  PRINT TITLE
C
      WRITE(N6,200) TITLE
C
C  PRINT INPUT PARAMETERS
C
      WRITE(N6,205) LID
      WRITE(N6,210) LTH
      WRITE(N6,215) LGE
      WRITE(N6,220) NGRP
      WRITE(N6,225) NAS
      WRITE(N6,230) IZN
      WRITE(N6,235) INTVAL
      WRITE(N6,240) IPOS
      WRITE(N6,242) RTORUS
C
  200 FORMAT('1',10X,A72)
  205 FORMAT('0',10X,'IDENTIFICATION NUMBER - "LID"',34X,I6)
  210 FORMAT(' ',10X,'EXECUTION OPTION - "LTH" 1/2; FORWARD/ADJOINT',
     >                 18X,I6)
  215 FORMAT(' ',10X,'GEOMETRY OPTION - "LGE" 1/2/3/4; SLAB/CYLINDER/',
     >                'SPHERE/TORUS',4X,I6)
  220 FORMAT(' ',10X,'NUMBER OF ENERGY GROUPS - "NGRP" 21/25; GAMMA/',
     >                'NEUTRON',10X,I6)
  225 FORMAT(' ',10X,'NUMBER OF AFTER SHUTDOWN TIMES - "NAS"',25X,I6)
  230 FORMAT(' ',10X,'NUMBER OF MATERIALS ZONES - "IZN"',30X,I6)
  235 FORMAT(' ',10X,'NUMBER OF MESH INTERVALS - "INTVAL"',28X,I6)
  240 FORMAT(' ',10X,'INTERVAL NUMBER OF TISSUE - "IPOS" 0/NMBR; ALL/',
     >                'INTERVAL',8X,I6)
  242 FORMAT(' ',10X,'RADIUS OF TORUS - "RTORUS"',34X,F9.3)
C
C  PRINT THE ZONE RADII
C
      WRITE(N6,245)
      WRITE(N6,250) (RADIUS(I),I=1,IZN+1)
```

```
C
C  PRINT THE NUMBER OF MESH INTERVALS PER ZONE
C
      WRITE(N6,255)
      WRITE(N6,260) (NINT(I),I=1,IZN)
C
C  PRINT THE ALPHANUMERIC FOR THE AFTER-SHUTDOWN TIMES
C
      WRITE(N6,265)
      WRITE(N6,270) (BAS(I),I=1,NAS)


C
  245 FORMAT('0',10X,'RADIUS(I)')
  250 FORMAT(' ',(10X,3P10E12.3),(/,11X,3P10E12.3))
  255 FORMAT('0',10X,'INT(I)')
  260 FORMAT(' ',10X,20I6)
  265 FORMAT('0',10X,'BAS(I)')
  270 FORMAT(' ',12X,12(A4,3X))
      RETURN
      END
C
C  ---------------------- SUBROUTINE VFIDO ---------------------------
C
C  THIS SUBROUTINE DECIPHERS THE ANISN FIDO FORMATTED ADJOINT FIELD OR
C  FORWARD FLUX WHICH IS PRINTED ON FILE 19
C
      SUBROUTINE VFIDO(
     1 J9, J6, INTVAL,
     2
     3 X1 )
C
      DIMENSION IN(6), K(6), V(6), X1(INTVAL)
      INTEGER COUNT
C
      DATA LR, LT / 'R' , 'T' /
C
C  BEGIN THE DECODING PROCESS
C
      COUNT = 0
   10 CONTINUE
C
C  READING ONE LINE AT A TIME
C
      READ(J9,100) (IN(I),K(I),V(I),I=1,6),M
      DO 20 I=1,6
         IF( COUNT .EQ. INTVAL ) THEN
            RETURN
         ELSE IF( K(I) .EQ. LR ) THEN
C
C  IF A "R" IS ENCOUNTERED REPEAT V(I) VALUE "C" TIMES WHERE "C" IS THE
C  CONSTANT PRECEEDING "R"
C
            L = IN(I)
            DO 30 J=1,L
               COUNT = COUNT + 1
               X1(COUNT) = V(I)
```

```
 30       CONTINUE
       ELSE IF( K(I) .EQ. LT ) THEN
C
C  IF A "T" IS ENCOUNTERED TERMINATE READING
C
          WRITE(J6,200) COUNT
          STOP
       ELSE
          COUNT = COUNT + 1
          X1(COUNT) = V(I)
       ENDIF
 20 CONTINUE
    IF( COUNT .EQ. INTVAL ) THEN
       RETURN
    ELSE
       GO TO 10
    ENDIF
C
100 FORMAT(6(I2,A1,F9.0),I8)
200 FORMAT('0','ERROR ----> ONLY ',I7,' ENTRIES READ')
    END
C
C  ------------------------ SUBROUTINE CLCV --------------------------
C
C  THIS SUBROUTINE COMPUTES THE AVERAGE RADIUS AND VOLUME FOR EACH MESH
C  INTERVAL FOR THE THREE MAJOR GEOMETRIES; SLAB, CYLINDER, AND SPHERE
C
    SUBROUTINE CLCV(
   1 N6, LGE, IZN, NINT, RADIUS, RTORUS,
   2
   3 VOL, AVRAD )
C
    DIMENSION VOL(400), AVRAD(400), RADIUS(101), NINT(100)
    INTEGER COUNT
C
C  DEFINING PI AND 4*PI/3
C
    PI = 4.0 * ATAN( 1.0 )
    PIQ = PI * PI
    PIV = 4.0 * PI / 3.0
C
C NOW TO COMPUTE THE INTERVAL VOLUMES
C
    COUNT = 0
    XI = RADIUS(1)
    DO 10 I=1,IZN
       NNT = NINT(I)
       DX = RADIUS(I+1) - RADIUS(I)
       DO 20 J=1,NNT
          COUNT = COUNT + 1
          XO = (NNT * RADIUS(I) + J * DX) / NNT
          DIF = XO - XI
          IF( LGE .EQ. 1 ) THEN
             VOL(COUNT) = DIF
          ELSE IF( LGE .EQ. 2 ) THEN
             VOL(COUNT) = PI * DIF * (XO + XI)
          ELSE IF( LGE .EQ. 3 ) THEN
```

```
              VOL(COUNT) = PIV * DIF * (XO*XO + XO*XI + XI*XI)
           ELSE IF( LGE .EQ. 4 ) THEN
              VOL(COUNT) = 2.0 * PIQ * DIF * (XO + XI) * RTORUS
           ELSE
              WRITE(N6,200) LGE
           ENDIF
C
C  NOW TO COMPUTE THE AVERAGE RADIUS OF EACH INTERVAL
C
           AVRAD(COUNT) = .5 * (XO + XI)
           XI = XO
   20    CONTINUE
   10 CONTINUE
C
  200 FORMAT('0','ERROR ----> IN "LGE" INPUT.  READ AS ',I4)
      RETURN
      END
C
C  ------------------- SUBROUTINE FORWD --------------------------------
C
C  THIS SUBROUTINE COMPUTES THE DOSE RATE RECEIVED BY TISSUE AT A GIVEN
C  POSITION OR POSITIONS DUE TO NEUTRONS OR GAMMAS USING THE FORWARD
C  CASE ANISN SCALAR FLUX VALUES
C
      SUBROUTINE FORWD(
     1 N6, N9, INTVAL, NGRP, IPOS,
     2
     3 RATE )
C
      DIMENSION FLUX(400,25), DD(400), FKERMA(25), GKERMA(21), RATE(400)
      REAL NKERMA(25)
      CHARACTER TITLE*72, SMARK*4
C
C  THE DATA VALUES GIVEN BELOW ARE GAMMA AND NEUTRON FLUX-TO-DOSE
C  CONVERSION FACTORS IN UNITS OF "MREM/HR"
C
      DATA GKERMA/ 1.180E-02, 1.030E-02, 8.776E-03, 7.845E-03,
     >             7.477E-03, 7.110E-03, 6.740E-03, 6.371E-03,
     >             6.003E-03, 5.604E-03, 5.226E-03, 4.828E-03,
     >             4.407E-03, 3.960E-03, 3.467E-03, 2.925E-03,
     >             2.310E-03, 1.508E-03, 7.533E-04, 3.833E-04,
     >             5.741E-04 /
C
      DATA NKERMA/ 2.081E-01, 1.908E-01, 1.720E-01, 1.551E-01,
     >             1.471E-01, 1.471E-01, 1.471E-01, 1.473E-01,
     >             1.495E-01, 1.522E-01, 1.543E-01, 1.464E-01,
     >             1.372E-01, 1.287E-01, 1.270E-01, 1.271E-01,
     >             9.815E-02, 5.596E-02, 2.167E-02, 5.695E-03,
     >             3.692E-03, 4.081E-03, 4.472E-03, 4.524E-03,
     >             3.973E-03 /
C
C  DETERMINING IF COMPUTATION IS A NEUTRON OR GAMMA DOSE CALCULATION
C
      IF( NGRP .EQ. 25 ) THEN
         DO 10 I=1,NGRP
            FKERMA(I) = NKERMA(I)
   10    CONTINUE
```

```
      ELSE IF( NGRP .EQ. 21 ) THEN
         DO 20 I=1,NGRP
            FKERMA(I) = GKERMA(I)
   20    CONTINUE
      ELSE
         WRITE(N6,200) NGRP
         STOP
      ENDIF
C
C  READ SCALAR FLUX FILE
C
      READ(N9,100) TITLE
      READ(N9,105) SMARK
      DO 30 N=1,NGRP
         CALL VFIDO( N9, N6, INTVAL, DD )
         DO 40 I=1,INTVAL
            FLUX(I,N) = DD(I)
   40    CONTINUE
   30 CONTINUE
      WRITE(N6,205) TITLE
C
C  COMPUTE DOSE RATE.  IF "IPOS" = 0 COMPUTE DOSE RATE FOR ALL POSITIONS
C
      IF( IPOS .EQ. 0 ) THEN
         DO 50 I=1,INTVAL
            RATE(I) = 0.0
            DO 60 N=1,NGRP
               RATE(I) = RATE(I) + FKERMA(N) * FLUX(I,N)
   60       CONTINUE
   50    CONTINUE
      ELSE
         DRATE = 0.0
         DO 70 N=1,NGRP
            DRATE = DRATE + FKERMA(N) * FLUX(IPOS,N)
   70    CONTINUE
         RATE(IPOS) = DRATE
      ENDIF
C
  100 FORMAT(A72)
  105 FORMAT(A4)
  200 FORMAT('0','ERROR ----> ',I4,' SCALAR FLUX ENERGY GROUPS READ')
  205 FORMAT('0',10X,'ANISN FORWARD CASE SCALAR FLUX FILE READ: ',A72)
      RETURN
      END
C
C  ----------------- SUBROUTINE ADJNT ----------------------------------
C
C  THIS SUBROUTINE COMPUTES THE DOSE RATE AT A POSITION, "IPOS" FOR
C  SEVERAL TIMES AFTER SHUTDOWN USING THE ADJOINT FLUX FIELD COMPUTED
C  BY ANISN
C
      SUBROUTINE ADJNT(
     1 N6, N8, N9, INTVAL, NGRP, IPOS, NAS, IZN, NINT, VOL,
     2
     3 TOTAL )
C
      DIMENSION DD(400), FLUX(400,25), NINT(100), ZRATE(100), RATE(100),
```

```
     >          RFUN(25,400), TOTAL(12), VOL(400)
      INTEGER COUNT
      CHARACTER TITLE*72, SMARK*4
C
C  READ ADJOINT FLUX FIELD FILE AND ALSO INVERTING THE FLUX IN ENERGY
C
      READ(N9,100) TITLE
      READ(N9,105) SMARK
      DO 10 N=1,NGRP
         CALL VFIDO( N9, N6, INTVAL, DD )
         IF( NGRP .EQ. 25 ) THEN
            NINV = 26 - N
         ELSE IF( NGRP .EQ. 21 ) THEN
            NINV = 22 - N
         ELSE
            WRITE(N6,200) NGRP
            STOP
         ENDIF
         DO 20 I=1,INTVAL
            FLUX(I,NINV) = DD(I)
   20    CONTINUE
   10 CONTINUE
      WRITE(N6,205) TITLE
C
C  READ FILE CONTAINING GAMMA OR NEUTRON SOURCES
C
      DO 30 KS=1,NAS
         DO 40 N=1,NGRP
            CALL VFIDO( N8, N6, INTVAL, DD )
            DO 50 I=1,INTVAL
               RFUN(N,I) = DD(I)
   50       CONTINUE
   40    CONTINUE
C
         IF( NGRP .EQ. 21 ) THEN
            WRITE(N6,210) KS
         ELSE IF( NGRP .EQ. 25 ) THEN
            WRITE(N6,215) KS
         ENDIF
C
C  COMPUTE DOSE RATE FOR "NAS" AFTER SHUTDOWN TIMES
C
         TOTAL(KS) = 0.0
         COUNT = 0
         DO 60 IZ=1,IZN
            NZI = NINT(IZ)
            ZRATE(IZ) = 0.0
            DO 70 I=1,NZI
               COUNT = COUNT + 1
               RATE(I) = 0.0
               DO 80 N=1,NGRP
                  RATE(I) = RATE(I) + RFUN(N,COUNT) * FLUX(COUNT,N)
   80          CONTINUE
               RATE(I) = RATE(I) * VOL(COUNT)
               ZRATE(IZ) = ZRATE(IZ) + RATE(I)
   70       CONTINUE
            TOTAL(KS) = TOTAL(KS) + ZRATE(IZ)
```

```
   60    CONTINUE
         TOTAL(KS) = TOTAL(KS) / VOL(IPOS)
   30 CONTINUE
C
  100 FORMAT(A72)
  105 FORMAT(A4)
  200 FORMAT('0','ERROR ----> ',I4,' ADJOINT FIELD ENERGY GROUPS READ')
  205 FORMAT('0',10X,'ANISN ADJOINT FLUX FILE READ: ',A72)
  210 FORMAT('0',10X,'GAMMA SOURCE FILE READ FOR ',I3,' AFTER'
     >                ' SHUTDOWN TIME')
  215 FORMAT('0',10X,'NEUTRON SOURCE FILE READ FOR ',I3,' AFTER'
     >                ' SHUTDOWN TIME')
      RETURN
      END
```

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D. DKRCONVERT Program Listing

Key listing of 1125297216*DKRCONVRT.PRINT

```
C  ------------------ PROGRAM DKRCONVERT ------------------------------
C  THIS PROGRAM TAKES THE BINARY GAMMA-RAY SOURCE FILE CREATED BY THE
C  DKR CODE AND CONVERTS IT TO A FIDO FORMATTED FILE USED AS AN INPUT
C  GAMMA-RAY SOURCE FILE EITHER FOR AN ANISN GAMMA-RAY TRANSPORT CAL-
C  CULATION OR FOR A DOSE RATE CALCULATION USING THE DOSE CODE.  THE
C  PROGRAM IS SET TO READ UP TO FIVE BINARY GAMMA-RAY SOURCE FILES AND
C  COMBINE THEM INTO ONE FIDO FORMATTED GAMMA-RAY SOURCE FILE.  THE
C  FILE UNITS ARE SPECIFIED BY THE USER.  ADDITIONAL GAMMA-RAY VALUES
C  PER AFTER SHUTDOWN TIME CAN BE ADDED TO THE SOURCE FILE. THE LIMIT
C  ON THE ARRAY SIZES ARE; 150 FINAL MESH INTERVALS, 25 ENERGY GROUPS,
C  AND 12 AFTER SHUTDOWN TIMES (SEE DKR INPUT SECTION).
C
      DIMENSION GS(12,25,150), NT(5), INTR(5), VALUE(25), ZERO(25)
      INTEGER CONST(150), COUNT
      CHARACTER RR*1, BLNK*1, REPEAT(150)*1
C
      DATA RR, BLNK / 'R' , ' ' /
      DATA ZERO / 25 * 0.0 /
C
C  ASSIGNING THE STANDARD INPUT AND OUTPUT UNITS AND THE NEW FILE UNIT
C
      N5 = 5
      N6 = 6
      NT12 = 12
C
C  READ INPUT DATA
C
      CALL RDINPT(N5, N6, NT, INTR, ISRT, NF)
C
C  READ BINARY GAMMA-RAY SOURCE FILE
C
      CALL RDBNRY(N6, NT, INTR, NF, GS, NAS, NGRP, INT)
C
C  NOW TO INSERT THE ADDITIONAL VALUES
C
   25 IF( ISRT .GT. 0 ) THEN
          IT = 0
          READ(N5,100) LAS, IPOS
          WRITE(N6,200) LAS, IPOS
          DO 5 JT=1,NAS
             IT = IT + 1
             IF( LAS .EQ. IT ) THEN
                READ(N5,105) (VALUE(J),J=1,NGRP)
                WRITE(N6,205)
                WRITE(N6,210) (VALUE(J),J=1,NGRP)
             ELSE
                DO 10 J=1,NGRP
                   VALUE(J) = ZERO(J)
   10           CONTINUE
             ENDIF
             DO 15 JG=1,NGRP
                DO 20 I=INT,IPOS,-1
```

```
                  GS(JT,JG,I+1) = GS(JT,JG,I)
   20          CONTINUE
               GS(JT,JG,IPOS) = VALUE(JG)
   15       CONTINUE
    5    CONTINUE
         ISRT = ISRT - 1
         INT = INT + 1
         GO TO 25
      ENDIF
C
  100 FORMAT(2I6)
  105 FORMAT(6E12.3)
C
C  NOW TO CREATE THE FIDO FORMATTED FILE
C
      DO 50 JT=1,NAS
      DO 55 JG=1,NGRP
         INTRL = 0
         COUNT = 0
         DO 60 JK=2,INT
            IF( GS(JT,JG,JK) .EQ. GS(JT,JG,JK-1) ) THEN
               COUNT = COUNT + 1
               IF( JK .NE. INT ) GO TO 60
            ENDIF
            INTRL = INTRL + 1
            IF( COUNT .GT. 0 ) THEN
               COUNT = COUNT + 1
               CONST(INTRL) = COUNT
               REPEAT(INTRL) = RR
               GS(JT,JG,INTRL) = GS(JT,JG,JK-1)
   65          IF( COUNT .GT. 99 ) THEN
                  CONST(INTRL) = 99
                  COUNT = COUNT - 99
                  INTRL = INTRL + 1
                  CONST(INTRL) = COUNT
                  REPEAT(INTRL) = RR
                  GS(JT,JG,INTRL) = GS(JT,JG,JK-1)
                  GO TO 65
               ENDIF
               IF(JK.EQ.INT .AND. GS(JT,JG,JK).NE.GS(JT,JG,JK-1)) THEN
                  INTRL = INTRL + 1
                  CONST(INTRL) = 0
                  REPEAT(INTRL) = BLNK
                  GS(JT,JG,INTRL) = GS(JT,JG,JK)
               ENDIF
            ELSE
               CONST(INTRL) = COUNT
               REPEAT(INTRL) = BLNK
               GS(JT,JG,INTRL) = GS(JT,JG,JK-1)
               IF( JK .EQ. INT ) THEN
                  INTRL = INTRL + 1
                  CONST(INTRL) = COUNT
                  REPEAT(INTRL) = BLNK
                  GS(JT,JG,INTRL) = GS(JT,JG,JK)
               ENDIF
            ENDIF
            COUNT = 0
```

```
   60    CONTINUE
         WRITE(NT12,220) (CONST(J),REPEAT(J),GS(JT,JG,J),J=1,INTRL)
         IF( JT .EQ. 1 ) THEN
            WRITE(N6,220) (CONST(J),REPEAT(J),GS(JT,JG,J),J=1,INTRL)
         ENDIF
   55 CONTINUE
   50 CONTINUE
C
  200 FORMAT('0',10X,'INSERT VALUES FOR AFTER SHUTDOWN NO.',I3,' AND'
     1                ' POSITION',I3,/)
  205 FORMAT('0',10X,'VALUE(G),G=1-->NGRP')
  210 FORMAT(' ',(10X,7(3X,E9.3)),7(/,11X,7(3X,E9.3)))
  220 FORMAT(6(I2,A1,E9.3))
      STOP
      END
C
C  ---------------------- SUBROUTINE RDINPT ---------------------------
C
C  THIS SUBROUTINE READS AND PRINTS THE INPUT DATA FOR THE DKRCONVERT
C  CODE
C
      SUBROUTINE RDINPT(
     1 N5, N6,
     2
     3 NT, INTR, ISRT, NF)
C
      DIMENSION NT(5), INTR(5)
C
C  READ NUMBER OF BINARY FILES AND NUMBER OF INSERTS
C
      READ(N5,100) NF, ISRT
C
C  READ BINARY FILE NUMBER AND LAST INTERVAL
C
      READ(N5,105) (NT(I),INTR(I),I=1,NF)
C
  100 FORMAT(2I6)
  105 FORMAT(10I6)
C
C  IN THIS SECTION SOME OF THE INPUT PARAMETERS ARE PRINTED
C
C  PRINT NUMBER OF FILES TO BE READ AND NUMBER OF INSERTS
C
      WRITE(N6,200)
      WRITE(N6,205) NF
      WRITE(N6,210) ISRT
C
C  PRINT BINARY FILE NUMBERS AND LAST INTERVAL TO BE READ
C
      WRITE(N6,215)
      WRITE(N6,220) (NT(I),I=1,NF)
      WRITE(N6,225)
      WRITE(N6,220) (INTR(I),I=1,NF)
C
  200 FORMAT('1',10X,'----- INPUT VALUES -----')
  205 FORMAT('0',10X,'NUMBER OF BINARY FILES TO BE READ - "NF"',8X,I6)
  210 FORMAT(' ',10X,'NUMBER OF VALUES TO BE INSERTED - "ISRT"',8X,I6)
```

```
  215 FORMAT('0',10X,'FILE NUMBER UNITS - "NT(I)"')
  220 FORMAT(' ',10X,5(2X,I6))
  225 FORMAT('0',10X,'LAST INTERVAL TO BE READ ON FILES - "INTR(I)"')
C
      RETURN
      END
C
C  ------------------- SUBROUTINE RDBNRY -------------------------------
C
C  THIS SUBROUTINE READS THE BINARY GAMMA-RAY SOURCE FILE
C
      SUBROUTINE RDBNRY(
     1 N6, NT, INTR, NF,
     2
     3 GS, NAS, MGGNEW, INT)
C
      DIMENSION GSNS(12,25), GS(12,25,150), NT(5), INTR(5)
C
C     KRGN: MESH INTERVAL NUMBER
C     NAS: NUMBER OF TIMES AFTER SHUTDOWN
C     MGGNEW: NUMBER OF ENERGY GROUPS
C     JOP: NUMBER OF OPERATION TIMES
C
      INT = 0
      DO 10 I=1,NF
    1    READ(NT(I),END=88) KRGN, NAS, MGGNEW, JOP
         READ(NT(I)) ((GSNS(JS,JG),JG=1,MGGNEW),JS=1,NAS)
         DO 5 JS=1,NAS
         DO 5 JG=1,MGGNEW
            IF( I .EQ. 1 ) THEN
               GS(JS,JG,KRGN) = GSNS(JS,JG)
            ELSE
               GS(JS,JG,KRGN) = GS(JS,JG,KRGN) + GSNS(JS,JG)
            ENDIF
    5    CONTINUE
         IF( KRGN .LT. INTR(I) ) GO TO 1
   88    CONTINUE
         WRITE(N6,100) NT(I)
  100    FORMAT('0',10X,'READING OF BINARY FILE',I3,' COMPLETED')
C
         IF(KRGN .GT. INT) INT = KRGN
   10 CONTINUE
C
      RETURN
      END
```

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