JAERI 1301

JAERI 1301

THIDA-2 : An Advanced Code System for Calculation of Transmutation, Activation, Decay Heat and Dose Rate

March 1986

日本原子力研究所
Japan Atomic Energy Research Institute

日本原子力研究所研究成果編集委員会

委員長　森　　　茂（理事）

委　　　員

飯泉　　仁（物理部）
石川　迪夫（動力試験炉部）
伊藤　彰彦（環境安全研究部）
梅沢　弘一（企画室）
岡下　　宏（化学部）
小幡　行雄（技術情報部）
金子　義彦（原子炉工学部）
川崎　　了（燃料安全工学部）
河村　　洋（高温工学部）
工藤　博司（アイソトープ部）
小森　卓二（化学部）
佐藤　雅幸（材料試験炉部）
鹿園　直基（物理部）
鈴木　伸武（研究部）
鈴木　康夫（臨界プラズマ研究部）
田中　正俊（核融合研究部）
田村　和行（原子力船技術部）
沼宮内弼雄（保健物理部）
萩原　　幸（開発部）
半田　宗男（燃料工学部）
二村　嘉明（研究炉管理部）
幕内　恵三（開発部）
村尾　良夫（原子炉安全工学部）
安野　武彦（動力炉開発・安全性研究管理部）
横田　光雄（動力試験炉部）

Japan Atomic Energy Research Institute
Board of Editors

Sigeru Mori (Chief Editor)

Yoshiaki Futamura
Miyuki Hagiwara
Muneo Handa
Masashi Iizumi
Michio Ishikawa
Akihiko Ito
Yoshihiko Kaneko
Hiroshi Kawamura
Satoru Kawasaki
Takuji Komori
Hiroshi Kudo
Keizo Makuuchi
Yoshio Murao
Takao Numakunai
Yukio Obata
Hiroshi Okashita
Masayuki Sato
Naomoto Shikazono
Nobutake Suzuki
Yasuo Suzuki
Kazuyuki Tamura
Masatoshi Tanaka
Hirokazu Umezawa
Takehiko Yasuno
Mitsuo Yokota

JAERI レポートは，日本原子力研究所が研究成果編集委員会の審査を経て不定期に公刊している研究報告書です。

入手の問合わせは，日本原子力研究所技術情報部情報資料課（〒319-11茨城県那珂郡東海村）あて，お申しこしください。なお，このほかに財団法人原子力弘済会資料センター（〒319-11 茨城県那珂郡東海村日本原子力研究所内）で複写による実費頒布をおこなっております。

JAERI reports are reviewed by the Board of Editors and issued irregularly.

Inquiries about availability of the reports should be addressed to Information Division Department of Technical Information, Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki-ken 319-11, Japan.

©Japan Atomic Energy Research Institute, 1986

編集兼発行　日本原子力研究所
印　　　刷　いばらき印刷㈱

THIDA-2 : An Advanced Code System for Calculation of Transmutation, Activation, Decay Heat and Dose Rate

Yasushi SEKI, Hiromasa IIDA, Hiromitsu KAWASAKI*
and Koubun YAMADA*

Department of Large Tokamak Research
Naka Fusion Research Establishment
Japan Atomic Energy Research Institute
Naka-machi, Naka-gun, Ibaraki-ken, Japan

(Received September 17, 1985)

Abstract

In a D-T burning fusion reactor, the radioactivity induced by the 14 MeV neutrons causes many problems. It limits personnel access to the reactor during shutdown, generates decay heat and produces radwastes. A code system THIDA had been developed in 1978 to calculate the radioactivity and dose rate around a fusion device. The THIDA system consisted of the followings: one- and two-dimensional discrete ordinates radiation transport codes; induced activity calculation code; three libraries for transmutation and decay chain data, transmutation cross sections and delayed gamma-ray emission data.

The present report gives a complete description of THIDA-2, a new advanced version of the THIDA system which has the following major improvements:

1. Capability to treat three-dimensional calculation models by the use of a Monte Carlo transport code.
2. Accurate decay heat calculation following the transport of delayed gamma rays.
3. Simplification of the data input process by the use of free format scheme and closer coupling between the radiation transport codes and the induced activity calculation code.
4. Self-descriptive output format and additional plotter output.
5. Capability to calculate problems requiring larger core memory by the use of variable dimension.

Keywords: D-T Neutron, Fusion Reactor, Radioactivation, Induced Activity, Transmutation, Decay Chain, Delayed Gamma-Ray, Decay Heat, Radwaste, Dose Rate

---

* Century Research Center Corporation

THIDA-2：核種変換，放射化，崩壊熱と線量率計算を行うための進歩したコードシステム

日本原子力研究所那珂研究所臨界プラズマ研究部

関　泰・飯田　浩正・川崎　弘光*・山田　光文*

（1985年9月17日受理）

要　旨

D－T燃焼を行う核融合炉において，14 MeV中性子によって惹起される放射能は多くの問題の原因となる．誘導放射能は炉停止時に従事者の近接を制限し，崩壊熱を生成し，放射性廃棄物を生み出す．核融合装置の誘導放射能と周辺の線量率を計算するためのTHIDAコードシステムが1978年に開発された．THIDAシステムは以下のもので構成されている：1次元と2次元のディスクリート・オーディネート型放射線輸送計算コード；誘導放射能計算コード；核種変換と崩壊連鎖データ，核種変換断面積と遅発ガンマ線放出データに関する3本のライブラリー．

本報告書はTHIDAシステムを進歩させた新しいコードTHIDA－2を完全な形で説明したものであり，THIDA－2は次の主な改良点を有している：

1. モンテカルロ法輸送計算コードを利用することによる3次元計算モデルを取り扱える能力．
2. 遅発ガンマ線の輸送を考慮した精度良い崩壊熱計算．
3. フリーフォーマット法の採用および放射線輸送計算コードと誘導放射能計算コードとのより緊密な結合によるデータ入力の簡易化．
4. 出力形成をより明確なものにしたこととプロッター出力の追加．
5. バリアブル・ディメンションの採用による，より大きな記憶容量を要する問題の計算能力。

---

* センチュリー・リサーチ・センター㈱

CONTENTS

目　次

付　録

1. Introduction

The D-T fusion reaction produces 14 MeV neutrons which react with nuclides composing fusion reactor materials and cause the transmutation of the nuclides. Such transmutation results in not only the change of material properties but also generation of radioactive nuclides. These nuclides generate decay heat and radiations even after the reactor shutdown to become a potential biological hazard.

In a D-T burning fusion reactor, the neutron-induced radioactivity causes three major problems. The first is the high level of gamma-ray dose rate which restricts personnel access during shutdown. The second is the decay heat which necessitates an adequate removal measure in case of an accident like a loss of coolant or during maintenance operation at shutdown. The third is the production of radwastes, for which appropriate processing or storage scheme must be provided.

There are a number of computer codes developed for the purpose of evaluating radioactivity in fusion reactors, such as ACTIVE1), DKR2), ACT and ACTIVE3), THIDA4), RACC5), ANITA6), FORIG7) and REAC8). Most of these codes are made to calculate only the transmutation and induced activity. Exceptions are the codes ACTIVE1), THIDA4) and RACC5) which also calculate decay heat, biological hazard potential and delayed gamma-ray source. In the three codes, the delayed gamma-ray source is provided in the format which can be read by the transport calculation code for the delayed gamma-ray flux. It should also be noted that THIDA and RACC codes are provided with data libraries for transmutation and decay chains, transmutation cross sections and delayed gamma-ray emission spectra.

The code system THIDA4) has been developed in the Japan Atomic Energy Research Institute (JAERI) for the calculation of exposure dose rate around a fusion device. It consists of radiation transport codes, an induced activity calculation code and data libraries for transmutation and decay chains, transmutation cross sections and delayed gamma-ray emission spectra.

The present report gives a complete description of THIDA-2 code system which is an advanced version of the THIDA system. The following improvements are made:

(1) Simplification of the material composition input process by the use of the FIDO free format scheme9),

(2) Simplification of the geometry input for the induced activity calculation by utilizing the geometry input data for the neutron transport calculation,

(3) Coupling with the two-dimensional discrete ordinates code DOT-3.510)*,

(4) Capability to treat three-dimensional calculational models by coupling with the Monte Carlo code MORSE-GG11),

(5) Accurate calculation of decay heat following the transport of delayed gamma rays,

(6) Capability to calculate problems requiring larger core memory by the use of variable dimension,

(7) Extension of the upper bound of the delayed gamma rays from 3 MeV to 7.6 MeV by the optional use of 78-group cross sections,

(8) Self-descriptive output and additional explanations of the problem treated,

(9) Delayed gamma-ray spectrum and time evolution curves of induced activity can be plotted,

(10) Various options for input and output allow effective control of calculational procedure,

(11) Graphical plots of the data libraries are provided12),

(12) Prompt computation of induced activity by the use of vectorized version and

(13) Comprehensive user's manual is provided by this report.

---

*) Although the THIDA system had the capability to treat a two-dimensional model, its utilization was difficult as described in Section 2.3.

2. THIDA-2 Code System

The overview of the THIDA-2 code system is given in Section 2.1 and each calculational step is described in the following Sections 2.2 ~ 2.6.

2.1 Code System Structure

To obtain the dose rate during the reactor shutdown, the THIDA-2 code system employs a sequential coupling of a neutron transport calculation code, an induced activity calculation code, a gamma-ray calculation code and a response calculation and plotting code. The calculational flow chart of the code system is shown in **Fig. 2.1**.

At first, the neutron flux in and around a fusion device during operation is calculated using the transport calculation codes ANISN[9], DOT-3.5[10] or MORSE-GG[11]. Depending one-, two- or three-dimensional geometry, ANISN, DOT-3.5 or MORSE-GG may be chosen, respectively. The neutron flux is used as an input for the code ACT4 which calculates the induced activity, the approximate decay heat (described later in Section 2.6) and the delayed gamma-ray source after a pulsed operation of the fusion device. The delayed gamma-ray source serves as the input for the transport calculation of the delayed gamma-ray flux during the shutdown. The same transport calculation code is used for the calculations of the neutron flux and the delayed gamma-ray flux. Finally, the gamma-ray flux is converted to shutdown dose rate* and the exact decay heat (see Section 2.6) is calculated. These two quantities are plotted by the APPLE-2 code[13].

The following data libraries are required to calculate the shutdown dose rate by the THIDA-2 system.

(1) A 42-group neutron cross section library, which is a part of the coupled 42-group neutron and 21-group gamma-ray cross section library GICX40[14], for the neutron transport calculation.

(2) Transmutation and decay chain data library, CHAINLIB[12].

(3) A 42-group transmutation cross section data library, CROSSLIB[12]

---

* Shutdown dose rate means the dose rate of delayed gamma-ray during the shutdown.

having the same energy group structure as the GICX40 library.

(4) Delayed gamma-ray emission data library, GAMMALIB[12)].

(5) A 54-group gamma-ray cross section library, GROUPIN[4)] for delayed gamma-ray transport calculation which extends from 0.03 MeV to 3.0 MeV. A 78-group gamma-ray cross section library which extends up to 7.6 MeV may also be used as an option.

(6) Gamma-ray flux to dose rate conversion data, GFLXDOSE[14)].

The GICX40 library is used extensively in the nuclear design of fusion reactors. The contents of CHAINLIB, CROSSLIB and GAMMALIB have been graphically represented using the AMOEBA code[12)], and the consistencies among the three libraries have been checked.

2.2 Neutron Transport Calculation

Neutron flux distribution in and around a fusion device during operation is calculated using ANISN[9)], DOT-3.5[10)] or MORSE-GG[11)] according respectively to the selection of one-, two- or three-dimensional model for the problem. The 42-group neutron cross sections in the GICX40 library[14)] must be used for the transport calculation because the energy group structure must be same as that of the transmutation cross section library, CROSSLIB, which is used for the nuclide transmutation calculation (as described later in Section 2.3.). The 42-group energy structure used commonly in the two libraries is shown in **Table 2.1**. The content and arrangement of nuclides in the GICX40 library are shown in **Table 2.2**. The GICX40 has up to P_5 Legendre terms of scattering cross section and includes kerma factors for nuclear heating calculation. Details of the library may be found in Ref. 14. It should be noted that the GROUPIN library[4)] for the delayed gamma-ray flux calculation (described later in Section 2.4) has exactly the same nuclides and the common arrangement. This correspondence allows the duplicate use of the input data of the neutron transport calculation for the delayed gamma-ray flux calculation by slight modifications.

2.3 Induced Activity Calculation

Induced activity calculation code ACT4 performs the most important calculational step in the THIDA-2 code system. It calculates the number of radioactive nuclides produced during a continuous or pulsed operation of a fusion device using the neutron flux obtained by the transport calculation described in Section 2.2. It gives the transmutation rates of nuclides, induced activity, the approximate decay heat (described later in Section 2.6), biological hazard potential and delayed gamma-ray source distribution.

The ACT4 code originates from the ACTIVE code[1)] which was developed in 1976 to evaluate the neutron-induced transmutation and the induced activity of a D-T burning experiment[15)]. The ACTIVE code was revised to form the ACT3 code[4)] which had the capability to treat two-dimensional problems coupled with the TWOTRAN code[16)*]. Three activation data libraries for transmutation and decay, transmutation cross sections and delayed gamma-ray emission spectra were provided for the ACT3 code. The computer codes and data libraries required in the calculation of a shutdown dose rate was named the THIDA code system[4)]. It included the ACT3 code with three activation data libraries, one- and two-dimensional codes for neutron and gamma-ray transport calculations together with cross section libraries and other two smaller codes for the coupling of the codes and conversion of the relevant data.

The THIDA-2 code system is an advanced version of the THIDA code system with the many improvements as described in Chapter 1. The ACT4 code which replaced the ACT3 code, is explained in detail in Chapter 3.

2.4 Gamma-Ray Calculation

Delayed gamma-ray source obtained by the ACT4 code is used as an input to a transport code for the gamma-ray distribution calculation.

The same code as in the neutron transport calculation may be used utilizing the same input data except for the input parameters related to energy group number, normalization factor and source input procedure. The source input procedures for one-, two- and three-dimensional problems are described in detail in Chapter 4.

As for the cross section library for the delayed gamma-ray

---

* The use of the TWOTRAN code was greatly limited by the inability to use a groupwise cross section library and the complexity of the coupling procedure.

transport calculation, a 54-energy group set named GROUPIN which extends from 0.03 MeV to 3.0 MeV has been generated by the GAMLEG-JR code$^{17)}$. If the calculation of gamma rays with energy greater than 3.0 MeV is required, another cross section library with 78-groups extending from 0.03 MeV to 7.6 MeV is available. The 78-energy group structure is given in **Table 2.3**. The 54-energy-group of the GROUPIN library employs the same energy group structure as that in **Table 2.3** below 3.0 MeV.

The contents and arrangement of nuclides in the GROUPIN library is exactly the same as those in the GICX40 library which has been shown in **Table 2.2** As with the GICX40, the GROUPIN library has up to P_5 Legendre scattering terms and includes a kerma factor in the position one of the cross section table for nuclear heating calculation. These correspondence between the two libraries enables the common use of input data for material mixture description used in the transport calculations of neutron and delayed gamma-ray.

It should be noted that the unit of the kerma factor in the GROUPIN library is (barn.watt.sec/cm^3) which is different from the unit used in the GICX40 library, namely (barn.MeV/cm^3).

The group structure shown in **Table 2.3** is fine enough to give information of the separate contribution from individual source nuclides. To reflect the discrete nature of the gamma-ray source spectrum, the fine energy interval of **Table 2.3** was chosen. The same energy group structure should be used in the gamma-ray source calculation in ACT4 and the gamma-ray transport calculation.

2.5 Dose Rate Calculation

Since the external dose from the β-ray can be shielded easily, only the gamma-ray dose is considered as the shutdown dose. According to Ref. 18, the exposure dose rate $\dot{D}$ is denoted as

$$\dot{D} = \frac{\mu_a(E_\gamma) \cdot \phi_E(E_\gamma)}{7.08 \times 10^4} \quad (R \cdot s^{-1}) \qquad (2.1)$$

where $\mu_a(E_\gamma)$: the energy absorption coefficient for gamma-ray of energy E_γ (cm^{-1})

$\phi_E(E_\gamma) = E_\gamma \cdot \phi_\gamma(E_\gamma)$: energy flux of gamma ray(MeV$\cdot$cm$^{-2}\cdot$s^{-1}).

The dose rate equivalent 1 rem of gamma-ray irradiation can be approximately given as

$$1\ \mathrm{R} \sim 1\ \mathrm{rem}.^{18)} \qquad (2.2)$$

Applying this approximation to Eq.(2.1), the absorbed dose rate $\dot{D}$ ($\mathrm{rem.h^{-1}}$) becomes

$$\dot{D} = \frac{\mu_a(E_\gamma)\cdot E_\gamma\cdot\phi_\gamma(E_\gamma)\cdot 3600}{7.08\times10^4}\ (\mathrm{rem\cdot h^{-1}}) \quad . \qquad (2.3)$$

The APPLE-2 code[13)] is used to convert the gamma-ray flux to shutdown dose rate and to plot the spatial distribution of the dose rate. The flux-to-dose conversion factor $C(E_\gamma)(\mathrm{rem\cdot h^{-1}})/(\mathrm{photon\cdot cm^{-2}\cdot s^{-1}})$ is obtained as follows:

$$C(E_\gamma) = \mu_a(E_\gamma)\cdot E_\gamma \times \frac{3600}{7.08\times10^4}$$

$$= \frac{K(E_\gamma)}{1.6\times10^{-13}} \times 0.0508\ \left(\frac{\mathrm{rem\cdot h^{-1}}}{\mathrm{photon\cdot cm^{-2}\cdot s^{-1}}}\right)$$

where $K(E_\gamma)$: macroscopic kerma factor of the standard state air ($\mathrm{watt\cdot cm^{-1}}$),

1.6×10^{-13}: conversion factor ($\mathrm{watt/(MeV\cdot s^{-1}}$)

The $K(E_\gamma)/1.6\times10^{-13}$ was obtained from the kerma factors of oxygen and nitrogen calculated by the GAMLEG-JR code$^{17)}$. The flux-to-dose conversion factor in multigroup form is listed in **Table 2.4** where the macroscopic part $K(E_\gamma)/1.6\times10^{-13}$ in the 54-energy group (described in Section 2.4) is provided as the GFLXDOSE data. A normalization factor of 0.0508 in Eq.(2.4) should be applied when using the GFLXDOSE data.

2.6 Decay Heat Calculation

Figure 2.2 describes the procedure for the decay heat calculation$^{19)}$. The ACT4 code calculates an approximate value of the decay heat rate as the sum of the heat from β-decay and delayed gamma-ray generated. If an accurate spatial distribution of decay heat rate is not necessary, the approximate value DH_{approx} shown in **Fig. 2.2** will be given by the ACT4 code.

If an accurate decay heat rate (DH_{exact} in Fig. 2.2) considering the transport and deposition of the delayed gamma-ray is desired, the gamma-ray heat deposition rate should be calculated as the product of kerma factor $K_\gamma(E)$ in the GROUPIN library (as described in Section 2.4) and the delayed gamma-ray flux $\phi_\gamma(r, E, t)$. This gamma-ray heating rate is combined in the APPLE-2 code[13)] with the β-ray heating rate calculated by the ACT4 code.

A comparison of DH_{approx} with DH_{exact} in a typical fusion reactor blanket has been made.[19)] In this case, the DH_{exact} was found to be 60% lower than DH_{approx} at the first wall where the decay heat rate was largest.

Table 2.1 The 42-group neutron energy group structure adopted in the CROSSLIB and GICX40 libraries

Group	Energy Limits		Mid-Point Energy	
1	15.000 – 13.720	MeV	14.360	MeV
2	13.720 – 12.549		13.135	
3	12.549 – 11.478		12.014	
4	11.478 – 10.500		10.989	
5	10.500 – 9.314		9.907	
6	9.314 – 8.261		8.788	
7	8.261 – 7.328		7.795	
8	7.328 – 6.500		6.914	
9	6.500 – 5.757		6.129	
10	5.757 – 5.099		5.428	
11	5.099 – 4.516		4.808	
12	4.516 – 4.000		4.258	
13	4.000 – 3.162		3.581	
14	3.162 – 2.500		2.831	
15	2.500 – 1.871		2.186	
16	1.871 – 1.400		1.636	
17	1.400 – 1.058		1.229	
18	1.058 – 0.800		0.929	
19	0.800 – 0.566		0.683	
20	0.566 – 0.400		0.483	
21	0.400 – 0.283		0.342	
22	0.283 – 0.200		0.242	
23	0.200 – 0.141		0.171	
24	0.141 – 0.100		0.121	
25	100.0 – 46.5	keV	73.25	keV
26	46.5 – 21.5		34.0	
27	21.5 – 10.0		15.75	
28	10.0 – 4.65		7.325	
29	4.65 – 2.15		3.40	
30	2.15 – 1.00		1.575	
31	1.00 – 0.465		0.733	
32	0.465 – 0.215		0.340	
33	0.215 – 0.100		0.158	
34	100.0 – 46.5	eV	73.25	eV
35	46.5 – 21.5		34.0	
36	21.5 – 10.0		15.75	
37	10.0 – 4.65		7.325	
38	4.65 – 2.15		3.40	
39	2.15 – 1.00		1.58	
40	1.00 – 0.465		0.733	
41	0.465 – 0.215		0.340	
42	0.215 – 0.001		0.108	

Table 2.2 Content and organization of nuclides in the GICX40 and GROUPIN libraries

No.	Nuclide	Material No.	ENDF/B-4 File No.	Component (P_5)	No.	Nuclide	Material No.	ENDF/B-4 File No.	Component (P_5)
1	^{6}Li	1271	404	1 ~ 6	21	^{232}Th	1296	404	121 ~ 126
2	^{7}Li	1272	404	7 ~ 12	22	^{235}U	1261	407	127 ~ 132
3	^{12}C	1274	408	13 ~ 18	23	^{239}Pu	1264	407	133 ~ 138
4	^{16}O	1276	408	19 ~ 24	24	^{237}Np	1263	409	139 ~ 144
5	^{4}He	1270	401	25 ~ 30	25	Mg	1280	405	145 ~ 150
6	^{93}Nb	1189	411	31 ~ 36	26	K	1150	403	151 ~ 156
7	Mo	1287	409	37 ~ 42	27	Ca	1195	401	157 ~ 162
8	Cr	1191	406	43 ~ 48	28	^{11}B	1160	403	163 ~ 168
9	Ni	1190	406	49 ~ 54	29	Cl	1149	403	169 ~ 174
10	Fe	1192	406	55 ~ 60	30	^{23}Na	1156	403	175 ~ 180
11	^{1}H	1269	404	61 ~ 66	31	Cd	1281	411	181 ~ 186
12	^{2}H	1120	402	67 ~ 72	32	^{181}Ta	1285	411	187 ~ 192
13	^{3}He	1146	402	73 ~ 78	33	^{182}W	1128	401	193 ~ 198
14	^{9}Be	1289	404	79 ~ 84	34	^{183}W	1129	401	199 ~ 204
15	^{10}B	1273	404	85 ~ 90	35	^{184}W	1130	401	205 ~ 210
16	^{14}N	1275	408	91 ~ 96	36	^{186}W	1131	401	211 ~ 216
17	^{27}Al	1193	405	97 ~ 102	37	F	1277	411	217 ~ 222
18	V	1196	402	103 ~ 108	38	^{238}U	1262	409	223 ~ 228
19	Cu	1295	410	109 ~ 114	39	Si	1194	405	229 ~ 234
20	Pb	1288	408	115 ~ 120	40	Ti	1286	409	235 ~ 240

Table 2.3 The energy structure of 78-gamma ray groups

NO.	E(MeV)	NO.	E(MeV)	NO.	E(MeV)
1	7.6 – 7.4	27	2.5 – 2.3	53	0.27 – 0.25
2	7.4 – 7.2	28	2.3 – 2.1	54	0.25 – 0.23
3	7.2 – 7.0	29	2.1 – 2.0	55	0.23 – 0.21
4	7.0 – 6.8	30	2.0 – 1.9	56	0.21 – 0.20
5	6.8 – 6.6	31	1.9 – 1.8	57	0.20 – 0.19
6	6.6 – 6.4	32	1.8 – 1.7	58	0.19 – 0.18
7	6.4 – 6.2	33	1.7 – 1.6	59	0.18 – 0.17
8	6.2 – 6.0	34	1.6 – 1.5	60	0.17 – 0.16
9	6.0 – 5.8	35	1.5 – 1.4	61	0.16 – 0.15
10	5.8 – 5.6	36	1.4 – 1.3	62	0.15 – 0.14
11	5.6 – 5.4	37	1.3 – 1.2	63	0.14 – 0.13
12	5.4 – 5.2	38	1.2 – 1.1	64	0.13 – 0.12
13	5.2 – 5.0	39	1.1 – 1.0	65	0.12 – 0.11
14	5.0 – 4.8	40	1.0 – 0.9	66	0.11 – 0.10
15	4.8 – 4.6	41	0.9 – 0.81	67	0.10 – 0.09
16	4.6 – 4.4	42	0.81 – 0.73	68	0.09 – 0.081
17	4.4 – 4.2	43	0.73 – 0.66	69	0.081 – 0.073
18	4.2 – 4.0	44	0.66 – 0.60	70	0.073 – 0.066
19	4.0 – 3.8	45	0.60 – 0.55	71	0.066 – 0.060
20	3.8 – 3.6	46	0.55 – 0.50	72	0.060 – 0.055
21	3.6 – 3.4	47	0.50 – 0.45	73	0.055 – 0.050
22	3.4 – 3.2	48	0.45 – 0.40	74	0.050 – 0.045
23	3.2 – 3.1	49	0.40 – 0.36	75	0.045 – 0.040
24	3.1 – 3.0	50	0.36 – 0.33	76	0.040 – 0.036
25	3.0 – 2.7	51	0.33 – 0.30	77	0.036 – 0.033
26	2.7 – 2.5	52	0.30 – 0.27	78	0.033 – 0.030

Table 2.4 The 54-group gamma-ray flux to dose conversion factor GFLXDOSE (MeV/(photon. $cm^{-2}s^{-1}$))

NO.	E(MeV)	C(E)*	NO.	E(MeV)	C(E)*
1	3.0 – 2.7	1.3266×10^{-4}	28	0.30 – 0.27	1.2909×10^{-5}
2	2.7 – 2.5	1.3612×10^{-4}	29	0.27 – 0.25	1.1531×10^{-5}
3	2.5 – 2.3	1.2570×10^{-4}	30	0.25 – 0.23	1.0405×10^{-5}
4	2.3 – 2.1	1.1531×10^{-4}	31	0.23 – 0.21	9.3080×10^{-6}
5	2.1 – 2.0	1.0746×10^{-4}	32	0.21 – 0.20	8.4939×10^{-6}
6	2.0 – 1.9	1.0232×10^{-4}	33	0.20 – 0.19	7.9561×10^{-6}
7	1.9 – 1.8	9.7182×10^{-5}	34	0.19 – 0.18	7.4239×10^{-6}
8	1.8 – 1.7	9.1994×10^{-5}	35	0.18 – 0.17	6.8973×10^{-6}
9	1.7 – 1.6	8.6807×10^{-5}	36	0.17 – 0.16	6.3776×10^{-6}
10	1.6 – 1.5	8.1605×10^{-5}	37	0.16 – 0.15	5.8663×10^{-6}
11	1.5 – 1.4	7.6397×10^{-5}	38	0.15 – 0.14	5.3647×10^{-6}
12	1.4 – 1.3	7.1168×10^{-5}	39	0.14 – 0.13	4.8750×10^{-6}
13	1.3 – 1.2	6.5913×10^{-5}	40	0.13 – 0.12	4.3997×10^{-6}
14	1.2 – 1.1	6.0626×10^{-5}	41	0.12 – 0.11	3.9426×10^{-6}
15	1.1 – 1.0	5.5299×10^{-5}	42	0.11 – 0.10	3.5085×10^{-6}
16	1.0 – 0.9	4.9927×10^{-5}	43	0.10 – 0.09	3.1047×10^{-6}
17	0.9 – 0.81	4.4770×10^{-5}	44	0.09 – 0.081	2.7578×10^{-6}
18	0.81 – 0.73	4.0115×10^{-5}	45	0.081 – 0.073	2.4894×10^{-6}
19	0.73 – 0.66	3.5973×10^{-5}	46	0.073 – 0.066	2.2983×10^{-6}
20	0.66 – 0.60	3.2356×10^{-5}	47	0.066 – 0.060	2.1809×10^{-6}
21	0.60 – 0.55	2.9278×10^{-5}	48	0.060 – 0.055	2.1296×10^{-6}
22	0.55 – 0.50	2.6468×10^{-5}	49	0.055 – 0.050	2.1408×10^{-6}
23	0.50 – 0.45	2.3648×10^{-5}	50	0.050 – 0.045	2.2251×10^{-6}
24	0.45 – 0.40	2.0820×10^{-5}	51	0.045 – 0.040	2.4143×10^{-6}
25	0.40 – 0.36	1.8269×10^{-5}	52	0.040 – 0.036	2.6973×10^{-6}
26	0.36 – 0.33	1.6288×10^{-5}	53	0.036 – 0.033	3.0287×10^{-6}
27	0.33 – 0.30	1.4595×10^{-5}	54	0.033 – 0.030	3.4423×10^{-6}

* Normalization factor of 0.0508 should be used with GFLXDOSE.

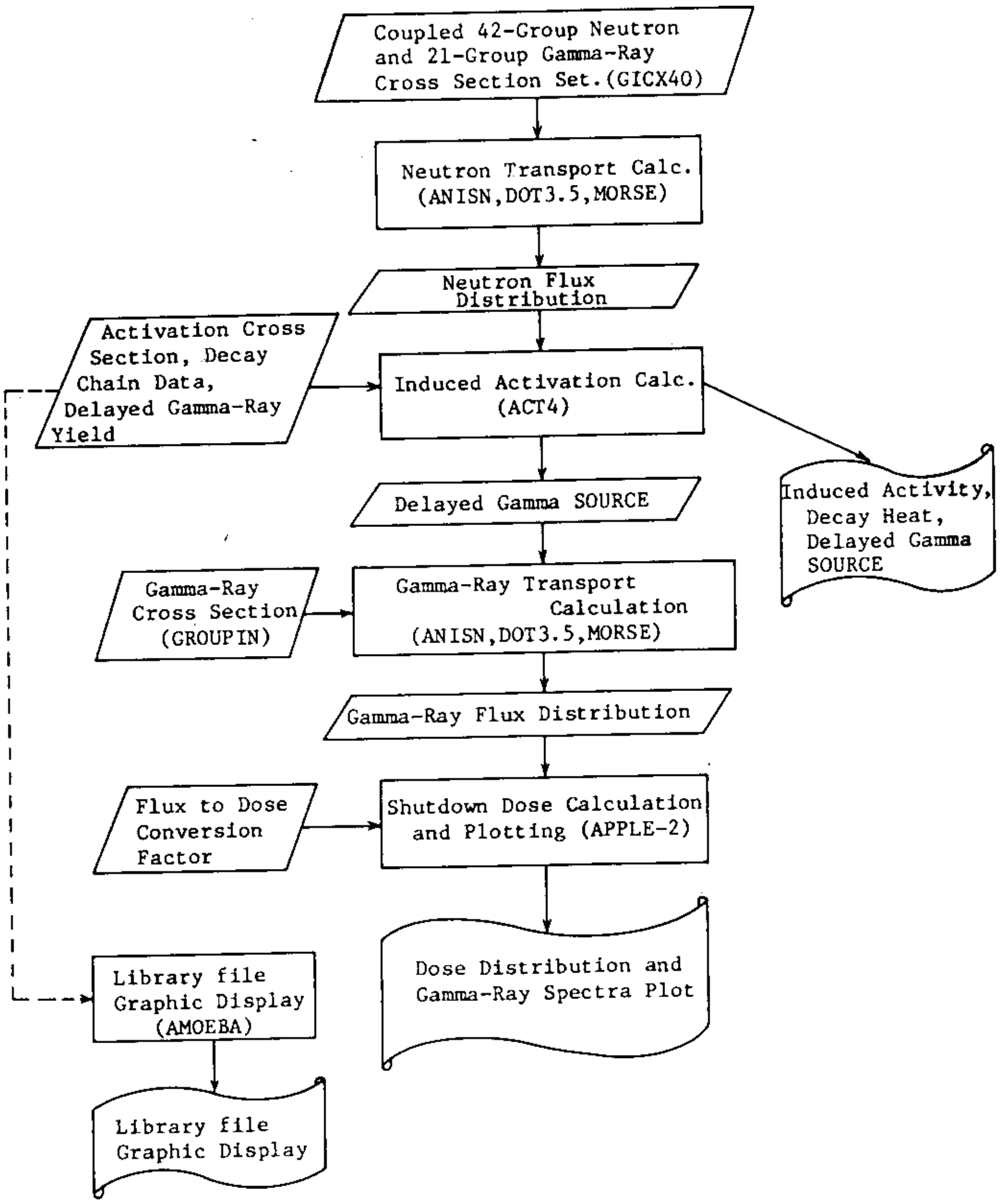


Fig. 2.1 Calculation flow chart for THIDA-2 system.

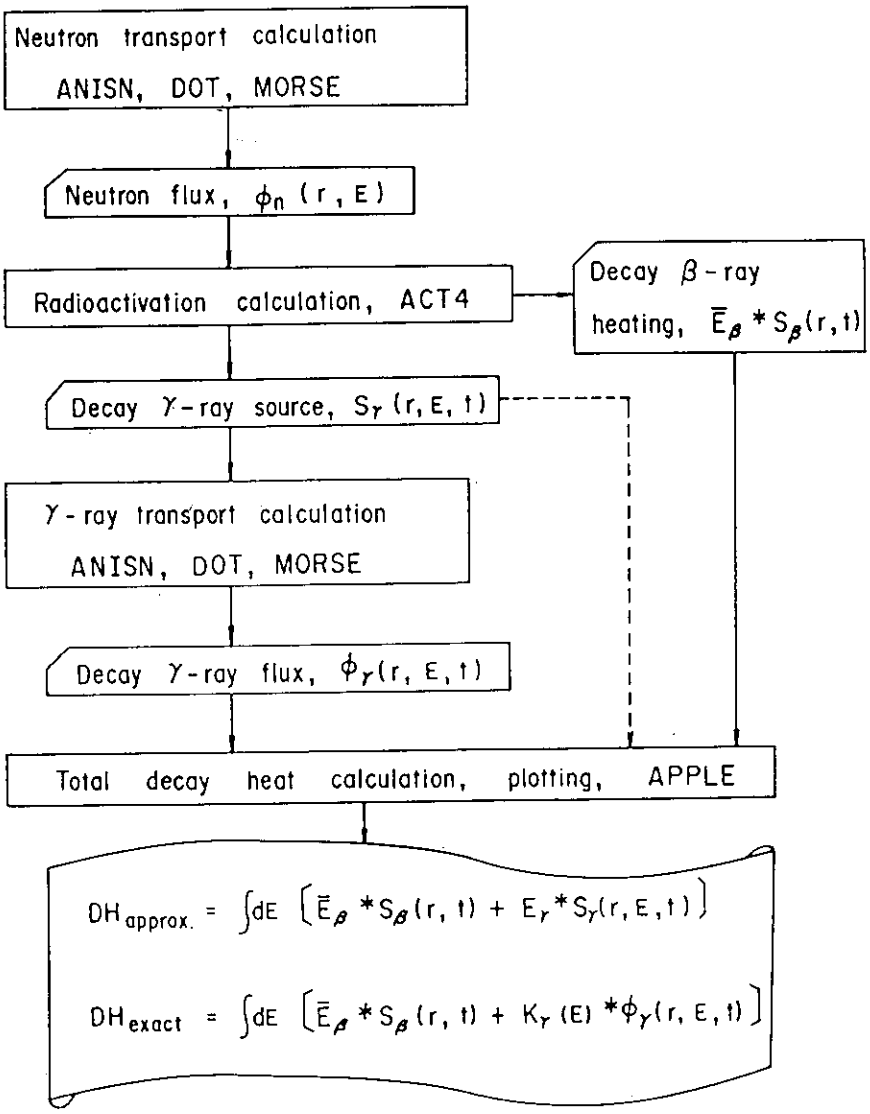


Fig. 2.2 Decay heat calculation procedures.

3. ACT4 Code for Induced Activity Calculation

As already described briefly in Section 2.3, the ACT4 code executes the most important step in the THIDA-2 code system, namely the induced activity calculation. In this chapter, the calculational method, program structure, calculational flow, functions and input/output data of the ACT4 code are described. The arrays of variables used in the ACT4 code are given in Appendix A.1.

3.1 Method of Calculation

3.1.1 Calculation of Atomic Density Change

Using the neutron flux ϕ_n as an input, the induced activity is calculated in the ACT4 code by solving the following coupled linear first-order differential equations:

$$\frac{d\mathbf{X}(t)}{dt} = \mathbf{A} \cdot \mathbf{X}(t) \tag{3.1}$$

where $\mathbf{X}(t)$ is a vector for the atomic density of nuclides and $\mathbf{A}$ is a matrix with elements denoting the reactions of the nuclides with neutrons and the decay of the nuclides. The elements of the **A**-matrix are formed as follows: In case of a reaction

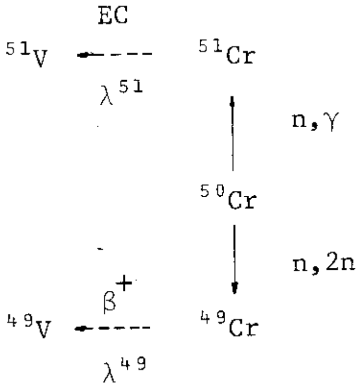
$$A = \sum_{g=1}^{G} \sigma_g \cdot \phi_g \cdot 10^{-24} \cdot \beta ,$$

where σ_g and ϕ_g are the reaction cross section and neutron flux, respectively, in the energy group g, and G is the number of energy groups. The σ_g is supplied from the CROSSLIB library[12)] and ϕ_g is obtained from the neutron transport calculation. The β is the branching ratio of the reaction products. The neutron flux ϕ_g is fixed to 0 when the atomic number change during shutdown time is calculated. In case of a nuclide decay

$$A = \lambda \cdot \beta \quad ,$$

where λ is the decay constant and β is the branching ratio of the decay. The values of λ and β are given from the CHAINLIB library[12].

As an example, a part of the **A**-matrix for the case of ^{50}Cr is shown. The two transmutation reactions and decays are as follows.



The vector equation (3.1) for this case is given as

$$\frac{d}{dt}\begin{pmatrix} ^{49}\mathrm{V} \\ ^{51}\mathrm{V} \\ ^{49}\mathrm{Cr} \\ ^{50}\mathrm{Cr} \\ ^{51}\mathrm{Cr} \end{pmatrix} = \begin{pmatrix} 0, & 0, & +\lambda^{49}, & 0, & 0 \\ 0, & 0, & 0, & 0, & +\lambda^{51} \\ 0, & 0, & -\lambda^{49}, & +\sigma_{n,2n}\phi, & 0 \\ 0, & 0, & 0, & -\sigma_t\phi, & 0 \\ 0, & 0, & 0, & +\sigma_{n,\gamma}\phi, & -\lambda^{51} \end{pmatrix} \begin{pmatrix} ^{49}\mathrm{V} \\ ^{51}\mathrm{V} \\ ^{49}\mathrm{Cr} \\ ^{50}\mathrm{Cr} \\ ^{51}\mathrm{Cr} \end{pmatrix} \quad . \tag{3.2}$$

The vector **X**(t) in Eq.(3.1) is solved by the Matrix Exponential Method described in Ref. 20. The Eq.(3.1) can be rewritten as

$$\mathbf{X}(T_o + t) = \mathbf{C}(t)\cdot\mathbf{X}(T_o) \tag{3.3}$$

where **C**(t) is a matrix called **C** matrix, which can be obtained as follows. First the $\mathbf{X}(T_o + t)$ is expanded about $t = T_o$ in a Taylor's series,

$$\mathbf{X}(T_o+t) = \mathbf{X}(T_o) + \frac{t}{1!}\cdot\frac{d\mathbf{X}(t)}{dt}\bigg|_{t=T_o} + \frac{t^2}{2!}\;\frac{d^2\mathbf{X}(t)}{dt^2}\bigg|_{t=T_o} + \cdots + \frac{t^m}{m!}\;\frac{d^m\mathbf{X}(t)}{dt^m}\bigg|_{t=T_o} + \cdots \quad . \tag{3.4}$$

On the other hand, if $\frac{d\mathbf{X}(t)}{dt}=\mathbf{A}\cdot\mathbf{X}(t)$, then $\frac{d^2\mathbf{X}(t)}{dt^2}=\frac{d}{dt}(\mathbf{A}\cdot\mathbf{X}(t))=\mathbf{A}^2\mathbf{X}(t)$; similarly,

$$\frac{d^m\mathbf{X}(t)}{dt^m} = \mathbf{A}^m\cdot\mathbf{X}(t) \quad . \tag{3.5}$$

With Eq.(3.5) substituted for the derivatives in Eq.(3.4), we have

$$\mathbf{X}(T_o+t) = \mathbf{X}(T_o) + \frac{t}{1!}\cdot\mathbf{A}\cdot\mathbf{X}(T_o) + \frac{t^2}{2!}\cdot\mathbf{A}^2\cdot\mathbf{X}(T_o) + \cdots + \frac{t^m}{m!}\cdot\mathbf{A}^m\cdot\mathbf{X}(T_o) + \cdots\cdot$$

$$= (\mathbf{E} + \frac{t}{1!}\mathbf{A} + \frac{t^2}{2!}\mathbf{A}^2 + \cdots + \frac{t^m}{m!}\mathbf{A}^m + \cdots)\cdot\mathbf{X}(T_o)\ , \tag{3.6}$$

where **E** is the unit matrix. Therefore **C**-matrix becomes

$$\mathbf{C}(t) = \mathbf{E} + \frac{t}{1!}\mathbf{A} + \frac{t^2}{2!}\mathbf{A}^2 + \cdots + \frac{t^m}{m!}\mathbf{A}^m + \cdots\cdot \quad . \tag{3.7}$$

Since **A**-matrix is known, **C**-matrix can be obtained by Eq.(3.7). Knowing $\mathbf{X}(T_o)$, the substitution of **C**-matrix to Eq.(3.3) will yield $\mathbf{X}(T_o + t)$. It should be noted that $\mathbf{C}(t) = e^{\mathbf{A}t}$ and $\mathbf{X}(T_o + t) = e^{\mathbf{A}t}\mathbf{X}(T_o)$.

In the calculation in the ACT4 code, a time step τ is fixed. By substituting $t = \tau$ in Eq.(3.7), $\mathbf{C}(\tau)$ can be calculated. Since $\mathbf{C}(m\tau) = \mathbf{C}^m(\tau)$, the atomic density vector at $m\tau$ after the start of a fusion reactor can be obtained by Eq.(3.3). The number of terms in the Taylor series expansion and the time step τ is determined by the input. Once the atomic density at time $m\tau$ is obtained, the induced activity can be calculated by simply applying the decay constant to the atomic density of a radioactive nuclide.

In order to obtain the induced activity at the time after shutdown, Eq.(3.3) can be used again with $\phi_g = 0$ in the **A**-matrix and replacing $\mathbf{X}(T_o)$ at the start of the operation by $\mathbf{X}(T_o + m\tau)$ at the end of the operation.

3.1.2 Treatment of Short Life Nuclides

The half life values of radioactive nuclides range from μsec to tens of thousands years. The decay constants λ_τ's which are inversely proportional to the half life values, are included in the elements of the **A**-matrix. In order to treat accurately the elements having the half life values very different in the orders of magnitude, the following methods are applied to the ACT4 code.

When there is an element with an exceptionally large λ_τ in the **A**-matrix, the numerical error of **C**-matrix by Eq.(3.7) becomes large. The element becomes large for the decay constant corresponding to short half life. In order to reduce such a numerical error, the half life shorter than 1 s is replaced by 1 s. This replacement has little effect on the induced activity later than several seconds after reactor shutdown.

Another method to cope with a large λ_τ is to multiply the time step τ by $(1/2)^n$ to reduce the product of $\lambda_\tau \cdot \tau$. If the **C**-matrix obtained by multiplying $(1/2)^n$ to τ is denoted as $\mathbf{C}_n$, the required **C**-matrix may be obtained as $\mathbf{C}_n^{2n}$. This method is applicable to a certain value of n (e.g. $n \sim 5$). When n becomes too large (e.g. $n>10$), the large computation time and the accumulation of numerical errors make this method ineffective.

The daughter nuclides (D's) with very small short life are treated by a special procedure. In this procedure **A**-matrix is calculated assuming that the grand daughter nuclide (G) is produced directly from the parent nuclide (P). The amount of the daughter nuclide is calculated by solving a differential equation assuming the atomic density of the parent nuclide to be a linear function with respect to time.

This procedure is employed when the half life of a daughter nuclide τ_D is

$$\tau_D < \frac{\ln 2}{2^{\mathrm{IHALV}}} \times \tau \ , \tag{3.8}$$

where τ: time step specified by input,
IHALV: integer specified by input.

When a τ_D satisfies Eq.(3.8), the **A**-matrix is composed assuming the grand daughter G is directly produced from the parent P. The **C**-matrix is obtained from the **A**-matrix and the atomic density vector $\mathbf{X}(T_o + t)$ is calculated using the relationship of Eq.(3.3), namely

$$\mathbf{X}(T_o + t) = \mathbf{C}(t) \cdot \mathbf{X}(T_o) \quad .$$

The atomic density in $\mathbf{X}(T_o + t)$ is unchanged in the procedure so that the reversal of the procedure in obtaining the **A**-matrix is followed. That is assuming the atomic density of P to be linearly dependent on time during the time interval dt, the production of D is calculated directly by solving a differential equation,

$$\begin{aligned}\frac{dD}{dt} &= \alpha P - \lambda D \\ &= \sum_i (\alpha_i a_i + \alpha_i b_i t) - \lambda_D D \\ &= a + bt - D\lambda , \end{aligned} \tag{3.9}$$

where P : atomic density of the parent nuclide,

D : atomic density of the daughter nuclide,

λ : decay constant of the daughter,

α : conversion factor of parent to daughter.

The solution of Eq.(3.9) is

$$D = D_o e^{-\lambda t} + \frac{a}{\lambda} (1 - e^{-\lambda t}) + \frac{bt}{\lambda} (1 - \frac{1 - e^{-\lambda t}}{\lambda t}) \quad . \tag{3.10}$$

The nuclide density of the grand daughter G is obtained by subtracting the production of the daughter D,

$$G_j = G'_j - \beta_j D \quad , \tag{3.11}$$

where G_j: atomic density of the grand daughter,

G'_j: atomic density of the grand daughter assuming the direct production from the parent,

β_j: branching ratio from the daughter D to produce G_j.

3.1.3 Quantities Related to Induced Activity

From the atomic densities of the relevant nuclides at time t, i) induced activity, ii) decay heat, iii) delayed gamma ray source, iv) transmutation rate and v) biological hazard potential (BHP) can be calculated.

i) Induced Activity

Induced activity concentration of a nuclide i at a spatial mesh r (Ci/cm^3) is given as

$$Q_{IA,i,r} = \lambda_i X_i(t)_r \ / \ 3.7 \times 10^{10} \tag{3.12}$$

and overall induced activity per unit fusion power (Ci/MW),

$$Q_{IA} = \sum_i \sum_r Q_{IA,i,r} \cdot \mathrm{Volume}_r / P_f \tag{3.13}$$

where λ_i : decay constant of nuclide i (s^{-1}),

$X_i(t)_{r=r_o}$: atomic density of nuclide i at mesh $r = r_o$, at time t (atoms$\cdot$cm^{-3}),

$\mathrm{Volume}_{r=r_o}$: volume of mesh region at $r = r_o$ (cm^3),

P_f : total fusion power in MW

1 Ci = 3.7×10^{10} dps (disintegrations per second).

ii) Decay Heat

Decay heat rate at mesh r (watt/cm^3) is given as

$$DH_{approx,i} = \sum_i Q_{ID,i,r}(\overline{E}_{\beta i} + XGAM_i \cdot E_{\gamma i}) \times 1.6021 \times 10^{-13}, \tag{3.14}$$

where $Q_{ID,i,r} = \lambda_i X_i(t)_r$: disintegration rate of nuclide i at mesh r (dps$\cdot$cm^{-3}),

$\overline{E}_{\beta i}$: mean energy of β-ray of nuclide i in MeV, given from the CHAINLIB library[12].

$XGAM_i$: gamma-ray intensity of nuclide i, given from the GAMMALIB library[12].

$E_{\gamma i}$: gamma-ray energy of nuclide i in MeV, given from the GAMMALIB library[12], and 1 MeV$\cdot$s^{-1} = 1.6021×10^{-13} watt.

As described in Section 2.6, DH_{approx} assumes that the gamma-ray energy is deposited at the location of its generation. Overall decay heat as a fraction of fusion power (MW/P_f MW) becomes

$$DH = \sum_r DH_{approx,r} \cdot \mathrm{Volume}_r \cdot 10^{-6} / P_f \tag{3.15}$$

where 1 watt = 10^{-6} MW.

iii) Delayed gamma-ray source

Delayed gamma-ray source is given in the 54-group energy structure for the further calculation of the gamma-ray transport. Gamma-ray source intensity (photons$\cdot$s$^{-1}\cdot$cm^{-3}) is

$$GS_r^g = \sum_i Q_{ID,I,R} \cdot XGAM_i \ . \tag{3.16}$$

The gamma-ray energy $E_{\gamma i}$ from nuclide i is compared with the 54-group energy structure and those belonging to the group g will be summed up to form GS_{ir}.

iv) Transmutation Rate

Atomic density of each nuclide is given as the fraction of total atomic density,

$$TR_{i,r} = X_i(t)_r \;/\; \sum_i X_i(t)_r . \qquad (3.17)$$

v) Biological Hazard Potential (BHP)

Biological hazard potential is defined as the volume of standard state air required to dilute the radioactive nuclides to maximum permissible concentration (km^3 air),

$$BHP = \sum_r \sum_i Q_{ID,i,r} \cdot Volume_i \;/\; XMPC_i \;/\; 3.7 \times 10^{19} , \qquad (3.18)$$

where $XMPC_i$: maximum permissible concentration of nuclide i ($\mu Ci/cm^3$),

$$1\ \mu Ci/cm^3 = 3.7 \times 10^{10} \cdot 10^{-6}\ dps/10^{-15}\ km^3$$

$$= 3.7 \times 10^{19}\ dps/km^3 .$$

The values of $XMPC_i$ as determined by the Japanese Regulation[21)] are listed in **Table 3.1**. For those nuclides not determined by the Regulation, the $XMPC_i$ value of $1.0 \times 10^{-10}\ \mu Ci/cm^3$ is assigned. These values have been provided in the BLOCK DATA of the ACT4 code and is used in the BHP calculation.

3.2 Code Structure and Subroutines

The program diagram of the ACT4 code is shown in **Fig. 3.1**. The subroutine CNTRL controls the calculational flow of the code which is shown in **Fig. 3.2**. It should be noted that most of the calculations are performed in the subroutine CALC. The calculational flow in the CALC is described in Subsection 3.2.2 with the aid of **Fig. 3.3**. Subroutines from ACTIN1 to GAMIN in **Fig. 3.2** are used for the data manipulation, namely to read input data and libraries, and to select the required data for use in the calculation conducted in CALC. Brief description of the function of subroutines in the ACT4 code is given in Subsection 3.2.1. The arrays of variables used in the ACT4 code are described in Appendix A.1.

3.2.1 Function of Subroutines

1) FTMAIN

Allocation and clearing of the blank COMMON.

2) CLEAR

Zero clearing of DIMENSIONs

3) CNTRL

Controls the calculational flow and allocates variable dimensions.

4) ACTIN1

Reads miscellaneous data and calculates some constants.

5) FILEFX

Reads group independent neutron flux and convert its arrangement to pointwise format, calculates and writes out total neutron fluence over the time interval DT.

6) MIX

Calculates atomic density and atomic fraction of each nuclides in each material zone using the mixing input data of 8¥, 9¥, 10¥, 11¥ and 12*, which are described later in Subsection 3.4.1.

7) ACHAIN

Selects the decay chain data required in the calculation from the CHAINLIB library$^{12)}$ in FT08, stores the required data in FT01, and determines the size of the chain table.

8) ACTCHN

Reads the chain table data from FT01 to construct the chain table.

9) ACTIN4

Reads the input data of nuclide group for which transmutation rate calculation is desired.

10) ACROSS

Reads transmutation cross sections in the CROSSLIB library$^{12)}$ in FT09 and produces cross section table ACTAB.

11) GAMIN

Reads input specifying the transmutation rate output, reads input for delayed gamma-ray emission from the GAMMALIB library$^{12)}$ in FT10 and produces gamma-ray data table.

12) KCSLOK (ACTAB, ACTYP, KEY) Function

A function used to form the transmutation reaction table. When KEY = 2, the table ACTAB is searched for ACTYP. If ACTYP is located in ACTAB, the location number is set to KCSLOK. If ACTYP is not found then KCSLOK becomes 0. When KEY = 1, the location number is set to KCSLOC if ACTYP is found in ACTAB. The ACTYP is added to ACTAB table if not found.

13) KIALOK (ZAPTAB, NMTAB, KIAMAX, ZAP) Function

A function used to tabulate radioactive nuclide in the table ZAPTAB. KIALOK becomes the number of the radioactive nuclide if not already listed in the table.

14) NXLOOK (ZA, ZANX, NX) Function

Searches ZANX table for the nuclide ZA and if ZA is found in ZANX, assigns the number in ZANX as NXLOOK. If ZA is not found, ZA is added to the ZANX table.

15) TIMECV (TIME, UNIT) Function

The unit of time UNIT is converted to second and multiplied by TIME. The value of the time in seconds is returned as TIMECV.

16) TIMERV

The time in seconds is converted to a specific time unit (do the reversal of TIMECV). It is used to write out the output.

17) LOCAT

Checks and prints the size of memory locations.

18) CALC

Controls overall calculations. It controls the DO loops for spatial mesh (IR,IZ), component nuclides (IC) and time step (IT) in this order. It controls the calculation for pulsed operations and cooling time after shutdown. It calculates transmutation rate, induced activity, decay heat, gamma ray source in each mesh point. The calculational flow in the subroutine CALC is described in Subsection 3.2.2.

19) GEOM

Calculates the volumes of spatial mesh regions and prints the geometrical data input.

20) PICTUR

Prints the zone map in case of a two-dimensional calculation.

21) AMAT

Composes **A**-matrix using cross sections, neutron flux, decay constants and branching ratios. When ID = 2, neutron flux is set to zero.

22) CMAT

Calculates $\mathbf{C}$-matrix using the Matrix Exponential Method, i.e. Eq.(3.7) or $\mathbf{C}(t) = e^{\mathbf{A}t}$.

23) XCALC

Calculates atomic density vector at time $T_o + t$ using the relation of Eq.(3.3) or

$$\mathbf{X}(T_o + t) = \mathbf{C}(t) \cdot \mathbf{X}(T_o) \ .$$

24) TRCAL

Calculates transmutation rates.

25) TRTM

Writes out calculated transmutation rates in the manner specified by the input.

26) QIADH

Compiles and writes out induced activity, decay heat, gamma-ray source at specified mesh points. It also calculates volume integrated values of these quantities and bilogical hazard potential.

27) MESHCK

Checks the write out options for each spatial mesh.

28) SOURCE

Selects the requested gamma-ray source and converts it to the format compatible with the gamma-ray transport calculation.

29) ITIME

Sets the time elapsed since the previous call of ITIME.

30) PAGEO, PAGE

Controls and prints the page number.

31) FIDO, FIDAS, FFREAD

Reads input data in free form FIDO format9).

32) PCURVE, APLOT, XYAXIS, INTERP, PENSET, SCALER

Plots time evolution curves of induced activity and decay heat.

33) SPECTR, SCALER, ZNORM, GRID

Plots gamma-ray source spectrum.

34) BLOCK DATA

Stores energy group structure data E(IEMAX) and maximum permissible concentrations of radioactive nuclides XMPC (260).

35) ERROR

Writes out error number.

3.2.2 Subroutine CALC

As shown in **Fig. 3.2**, the subroutine CALC is the key subroutine in the ACT4 code. The subroutine calculates the transmutation rate, induced activity, decay heat and delayed gamma-ray source. The calculational flow in CALC is described with the aid of **Fig. 3.3.**

The induced activity at a certain time after shutdown, from a single component nuclide, in a spatial mesh region is calculated one by one. The calculational loops exist for shutdown times, component nuclides, spatial meshes. As shown in P1 of **Fig. 3.3**, **A**-matrix with nonzero neutron flux ϕ is composed, followed by **B**-matrix, which is the **A**-matrix with $\phi = 0$. The **A**- and **B**-matrices are converted respectively to **C**- and **D**-matrices using the matrix exponential method.

The calculational flow to obtain the nuclide density changes during a pulsed operation and after shutdown is shown in P2 of **Fig. 3.3**. The nuclide densities at shutdown times are stored in QIAO(NXMAX, IS).

The calculational flow to obtain the nuclide density changes after shutdown is shown in P3 of **Fig. 3.3**. When the nuclide densities of radioactive nuclides are obtained, induced activity, decay heat, delayed gamma-ray source and biological hazard potential are calculated and printed for specified spatial mesh points as shown in P3 of **Fig. 3.3**. The volume integrated values over the whole system are also given for these quantities.

3.3 Characteristics and Limitations of ACT4

In this section, major characteristics and limitations of the ACT4 code are described.

3.3.1 Characteristics

(i) Variable dimension

The ACT4 employs variable dimension to allow the effective use of the core memory. The overall size of the data area is defined by the parameter NLFT defined in the FTMAIN of the code.

(ii) Simplification of input procedure

Geometrical data used in the neutron transport calculation can be utilized by storing them with the neutron flux. When the data are not stored with the flux, they can be input from FT05. Material composition input data follow the formats used in the ANISN code(9).

(iii) Pulsed operation calculation

Pulsed operation shown by **Fig. 3.4** can be treated by the ACT4 code. The induced activities after arbitrary shutdown times can be calculated.

3.3.2 Limitations

(i) Sequential decay of two short life nuclides

The special treatment of a short life nuclide was described in Subsection 3.1.2. This treatment works well for a short life parent nuclide with stable or long life daughter nuclide, e.g.

$$ {}^{60}\mathrm{Ni}(n,p)\underset{(\mathrm{P})}{{}^{60m}\mathrm{Co}} \xrightarrow[10.5\ \mathrm{m}]{\mathrm{IT}} \underset{(\mathrm{D})}{{}^{60}\mathrm{Co}} \xrightarrow[5.3\mathrm{y}]{\beta^-} \underset{(\mathrm{G})}{{}^{60}\mathrm{Ni}} \quad (\mathrm{stable}) $$

where ${}^{60m}\mathrm{Co}$ is the short life parent P, ${}^{60}\mathrm{Co}$ the long life daughter D and ${}^{60}\mathrm{Ni}$ is the grand daughter G. In this case, **A**-matrix is calculated as if G is produced directly from P and then D is subtracted from G, as described in Subsection 3.1.2.

However, when the parent and daughter are both short lived, the above treatment is not applicable, e.g.

$$ {}^{54}\mathrm{Fe}(n,2n)\ \underset{(\mathrm{P})}{{}^{53m}\mathrm{Fe}} \xrightarrow[2.5\mathrm{m}]{} \underset{(\mathrm{D})}{{}^{53}\mathrm{Fe}} \xrightarrow[8.5\mathrm{m}]{\beta^+,\mathrm{EC}} \underset{(\mathrm{G})}{{}^{53}\mathrm{Mn}} \xrightarrow[3.7\times10^{6}\,\mathrm{y}]{\mathrm{EC}} \underset{(\mathrm{GG})}{{}^{53}\mathrm{Cr}} \quad (\mathrm{stable}). $$

In this case the grand daughter nuclide G is subtracted from the great grand daughter nuclide GG but D is not subtracted from G. A correction is required for this type of decay sequences.

ii) Reaction of neutrons with reaction products

Only the primary transmutation reactions by neutron are considered. That is, neutron reactions with stable (long-lived naturally occurring) nuclides are considered but the neutron reactions with reaction product nuclides are neglected. (The exceptional cases are the ${}^{13}\mathrm{C}$ produced from the ${}^{12}\mathrm{C}(n,\gamma)$ reaction and ${}^{51}\mathrm{V}$ produced from the ${}^{52}\mathrm{V}(n,2n)$ reaction.) This guide line is adopted to avoid the complexity introduced by secondary reactions. However, the secondary reactions may be included if desired. When dealing with very high irradiation fluence, the secondary reaction should be properly considered, but in usual applications their effects are generally insignificant.

(iii) Assumption of constant neutron flux

When dealing with high irradiation fluence, the neutron flux changes gradually with the change of the atomic densities of the component nuclides. This change should be considered for the accurate estimation of radio-activation.

The ACT4 code uses the neutron flux at the initial state throughout the operating period. In order to take this change into consideration, the irradiation period should be divided into appropriate time intervals. The neutron flux obtained with the atomic density content at the end of the previous time interval should be used to calculate the atomic density change during each time interval.

3.4 Input Description of ACT4

The input data format, input data, instruction, location assigned for input data are described in this section.

3.4.1 Input Data Format

Item 1 (18A4) Title of the problem

Item 2 (6(E11.0, A1)) Operation schedule

1. DT ; time step used in the calculation [DT=2629800s]
2. TMAX; maximum calculation time
3. T1 ; short pulse time when power is on
4. T2 ; short power cycle time with T1 plus down time
5. T3 ; total time for a group of short pulses
6. T4 ; long cycle time including long cooling time

Figure 3.4 shows the operation schedule. For steady operation, T1 = 0 or T1 $\geq$ TMAX. The relation between T1 ~T4 should be T1 < T2 < T3 < T4. Time should be given by 11 digits and the last (twelfth column) is for time units. Time units are S for second, M for minute, H for hour, D for day, W for week, G for month and Y for year. When DT is input as 0, the default value of 2629800s is used. Such default values are shown hereafter in the parenthesis.

Item 3 (6(E11.0, A1)) Shutdown time

TSH(I); shutdown times (see **Fig. 3.4**), the time unit is the same as Item 1. Shutdown times should be input in the increasing order. If zero or a value exceeding TMAX appears, the rest of the values are neglected. Usually a single value is input. Up to 6 values can be input.

The lesser of the TMAX or the maximum value of TSH(I) will be the maximum calculation time for the reactor operation. The maximum calculation time divided by DT will be the number ITMAX of the time steps for the reactor operation. ITMAX should be around 10 to insure reasonable computation time.

Item 4 (12I6) Parameters to determine core size and options

1. IEMAX ; number of neutron energy groups [42] the default value is 42.
2. IRMAX ; number of spatial mesh in the X(or R) direction [1]
3. JZMAX ; number of spatial mesh in the Y(or Z) direction [1]
4. NZONE ; number of zones
5. MS ; length of the mixing table (described in more detail in Subsection 3.4.2)
6. IGMAX ; number of delayed gamma-ray energy groups [54]
7. ISM ; number of the times after shutdown at which induced activity is calculated and printed. If ISM = 0, the standard values of time after shutdown are provided by the code.
8. IGMODE; geometry data input mode
   = 0; input by file
   = 1; input from FT05
9. IMATX ; not used; IMATX must be 0.
10. KNGMAX; number of nuclide groups for transmutation calculations
11. LCMAx ; number of expansion terms in the **C**-matrix calculation [10]

Item 5 (12I6) Option parameters

1. IGEOM ; geometry type

One-dimensional geometry	Two-dimensional geometry	Three-dimensional geometry
=1; slab	=0; (X-Y)	= 7
=2; cylinder	=1; (R-Z)	
=3; sphere	=2; (R-θ)	

When JZMAX > 1, the geometry is considered to be two-dimensional.

2. IHALV ; integer for determination of short life nuclide; a nuclide is treated as short life when the half life is less than (ln 2 x DT)/(2^{IHALV}).[6]
3. IRLW ; lower bound mesh number in the X (or R) direction for induced activity calculation [1]
4. IRHI ; upper bound mesh number in the X (or R) direction for induced activity calculation [IRMAX]
5. JZLW ; lower bound mesh number in the Y (or Z) direction for induced activity calculation [1]
6. JZHI ; upper bound mesh number in the Y (or Z) direction for induced activity calculation [JZMAX]
7. IRINTV; number of mesh intervals in the X (or R) direction for induced activity calculation; the calculation is conducted for every IRINTV-th mesh beginning from IRLW. [1]
8. JZINTV; number of mesh intervals in the Y (or Z) direction for induced activity calculation. [1]
9. ITINTV; number of time step intervals for transmutation rate calculation [1]

Item 6-1 (12I6) Option parameters for calculation/output

1. IOPT(1); induced activity
2. IOPT(2); decay heat
3. IOPT(3); delayed gamma-ray source
4. IOPT(4); transmutation rate
    - = 1; both calculation and print out is conducted for all mesh points
    - = 0; neither calculation nor print out is conducted
    - =-1; only calculation is conducted
    - = 2; calculation is conducted for all mesh points but print out is only for the mesh points specified by Item 7-2. If any of IOPT(1) IOPT(4) is input as 2, IOPT(1) IOPT(4) specified as 1 will be changed to 2.

When IOPT(2) is positive, only β-ray decay energy is included in the decay heat. The sum of β-ray and gamma-ray energy is calculated following Eq. (3.14) and printed when IOPT(2) = -2.

5. IOPT(5); chain table input data print out

6. IOPT(6); activation cross section data print out
7. IOPT(7); delayed gamma-ray emission data print out
8. IOPT(8); intermediate calculational results for **A**-matrix and
 and **C**-matrix

$\begin{cases} = 0 \text{ print out} \\ = 1 \text{ no print out} \end{cases}$

Item 6-2 (12I6) Mesh points specification for print out

1. II1 ; Region number for storing specified mesh numbers

$\begin{cases} < 0 \text{ denotes the end of Item 6-2 input} \\ > 10 \text{ input is neglected for II1} > 10 \end{cases}$

2. II2
3. JJ3
4. JJ2
5. JJ3

(2.–5.) print out is for the mesh points from II2 to II3 in the X(R) direction and from JJ2 to JJ3 in the Y(Z,θ) direction.

The maximum number of Item 6-2 is 10.

Item 7 (6 E 12.0)

1. POWER ; total thermal power output of a reactor, P_f(MW-th) used to normalize overall decay heat [5.0E + 9]
2. PPFLUX; normalization factor, N_f for neutron flux [1.0]
3. RR ; torus major radius, R (cm) used to calculate a torus volume [500.0], see the note below for the use of RR.
4. PLOG ; number of log scaling for plotter outputs, no plotter output is given if PLOG = 0.0.
5. VAR ; calculational parameter used in **C**-matrix calculation [1.0]
6. PREC ; calculational parameter used in **C**-matrix calculation [10^{-6}]

Note on RR: When IGEOM = 2 and JZMAX = 1, treating a one-dimensional cylindrical geometry, the program assumes the height of the cylinder to be 2πR. In this case the volume of the cylinder becomes equivalent to the torus with major radius of R. If an ordinary cylinder with the height of 1 cm is to be treated, the R should satisfy the equation

$$\frac{1}{2\pi R} = 1.0 \quad ,$$

namely RR = 0.1592 should be input.

Item 8 (6(E 11.0, A1)) (Not required when ISM = 0)

(ST(I), I = 1, ISM); time after shutdown, the time unit is the same as defined in Item 1.

Item 9 (Free format*) Geometrical data (not required when IGMODE = 0) to be written in 1 – 72 columns.

4** IRMAX + 1 input data : mesh boundary values for X(R) direction

5** JZMAX + 1 : mesh boundary values for Y(Z) direction (not required when JZMAX = 1). These values correspond to 2** data in DOT-3.5[10].

8¥¥ IRMAX*JZMAX : zone numbers for mesh points. These should correspond to the ones used in neutron flux calculation. When IGEOM = 7, input media number for each region.

T : terminate

Item 10 (Free format) Atomic density data for mixtures to be written in 1 – 72 columns

9¥¥ NZONE : mixture number for each zone. (Input 0 for ZONE which does not require activation calculation)

10¥¥ MS : material number, i.e. atomic number (1 – 99) or mixture number (101 – 999)

11¥¥ MS : component number, i.e. nuclide number in CHAINLIB library[12] or atomic number or mixture number.

12** MS : natural abundance or atomic density in (10^{24} atoms cm^{-3})

T : terminate

An example of Item 10 for Li_2O atom density is given below. Additional informations are given in Subsection 3.4.2.

10¥¥	11¥¥	12**	
8	8016	0.9976	natural abundance
8	8017	0.00038	
8	8018	0.002	
101	3006	3.961E-3	atomic density
101	3007	4.9422E-2	
101	8	2.6692E-2	

---

* Free form FIDO format using symbols **, ¥¥ and T is explained in Ref.9.

The atomic density of a nuclide in a mixture is obtained as the product of element atomic density and abundance.

Item 11 Nuclide groups for transmutation calculation
(not required when KNGMAX = 0)

Item 11-1 (A8, 4X, I12)

TTLNG : name of nuclide groups (e.g. COPPER)

LMAX : number of nuclides in the group

Item 11-2 (6 E 12.0)

(ZANG(L), L = 1, LMAX): nuclide number in the group
(e.g. 29063, 29064, 29065, etc.)

KNGMAX sets of Item 11 are input.

Item 12 (A4)

AIC = 'CARD' : input Item 12 data specifying the output of transmutation calculations
(used only when KNGMAX > 0)

= 'GAMM' : input Item 14 data specifying the delayed gamma-ray source output

= 'END' : end of input data

Item 13 required when KNGMAX > 0 and AIC = 'CARD'

Item 13-1 (A4, 4X, 5I12)

1. AAS = 'REGI': specify output region
   ='TIME': specify output time
2. II1 = region number when AAS = 'REGI'
   = number of output time when AAS = 'TIME'
3. II2: } specify only when AAS = 'REGI',
4. II3: } region II1 is to be between II2 and II3 in the X(R)
5. JJ2: } direction and between JJ2 and JJ3 in the Y(Z, θ)
6. JJ3: } direction

Item 13-2 (6(E11.0, A1)) (required when AAS = 'TIME')

(TIME(I), I = 1, NTMX): irradiation times when transmutation output are given

Input as many Item 13-1 as required when AAS = 'REGI'. The maximum number of regions, LQMX should satisfy LQMX $\leq$ 8, and the maximum number of the irradiation times, NTMX $\leq$ 8.

Item 14 for delayed gamma-ray source output is required when IGMAX > 0 and AIC = 'GAMM'.

Item 14-1 (3I6) (see **Fig. 3.4**)

1. ISDRW : sequence number of shutdown time for the output, i.e. the output for the shutdown time at TSH(ISDRW) will be given.
2. ISTDRW: sequence number of the time after shutdown for the output, i.e. the output for the time ST(ISTDRW) after shutdown will be given.
3. IESW : option parameter for input of gamma-ray energy group data
   - = 0 : use the data stored in the program (54 groups described in **Table 2.4** is used when IGMAX = 54)
   - = 1 : input energy group data by Item 14-2

Item 14-2 (6 E 12.0) (required when IESW = 1)

(GLVL (IML), IML = 1, IGMAX+1): gamma-ray energy level in eV from the highest level

The input item ends when AIC = 'END' in Item 12.

Note) When transmutation is calculated and printed by specifying KNGMAX > 0, Item 11, Item 12 and Item 13 are required.
When delayed gamma-ray source is calculated by specifying IGMAX > 0, Item 12 and Item 14 is required.

3.4.2 Atomic Density Input

It is necessary to specify the atomic densities of naturally occurring isotopes of elements for which induced activity are to be calculated. The input method to specify the atomic densities is similar to the one used in the ANISN code.[9)]

At first the natural abundance of isotopes is given for elements and then the atomic densities of elements are given for materials. The following notations are introduced to give an example of a mixing table to specify the atomic densities.

Atomic density of an element Z_i is $N(Z_i)$. A naturally occurring j-th isotope of an element Z_i is denoted by (Z_i, A_{ij}) which is represented by five digits in the following manner.

$$\begin{array}{c} XX : X : XX \\ Z_i : M_i : A_{ij} \end{array}$$

where Z_i and A_{ij} are the atomic and mass numbers of the isotope, respectively. M_i is a metastable indicator which takes 0 for a stable isotope. When three digits are required to denote A, only the last two digits are given (e.g. 82003 for ${}^{103}_{82}\mathrm{Pb}$). Natural abundance of the j-th isotope of an element Z_i is denoted as $f(Z_i, A_{ij})$. Note that

$$\sum_j f(Z_i, A_{ij}) = 1.0 \quad .$$

An example of a mixing table is given below.

	10¥¥	11¥¥	12**
Natural abundance of isotopes is given for elements	Z_1	(Z_1,A_{11})	$f(Z_1,A_{11})$
	Z_1	(Z_1,A_{12})	$f(Z_1,A_{12})$
	:	:	:
	Z_1	(Z_1,A_{1J})	$f(Z_1,A_{1J})$
	Z_2	(Z_2,A_{21})	$f(Z_2,A_{21})$
	:	:	:
	Z_2		
	:		
	Z_I		
Mixture densities are specified	101	Z_1	$N(Z_1)$
	101	Z_2	$N(Z_2)$
	102	(Z_i,A_{ij})	$N(Z_i,A_{ij})$
	103	Z_3	$N(Z_3)$
	103	Z_I	$N(Z_I)$
	103	101	V(101)

Note 1) Mixture numbers specified by 10¥¥ data are to be sequentially assigned from 101. Mixture numbers of regions are specified by 9¥¥ data. Induced activities are not calculated for regions with the entry of 0 for the mixture number.

Note 2) As may be seen for the mixture numbered 102, direct specification of an isotope as a mixuture is allowed.

Note 3) As may be seen for the mixture numbered 103, a mixture already specified (e.g. 101) can become one of the components. In this case, the value of 12** data usually represents a volume fraction.

A mixing table for a stainless steel is shown in the top half of **Table 3.2** as an example.

3.4.3 Location Structure of Variable Commons

Location structure of variable commons is shown in **Fig. 3.5**. There stored are the geometry data and data for constructing mixing table for atomic density. The locations 14 and 15 are used as the operational area for the density mixing in the Subroutine MIX.

In the Subroutine MIX, the mixing table data are converted so that the fractions of all the component nuclides are tabulated for each mixture in zones as shown in the bottom half of **Table 3.2**.

3.5 Output Description of ACT4

The output is described in this section for an ACT4 calculation with both transmutation and delayed gamma-ray source calculations. A complete output example for a one-dimensional problem is shown in Appendix A.4.

(1) Input data print out

Input data are printed out in both card image format and with additional explanations. There printed are the option parameters, geometrical input data, input neutron flux integrated over time, mixing table data input and the atomic density fraction for regions derived from the mixing table, as well as comments for the transmutation cross sections in the CHAINLIB library, the delayed gamma-ray emission data in the GAMMALIB library and gamma-ray energy group structure.

(2) Transmutation rates

The changes in the atomic fractions among a group of nuclides with irradiation time are printed when KNGMAX is not zero and when

Items 11, 12 and 13 are provided. The sample output in Appendix A.4 is for the case where KNGMAX is equal to 0.

(3) Induced activity at mesh points

Induced activities of component nuclides at the specified mesh points are printed with the unit of Ci/cm^3 for the time steps after shutdown.

(4) Decay heat at mesh points

Decay heat rate (W/cm^3) from component nuclides at the specified mesh points are printed for the time steps after shutdown.

(5) Delayed gamma-ray source

Delayed gamma-ray intensity per energy group for the specified mesh points is printed for the time steps after shutdown.

(6) Delayed gamma-ray source from nuclides

Delayed gamma-ray intensity from nuclides per energy group for the specified mesh points is printed for the specified time steps after shutdown.

(7) Overall induced activity

Induced activities of component nuclides integrated over the whole system are printed with the unit of Ci/MW-th, i.e. induced activity normalized by the thermal power output.

(8) Total decay heat

Decay heat from component nuclides and their sum integrated over the whole system are printed as the fraction of the thermal power output of the reactor P_f, i.e. MW-th/P_f MW-th.

(9) Total delayed gamma-ray source

Delayed gamma-ray intensity per energy group for the whole system is printed.

(10) Total delayed gamma-ray source from nuclides

Delayed gamma-ray intensity from nuclides per energy group for the whole system is printed.

(11) Biological hazard potential

Biological hazard potential integrated over the whole system is printed.

(12) Decay heat (DH_{approx})

Spatial distribution of the approximate value of the decay heat rate DH_{approx} described in Section 2.6 is printed. This approximate value assumes the deposition of gamma-ray energy at the point of its generation.

Table 3.1 Maximum Permissible Concentration, MPC (μCi/cm^3)

Nuclide	Nuclide Number	MPC	Nuclide	Nuclide Number	MPC	Nuclide	Nuclide Number	MPC
H – 3	1003	2.0E–06*	Sr – 85m	38185	1.0E–05	Te –129m	52129	1.0E–08
Be – 7	4007	4.0E–07	Sr – 85	38085	4.0E–08	Te –129	52029	1.0E–06
C –14	6014	1.0E–06	Sr – 89	38089	1.0E–08	Te –131m	52131	6.0E–08
F –18	9018	9.0E–07	Sr – 90	38090	4.0E–10	Te –132	52032	4.0E–08
Na–22	11022	3.0E–09	Sr – 91	38091	9.0E–08	I –126	53026	3.0E–09
Na–24	11024	5.0E–08	Sr – 92	38092	1.0E–07	I –129	53029	6.0E–10
Si –31	14031	3.0E–07	Y – 90	39090	3.0E–08	I –131	53031	3.0E–09
P –32	15032	2.0E–08	Y – 91m	39191	6.0E–06	I –132	53032	8.0E–08
S –35	16035	9.0E–08	Y – 91	39091	1.0E–08	I –133	53033	1.0E–08
Cl –36	17036	8.0E–09	Y – 92	39092	1.0E–07	I –134	53034	2.0E–07
Cl –38	17038	7.0E–07	Y – 93	39093	5.0E–08	I –135	53035	4.0E–08
A –37	18037	1.0E–03	Zr – 93	40093	4.0E–08	Xe–131m	54131	4.0E–06
A –41	18041	4.0E–07	Zr – 95	40095	1.0E–08	Xe–133	54033	3.0E–06
K –42	19042	4.0E–08	Zr – 97	40097	3.0E–08	Xe–135	54035	1.0E–06
Ca –45	20045	1.0E–08	Nb– 93m	41193	4.0E–08	Cs –131	55031	1.0E–06
Ca –47	20047	6.0E–08	Nb– 95	41095	3.0E–08	Cs –134m	55134	2.0E–06
Sc –46	21046	8.0E–09	Nb– 97	41097	2.0E–06	Cs –134	55034	4.0E–09
Sc –47	21047	2.0E–07	Mo– 99	42099	7.0E–08	Cs –135	55035	3.0E–08
Sc –48	21048	5.0E–08	Tc– 96m	43196	1.0E–05	Cs –136	55036	6.0E–08
V –48	23048	2.0E–08	Tc– 96	43096	8.0E–08	Cs –137	55037	5.0E–09
Cr –51	24051	8.0E–07	Tc– 97m	43197	5.0E–08	Ba –131	56031	1.0E–07
Mn–52	25052	5.0E–08	Tc– 97	43097	1.0E–07	Ba –140	56040	1.0E–08
Mn–54	25054	1.0E–08	Tc– 99m	43199	5.0E–06	La –140	57040	4.0E–08
Mn–56	25056	2.0E–07	Tc– 99	43099	2.0E–08	Ce –141	58041	5.0E–08
Fe –55	26055	3.0E–07	Ru– 97	44097	6.0E–07	Ce –143	58043	7.0E–08
Fe –59	26059	2.0E–08	Ru–103	44003	3.0E–08	Ce –144	58044	2.0E–09
Co–57	27057	6.0E–08	Ru–105	44005	2.0E–07	Pr –142	59042	5.0E–08
Co–58m	27158	3.0E–06	Ru–106	44006	2.0E–09	Pr –143	59043	6.0E–08
Co–58	27058	2.0E–08	Rh–103m	45103	2.0E–05	Nd–144	60044	3.0E–11
Co–60	27060	3.0E–09	Rh–105	45005	2.0E–07	Nd–147	60047	8.0E–08
Ni –59	28059	2.0E–07	Pb –103	46003	3.0E–07	Nd–149	60049	5.0E–07
Ni –63	28063	2.0E–08	Pb –109	46009	1.0E–07	Pm–147	61047	2.0E–08
Ni –65	28065	2.0E–07	Ag–105	47005	2.0E–08	Pm–149	61049	8.0E–08
Cu –64	29064	4.0E–07	Ag–110m	47110	3.0E–09	Sm–147	62047	2.0E–11
Zn–65	30065	2.0E–08	Ag–111	47011	8.0E–08	Sm–151	62051	2.0E–08
Zn–69m	30169	1.0E–07	Cd–109	48009	2.0E–08	Sm–153	62053	1.0E–07
Zn–69	30069	2.0E–06	Cd–115m	48115	1.0E–08	Eu–152ml	63152	1.0E–07
Ga–72	31072	6.0E–08	Cd–115	48015	6.0E–08	Eu–152m2	63252	4.0E–09
Ge–71	32071	2.0E–06	In –113	49013	2.0E–06	Eu–154	63054	1.0E–09
As–72	33072	1.0E–07	In –114	49014	7.0E–09	Eu–155	63055	3.0E–08
As–74	33074	4.0E–08	In –115m	49115	6.0E–07	Gd–153	64053	3.0E–08
As–76	33076	3.0E–08	In –115	49015	1.0E–08	Gd–159	64059	1.0E–07
As–77	33077	1.0E–07	Sn –113	50013	2.0E–08	Tb–160	65060	1.0E–08
Se –75	34075	4.0E–08	Sn –125	50025	3.0E–08	Dy–165	66065	7.0E–07
Br –82	35082	6.0E–08	Sb –122	51022	5.0E–08	Dy–166	66066	7.0E–08
Kr –85m	36185	1.0E–06	Sb –124	51024	7.0E–09	Ho–166	67066	6.0E–08
Kr –85	36085	3.0E–06	Sb –125	51025	9.0E–09	Er –169	68069	1.0E–07
Kr –87	36087	2.0E–07	Te –125m	52125	4.0E–08	Er –171	68071	2.0E–07
Rb–86	37086	2.0E–08	Te –127m	52127	1.0E–08	Tm–170	69070	1.0E–08
Rb–87	37087	2.0E–08	Te –127	52027	3.0E–07	Tm–171	69071	4.0E–08

* Read as 2×10^{-6}

Table 3.1 Maximum Permissible Concentration (continued)

Nuclide	Nuclide Number	MPC	Nuclide	Nuclide Number	MPC	Nuclide	Nuclide Number	MPC
Yb-175	70075	2.0E-07	Bi-207	83007	5.0E-09	Pu-241	94041	3.0E-11
Lu-177	71077	2.0E-07	Bi-210	83010	2.0E-09	Pu-242	94042	6.0E-13
Hf-181	72081	1.0E-08	Bi-212	83012	3.0E-08	Pu-243	94043	6.0E-07
Ta-182	73082	7.0E-09	Po-210	84010	7.0E-11	Pu-244	94044	6.0E-13
W-181	74081	4.0E-08	At-211	85011	2.0E-09	Am-241	95041	2.0E-12
W-185	74085	4.0E-08	Rn-220	86020	1.0E-07	Am-242m	95142	2.0E-12
W-187	74087	1.0E-07	Rn-222	86022	1.0E-08	Am-242	95042	1.0E-08
Re-183	75083	5.0E-08	Ra-223	88023	8.0E-11	Am-243	95043	2.0E-12
Re-186	75086	8.0E-08	Ra-224	88024	2.0E-10	Am-244	95044	1.0E-06
Re-187	75087	2.0E-07	Ra-226	88026	1.0E-11	Cm-242	96042	4.0E-11
Re-188	75088	6.0E-08	Ra-228	88028	1.0E-11	Cm-243	96043	2.0E-12
Os-185	76085	2.0E-08	Ac-227	89027	8.0E-13	Cm-244	96044	3.0E-12
Os-191m	76191	3.0E-06	Ac-228	89028	6.0E-09	Cm-245	96045	2.0E-12
Os-191	76091	1.0E-07	Th-227	90027	6.0E-11	Cm-246	96046	2.0E-12
Os-193	76093	9.0E-08	Th-228	90028	2.0E-12	Cm-247	96047	2.0E-12
Ir-190	77090	1.0E-07	Th-230	90030	8.0E-13	Cm-248	96048	2.0E-13
Ir-192	77092	9.0E-09	Th-231	90031	4.0E-07	Cm-249	96049	4.0E-06
Ir-194	77094	5.0E-08	Th-232	90032	7.0E-13	Bk-249	97049	3.0E-10
Pt-191	78091	2.0E-07	Th-234	90034	1.0E-08	Bk-250	97050	5.0E-08
Pt-193m	78193	2.0E-06	Th-nat	90000	6.0E-13	Cf-249	98049	5.0E-13
Pt-193	78093	1.0E-07	Pa-230	91030	3.0E-10	Cf-250	98050	2.0E-12
Pt-197m	78197	2.0E-06	Pa-231	91031	4.0E-13	Cf-251	98051	6.0E-13
Pt-197	78097	2.0E-07	Pa-233	91033	6.0E-08	Cf-252	98052	2.0E-12
Au-196	79096	2.0E-07	U-230	92030	4.0E-11	Cf-253	98053	3.0E-10
Au-198	79098	8.0E-08	U-232	92032	9.0E-12	Cf-254	98054	2.0E-12
Au-199	79099	3.0E-07	U-233	92033	4.0E-11	Es-253	99053	2.0E-10
Hg-197m	80197	3.0E-07	U-234	92034	4.0E-11	Es-254m	99154	2.0E-09
Hg-197	80097	4.0E-07	U-235	92035	4.0E-11	Es-254	99054	6.0E-12
Hg-203	80003	2.0E-08	U-236	92036	4.0E-11	Es-255	99055	1.0E-10
Tl-200	81000	4.0E-07	U-238	92038	3.0E-11	Fm-254	100054	2.0E-08
Tl-201	81001	3.0E-07	U-nat	92000	2.0E-11	Fm-255	100055	4.0E-09
Tl-202	81002	8.0E-08	U-240	92040	6.0E-08	Fm-256	100056	6.0E-10
Tl-204	81004	9.0E-09	Np-237	93037	1.0E-12	Mg-27	12027	1.0E-10
Pb-203	82003	6.0E-07	Np-239	93039	2.0E-07	Al-26	13026	1.0E-10
Pb-210	82010	4.0E-11	Pu-238	94038	7.0E-13	Al-28	13028	9.0E-06
Pb-212	82012	6.0E-09	Pu-239	94039	6.0E-13	Al-26m	13126	1.0E-10
Bi-206	83006	5.0E-08	Pu-240	94040	6.0E-13			

Table 3.2 Example of an atomic density mixing table

```
          ATOMIC DENSITY MIXING TABLE

    MIXTURE       COMPONENT    NO.DENSITY  ABUNDANCE       MAT,L/ZONE
  1      24        24050                    4.3500E-02          0
  2      24        24052                    8.3790E-01        102
  3      24        24053                    9.5000E-02        103
  4      24        24054                    2.3600E-02        104
  5      26        26054                    5.8000E-02          0
  6      26        26056                    9.1800E-01          0
  7      26        26057                    2.1500E-02        105
  8      26        26058                    2.9000E-03        106
  9      28        28058                    6.8300E-01        107
 10      28        28060                    2.6100E-01        101
 11      28        28061                    1.1300E-02          0
 12      28        28062                    3.5900E-02        101
 13      28        28064                    9.1000E-03          0
 14     101           24       1.5750E-02
 15     101           26       6.0345E-02
 16     101           28       9.8268E-03
 17     101        27059       2.1173E-05
 18     102          101       9.4000E-01
 19     103          101       6.9900E-02
 20     104          101       7.0000E-01
 21     105          101       7.0000E-01
 22     106          101       1.2350E-01
 23     107          101       9.0000E-02




          ATOMIC DENSITY AND RATIO DATA BY ZONE


                        ZONE- 1         ZONE- 2         ZONE- 3         ZONE- 4

      DENSITY           0.0             8.07859E+22     6.00737E+21     6.01599E+22

   ISOTOPES             //    RATIO BY ZONE
  1   24050               0.0           0.00797         0.00797         0.00797
  2   24052               0.0           0.15355         0.15355         0.15355
  3   24053               0.0           0.01741         0.01741         0.01741
  4   24054               0.0           0.00432         0.00432         0.00432
  5   26054               0.0           0.04072         0.04072         0.04072
  6   26056               0.0           0.64458         0.64457         0.64457
  7   26057               0.0           0.01510         0.01510         0.01510
  8   26058               0.0           0.00204         0.00204         0.00204
  9   28058               0.0           0.07809         0.07809         0.07809
 10   28060               0.0           0.02984         0.02984         0.02984
 11   28061               0.0           0.00129         0.00129         0.00129
 12   28062               0.0           0.00410         0.00410         0.00410
 13   28064               0.0           0.00104         0.00104         0.00104
 14   27059               0.0           0.00025         0.00025         0.00025
```

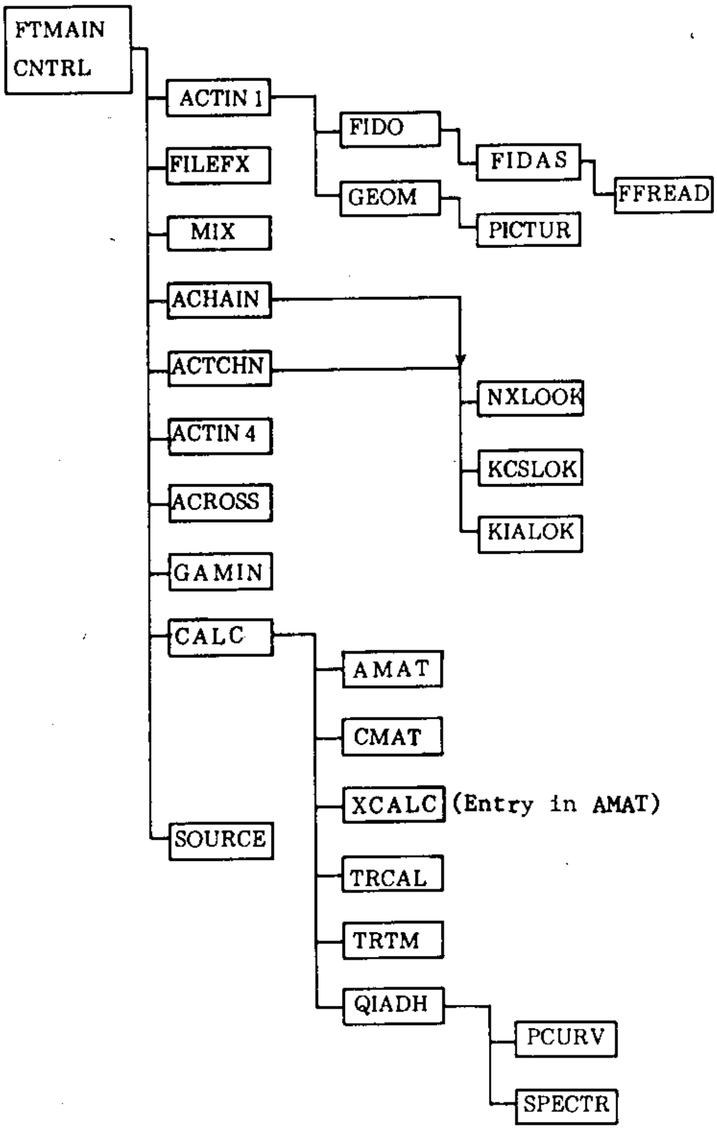
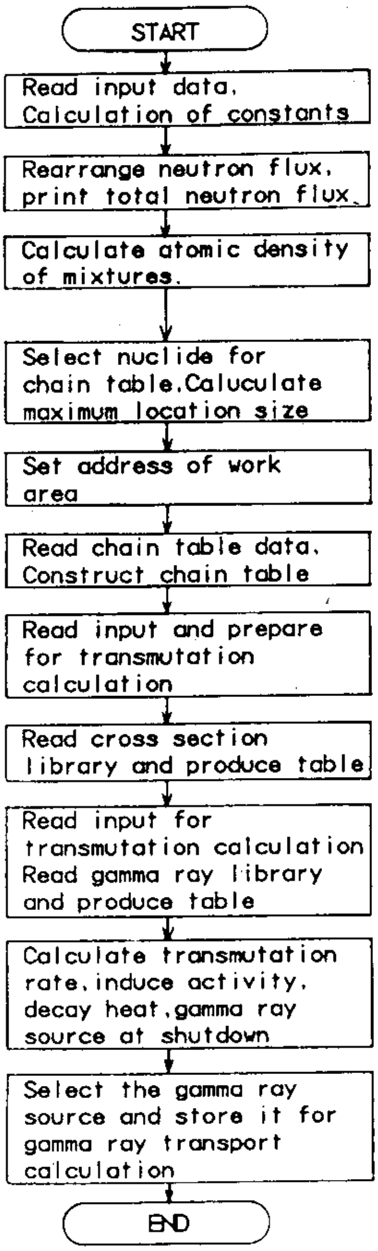


Fig. 3.1 Program diagram of ACT4 code.



	Relevant Subroutine	Reference
Read input data, Calculation of constants	ACTIN1	Set operation schedule.Set options
Rearrange neutron flux, print total neutron flux	FILEFX	Rearrange neutron flux to group dependent form (FT04→FT02).Print total flux at time DT.
Calculate atomic density of mixtures.	MIX	Calculate atomic density,atomic ratio of nuclides in each zone from 8¥,9¥,10¥,11¥, 12* data.
Select nuclide for chain table.Caluculate maximum location size	ACHAIN	Select chain table nuclides(FT08→FT01) calculate KIAMAX,NXPMAX,NXQMAX,KCSMAX, KACPMX
Set address of work area	CNTRL	Set values of COMMON/POINT/
Read chain table data, Construct chain table	ACTCHN	Read chain table data from FT01. Construct chain table
Read input and prepare for transmutation calculation	ACTIN4	Skipped when transmutation calculation is not requested (KNGMAX=0)
Read cross section library and produce table	ACROSS	Read CROSSLIB in FT09 ,Produce cross section table.ACTAB
Read input for transmutation calculation Read gamma ray library and produce table	GAMIN	Read input for transmutation rate output, Read input for delayed gamma ray emission from GAMMALIB in FT10. Produce gamma ray data table
Calculate transmutation rate, induce activity, decay heat, gamma ray source at shutdown	CALC QIADH	Calculate and Write out (See Fig.3.3) T.R. (Transmutation rate) I.A. (Induced activity) D.H. (Decay heat) G.S. (Gamma source)
Select the gamma ray source and store it for gamma ray transport calculation	SOURCE	Gamma ray source after shutdown is selected,converted to the input format for transport calculation and stored in FT17.

Fig. 3.2 Calculational flow in ACT4 code.

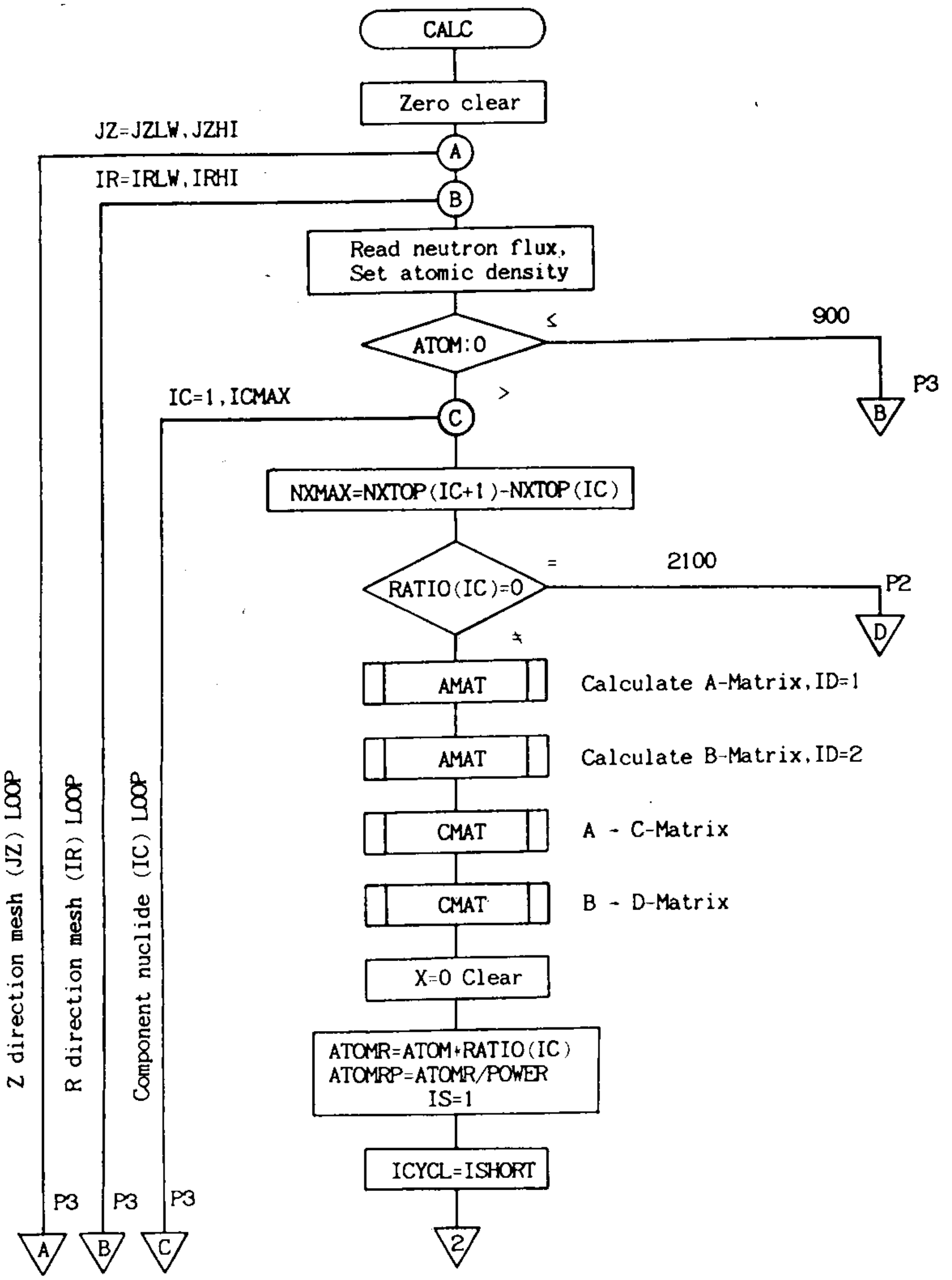


Fig. 3.3 Calcualtional flow in Subroutine CALC (P1).

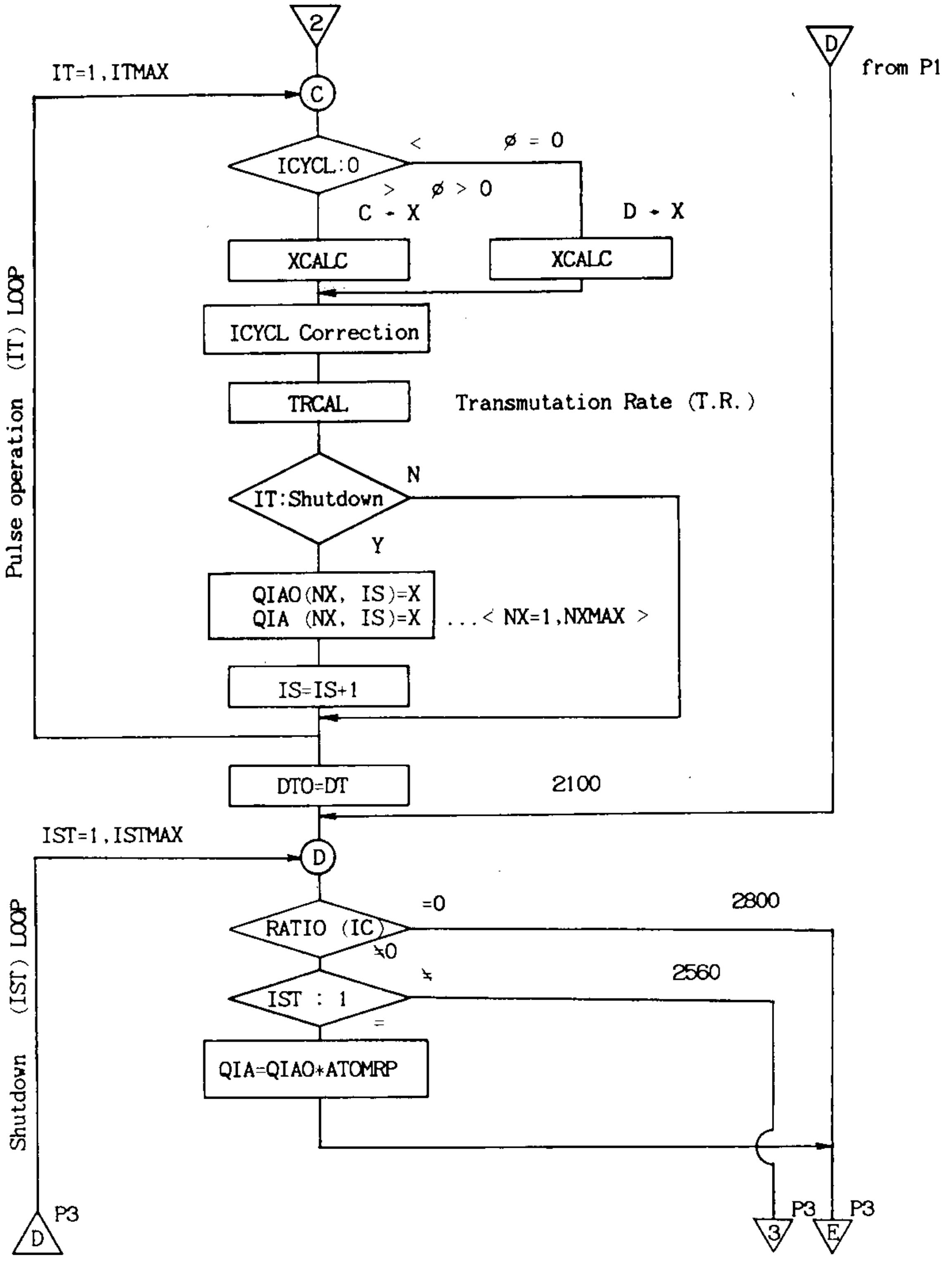


Fig. 3.3 Continued (P2).

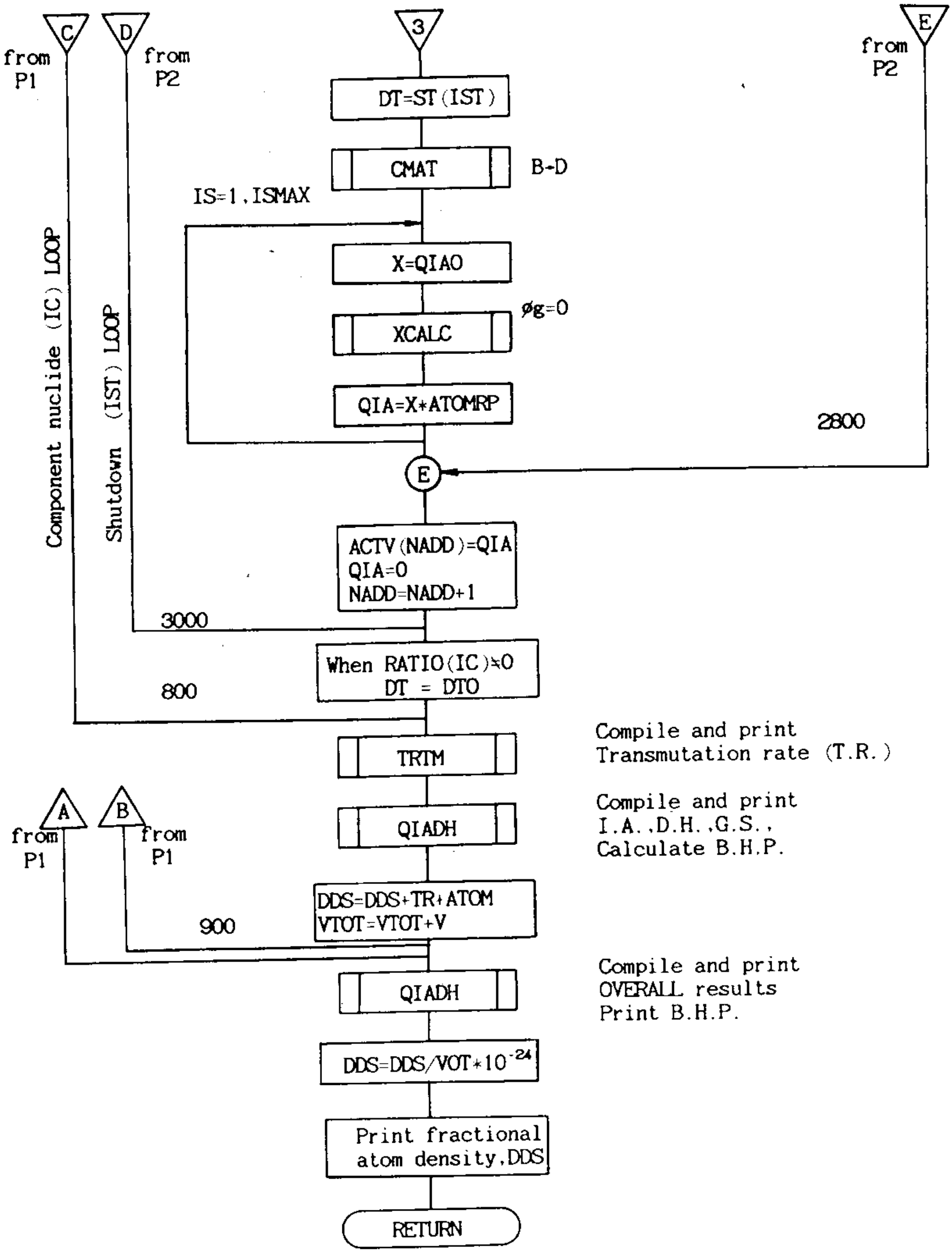


Fig. 3.3 Continued (P3).

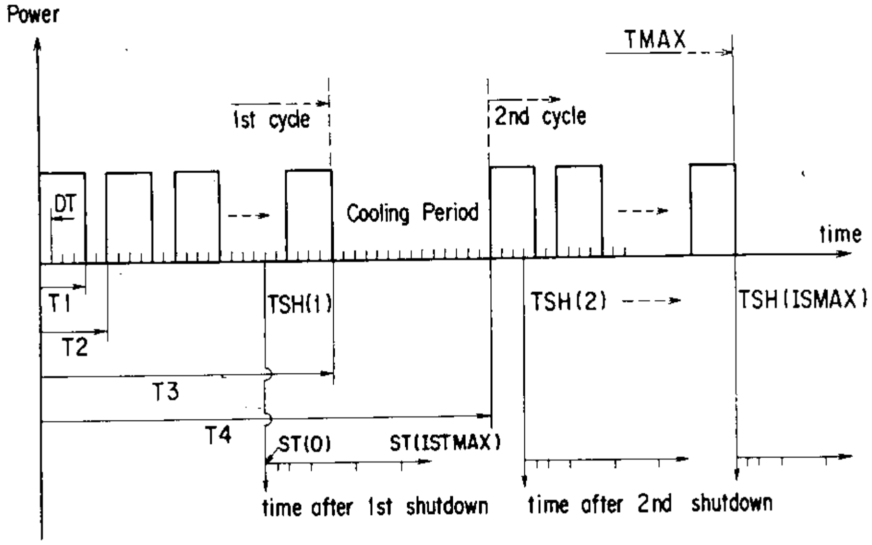


Fig. 3.4 Pulsed operation treated by ACT4.

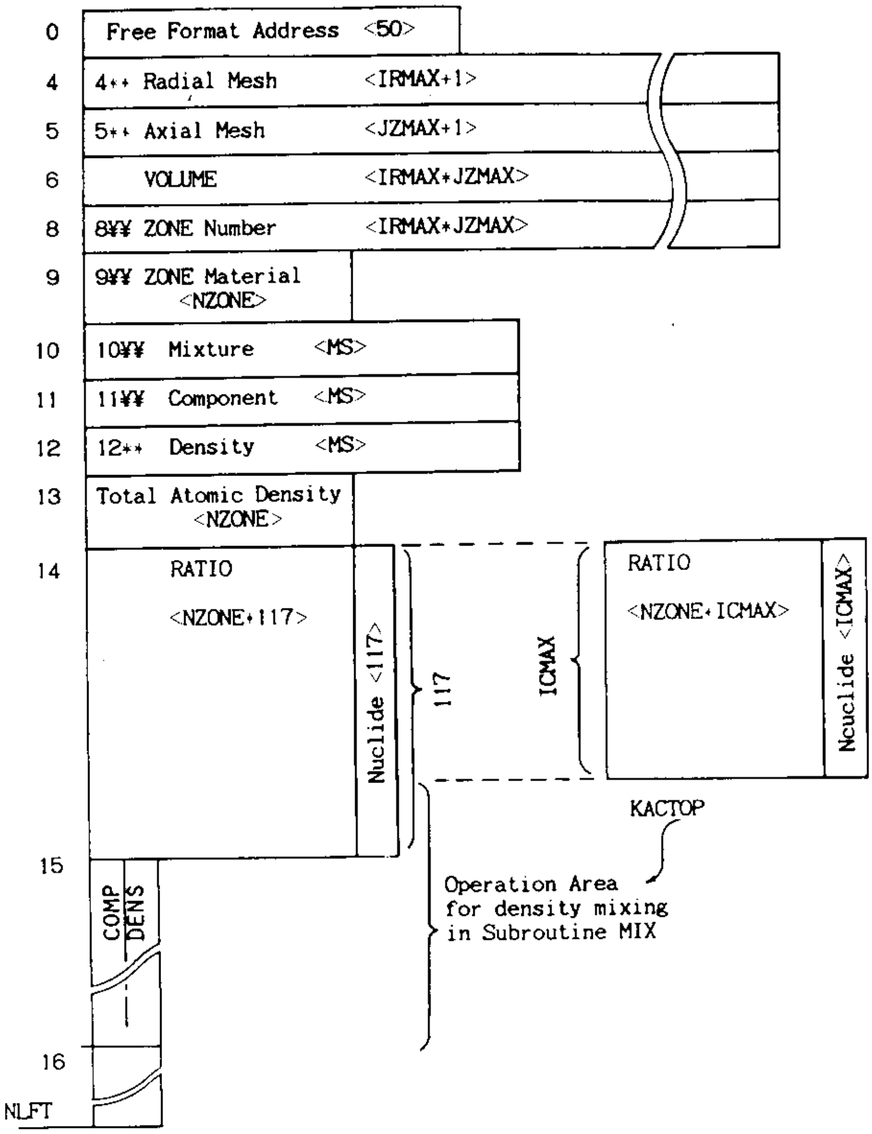


Fig. 3.5 Location structure of the variable common.

4. Calculational Procedure of THIDA-2

As described in Section 2.1, the THIDA-2 code system has been made up by sequentially coupling a neutron transport calculation code, an induced activity calculation code, a gamma-ray transport calculation code and a response calculation and plotting code. In this chapter the coupling method of the four codes are described for the cases of one-, two- and three-dimensional activation calculations using the radiation transport codes, ANISN$^{9)}$, DOT-3.5$^{10)}$ and MORSE-GG$^{11)}$, respectively.

4.1 One-Dimensional Problem

The calculational flow for obtaining the dose rate during shutdown using a one-dimensional model is shown in **Fig. 4.1**. The ANISN code$^{9)}$ is used to calculate the neutron flux during the reactor operation and gamma-ray flux during shutdown. The required procedures to achieve the coupling of the codes (namely, transfer of relevant data) in **Fig. 4.1** are described stepwise. The normalization is performed as follows. In the neutron flux calculation by ANISN, the normalization factor XNF = 1.0 is employed. The conversion to absolute value is done by the factor PPFLUX used in the ACT4. In the delayed gamma-ray calculation, XNF = 0.0 is fixed so as not to renormalize the absolute gamma-ray source.

(1) Neutron flux calculation by ANISN

In the neutron flux calculation using the ANISN code$^{9)}$, the 42-group neutron cross sections in the GICX40 library$^{14)}$ must be used.

A single change in the input data is necessary. Namely, the 25th item of the 15¥¥ data ID1 should be changed to -3. When ID1 is -3, the relevant data and calculated neutron flux are written on the file FT10 in the following record format:

Record 1

IGM ; number of energy groups
IM ; number of spatial mesh intervals
IZM ; number of zones
IGE ; number of geometry type specification

1-slab; 2-cylinder; 3-sphere

Record 2

RA [IM + 1] ; interval boundaries
MA [IM] ; zone numbers by interval
V [IM] ; volumes by interval

Record 3

(XN(J,I),J = 1,IM) ; scalar flux repeating IGM times

The FINPR subroutine of the ANISN code[9)] must be replaced with the modified one for the data transmission. The modification of the FINPR subroutine is listed in **Fig. 4.2**.

(2) Induced activity calculation by ACT4

In the calculation of induced activity and delayed gamma-ray source using the ACT4 code, the neutron flux calculated by ANISN and three data libraries are necessary as the input. As the output, delayed gamma-ray source is written on the file FT17 in the following record format:

Record 1 (A3, 77X)
'17*'

Record 2 (6E12.3) Delayed gamma-ray source at shutdown
((GS(IR,IG), IR = 1, IRMAX), IG =1, IGMAX)
where, IRMAX and IGMAX are the maximum numbers for spatial mesh and energy group, respectively.

Record 3 (A3, 77X)
' T' : terminate

(3) Gamma-ray flux calculation by ANISN

The gamma-ray source is supplied from the file FT17 as the 17* data. The subroutine FIDAS in the ANISN code is modified to read 17* data from the file FT17. The modified portion of the FIDAS subroutine is listed in **Fig. 4.3**. The normalization factor XNF should be zero so as not to renormalize the absolute gamma-ray source obtained by the ACT4 calculation.

The 54-group gamma-ray cross section library GROUPIN which extends up to 3 MeV should be used for usual problem (see Section

2.4). If delayed gamma-rays of up to 7.6 MeV are to be treated, the 78-group cross section library should be used.

The transmission of the calculated gamma-ray flux and other relevant data can be done in the similar manner as in the case of neutron flux described above. The modified FINPR subroutine in **Fig. 4.2** is used again.

(4) Dose rate calculation and plotting by APPLE-2[13)]

Using the calculated gamma-ray flux and the flux-to-dose conversion factor GFLXDOSE (described in Section 2.5) the dose rate distribution is calculated and plotted by the APPLE-2 code[13)].

4.2 Two-Dimensional Problem

The procedure to obtain the dose rate from the induced activity in the two-dimensional geometry is described. A two-dimensional discrete ordinates radiation transport code DOT-3.5[10)] is used for the two-dimensional problem. The calculational flow chart for this case is shown in **Fig. 4.4**.

(1) Neutron flux calculation by DOT-3.5

In the DOT-3.5 calculation, the 42-group neutron cross sections in the GICX40 library[14)] must be used. The DOT-3.5 requires the area for the mixture cross sections to be allocated in the group-organized cross section library[10)]. Therefore, a small mixture editing program shown in **Fig. 4.5** is run before the DOT-3.5 calculations to convert the GICX40 to the compatible form. The newly edited library is denoted as GICX40' in **Fig. 4.4**.

The input data required for this editing code are the following three:

MS, IOR and IGM in the format of (3I3).

MS ; number of mixtures to be used in the DOT-3.5 calculation

IOR; order of scattering. IOR may be reduced from 5 used in the GICX40 library

IGM; number of neutron energy groups [42]

As in the one-dimensional case described in Section 4.1, the neutron flux calculated by the DOT-3.5 and relevant data are transmitted to the ACT4 code or the APPLE-2 code. Those data are written on the file number, NFLSV (usually FT09F001) specified in DOT-

3.5 in the following format:

Record 1

IGM ; number of energy groups
IM ; number of radial mesh intervals
JM ; number of axial mesh intervals
IZM ; number of zones
IGE ; number of geometry type specification
0 / 1/ 2 = R-Z /X-Y / R-THETA

Record 2

RA [IM + 1] ; radial interval boundaries
ZA [JM + 1] ; axial interval boundaries
MA [IM * JM]; zone numbers by interval
V [IM * JM]; volumes by interval

Record 3

((XN(I,J),I = 1,IM), J = 1,JM) ; scalar flux repeating IGM times

The OUTER, TPSAVE and TPXF subroutines of the DOT-3.5 must be replaced with modified ones for the data transmission. The modifications of these subroutines are listed in **Fig. 4.6**.

(2) Induced activity calculation of ACT4

The option parameter for geometry IGEOM used in the ACT4 is equivalent to IGE in DOT-3.5.

It should be noted that the computation time (time on central processing unit, CPU time) for the ACT4 calculation is nearly proportional to the number of mesh points at which induced activity is calculated. The CPU time is also nearly proportional to the number of component nuclides (ICMAX) for which induced activity is calculated and to the number of time steps (ITMAX) to be calculated. (The CPU time for sample problems are given in **Table 5.2**). Since the ACT4 code does not have the restart capability, careful estimation of the CPU time is requested prior to the calculation of a job with a large mesh number.

The delayed gamma-ray source is written in the following binary format which can be read by the DOT-3.5 code:

((GS(IR,JZ,IG), IR=1, IRMAX) JZ=1, JZMAX) repeating IGMAX times.

(3) Gamma-ray flux calculation by DOT-3.5

The group-organized cross section library including the area for the mixture cross sections is processed from the GROUPIN library in the same manner as for the neutron flux calculation.

The delayed gamma-ray source is read in from the file NBSO (usually FT14F001) when the source input option M06 = 6 is specified. As in the one-dimensional case, the normalization factor is fixed as XNF = 0.0 so as not to renormalize the absolute gamma-ray source obtained in the ACT4 calculation.

The calculated gamma-ray flux and relevant data are written on the file NFLSV in the same manner as the neutron flux described in (1).

(4) Dose rate calculation and plotting by APPLE-2[13)]

By applying the flux-to-dose coversion factor GFLXDOSE on the gamma-ray flux calculated by the DOT-3.5, the dose rate of the delayed gamma-ray is calculated. The contour map of the dose rate in two-dimensional geometry may be plotted (see **Fig. 5.4** where contours are shown by straight lines for an example).

4.3 Three-Dimensional Problem

A three-dimensional Monte Carlo radiation transport code MORSE-GG[11)] is used to obtain the delayed gamma-ray dose in three-dimensional geometry. The procedure of data transmission between the codes and calculation of gamma-ray source generation is described in this section.

(1) Production of macroscopic cross sections

The group-organized cross sections cannot be used in the MORSE calculation. On the other hand, we are required to perform calculation in which the energy group number is 42 for neutron and 54 for delayed gamma-rays. These two conditions tend to increase the memory required in the MORSE calculation. To reduce the required memory, the macroscopic cross sections of the mixtures to be used are processed in the material-wise format. Although this process may be achieved by the use of the code like the AXMIX[22)], the procedure shown in **Fig. 4.7** using the ANISN code is employed. The reasons are; 1) the AXMIX code was not available for use in the Japan Atomic Energy

Research Institute and 2) it is convenient to know a preliminary estimate of dose rate values by the one-dimensional calculation well before obtaining the accurate result by three-dimensional calculation which usually takes a long time.

The calculational flow in **Fig. 4.7** is similar to the one in **Fig. 4.1** except for the output of the macroscopic cross sections of mixtures. Therefore the procedure described in Section 4.1 can be used for obtaining the macroscopic cross sections in 42-group for neutrons and 54-group for delayed gamma rays.

(2) Calculational flow for a three-dimensional problem

The calculational flow for a three-dimensional problem is shown in **Fig. 4.8** . Except for the use of the macroscopic cross-sections in place of the microscopic cross-section libraries, the calculational flow looks similar to the one- or two-dimensional case in **Fig. 4.1** and **Fig. 4.4** , respectively.

In the discrete ordinates transport codes like the ANISN and the DOT-3.5, the neutron flux for each spatial mesh point could be calculated. In the case of Monte Carlo code like the MORSE-GG, the neutron or gamma-ray flux is calculated in each region using track length estimators or at certain specified points using point detectors. The volumes of the regions are usually larger than those for mesh points due mainly to computational limitations.

Another restriction in the Monte Carlo calculations is that it is difficult to obtain the neutron or gamma-ray flux with small statistical errors at the regions well shielded from the source.

These factors must be fully taken into account in dividing the actual geometry into regions.

(3) Neutron flux calculation using MORSE-GG$^{11)}$

Using the 42-group neutron cross sections for the mixtures, the neutron flux in the regions is calculated by the MORSE-GG code$^{11)}$. The TOPIC code$^{23)}$ is useful in preparing the geometrical data and also in providing the visual image of the geometry (see **Figs. 5.2** and **5.3** for examples). It can also calculate the volumes of the regions.

The neutron flux in the regions is calculated using the track length estimator method. Point detectors should not be used because the detector number should be equal to the number of regions. The neutron flux and the relevant data are written on the file FT10 in the following record format:

Record 1

NNE ; number of energy groups of the primary particle
NE ; number of total energy group
ND ; number of detector regions

Record 2

EFIRST ; upper bound energy of the primary particle
EGTOP ; upper bound energy of the secondary particle
(ENE(IE), IE = 1, NE) ; boundary energies
(VOL(I), I = 1, MXREG) ; volumes of the regions

Record 3

(FNE(IE, ID), IE = 1, NE) ; neutron flux
(FSD(IE, ID), IE = 1, NE) ; fractional standard deviation of flux

The record 3 is repeated ND (number of detector regions) times

The NRUN subroutine in the MORSE-GG code must be replaced by a modified version for the data transmission. The modified portion of the NRUN subroutine is listed in **Fig. 4.9**.

(4) Induced activity calculation by ACT4

Geometry option parameter IGEOM should be 7. Neutron flux and volume of regions are read in from the file (FT04F001) by the subroutines FILEFX and ACTIN1 of the ACT4 code, respectively. For the specification of the material numbers for the regions (8¥¥ data), the media numbers specified in the MORSE-GG calculation should be used.

The delayed gamma-ray source output is written on the file FT17 in the following record format:

((GS(IR,J), J = 1, IGMAX), IR = 1, IRMAX) where
IGMAX : delayed gamma-ray energy group number [54]
IRMAX : total region number

(5) Gamma-ray flux and dose rate calculation by MORSE-GG

Some explanations are necessary for generating procedure of the 54-group source gamma-rays so that it will be described in detail below. Once the source gamma rays are generated, the gamma-ray flux can be calculated in the usual manner using MORSE-GG and the point detectors may be used if desired. The dose rate due to gamma rays can be obtained by simply giving the flux-to-dose conversion factor as a response function in the MORSE-GG calculation.

(6) Generation of source gamma rays

Source gamma rays during shutdown are generated using the gamma-ray source data for each region calculated by ACT4. the following assumptions are made:

a) Gamma rays are generated uniformly over a region volume.
b) Gamma rays are emitted isotropically.

The first assumption necessitates the division of the actual geometry into relatively small regions to improve accuracy. However, too small regions will cause difficulty in reducing the statistical error of the neutron flux and dose rate in the region.

The source gamma-ray generation process is described here: (For completeness in description, the listings of the modified subroutines, INSCOR, MOSRAD, MSOUR and SOINP are given in Appendix A.2)

i) Reading in and processing gamma-ray source (Subroutine INSCOR)

A cumulative probability distribution of the region integrated gamma-ray source,

$$GS(r) = \sum_{g=1}^{G} GS(g,r)$$

is produced to be used for the determination of the region number in which a gamma-ray is generated. A normalized cumulative distribution is schematically shown in **Fig. 4.10**.

A cumulative probability distribution of the gamma-ray source spectrum is produced for each region to determine the energy group of the gamma-ray generation. An example is shown in **Fig. 4.11**.

ii) Determination of the source generation positions (X,Y,Z) (Subroutine MSOUR, SOINP)

To generate source gamma rays uniformly from each region, candidate positions of the generation are selected uniformly from the source generation volume containing the regions. This source generation volume should be of simple shape (e.g. rectangular parallelepiped, sphere, cylinder) so as to allow uniform generation of the candidate positions by a simple procedure. Although a source generation volume with the shape of a rectangular parallelepiped is provided in the MSOUR subroutine, the users should replace it with a source volume with more appropriate shape for each problem to increase the efficiency of the calculation.

On the other hand, the number of source gamma rays to be generated per batch for each region should be determined using the cumulative probability distribution shown in **Fig. 4.10**. These number allocated for the regions should be stored in the working area NITS (MXREG).

Once candidate positions (X,Y,Z) for the source generation are selected uniformly from the source volume, the subroutine LOOKZ is called to identify the region numbers in which the positions (X,Y,Z) are located.

If there is a storage area remaining in the region, the positions (X,Y,Z) are stored in that area. If the storage area for the region is full, the position is rejected and another position is selected from the source volume. These processes are repeated until all the storage areas for the regions are filled by the number of particle histories per batch NMEM.

When the required number of generation positions (X,Y,Z) for a region are not found after a specified number of trials, the previously found position (X,Y,Z) is used repeatedly to fill the storage area for the region. If there is no previously found position (X,Y,Z) for the region, a collision point in that region will be used as a substitute.

If the storage areas for the regions still cannot be filled by the NMEM source particles after these procedures, an error message is given out and the computation is terminated. The problem must be run again with the increased volume for the regions where the source particles could not be filled or with the reduction of the source generation volume.

iii) Determination of the direction of emission

Direction cosines (U,V,W) are determined as an isotropic emission.

iv) Determination of energy group (IG)

The energy group of a source gamma rays generated in a region is determined with the use of a cumulative probability distribution of the gamma-ray source spectrum for the region as shown in **Fig. 4.11**.

v) Initial weight (WATE) and normalization

The source gamma rays are all generated with the initial weight of 1.0. The calculated gamma-ray dose rate is normalized to a unit generation rate of gamma-ray source. Therefore, the total source intensity, namely the integration over the whole energy range and regions, should be multiplied to obtain the absolute value. The total source intensity is determined in the process of obtaining the cumulative probability distribution of source gamma-ray (see **Fig. 4.10**).

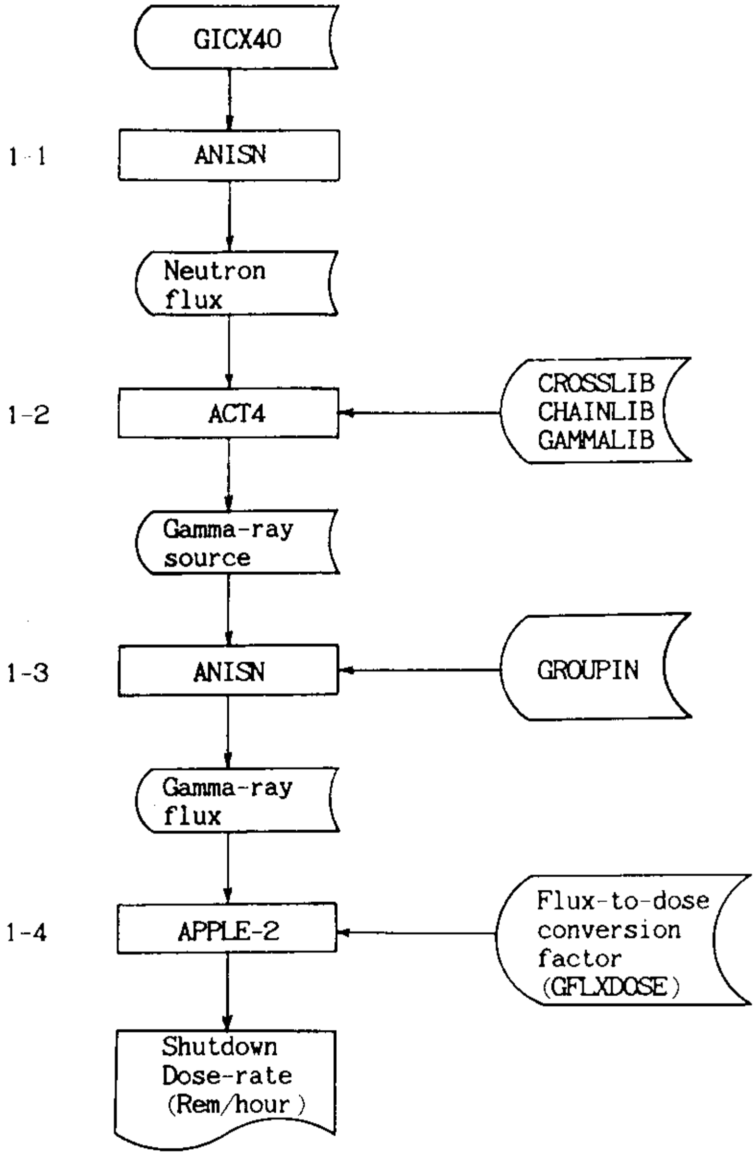


Fig. 4.1 Calculational flow for a one dimensional problem.

```
      IF(IGMNEW.NE.IGMNEU.AND.JJ1.EQ.1) GO TO 800                       ANS27741
      IF(IDAT1.NE.0)REWIND NT3                                          ANS27640
      IF(IDAT1.EQ.2)REWIND NT1                                          ANS27650
      IF(NACTPR.EQ.1) CALL ACTPRT(XNXNXN(1),XNXNXN(NXADRS),IM,IGM,ID3,  ANS27742
     *          IZP,IIG,J,I,KK,E2,E3,T3,1)                              ANS27743
      IF(ID4.GE.0)GO TO 1                                               ANS27750
      DO 42 I=1,ID3                                                     ANS27760
   42 CALL PUNSH(T3(1,I),IM)                                            ANS27770
    1 CONTINUE
      IF(IDAT1.EQ.2)GO TO 26                                            ANS27790
      IF(ID1.LT.2)GO TO 18                                              ANS27800
      DO 43 I=1,IGM                                                     ANS27810
   43 CALL PUNSH(XN(1,I),IM)                                            ANS27820
  160 FORMAT(12A4,8X/1X,2H3*,69X,4HFLUX,3X,1HO)                         ANS27830
   18   IF(ID1.GT.-2) GO TO 110
      NFX=10
      REWIND NFX
      IF(ID1.EQ.-2)   GO  TO  104
      WRITE(NFX) IGM,IM,IZM,IGE
  104 CONTINUE                                            inserted portion
      WRITE(NFX) (RA(I),I=1,IP),(MA(I),I=1,IM),(V(I),I=1,IM)
      DO 105 I=1,IGM
  105 WRITE(NFX) (XN(J,I),J=1,IM)
      WRITE(6,600) IGM,IM,NFX
      REWIND NFX
C  18 WRITE (NOU,170) T                                                 ANS27840←deleted
  110 WRITE (NOU,170) T
C    *** PRINT FLUX IF IN CORE                                          ANS27850
      WRITE (NOU,60)                                                    ANS27860
   60 FORMAT(12HO TOTAL FLUX)                                           ANS27870
      IF(IIBOUD.EQ.1)   REWIND  20                                      ANS27871
C     IF(IIBOUD.EQ.1) CALL NWSUB4(D(LXND),IP,MM,XNXNXN,IGM,NT4)         ANS27872
      IF(IIBOUD.EQ.1) CALL NWSUB4(D(LXND),IP,MM,XNXNXN,IGM,NT4,D(LW))
      IF(IIBOUD.NE.1)   GO TO 3333                                      ANS27873
      REWIND 20                                                         ANS27874
      CALL  NWSUB1(XNXNXN,IP,IGM)                                       ANS27875
      GO TO 3334                                                        ANS27876
 3333 CONTINUE                                                          ANS27877
      CALL WOT(XN,IGM,IM,1,'INT.','GRP.',0)                             ANS27880
 3334 CONTINUE                                                          ANS27881
      IF(IISPTM.EQ.1)     CALL  NWSUB2(XN,IP,IGM,IM,XNXNXN)             ANS27882
      CALL  WOTYT(XN,IGM,IM,1,IGMNEU)                                   ANS27883
      CALL  WOTYT(XN,IGM,IM,IGMNEU+1,IGM)                               ANS27884
   19 IF(IDAT1.EQ.1)GO TO 22                                            ANS27890
C    *** PRINT DIST. SOURCE IF ANY AND IN CORE                          ANS27900
      IF(IQM.EQ.0)GO TO 23                                              ANS27910
      WRITE (NOU,170) T                                                 ANS27920
      WRITE (NOU,70)                                                    ANS27930
   70 FORMAT(20HO DISTRIBUTED SOURCE)                                   ANS27940
      CALL WOT(Q,IGM,IM,1,'INT.','GRP.',0)                              ANS27950
      GO TO 24                                                          ANS27960
C    *** PRINT SHELL SOURCE IF ANY AND IN CORE                          ANS27970
   23 IF(IPM.EQ.0)GO TO 24                                              ANS27980
      WRITE (NOU,170) T                                                 ANS27990
      IF(IPM.GT.1)GO TO 25                                              ANS28000
      WRITE (NOU,80) IPP                                                ANS28010
   80 FORMAT(27HO SHELL SOURCE IN INTERVAL I3)                          ANS28020
      CALL WOT(PA,IGM,MM,1,'ANGL','GRP.',0)                             ANS28030
      GO TO  24                                                         ANS28040
   25 WRITE (NOU,90)                                                    ANS28050
   90 FORMAT(14HO SHELL SOURCE)                                         ANS28060
      CALL WOT(PA,IM,MM,IGM,'ANGL','INT.','GRP.')                       ANS28070
      GO TO 24                                                          ANS28080
   26 IF(ID1.GT.-2)   GO  TO  120
      NFX=10
      REWIND NFX
      IF(ID1.EQ.-2)   GO  TO  114
      WRITE(NFX) IGM,IM,IZM,IGE
  114 CONTINUE
      WRITE(NFX) (RA(I),I=1,IP),(MA(I),I=1,IM),(V(I),I=1,IM)
      DO 115 I=1,IGM
      READ (NT1) (X(J,1),J=1,IM)                          inserted portion
      WRITE(NFX) (X(J,1),J=1,IM)
      IF(ISCT.GT.0) READ (NT1)
  115 CONTINUE
      WRITE(6,600) IGM,IM,NFX
      REWIND NT1
      REWIND NFX
  600 FORMAT(1H1////,5X,'*** SCALAR FLUX (',I3,' GROUPS,',I4,
     1  ' INTERVALS ) WAS WRITTEN ON MT=',I3,' ***')
C  26 IO2=0                                                             ANS28090←deleted
  120 IO2=0
   29 IO1=MINO(IGM-IO2,8)                                               ANS28100
      WRITE (NOU,170) T                                                 ANS28110
      WRITE (NOU,140) IO2                                               ANS28120
  140 FORMAT(32HO TOTAL FLUX - G=GROUP NO.    N=I3)                     ANS28130
      DO 31 I=1,IO1                                                     ANS28140
      READ (NT1) (X(J,I),J=1,IM)                                        ANS28150
   31 IF(ISCT.GT.0)READ (NT1)                                           ANS28160
      CALL WOT(X,IO1,IM,1,'INT.','G=N*',0)                              ANS28170
      IO3=IO1*IM                                                        ANS28180
```

Fig. 4.2 Modification of Subroutine FINPR of the ANISN code for the data transmission to ACT4 and APPLE-2.

```
      IF(K(I).EQ.LLI)GO TO 42                                           FID00560
      IF(K(I).EQ.LKI)GO TO 46                                           FID00570
      IF(K(I).EQ.LO)GO TO 55                                            FID00580
      IF(K(I).EQ.LC)GO TO 56                                            FID00590
      IF (K(I) .EQ. LSLS)  GO TO 13                                     FID00600
      GO TO 14                                                          FID00610
C    *** TERMINATE (T)                                                  FID00620
    9 J2=0                                                              FID00630
      ITEST=IN(I)                                                       FID00640
      IF(J.EQ.0)GO TO 16                                                FID00650
      GO TO 12                                                          FID00660
C    *** VARIABLE FORMAT CONTROL (U,V)                                  FID00670
   33 READ(N5,80)VMT                                                    FID00680
   34 IVMT=1                                                            FID00690
C    *** BEGIN NEW ARRAY (*,¥)                                          FID00700
    6 KKK=0                                                             FID00710
      IF(IN(I)-17) 13,99,13                                             FID00711
   99 N5=17                                                             FID00712
      GO TO 13                                                          FID00720
    5 KKK=1                                                             FID00730
   13 IF(NCOUNT+J .EQ. 0)GO TO 15                                       FID00740
      J2=1                                                              FID00750
   12 WRITE (N6,20) LL,LB,J                                             FID00760
      IF(J.EQ.NCOUNT)GO TO 16                                           FID00770
      IMAX=J1 + J - 1                                                   FID00780
      IF(J.GT.10000) IMAX = J + 99                                      FID00790
      FMT(2)=E1                                                         FID00800
      FMT(3)=E2                                                         FID00810
      IF(KK.NE.1)GO TO 22                        these cards are inserted  FID00820
      FMT(2)=E3                                                         FID00830
      FMT(3)=E4                                                         FID00840
   22 WRITE (N6,FMT) (D(II),II=J1,IMAX)                                 FID00850
      J3=J3 + 1                                                         FID00860
      WRITE (N6,30) NCOUNT,LL,LB                                        FID00870
   16 IF(J2.NE.0)GO TO 15                                               FID00880
      WRITE(N6,50)IN(I),LT                                              FID00890
       N5=5                                                             FID00891
  999 RETURN                                                            FID00900
   15 IF (K(I) .EQ. LSLS)  GO TO 935                                    FID00910
  915 LL=IN(I)                                                          FID00920
      LL3=LL + LL2 - 1                                                  FID00930
      KK=KKK                                                            FID00940
      LB=K(I)                                                           FID00950
      J=V(I)                                                            FID00960
      IF ( LLJ.NE.0 ) GO TO 412                                         FID00970
      IF(LL.GT.60) GO TO 411                                            FID00980
      J1=LDTK(LL3) + J                                                  FID00990
      NCOUNT=LDTK(LL3+1) - J1                                           FID01000
      GO TO 41                                                          FID01010
  411 LL3 = LL3 - 60                                                    FID01020
  412 J1 = LDAI(LL3    ) + J                                            FID01030
      NCOUNT = LDAI(LL3+ 1) - J1                                        FID01040
   41 J=0                                                               FID01050
      IF(IVMT.EQ.0)GO TO 2                                              FID01060
C    *** VARIABLE FORMAT CONTROL (U,V)                                  FID01070
   32 IF(NCOUNT.EQ.0)GO TO 1                                            FID01080
      J=NCOUNT                                                          FID01090
      NCC=J1 + NCOUNT - 1                                               FID01100
```

Fig. 4.3 Modification of Subroutine FIDAS for reading gamma-ray source.

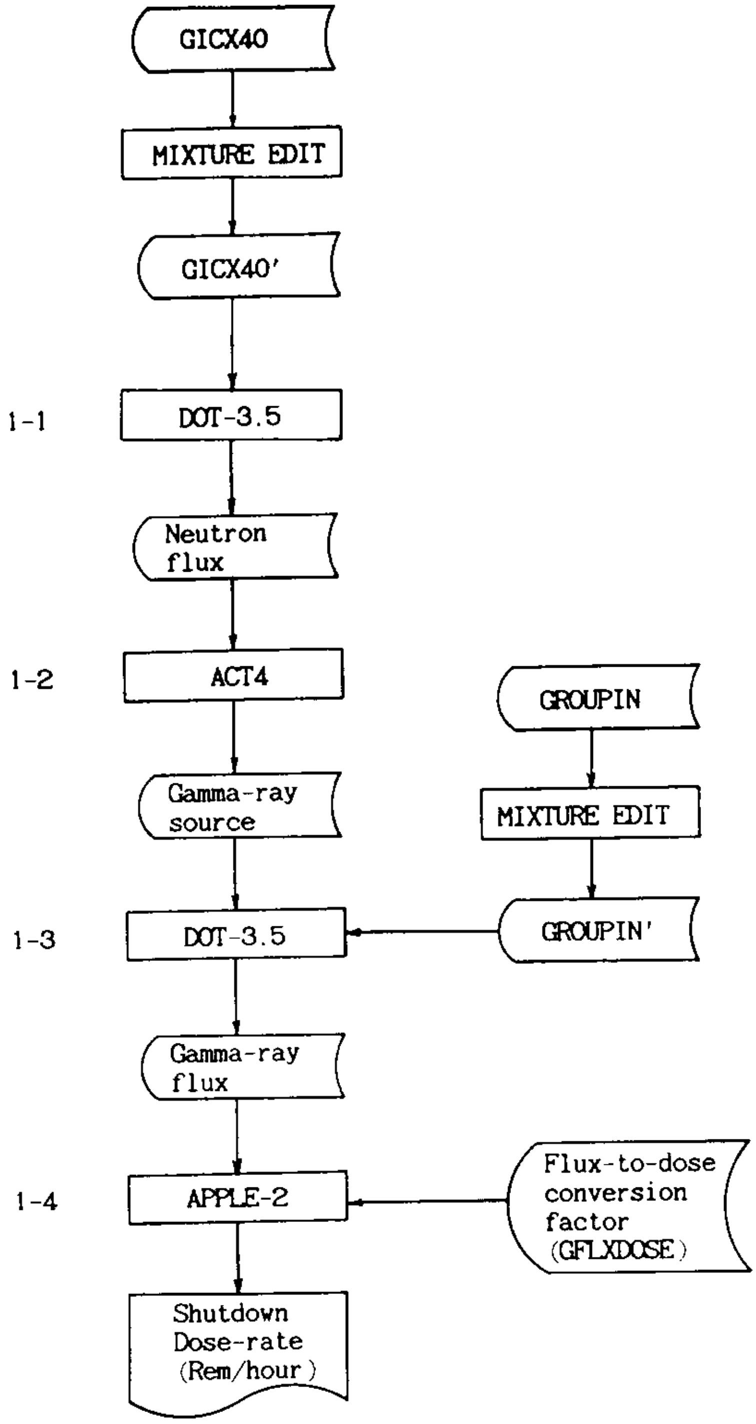
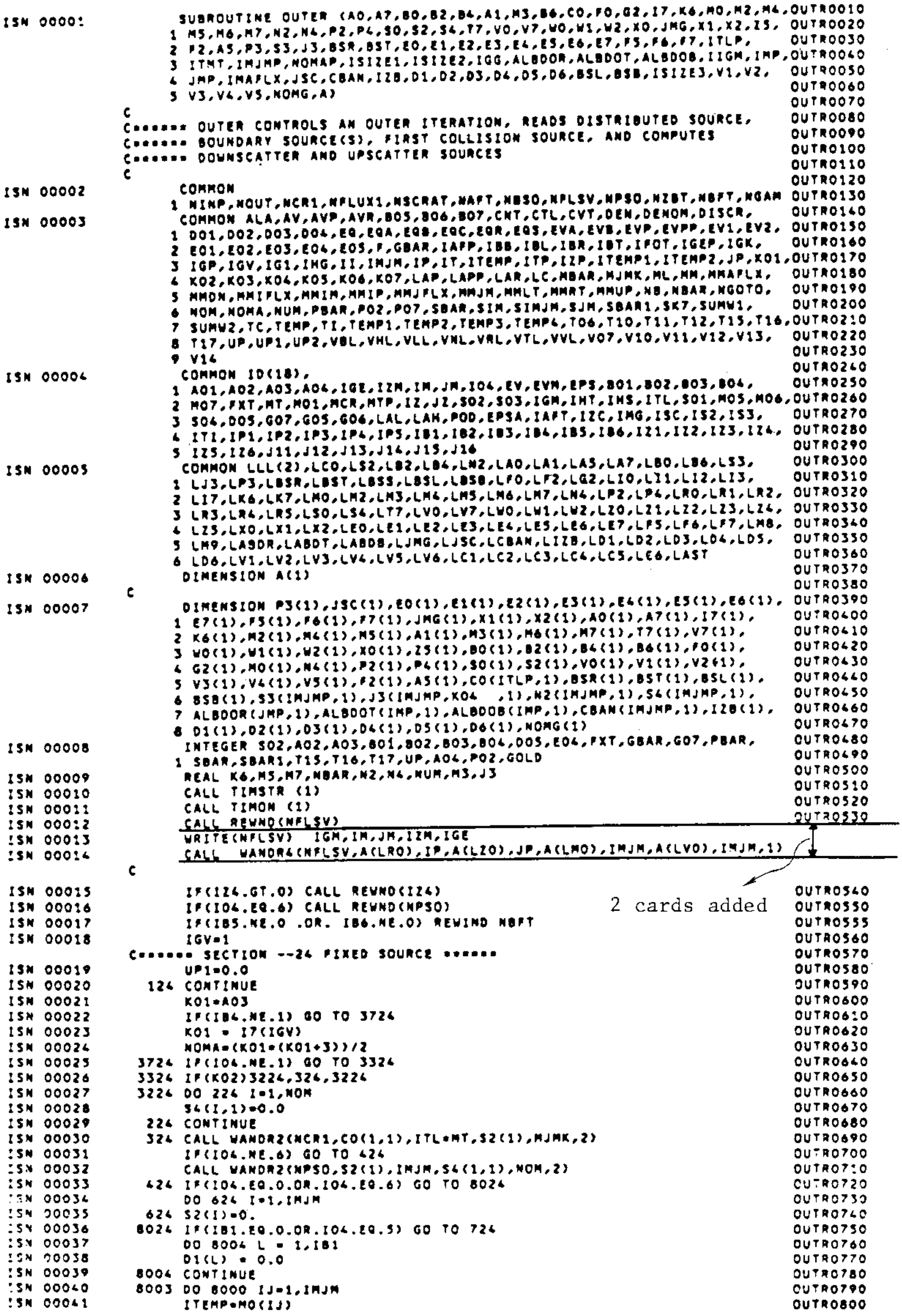


Fig. 4.4 Calculational flow for a two dimensional problem.

```
C ***  GICX40 EDIT FOR READ IN DOT 3.5
C **
      DIMENSION  C(67,300)
      MTMAX  = 300
      IHMAX  = 67
      LGM    = 63
      MT     = 40
      LOR    = 5
      LORP   = LOR + 1
      READ(5,1000)  MS,IOR,IGM
 1000 FORMAT(3I3)
      IF(IOR.EQ.0)  IOR = LOR
      IF(IGM.EQ.0)  IGM = LGM
      IHM    = IGM + 4
      IORP   = IOR + 1
      WRITE(6,2000) LGM,IGM,MT   ,LOR,IOR, MS
 2000 FORMAT(1H1,'*** GICX40 EDIT FOR READ IN  DOT 3.5*****'/
     1      ,1H0,25X,'ORIGINAL FILE DATA SIZE     NEW FILE DATA SIZE'/
     2      ,5X,'NUMBER OF GROUPS   ', I5,' --------->',I5/
     2      ,5X,'NUMBER OF MATERIAL ', I5,' --------->',4X,1H*/
     2      ,5X,'NUMBER OF P-N      ', I5,' --------->',I5/
     2      ,5X,'NUMBER OF MIXURE   ',4X,1H*,' --------->',I5)
      IF(IGM.GT.LGM)                      GO  TO  900
      IF(IOR.GT.LOR)                      GO  TO  900
      MT1    = MT*IORP + 1
      MT2    = MT1 + MS*IORP - 1
      IF(MT2.GT.MTMAX)                    GO  TO  900
C
      DO  20  I=1,IGM
      DO  30  M1=1,MT
      DO  30  M2=1,LORP
      IF(M2.LE.IORP)   GO  TO  33
      READ(1)
      GO  TO  30
   33 M=(IORP*(M1-1)) + M2
      READ(1)  (C(IH,M),IH=1,IHM)
   30 CONTINUE
      DO  40  M=MT1,MT2
      DO  40  IH=1,IHM
      C(IH,M)=0.0
   40 CONTINUE
      WRITE(2)  ((C(IH,M),IH=1,IHM),M=1,MT2)
   20 CONTINUE
      STOP
C **   ERROR MESAGE
  900 CONTINUE
      WRITE(6,9000)
 9000 FORMAT(1H0,'**** DIMENSION OVER ****  JOB STOPPED.')
      STOP
      END
```

Fig. 4.5 Mixture editing program for the DOT-3.5 calculation using group-organized cross sections.



```
ISN 00001          SUBROUTINE OUTER (A0,A7,B0,B2,B4,A1,M3,B6,C0,F0,G2,I7,K6,M0,M2,M4,OUTR0010
                 1 M5,M6,M7,N2,N4,P2,P4,S0,S2,S4,T7,V0,V7,W0,W1,W2,X0,JMG,X1,X2,Z5, OUTR0020
                 2 F2,A5,P3,S3,J3,BSR,BST,E0,E1,E2,E3,E4,E5,E6,E7,F5,F6,F7,ITLP,    OUTR0030
                 3 ITMT,IMJMP,NOMAP,ISIZE1,ISIZE2,IGG,ALBDOR,ALBDOT,ALBDOB,IIGM,IMP,OUTR0040
                 4 JMP,IMAFLX,JSC,CBAN,IZB,D1,D2,D3,D4,D5,D6,BSL,BSB,ISIZE3,V1,V2,  OUTR0050
                 5 V3,V4,V5,NOMG,A)                                                 OUTR0060
                                                                                    OUTR0070
             C                                                                      OUTR0080
             C****** OUTER CONTROLS AN OUTER ITERATION, READS DISTRIBUTED SOURCE,   OUTR0090
             C****** BOUNDARY SOURCE(S), FIRST COLLISION SOURCE, AND COMPUTES       OUTR0100
             C****** DOWNSCATTER AND UPSCATTER SOURCES                              OUTR0110
             C                                                                      OUTR0120
ISN 00002          COMMON
                 1 NINP,NOUT,NCR1,NFLUX1,NSCRAT,NAFT,NBSO,NPLSV,NPSO,NZBT,NBFT,NGAM OUTR0130
ISN 00003          COMMON ALA,AV,AVP,AVR,B05,B06,B07,CNT,CTL,CVT,DEN,DENOM,DISCR,   OUTR0140
                 1 D01,D02,D03,D04,EQ,EQA,EQB,EQC,EQR,EQS,EVA,EVB,EVP,EVPP,EV1,EV2, OUTR0150
                 2 E01,E02,E03,E04,E05,F,GBAR,IAFP,IBB,IBL,IBR,IBT,IFOT,IGEP,IGK,   OUTR0160
                 3 IGP,IGV,IG1,IMG,II,IMJM,IP,IT,ITEMP,ITP,IZP,ITEMP1,ITEMP2,JP,K01,OUTR0170
                 4 K02,K03,K04,K05,K06,K07,LAP,LAPP,LAR,LC,MBAR,MJMK,ML,MM,MMAFLX,  OUTR0180
                 5 MMDN,MMIFLX,MMIM,MMIP,MMJFLX,MMJM,MMLT,MMRT,MMUP,NB,NBAR,NGOTO,  OUTR0190
                 6 NOM,NOMA,NUM,PBAR,P02,P07,SBAR,SIM,SIMJM,SJM,SBAR1,SK7,SUMW1,    OUTR0200
                 7 SUMW2,TC,TEMP,TI,TEMP1,TEMP2,TEMP3,TEMP4,T06,T10,T11,T12,T15,T16,OUTR0210
                 8 T17,UP,UP1,UP2,VBL,VHL,VLL,VNL,VRL,VTL,VVL,V07,V10,V11,V12,V13,  OUTR0220
                 9 V14                                                              OUTR0230
                                                                                    OUTR0240
ISN 00004          COMMON ID(18),                                                   OUTR0250
                 1 A01,A02,A03,A04,IGE,IZM,IM,JM,I04,EV,EVM,EPS,B01,B02,B03,B04,    OUTR0260
                 2 M07,FXT,MT,M01,MCR,MTP,IZ,JZ,S02,S03,IGM,IHT,IHS,ITL,S01,M05,M06,OUTR0270
                 3 S04,D05,G07,G05,G06,LAL,LAH,POD,EPSA,IAFT,IZC,IMG,ISC,IS2,IS3,   OUTR0280
                 4 IT1,IP1,IP2,IP3,IP4,IP5,IB1,IB2,IB3,IB4,IB5,IB6,IZ1,IZ2,IZ3,IZ4, OUTR0290
                 5 IZ5,IZ6,J11,J12,J13,J14,J15,J16
ISN 00005          COMMON LLL(2),LC0,LS2,LB2,LB4,LN2,LA0,LA1,LA5,LA7,LB0,LB6,LS3,   OUTR0300
                 1 LJ3,LP3,LBSR,LBST,LBSS,LBSL,LBSB,LF0,LF2,LG2,LI0,LI1,LI2,LI3,    OUTR0310
                 2 LI7,LK6,LK7,LM0,LM2,LM3,LM4,LM5,LM6,LM7,LN4,LP2,LP4,LR0,LR1,LR2, OUTR0320
                 3 LR3,LR4,LR5,LS0,LS4,LT7,LV0,LV7,LW0,LW1,LW2,LZ0,LZ1,LZ2,LZ3,LZ4, OUTR0330
                 4 LZ5,LX0,LX1,LX2,LE0,LE1,LE2,LE3,LE4,LE5,LE6,LE7,LF5,LF6,LF7,LM8, OUTR0340
                 5 LM9,LASDR,LABDT,LABDB,LJMG,LJSC,LCBAN,LIZB,LD1,LD2,LD3,LD4,LD5,  OUTR0350
                 6 LD6,LV1,LV2,LV3,LV4,LV5,LV6,LC1,LC2,LC3,LC4,LC5,LE6,LAST         OUTR0360
ISN 00006          DIMENSION A(1)                                                   OUTR0370
                                                                                    OUTR0380
             C
ISN 00007          DIMENSION P3(1),JSC(1),E0(1),E1(1),E2(1),E3(1),E4(1),E5(1),E6(1), OUTR0390
                 1 E7(1),F5(1),F6(1),F7(1),JMG(1),X1(1),X2(1),A0(1),A7(1),I7(1),    OUTR0400
                 2 K6(1),M2(1),M4(1),M5(1),A1(1),M3(1),M6(1),M7(1),T7(1),V7(1),     OUTR0410
                 3 W0(1),W1(1),W2(1),X0(1),Z5(1),B0(1),B2(1),B4(1),B6(1),F0(1),     OUTR0420
                 4 G2(1),M0(1),N4(1),P2(1),P4(1),S0(1),S2(1),V0(1),V1(1),V2(1),     OUTR0430
                 5 V3(1),V4(1),V5(1),F2(1),A5(1),C0(ITLP,1),BSR(1),BST(1),BSL(1),   OUTR0440
                 6 BSB(1),S3(IMJMP,1),J3(IMJMP,K04  ,1),N2(IMJMP,1),S4(IMJMP,1),    OUTR0450
                 7 ALBDOR(JMP,1),ALBDOT(IMP,1),ALBDOB(IMP,1),CBAN(IMJMP,1),IZB(1),  OUTR0460
                 8 D1(1),D2(1),D3(1),D4(1),D5(1),D6(1),NOMG(1)                      OUTR0470
ISN 00008          INTEGER S02,A02,A03,B01,B02,B03,B04,D05,E04,FXT,GBAR,G07,PBAR,   OUTR0480
                 1 SBAR,SBAR1,T15,T16,T17,UP,A04,P02,GOLD                           OUTR0490
ISN 00009          REAL K6,M5,M7,NBAR,N2,N4,NUM,M3,J3                               OUTR0500
ISN 00010          CALL TIMSTR (1)                                                  OUTR0510
ISN 00011          CALL TIMON (1)                                                   OUTR0520
ISN 00012          CALL REWND(NFLSV)                                                OUTR0530
ISN 00013          WRITE(NFLSV)  IGM,IM,JM,IZM,IGE
ISN 00014          CALL  WANDR4(NFLSV,A(LR0),IP,A(LZ0),JP,A(LM0),IMJM,A(LV0),IMJM,1)
             C
ISN 00015          IF(IZ4.GT.0) CALL REWND(IZ4)                                     OUTR0540
ISN 00016          IF(I04.EQ.6) CALL REWND(NPSO)                                    OUTR0550
ISN 00017          IF(IB5.NE.0 .OR. IB6.NE.0) REWIND NBFT                           OUTR0555
ISN 00018          IGV=1                                                            OUTR0560
             C****** SECTION --24 FIXED SOURCE ******                               OUTR0570
ISN 00019          UP1=0.0                                                          OUTR0580
ISN 00020      124 CONTINUE                                                         OUTR0590
ISN 00021          K01=A03                                                          OUTR0600
ISN 00022          IF(IB4.NE.1) GO TO 3724                                          OUTR0610
ISN 00023          K01 = I7(IGV)                                                    OUTR0620
ISN 00024          NOMA=(K01*(K01+3))/2                                             OUTR0630
ISN 00025     3724 IF(I04.NE.1) GO TO 3324                                          OUTR0640
ISN 00026     3324 IF(K02)3224,324,3224                                             OUTR0650
ISN 00027     3224 DO 224 I=1,NOM                                                   OUTR0660
ISN 00028          S4(I,1)=0.0                                                      OUTR0670
ISN 00029      224 CONTINUE                                                         OUTR0680
ISN 00030      324 CALL WANDR2(NCR1,C0(1,1),ITL*MT,S2(1),MJMK,2)                    OUTR0690
ISN 00031          IF(I04.NE.6) GO TO 424                                           OUTR0700
ISN 00032          CALL WANDR2(NPSO,S2(1),IMJM,S4(1,1),NOM,2)                       OUTR0710
ISN 00033      424 IF(I04.EQ.0.OR.I04.EQ.6) GO TO 8024                              OUTR0720
ISN 00034          DO 624 I=1,IMJM                                                  OUTR0730
ISN 00035      624 S2(I)=0.                                                         OUTR0740
ISN 00036     8024 IF(IB1.EQ.0.OR.I04.EQ.5) GO TO 724                               OUTR0750
ISN 00037          DO 8004 L = 1,IB1                                                OUTR0760
ISN 00038          D1(L) = 0.0                                                      OUTR0770
ISN 00039     8004 CONTINUE                                                         OUTR0780
ISN 00040     8003 DO 8000 IJ=1,IMJM                                                OUTR0790
ISN 00041          ITEMP=M0(IJ)                                                     OUTR0800
```

2 cards added

Fig. 4.6 Modification of Subroutines OUTER, TPSAVE, TPXF of the DOT-3.5 code for the data transmission to ACT4 and APPLE-2.

```
ISN 00001          SUBROUTINE TPSAVE(N2,IMJM,IGM,IGG,IFOT,J3,NOM,B2,B4,MMIM,MMJM,ITI,TPSV0010
                  1 NOMG)                                                          TPSV0020
             C                                                                     TPSV0030
             C****** TPSAVE WRITES SCALAR FLUXES, MOMENTS AND SYSTEM BOUNDARY       TPSV0040
             C****** ANGULAR FLUXES ON NFLSV                                       TPSV0050
             C                                                                     TPSV0060
ISN 00002          COMMON NINP,NOUT,NCR1,NFLUX1,NSCRAT,NAFT,NBSO,NFLSV,NPSO        TPSV0070
ISN 00003          DIMENSION  N2(IMJM,IGG),J3(NOM,IGG),B2(9),B4(9),NOMG(1)        TPSV0080
ISN 00004          REAL N2,J3                                                      TPSV0090
ISN 00005     1234 REWIND NFLUX1                                                   TPSV0100
             CRC   REWIND NFLSV                this statement is deleted          TPSV0110
ISN 00006          DO 1236  IIG =1,IGM                                             TPSV0120
ISN 00007          IG1 = IIG                                                       TPSV0130
ISN 00008          IF(IFOT.EQ.0) GO TO 1233                                        TPSV0140
ISN 00009          IG1 = 1                                                         TPSV0150
ISN 00010          IF(NFLUX1.EQ.NFLSV) GO TO 1237                                  TPSV0160
ISN 00011          CALL WANDR4(NFLUX1,N2(1,IG1),IMJM,J3(1,IG1),NOMG(IIG),B2(1),MMJM, TPSV0170
                  1B4(1),MMIM,2)                                                   TPSV0180
ISN 00012          GO TO 1235                                                      TPSV0190
ISN 00013     1233 CALL WANDR2(NFLUX1,B2(1),MMJM,B4(1),MMIM,2)                     TPSV0200
ISN 00014     1235 CALL WANDR4 (NFLSV,N2(1,IG1),IMJM,J3(1,IG1),NOM,B2(1),MMJM,B4(1), TPSV0210
                  1MMIM,1)                                                         TPSV0220
ISN 00015     1236 CONTINUE                                                        TPSV0230
ISN 00016     1237 RETURN                                                          TPSV0240
ISN 00017          END                                                             TPSV0250
```

```
ISN 00001          SUBROUTINE TPXF(NFLUX,NFLUX1,N2,J3,B2,B4,UF,IGRP,FO,FN,N20,J30,   TPXF0010
                  1 B20,B40,FI,FJ,ICF,IUCF,IK,JK,IKJK,NOM,NOMA,IEDIT,NOUT,NPSO,A)   TPXF0020
ISN 00002          COMMON/COPYBU/X(1),LIMX,LBEGIN,LFP,LE,LIGRP,LFN,LFO,LN20,LJ30,    TPXF0030
                  1 LB20,LB40,LSP,L1,L2,L3,L4,L5,L6,LAST,IA04,IA03,     NOMI,NOMAI,  TPXF0040
                  2 IB01,IB02,IB03,IB04,JZ1,JZ2,ML,IMK,JMK,IMJMK,IGMA,MMJKI,MMIKI,  TPXF0050
                  3 IFLUX,IGMI,IA03I,IA04I,ISRCE,IGIXS,DUMBU(4)                    TPXF0060
ISN 00003          DIMENSION A(1)                                                  TPXF0070
ISN 00004          DIMENSION N2(1),J3(IKJK,1),B2(1),B4(1),IGRP(1),FO(1),FN(1),N20(1),TPXF0080
                  1 J30(IKJK,1),B20(1),B40(1),FI(IK,1),FJ(JK,1),UF(1),QO(1)         TPXF0090
ISN 00005          REAL N2,N20,J3,J30                                              TPXF0100
             C
ISN 00006          IF(ICF.EQ.3)                   GO  TO  11                       TPXF0110
ISN 00007          REWIND  IFLUX
ISN 00008          CALL  WANDRO(IFLUX,2)          this statement is inserted
ISN 00009       11 CONTINUE
ISN 00010          REWIND NFLUX1                                                   TPXF0120
ISN 00011          MMJK=IA04*JMK                                                   TPXF0130
ISN 00012          MMIK=IA04*IMK                                                   TPXF0140
ISN 00013          IF(IUCF.GT.0) CALL WANDRO(NPSO,IGMA)                            TPXF0150
ISN 00014          DO 12 I=1,IGMA                                                  TPXF0160
ISN 00015       12 IF(IGRP(I).LE.0) IGRP(I)=I                                      TPXF0170
             C****** SEARCH FOR FLUX GROUP TO USE ******                           TPXF0180
ISN 00016          IGOT=0                                                          TPXF0190
ISN 00017          DO 100 IIG=1,IGMA                                               TPXF0200
ISN 00018          IGRO=IGRP(IIG)                                                  TPXF0210
ISN 00019       80 IF(IGRO.EQ.IGOT) GO TO 90                                       TPXF0220
ISN 00020          IGOT=IGOT+1                                                     TPXF0230
```

Fig. 4.6 Modification of Subroutines OUTER, TPSAVE, TPXF of the DOT-3.5 code for the data transmission to ACT4 and APPLE-2 (Continued).

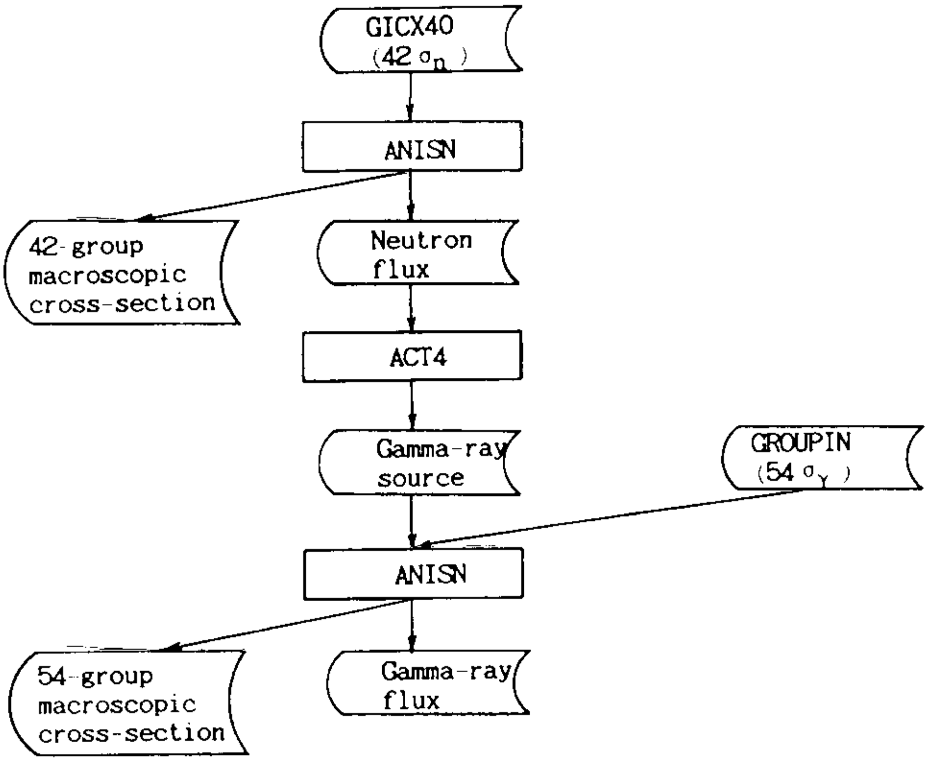


Fig. 4.7 Processing of macroscopic cross section.

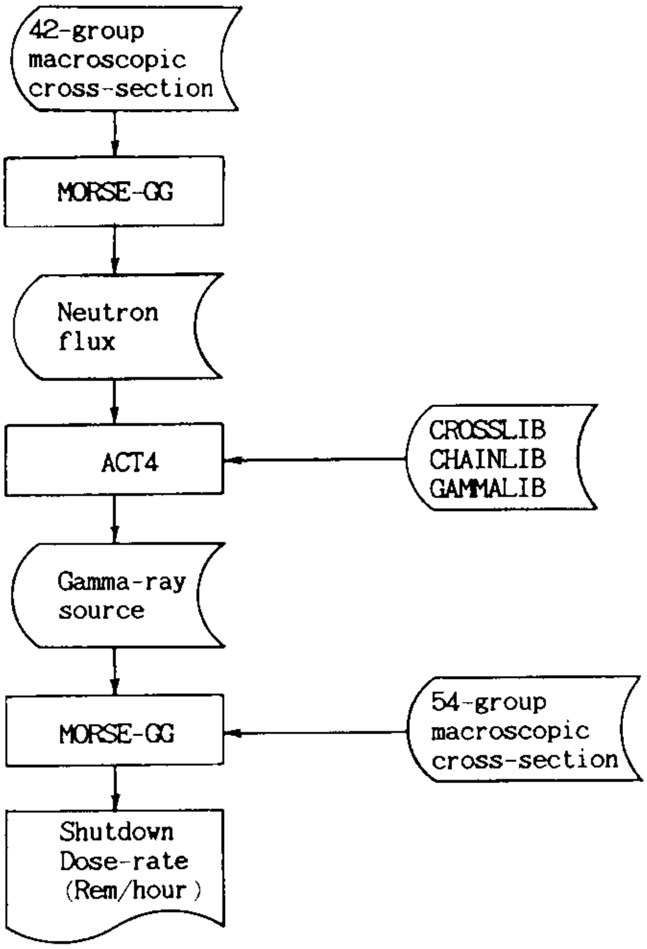


Fig. 4.8 Calculational flow for a three dimensional problem.

```
C * * OUTPUT OPTION ADDED BY MR.SEKI * * * * * * * * * * * * * * * * * * *
C * * OPTION PARAMETER IF NFOUT.LT.0  FLUX PER UNIT ENERGY
C                      IF NFOUT.GT.0  FLUX PER UNIT LETHARGY
C                      IF NFOUT.EQ.0  SCALAR FLUX
      NFOUT  = 0
CCC   FACTR  = 570.0*8.37E+15
      FACTR  = 1.0
      NNE1   = NNE+1
      IF(IE.NE.1 .AND. IE.NE.NNE1)                GO TO 1979
C **    ENERGY WIDTH
      IF( IE.EQ.NNE1 )      ETOP=EGTOP


      DO 1977 I=ID11,ID12,NE
      IF(NFOUT)   1977,1982,1983
C1982 E(I)   = E(I)*EDELTA
 1982 E(I)   = E(I)*EDELTA*FACTR
      GO  TO  1977
 1983 E(I)   = E(I)*EDELTA/UDELTA
 1977 CONTINUE
C * *  OUTPUT FOR FLUX * * *
      WRITE (IO,1070)          (E(I),I=ID11,ID12,NE)
 1070 FORMAT (17X,1P10E10.3)
      J       = ID1
      DO   2030  I=ID11,ID12,NE
      FNE(IE,J) = E(I)
      J       = J+1
 2030 CONTINUE
C * *  FLUX RESTORE
      DO   1978 I=ID11,ID12,NE
      IF(NFOUT)   1978,1984,1985
C1984 E(I)   = E(I)/EDELTA
 1984 E(I)   = E(I)/EDELTA/FACTR
      GO  TO  1978
 1985 E(I)   = E(I)/EDELTA*UDELTA
 1978 CONTINUE
C * *  OUTPUT FOR F.S.D
      ID11    = ID11 + NEND
      ID12    = ID12 + NEND
      WRITE (IO,1080) (E(I),I=ID11,ID12,NE)
 1080 FORMAT (17X,10(F9.3,1X))
      J       = ID1
      DO   2040  I=ID11,ID12,NE
      FSD(IE,J) = E(I)
      J       = J+1
 2040 CONTINUE
      ENE(IE) = E(IEP)
 205  WRITE (IO,1090) E(IEP)
 1090 FORMAT (1X,1PE11.3)
C * * PUNCH OUT ENERGY BOUNDARIES * *
      NFX     = 10
      REWIND   NFX
      WRITE(NFX)   NNE,NE,ND
      WRITE(NFX)   EFIRST,EGTOP,(ENE(IE),IE=1,NE),(VOL(I),I=1,MXREG)
      DO   2050  ID=1,ND
      WRITE(NFX)       (FNE(IE,ID),IE=1,NE)
      WRITE(NFX)       (FSD(IE,ID),IE=1,NE)
 2050 CONTINUE
      ENDFILE  NFX
      REWIND   NFX
 2010 FORMAT(12I6)
 2020 FORMAT(6E12.5)
 210  IF (NT)    375,375,215
```

These cards are inserted

Fig. 4.9 Modification of Subroutine NRUN of the MORSE-GG code for the data transmission to ACT4.

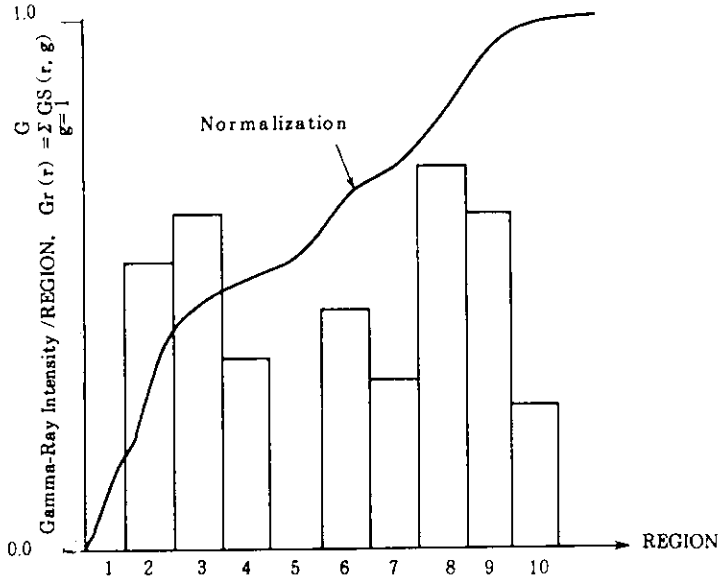


Fig. 4.10 Cumulative probability distribution for determination of region number.

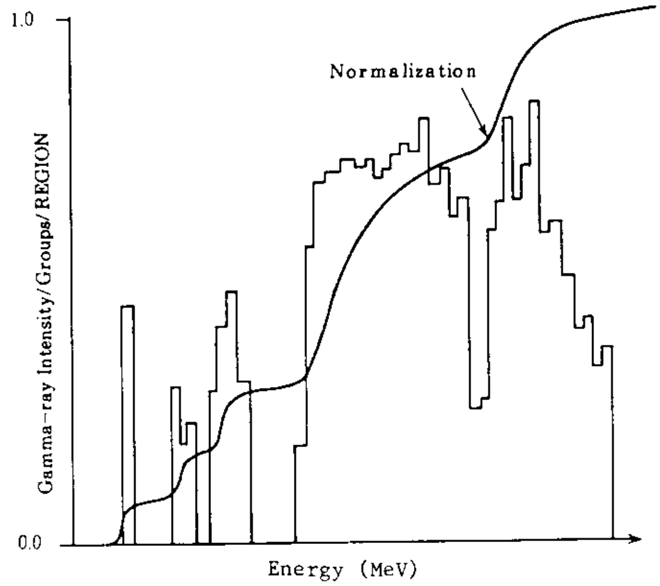


Fig. 4.11 Cumulative probability distribution for determination of energy group number.

5. Sample Problem

A comprehensive set of calculations for a sample problem is described in this chapter. It includes one-, two- and three-dimensional calculations of a same problem. The results of the three calculations are compared to show the degree of agreement in the calculations.

5.1 Problem Description

The induced activity in an iron cylinder of 30 cm radius and 30 cm height irradiated by a source of 14 MeV neutrons is calculated. The iron cylinder is surrounded by air as shown in **Fig. 5.1**. The 14 MeV neutrons with the intensity of 4.52×10^{16} $n \cdot s^{-1}$ are generated isotropically and uniformly within the central cylinder with radius 3 cm.

Firstly the neutron flux distribution in the iron cylinder is calculated using the ANISN9), DOT-3.510) and MORSE-GG11). Secondly, the delayed gamma-ray source is calculated by the ACT4 code at one day after shutdown following a continuous generation of the neutrons for 2 years. Thirdly, the gamma-ray flux at one day after shutdown is calculated using the transport codes. Finally, the gamma-ray flux is converted to dose rate.

5.2 Calculations

The one-, two- and three dimensional calculations of the sample problem are described in more detail in this section.

5.2.1 One-Dimensional Calculation

The calculational flow employed in the one-dimensional calculation is shown in **Fig. 4.1**. In the one-dimensional transport calculation using the ANISN code[9], an infinite cylinder model is used. The model assumes an infinite height (or no net neutron flow in the axial(Z) direction) but the height is taken to be 1.0 cm for volume calculation.

The input data for all the calculation steps are listed in Appendix A.3.1. The printed output of the ACT4 calculation is listed in Appendix A.4.1. The plotter output from the ACT4 and APPLE-2 calculations are given in Appendices A.4.2 and A.4.3, respectively. The job control language (JCL) used in the one-dimensional calculation is listed in Appendix A.5.1.

5.2.2 Two-Dimensional Calculation

In the two-dimensional calculation using the DOT-3.5 code 10), the R-Z geometry is used with a reflective boundary condition used on left, top and bottom boundaries and vacuum boundary condition at the right boundary. The choice of the reflective boundary condition at the top and bottom allows equivalence to the infinite height condition used in the ANISN calculation.

The calculational flow for the two-dimensional calculation is shown in **Fig. 4.4**. As described in Section 4.2, the calculational flow for the two-dimensional case is essentially the same as the one-dimensional case except for the pre-processing of the cross sections before the DOT-3.5 calculations. The input data listings and the JCL listings for the two-dimensional calculation are given in Appendices A.3.2 and A.5.2, respectively.

5.2.3 Three-Dimensional Calculation

The calculational flow for the three-dimensional case is shown in **Fig. 4.8**. In the three-dimensional calculation, the exact cylindrical geometry may be taken into account as shown in **Fig. 5.2a** and **Fig. 5.2b**. These figures are drawn by the TOPIC code23) and depict the regions in the horizontal and vertical cross sections of the model.

Figure 5.3 shows the media specifications in the cross sections. Note that in the iron cylinder at radius less than 30 cm, the regions are specified alternately with media 1 and 2 both of iron. This convention is required to define the regions for the track length detector used in the MORSE-GG code in use. Note also that the media 10 in the vertical cross section in **Fig. 5.3** is an albedo media so as to make the top and bottom boundary conditions equivalent to those of the one- and two-dimensional calculations.

The input data for the three-dimensional calculation are listed in Appendix A.3.3. The JCL's for the same calculation are listed in Appendix A.5.3. The neutron flux calculation can be done in a similar manner as the gamma-ray flux. The induced activity calculation is not much different from the one- or two-dimensional case.

5.3 Comparison of Calculated Results

Calculated results of one-, two- and three-dimensional calculations are compared in this section. These calculations are denoted as 1D, 2D and 3D calculations in this section. The calculational conditions and some of the results are compared in **Table 5.1**.

5.3.1 Neutron Flux Calculation

In the step 1 for neutron flux calculation, the flux is normalized to one source neutron in the 2D and 3D calculations in which the height of the cylinder is 30 cm whereas it is normalized to 1/30 source neutron in the 1D calculation in which the height is 1 cm. Thus the neutron density is the same in all three calculations.

5.3.2 Induced Activity Calculation

In the step 2 for induced activity calculation, the conversion factor f_N of 4.52×10^{16} is multiplied to the neutron flux and the fusion power P_f is assumed to be 440 MW, for all three calculations. These values of f_N and P_f are used in the induced activity calculation of a fusion reactor but they are insignificant in the present calculations. In the 1D cylindrical calculation, the torus radius $R= 1/2\pi = 0.15915$ is entered to make "$2\pi R$ to be multiplied to the volume" be 1.0. The calculated total induced activity at shutdown after 2 years of continuous neutron generation for the 2D calculation is 30 times larger than that for the 1D calculation. The corresponding value for the 3D calculation is about 2% larger than that for the 2D calculation. This 2% difference is believed to be due to the statistical error in the neutron flux of the 3D calculation.

5.3.3 Gamma-Ray Flux Calculation

In the step 3 for gamma-ray flux calculation, gamma-ray source is not renormalized in the 1D and 2D calculations. However, the gamma-ray source is renormalized to 1.0 in the 3D calculation so that the total gamma-ray source intensity is multiplied to the calculated gamma-ray flux.

5.3.4 Dose-Rate Calculation and Plotting

The dose rates obtained in the step 4 by the APPLE-2 calculations are compared in **Table 5.1** at the radial positions r = 3 cm and r = 27 cm. The 1D and 2D results are almost equal. The contour map of the dose rate obtained by the 2D calculation is shown in **Fig. 5.4** together with the list of the input data for the APPLE-2 calculation. The contour curves appear to be straight lines in the figure. The solid curves in **Fig. 5.4** are the contour of the dose rate at 10^n rem/h, and the dotted curves are the dose rate at 5×10^n rem/h. The arrows perpendicular to the contour curves show the direction of the gradient of the dose rate value.

The dose rates calculated by the 1D ANISN calculation and 3D MORSE-GG calculation are compared in **Fig. 5.5**. The figure shows a good agreement between the 1D and 3D results in the iron cylinder at $r < 30$ cm but not so good in the air at 30 cm $< r <$ 100 cm. The poor agreement in the air is believed to be due to the statistical errors in the 3D calculations. The magnitude of the statistical errors showing the range of one fractional standard deviation (fsd) are partly shown by error bars in the figure. These errors can be reduced if more histories are followed in the 3D calculation.

5.4 Comparison of Computation Time

Computation time (central processing unit time, CPU time) for the three calculations are compared in **Table 5.2**. Most of the CPU time is spent on calculating neutron and gamma-ray fluxes. The 3D calculations for the fluxes are artificially terminated at 550 seconds to hold the CPU time to be less than 10 minutes. Very rough estimates of the CPU times for this sample problem are that the 2D calculation takes twice that for the 1D calculation and the 3D calculation takes more than 10 times that of the 1D calculation.

Table 5.1 Comparison of Calculational Conditions and Results of One-, Two- and Three-Dimensional Calculations

Calculational Items	1D Calculation by ANISN	2D Calculation by DOT-3.5	3D Calculation by MORSE-GG
Step-1 Neutron flux			
Normalization factor	XNF = 1/30	XNF = 1.0	XNF = 1.0
Axial height	1.0 cm	30 cm	30 cm
Step-2 Induced activity			
Normalization factor	$f_N = 4.52 \times 10^{16}$	$f_N = 4.52 \times 10^{16}$	$f_N = 4.52 \times 10^{16}$
Fusion power	$P_f = 440$ MW	$P_f = 440$ MW	$P_f = 440$ MW
Torus radius	$R = 1/2\pi$	–	–
Total neutrons	$f_N \cdot 2\pi R = f_N$	$f_N \times 30$	$f_N \times 30$
Total activity (Ci/MW) at shutdown	1.88×10^1	5.63×10^2	5.73×10^2
Step-3 Gamma-ray flux	XNF = 0.0	XNF = 0.0	XNF = 1.0
Total source gamma-rays 1 day after shutdown	2.51×10^{13}	7.51×10^{14}	7.58×10^{14}
Step-4 Dose rate (rem/h)			
at R = 3 cm	$9.4 \times 10^{5*}$	$9.4 \times 10^{5*}$	7.8×10^5 (0.01)**
at R = 27 cm	$5.0 \times 10^{3*}$	$5.0 \times 10^{3*}$	6.4×10^3 (0.06)**

* Values read from dose rate curves such as in Fig. 5.5.

** Dose rate value average over region with fractional standardard deviation in blacket.

Table 5.2 Comparison of Computation (CPU) Time⁺ of One-, Two- and Three-Dimensional Calculations

Calculational Items	1D Calculation by ANISN	2D Calculation by DOT-3.5	3D Calculation by MORSE-GG
Step-1 Neutron flux	30.4 S	61.6 S*	550.4 S*
Step-2 Induced activity and Gamma-ray source	7.2 S	13.2 S	2.4 S
Step-3 Gamma-ray flux	41.3 S	57.5 S*	550.3 S**
Step-4 Dose rate and plotting	1.0 S	2.4 S	
Total	79.9 S	134.9 S	1103.1 S

\+ CPU time in the FACOM M-200 computer in JAERI.

* CPU time for processing macroscopic cross sections not included.

** Calculations terminated after CPU time of 550 seconds.

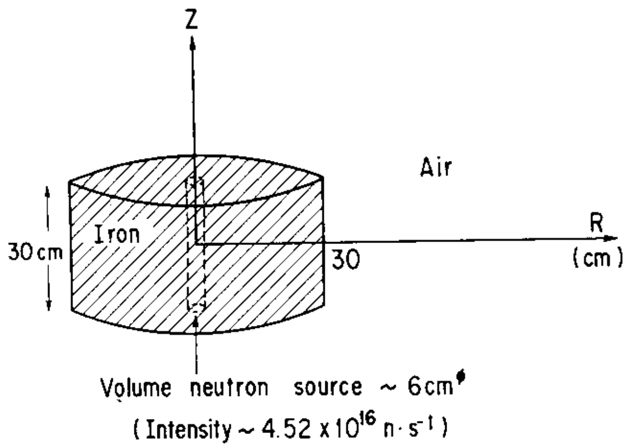


Fig. 5.1 Iron Cylinder for the Sample Problem.

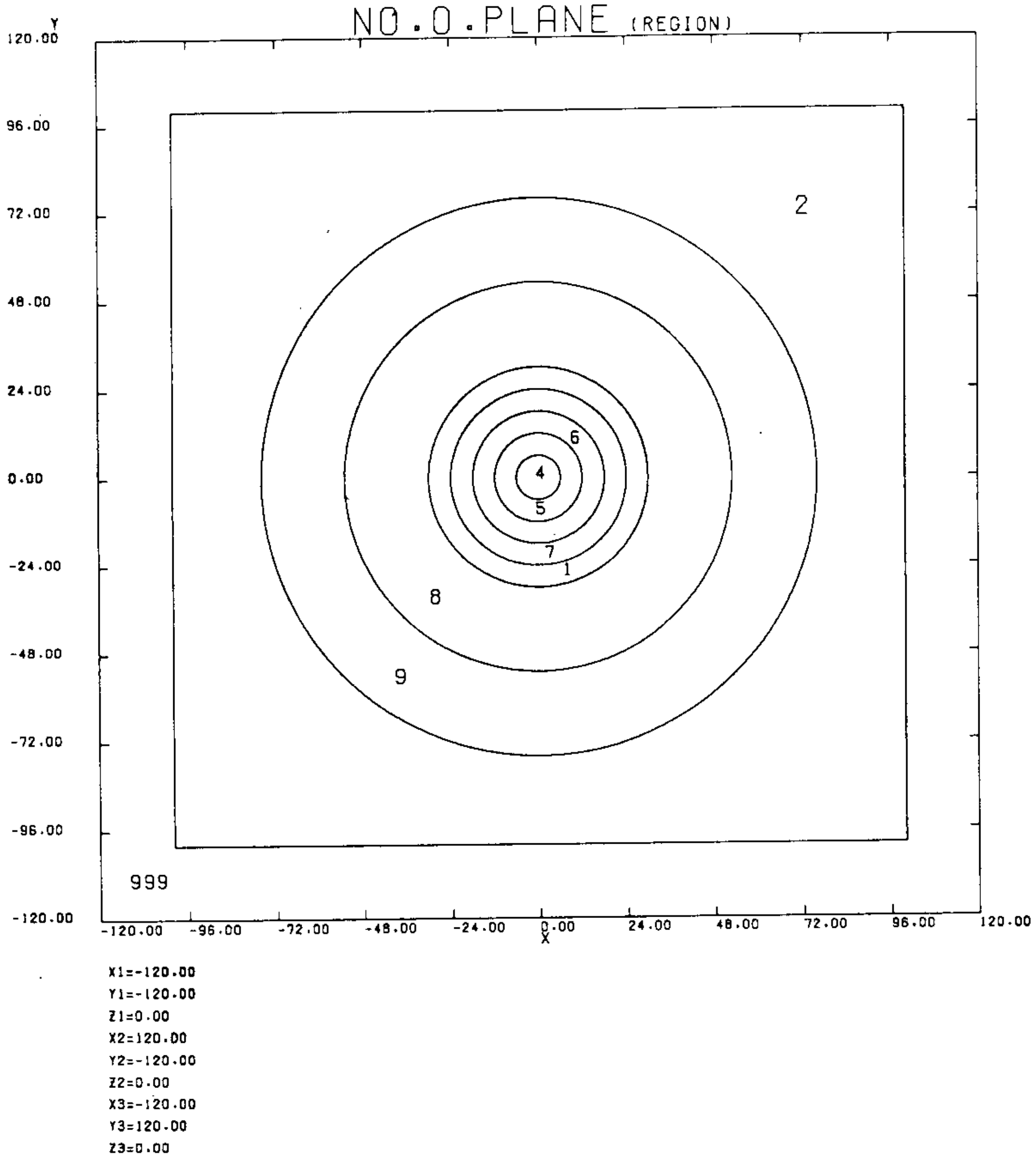
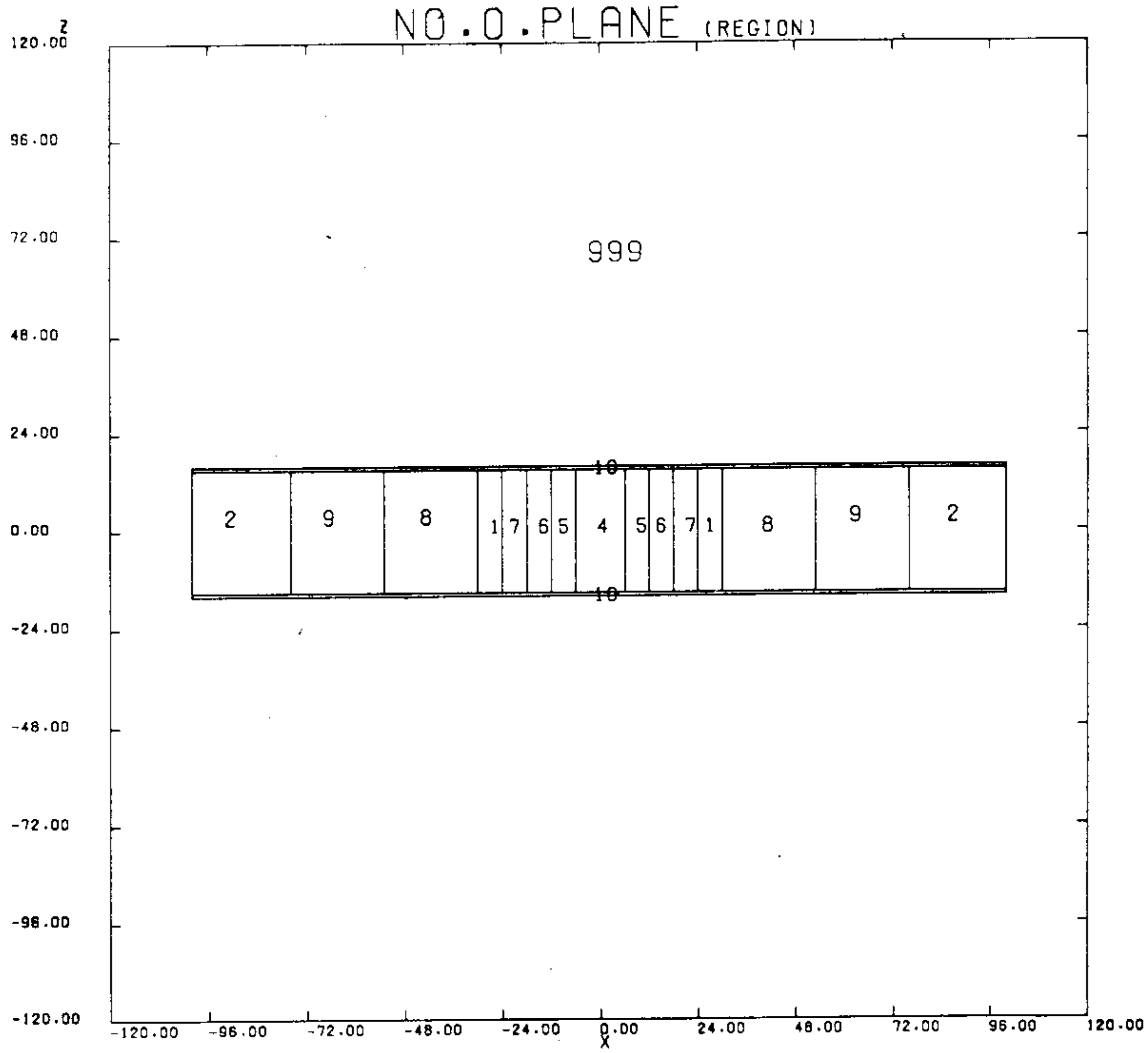
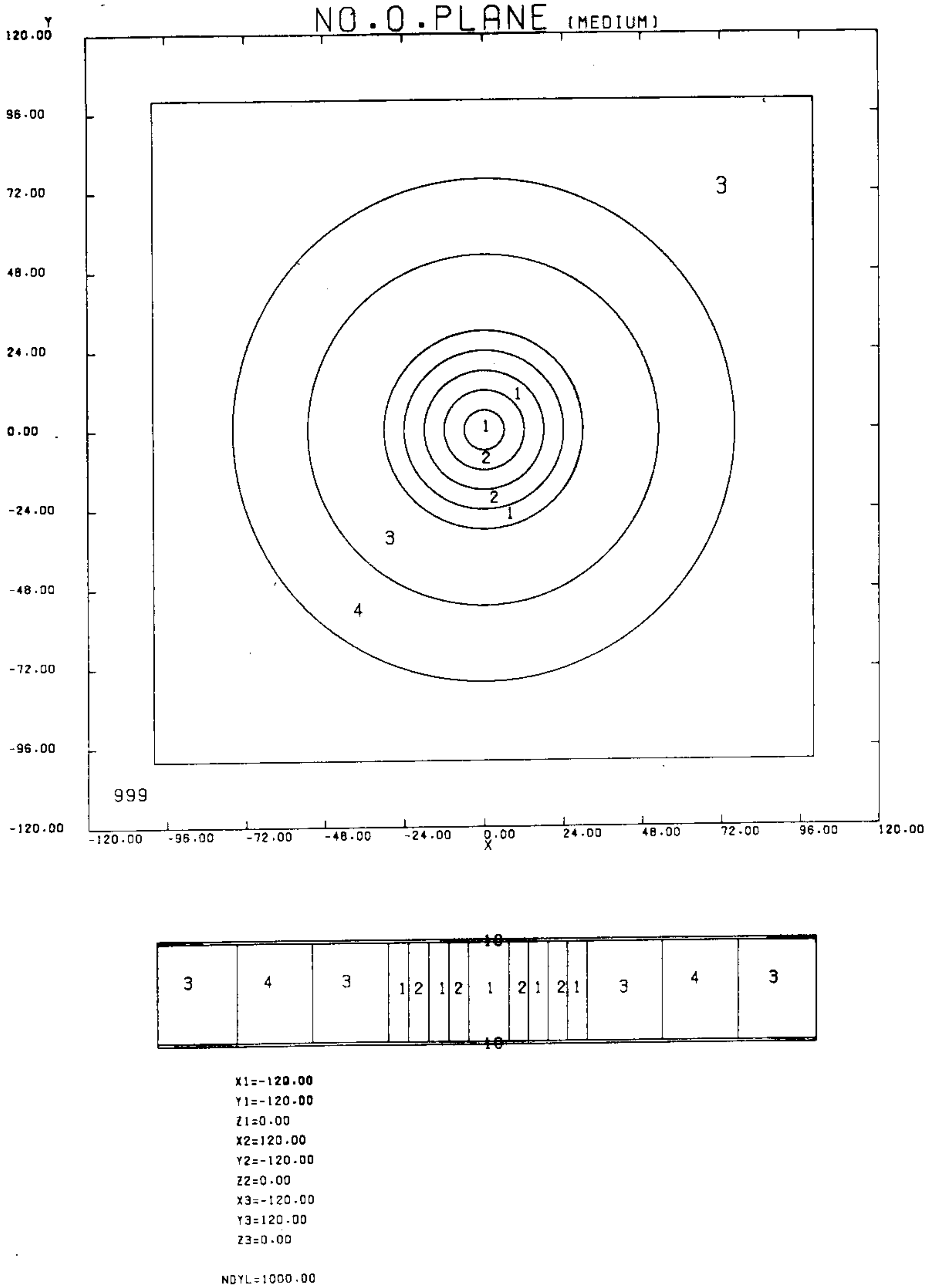


Fig. 5.2a Horizontal cross section of the cylindrical model showing regions.



```
X1=-120.00
Y1=0.00
Z1=-120.00
X2=120.00
Y2=0.00
Z2=-120.00
X3=-120.00
Y3=0.00
Z3=120.00

NDYL=1000.00
```

Fig. 5.2b Vertical cross section of the cylindrical model showing regions.



X1=-120.00
Y1=-120.00
Z1=0.00
X2=120.00
Y2=-120.00
Z2=0.00
X3=-120.00
Y3=120.00
Z3=0.00

NDYL=1000.00

Fig. 5.3 Horizontal and vertical cross sections of the cylindrical model showing media.

```
                *** APPLE INPUT DATA CARD IMAGE LIST ***
----*----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8
SHUTDOWN  DOSE RATE.  ( DOT3.5 )                                        00000100
FLUX    1                                                               00000200
  2  0                                                                  00000300
CROS    1                                                               00000400
  1  1  1  1                                                            00000500
10**  1                                                                 00000600
11**  1                                                                 00000700
12** F1 T                                                               00000800
RCAL    1                                                               00000900
  1  1  1  1  0.0508                                                    00001000
 9** F1                                                                 00001100
22**  1                                                                 00001200
23** F1 T                                                               00001300
SAMPLE                                                                  00001400
RPLT    1                                                               00001500
  2  5Z                                                                 00001600
 15.0         20.0                                                      00001700
  SHUTDOWN DOSE RATE (Z=15CM)                                           00001800
DISTANCE FROM THE PLASMA AXIS (CM)                                      00001900
      DOSE RATE ( REM/HOUR)                                             00002000
RPLT    1                                                               00002100
  3  1                                                                  00002200
 -1  1-10  0  0  0    0.0       90.0        1.0    +10  15.0        30.000002300
   SHUTDOWN DOSE RATE                                                   00002400
SPEC    1                                                               00002500
  2  1  1-54  0  2                                                      00002600
  1  1                                                                  00002700
  3 12                                                                  00002800
 15.0         20.0                                                      00002900
 GAMMA   ENERGY SPECTRA                                                 00003000
    GAMMA   ENERGY (EV)                                                 00003100
  GAMMA   FLUX PER UNIT LETHARGY                                        00003200
IRON    AIR                                                             00003300
END     0                                                               00003400
----*----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8
```

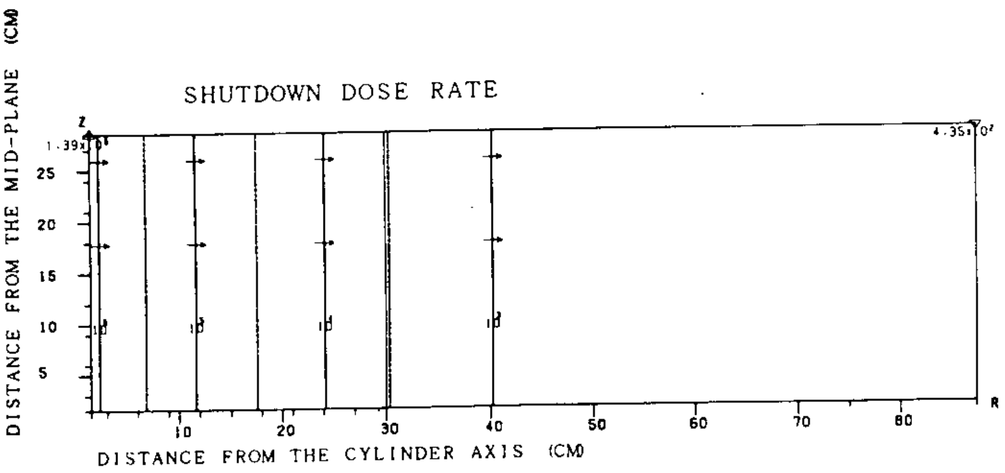


Fig. 5.4 Contour map of dose rate calculated by 2D calculation and the input list of APPLE-2 for obtaining the contour map.

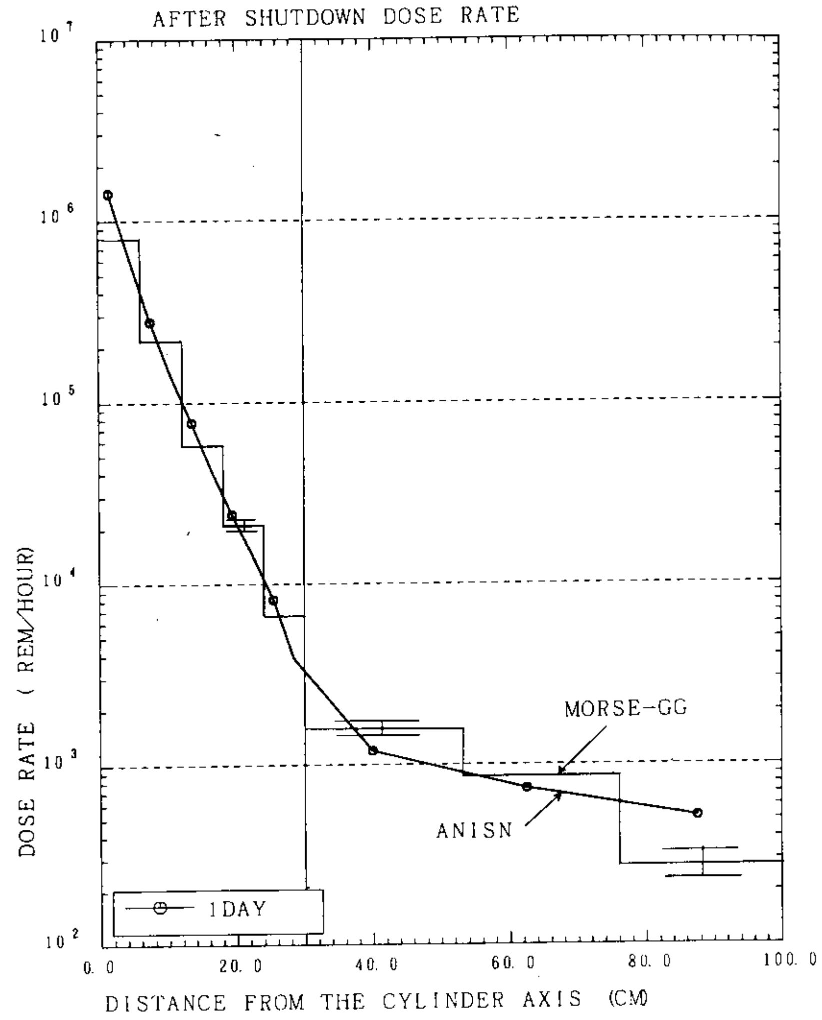


Fig. 5.5 Comparison of dose rates calculated by 1D and 3D calculations.

6. Concluding Remarks

The THIDA-2 code system, an advanced version of the THIDA system for the calculation of exposure dose rate around a fusion device has been developed. The major improvements in the new system are; 1) Simplification in the data input, 2) Self descriptive printed output and plotter output, 3) Capability to treat a three-dimensional calculational model, 4) Accurate decay heat calculation considering the gamma-ray transport, and 5) Capability to treat problem of any size by the employment of variable dimensioning.

A complete description of the code system is given in this report, including its structure, the methodology and details of the induced activity calculation, the calculational procedures for one-, two- and three-dimensional problems and a solution of a sample problem. It is intended that all the informations required for the use of the THIDA-2 system are included in this report or may be obtained from the literatures referenced.

As the result of the present work, the following issues appeared to require further improvements in the future and some are already being pursued.

(1) Automatic generation of data libraries for the ACT4; Using the Evaluated Nuclear Structure Data File (ENSDF)24), the libraries for the decay chain data (CHAINLIB) and delayed gamma-ray data (GAMMALIB) as the input to the ACT4 code should be generated automatically.

(2) Improvement of the library of activation cross sections; Based on the recent measurements and evaluations, the activation cross section library (CROSSLIB) should be updated and expanded.

(3) Enhancement of the accuracy in the treatment of a sequential decay of two short-life nuclides in the ACT4 code.

(4) Reduction of computation time in the ACT4 calculation; The reduction of the computation time by a factor of 3∿4 has already been accomplished25) by using the vectorized ACT4 code in the vector computer, FACOM VP-100. Further reduction is desired.

(5) Although the validation of the THIDA-2 system has been made by the measurements of delayed gamma-ray from the samples of type 316 stainless steel26) and of aluminum alloys27) irradiated by 14 MeV neutrons, further experiments using other materials are

needed.

Acknowledgments

The authors thank Drs. Tatsuzo Tone, Sanae Tamura, Masaji Yoshikawa, Ken Tomabechi and Sigeru Mori of JAERI for their encouragements in performing this work.

References

1) Ioki K., Harada Y. and Asami N.: "Code ACTIVE for Calculation of the Transmutation, Induced Activity and Decay Heat in Neutron Irradiation", JAERI-M 6471 (1976) (in Japanese).

2) Sung T.Y. and Vogelsang W.F.: "DKR: A Radioactivity Calculation Code for Fusion Reactors", UWFDM-170 (1976).

3) Lessler R.M., Alley W.E. and Green J.B.: "ACT and ACTIVE Codes for Calculating Neutron-Induced Activation", UCRL-51292 (1978).

4) Iida H. and Igarashi M.: "THIDA-Code System for Calculation of the Exposure Dose Rate Around a Fusion Device", JAERI-M 8019 (1978) (in Japanese), published also as ORNL-tr-4713 and included in the RSIC Computer Codes Collection as CCC-410.

5) Jung J.: "Theory and Use of the Radioactivity Code RACC", ANL/FPP/TM-122 (1979).

6) Ponti C. and Stramaccia S.: "ANITA, A Code for the Analysis of Neutron Induced Transmutation and Activation", to be published.

7) Blink J.A: "FORIG: A Modification of the ORIGEN2 Isotope-Generation and Depletion Code for Fusion Problems", UCRL-53263 (1982).

8) Mann F.M.: "Transmutation of Alloys in MFE Facilities as Calculated by REAC (A Computer Code System for Activation and Transmutation", HEDL-TME 81-37 (1982).

9) Engle Jr. W.W.: "A User's Manual for ANISN, A One Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering", K-1693 (1967).

10) Rhoades W.A. and Mynatt F.R.: "The DOT-III Two Dimensional Discrete Ordinates Transport Code", ORNL/TM-4280 (1973).

needed.

Acknowledgments

The authors thank Drs. Tatsuzo Tone, Sanae Tamura, Masaji Yoshikawa, Ken Tomabechi and Sigeru Mori of JAERI for their encouragements in performing this work.

References

1) Ioki K., Harada Y. and Asami N.: "Code ACTIVE for Calculation of the Transmutation, Induced Activity and Decay Heat in Neutron Irradiation", JAERI-M 6471 (1976) (in Japanese).

2) Sung T.Y. and Vogelsang W.F.: "DKR: A Radioactivity Calculation Code for Fusion Reactors", UWFDM-170 (1976).

3) Lessler R.M., Alley W.E. and Green J.B.: "ACT and ACTIVE Codes for Calculating Neutron-Induced Activation", UCRL-51292 (1978).

4) Iida H. and Igarashi M.: "THIDA-Code System for Calculation of the Exposure Dose Rate Around a Fusion Device", JAERI-M 8019 (1978) (in Japanese), published also as ORNL-tr-4713 and included in the RSIC Computer Codes Collection as CCC-410.

5) Jung J.: "Theory and Use of the Radioactivity Code RACC", ANL/FPP/TM-122 (1979).

6) Ponti C. and Stramaccia S.: "ANITA, A Code for the Analysis of Neutron Induced Transmutation and Activation", to be published.

7) Blink J.A: "FORIG: A Modification of the ORIGEN2 Isotope-Generation and Depletion Code for Fusion Problems", UCRL-53263 (1982).

8) Mann F.M.: "Transmutation of Alloys in MFE Facilities as Calculated by REAC (A Computer Code System for Activation and Transmutation", HEDL-TME 81-37 (1982).

9) Engle Jr. W.W.: "A User's Manual for ANISN, A One Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering", K-1693 (1967).

10) Rhoades W.A. and Mynatt F.R.: "The DOT-III Two Dimensional Discrete Ordinates Transport Code", ORNL/TM-4280 (1973).

11) Straker E.A., Stevens P.N., Irving D.C. and Cain V.R.: "The MORSE Code-A Multigroup Neutron and Gamma-Ray Monte Carlo Transport Code", ORNL-4585 (1979).

12) Seki Y., Iida H. and Kawasaki H.: "Graphical Representation of Transmutation and Decay Chain Data, Transmutation Cross Section and Delayed Gamma Ray Emission Data", JAERI-1280 (1982).

13) Kawasaki H. and Seki Y.: "APPLE-2: An Improved Version of APPLE Code for Plotting Neutron and Gamma Ray Spectra and Reaction Rates", JAERI-M 82-091 (1982), Included in the RSIC Computer Codes Collection as PSR-111.

14) Seki Y. and Iida H.: "Coupled 42-Group Neutron and 21-Group Gamma Ray Cross Section Sets for Fusion Reactor Calculations", JAERI-M 8818 (1980).

15) Seki Y., Harada Y. and Asami N.: "Induced Activity of Copper Coil in a D-T Burning Experiment", JAERI-M 5862 (1974) (in Japanese)

16) Lathrop K.D. and Brinkley F.W.: "Theory and Use of the General Geometry TWOTRAN Program", LA-4432 (1970)

17) Miyasaka S., Koyama K., Minami K. and Taji Y.: "GAMLEG-JR, A Production Code of Multigroup Cross Sections and Energy Deposition Coefficients for Gamma-Rays", JAERI-M 7155 (1977).

18) Hyodo T.: "Introduction to Radiation Shielding (Second Edition)", Sangyo Tosho Publishing Co. (1979) (in Japanese).

19) Seki Y., Yamada K. and Kawasaki H.: J. Nucl. Sci. Technol., 21 [10], 727 (1984).

20) Ball S.J. and Adams R.K.: "MATEXP, A General Purpose Digital Computer Program for Solving Ordinary Differential Equations by the Matrix Exponential Method", ORNL-TM-1933 (1967).

21) Science and Technology Agency (Japan): "Regulation 21, The Item on the Determination of Permissible Irradiation Dose Based on the Regulation on the Principle of Construction and Operation of Nuclear Fission Reactor", (1960) (in Japanese).

22) RSIC Computer Code Collection: "AXMIX, ANISN Cross Section Code", PSR-75, Radiation Shielding Information Center (1976).

23) Iida H. and Kawasaki H.: "TOPIC: A Debugging Code for Torus Geometry Input Data of Monte Carlo Transport Code", JAERI-M 8289 (1979) (in Japanese).

24) Ewbank W.B. et al.: "Evaluated Nuclear Structure Data File, A Manual Preparation of Data Sets", ORNL-5054/RI (1978).

25) Shiozawa N.: private communication.

26) Ikeda Y. et al.: "An Experimental Study of Induced Activity in Type 316 Stainless Steel by Irradiation in D-T Neutron Fields", JAERI-M 83-177 (1983).

27) Ogawa Y. et al.: J. Nucl. Sci. Technol., 21 [7], 561 (1984).

Appendices

A.1 Arrays of Variables in ACT4 Code

The contents of variable arrays and their sizes are described in this Appendix A.1. These informations are useful when following the program structure.

Variable	Size	Content
R	(IRMAX + 1)	Mesh boundaries for the X(R) direction specified by the 4* input data.
RR	(IZMAX + 1)	Mesh boundaries for the Z(Y or θ) direction specified by the 5* input data.
KACTOP	(ICMAX + 1)	Address of the first line number KAC in the activity chain table for the component nuclide IC. ICMAX is the total number of the component nuclides.
NXTOP	(ICMAX + 1)	Address of the first nuclide number NX in the activity chain table for the component nuclide IC.
KACN	(NXPMAX)	Sequence number of a nuclide in the activity chain table
KIAN	(NXPAMX)	Address of an unstable parent nuclide in ZAPTAB table
ZANX	(NXPMAX)	Table for the number of mother and daughter nuclides. NXPMAX is the total number of parent and daughter nuclides in the chain table
NXPN	(KACPAMX)	Address of parent nuclides in the ZANX table. KACPMX is the total number of locations in the chain table, i.e. $\mathrm{KACPMAX} = \sum_{\mathrm{IC}=1}^{\mathrm{ICMAX}} \mathrm{IPAIR}_{\mathrm{IC}}.$
NXDN	(KACPMX)	Address of daughter nuclides in the ZANX table.

Variable	Size	Content
KCSN	(KACPMX)	Address of the transmutation cross section in the ACTAB table.
BETA	(KACPMX)	Branching ratio
DCY	(KACPMX)	Decay constant λ (sec^{-1}).
EMEAN	(KACPMX)	Mean energy of β rays (eV)
KACSN	(KACPMX)	Option for short life treatment (treated as a shortlife nuclide if negative)
ZAPTAB	(KIAMAX)	Table of nuclides which are radioacitive. KIAMAX is the number of radioactive nuclides.
DCYK	(KIAMAX)	Same as EMEAN
NMTAB	(KIAMAX)	Address of the nuclide ZAP in the maximum permissible concentration table, XMPC
ACTAB	(KCSMAX*2)	Table of transmutation cross section name. KCSMAX is the number of cross sections.
CS	(KCSMAX*IEMAX)	Group cross sections
KCSCHK	(KCSMAX)	Option for the cross sections (=1; non zero, =0; zero)
IOKMX	(KIAMAX)	Number of gamma-ray species emitted from the radioactive nuclide
NGAM	(KIAMAX)	Address of gamma-ray emission data
GLVL	(IGMX + 1)	Energy group boundaries of gamma-ray transport calculation.
AMARK	(KIAMAX)	Subtitle SHORT is assigned for the gamma-ray emission data output in GAMIN.
ACALL	(KIAMAX)	Nuclide symbol is assigned for the gamma-ray emission data output.
IAA	(KIAMAX)	Nuclide symbol is assigned for the gamma-ray emission data output.
RATIO	(ICMAX)	Nuclide density fraction at (IR, IZ) mesh
FLUX	(IEMAX)	Neutron flux at (IR, IZ) mesh
QIA	(KIAMAX*ISTMAX)	Induced activity after shutdown integrated over the whole system
PQIA	(KIAMAX*ISTMAX*ISMAX)	Induced activity for each spatial mesh
X	(NXQMAX*2)	Area for atomic density fractions of nuclides **X**

Variable	Size	Content
Q	(NXQMAX*NXQMAX*2)	Work area for **A**-matrix and **C**-matrix calculation
Y	(NXAMAX*2)	Work area for **A**-matrix and **C**-matrix calculation
Z	(NXQMAX*2)	Work area for **A**-matrix and **C**-matrix calculation
BHP	(ISTMAX*ISMAX)	Biological hazard potential
A	(NXAMAX*NXQMAX*2)	**A**-matrix
B	(NXQMAX*NXQMAX*2)	**B**-matrix
C	(NXQMAX*NXQMAX*2)	**C**-matrix
D	(NXQMAX*NXQMAX*2)	**D**-matrix
QIAO	(NXQMAX*ISMAX)	Value of **X** after shutdown
XO	(NXQMAX)	$\mathbf{X}_o$
ZO	(NXQMAX)	$\mathbf{Z}_o$
GS	(IGMX*USTNAX)	Gamma-ray source for each spatial mesh
PGS	(IGMX*ISTMAX)	Gamma-ray source integrated over the whole system
ACTV	(ISMAX*NXQMAX*ISTMAX*ICMAX)	Compilation area of induced activity.

A.2 List of Modified Subroutines for Calculation of Gamma-Ray Source Generation in MORSE-GG

```
      SUBROUTINE INSCOR                                                 00000100
      COMMON/SOURC/LGSR,LGS,LNGSTR,LSPINT,NSLOSS                        00000200
      COMMON /PDET/ ND,NNE,NE,NT,NA,NRESP,NEX,NEXND,NEND,NDNR,NTNR,NTNE,00000300
     1 NANE,NTNDNR,NTNEND,NANEND,LOCRSP,LOCXD,LOCIB,LOCCO,LOCT,LOCUD,   00000400
     2 LOCSD,LOCQE,LOCQT,LOCQTE,LOCQAE,LMAX,EFIRST,EGTOP                00000500
      COMMON/USER/ DUM(9),IO,I1,DUM1(7),NLAST,NLEFT,NMGP,NMTG,NSTRT     00000600
      COMMON /APOLLO/ DUM2(28),ITOUT,ITIN,DUM3(16),MXREG,DUM4(52)       00000700
      COMMON /VOLUME/ VOL(200)                                          00000800
      DIMENSION IQ(1)                                                   00000900
      COMMON    Q(1)                                                    00001000
      EQUIVALENCE(Q(1),IQ(1))                                           00001100
CC                                                                      00001200
CC ***   READ OF VOLUME  ****                                           00001300
      IF(MXREG.EQ.0)    GO  TO  100                                     00001400
      READ (ITIN,1000) (VOL(I),I=1,MXREG)                               00001500
      WRITE(IO,1001)                                                    00001600
      WRITE(IO,1002)   (I,VOL(I),I=1,MXREG)                             00001700
 1000 FORMAT(7E10.3)                                                    00001800
 1001 FORMAT(//1H0,' VOLUME FOR TRACK LENGTH METHOD.  (CM**3) ' )       00001900
 1002 FORMAT(7(I5,1PE13.3))                                             00002000
  100 CONTINUE                                                          00002100
      IDM    = 17                                                       00002200
      LGSR   = LMAX                                                     00002300
      LGS    = LGSR   + MXREG                                           00002400
      LNGSTR = LGS    + MXREG*NMTG                                      00002500
      LSPINT = LNGSTR + MXREG                                           00002600
      LMAX   = LSPINT + 4*MXREG                                         00002700
      LUSD   = LMAX   - NLAST                                           00002800
      NLFT   = NLEFT  - LUSD                                            00002900
      WRITE(IO,1010) NLFT                                               00003000
 1010 FORMAT(  7H0NLFT = I7)                                            00003100
      IF(NLFT .GT. 0) GO TO 110                                         00003200
      WRITE(IO,1015)                                                    00003300
 1015 FORMAT( '0 BLANK COMMON LOCATION OVER.   JOB STOPPED. ')          00003400
      CALL  EXIT                                                        00003500
  110 CONTINUE                                                          00003600
      L1     = LGSR                                                     00003700
      L1E    = LMAX-1                                                   00003800
      DO  115  L=L1,L1E                                                 00003900
      Q(L) = 0.0                                                        00004000
  115 CONTINUE                                                          00004100
      L2     = LGS                                                      00004200
      L2E    = LNGSTR - 1                                               00004300
      REWIND  IDM                                                       00004400
      READ (IDM) (Q(L),L=L2,L2E)                                        00004500
      REWIND  IDM                                                       00004600
C                                                                       00004700
      GST    = 0.0                                                      00004800
      DO  120  IR=1,MXREG                                               00004900
      L1     = LGSR+IR-1                                                00005000
      L2     = LGS+(IR-1)*NMTG                                          00005100
      Q(L1)  = 0.0                                                      00005200
      DO  130  IG=1,NMTG                                                00005300
      Q(L2+IG-1) = Q(L2+IG-1)*VOL(IR)                                   00005400
      Q(L1)  = Q(L1) + Q(L2+IG-1)                                       00005500
  130 CONTINUE                                                          00005600
      GST    = GST + Q(L1)                                              00005700
  120 CONTINUE                                                          00005800
      L1     = LGSR                                                     00005900
      L1E    = L1 + MXREG-1                                             00006000
      WRITE(IO,1101)  MXREG                                             00006100
      WRITE(IO,1110) (Q(L),L=L1,L1E)                                    00006200
CC    GSFACT = GST * 0.0508                                             00006300
      GSFACT = GST                                                      00006310
      WRITE(IO,1120)  GSFACT                                            00006400
      Q(LGSR) = Q(LGSR)/GST                                             00006500
      DO  140  IR=2,MXREG                                               00006600
      Q(LGSR+IR-1) = Q(LGSR+IR-2) + Q(LGSR+IR-1)/GST                    00006700
  140 CONTINUE                                                          00006800
C                                                                       00006900
      DO  200  IR=1,MXREG                                               00007000
      GST    = 0.0                                                      00007100
```

```
      L2      = LGS+(IR-1)*NMTG                                          00007200
      DO  210  IG=1,NMTG                                                 00007300
      GST     = GST + Q(L2+IG-1)                                         00007400
  210 CONTINUE                                                           00007500
      IF(GST.GT.0.0)         GO  TO  230                                 00007600
      DO  220  IG=1,NMTG                                                 00007700
  220 Q(L2+IG-1) = 0.0                                                   00007800
      GO  TO  200                                                        00007900
  230 Q(L2)    = Q(L2)/GST                                               00008000
      DO  240  IG=2,NMTG                                                 00008100
      Q(L2+IG-1) = Q(L2+IG-2) + Q(L2+IG-1)/GST                           00008200
  240 CONTINUE                                                           00008300
  200 CONTINUE                                                           00008400
      L1      = LGSR                                                     00008500
      L1E     = L1 + MXREG-1                                             00008600
      WRITE(IO,1100)  MXREG                                              00008700
      WRITE(IO,1110)  (Q(L),L=L1,L1E)                                    00008800
 1100 FORMAT(1H0,5X,'SOURCE NORMALIZE IN REGION.  TOTAL REGION --',I5)   00008900
 1101 FORMAT(1H0,5X,'GAMMA SOURCE DISTRIBUTION.   TOTAL REGION --',I5)   00009000
 1110 FORMAT(5X,1P10E12.4)                                               00009100
 1120 FORMAT(1H0,5X,'SHUTDOWN TOTAL GAMMA-RAY SOURCE--',1PE15.5)         00009200
      RETURN                                                             00009300
      END                                                                00009400
```

```
       SUBROUTINE  MOSRAD(NLFT,BMU,ALBD,PALB,ALBTN,ALBTY,ALBTG,MEDIUM,
     1                    IANGL,IANGL1,NTGRP,NGRP,NMTRX,MEDAM)
      COMMON /IFXCNT/ IFX1,IFX2,IFX3,IFX4
      COMMON /FDBIAS/ NFDBS,UBN,UBP,VBN,VBP,WBN,WBP,WTBSMI,WTBSMA,WTBS
      COMMON /APOLLO/ AGSTRT,DDF,DEADWT(5),ETA,ETATH,ETAUSD,UINP,VINP,
     1 WINP,WTSTRT,XSTRT,YSTRT,ZSTRT,TCUT,XTRA(10),
     2   IO,I1,MEDIA,IADJM,ISBIAS,ISOUR,ITERS,IXTRA,ITSTR,LOCWTS,LOCFWL,
     3 LOCEPR,LOCNSC,LOCFSN,MAXGP,MAXTIM,MEDALB,MGPREG,MXREG,NALB,
     4 NDEAD(5),NEWNM,NGEOM,NGPQT1,NGPQT2,NGPQT3,NGPQTG,NGPQTN,NITS,
     5 NKCALC,NKILL,NLAST,NMEM,NMGP,NMOST,NMTG,NOLEAK,NORMF,NPAST,
     6 NPSCL(13),NQUIT,NSIGL,NSOUR,NSPLT,NSTRT,NXTRA(10)
      COMMON /NUTRON/ NAME,NAMEX,IG,IGO,NMED,MEDOLD,NREG,U,V,W,UOLD,VOLD
     1 ,WOLD,X,Y,Z,XOLD,YOLD,ZOLD,WATE,OLDWT,WTBC,BLZNT,BLZON,AGE,OLDAGE
      COMMON /FISBNK/ MFISTP,NFISBN,NFISH,FTOTL,FWATE,WATEF
      COMMON /LIBSOS/ J11,J22,J33,J44
      COMMON /WATEND/ WTLAST
      COMMON /JOB1  / NTAPE,NNBAT,JWRTE,NESP1,NESP2
      COMMON /TIMELT/ ITMAX
      COMMON /SOURC / LGSR,LGS,LNGSTR,LSPINT,NSLOSS
      DIMENSION NTS(1)
      COMMON WTS(1)
      EQUIVALENCE(WTS(1),NTS(1))
      COMMON /AXISCT/ AXISD (6),PLFLG,PTITLE(20)
      COMMON /FLAG  / IRGIN
      LOGICAL  PLFLG
      DIMENSION  BUF(1024)
      DATA  IPLOT / 16 /
      DIMENSION DUMMY(10)
      DIMENSION BMU(1)
      DIMENSION ALBD (IANGL,IANGL,1),PALB(IANGL1,IANGL,NMTRX,1),
     1           ALBTN(IANGL,NTGRP,1),ALBTY(IANGL,NTGRP,1),
     2           ALBTG(IANGL,NTGRP,1)
      DIMENSION MEDIUM(1)
C
      ENDMK   = 1.0E+9
      IFX1    = 0
      IFX2    = 0
      ITOLD   = 0
      XTRA(1) = 0.0
      IXTRA   = XTRA(1)
C *******  BEGIN NEW PROBLEM   ****************************************
 10   NLAST   = NLFT
CCC   CALL TIMER(-2,XTRA)
      CALL ITIME(IXTRA)
C     MXT     = ICLOCK(0)
      CALL INPUT(BMU,ALBD,PALB,ALBTN,ALBTY,ALBTG,MEDIUM,
     1            IANGL,IANGL1,NTGRP,NGRP,NMTRX,MEDAM)
CRC   IF (PLFLG)  CALL  PLOTS (BUF,1024)
      IF (PLFLG)  REWIND  16
      IF (PLFLG)  WRITE(IPLOT)  AXISD,PTITLE
      WTBS    = 0.0
      J11     = 0
      J22     = 0
      J33     = 0
C ***** READS CARDS A THRU D - CALLS SORIN FOR CARDS E IF ISOUR .LE. ZER
C ***** READS CARDS F THRU O - CALLS JOMIN, XSEC AND SCORIN
      NTSTW   = NKILL+NSPLT
      NGPREG  = NMTG*MXREG
      NCOMB   = NGPQTN*NGPQTG
      IA      = LOCFWL + 1
      IU      = LOCFWL + MXREG
      DO 15 I=IA,IU
      IB      = I + MXREG
 15   WTS(IB) = WTS(I)
      IAW     = LOCWTS + 1
      IUW     = LOCWTS + 3*MGPREG
      DO 20 I=IAW,IUW
      IB      = I + 12*MGPREG
 20   WTS(IB) = WTS(I)
      INITS   = NITS
      IRUNS   = NQUIT
      INDX    = 0
C     CALL TIMER(INDX,XTRA)
C     WRITE (IO,1010) (XTRA(I),I=1,INDX)
       CALL  RNDOUT(RANDOM)
       WRITE (IO,1011) RANDOM
C     CALL  CLOCK(IXTRA)
      CALL CLOCKY(IXTRA)
C *****   BEGIN NEW RUN    ********************************************
 25   NITS    = INITS
```

```
      CALL BANKR( 1)
      DO 30 I IA,IU
      IB        I + MXREG
 30   WTS(I)    WTS(IB)
      DO 35 I IAW,IUW
      IB        I + 12*MGPREG
 35   WTS(I)    WTS(IB)
      ITERS     NITS
      ITSTR     0
C ****   BEGIN NEW BATCH   *********************************************
 40   NMEM      NSTRT
C      IF (J44)                  43, 41, 43
C41    J11    = 0
C      J22      0
C      J33      0
 43    IF (ITSTR)                45, 50, 45
 45   NMEM    = NFISH
 50   CALL    BANKR(-2)
C ***   CALLS STBTCH
      NBATCH = NITS-ITERS+1
      CALL    RNDOUT(RANDOM)
      IF(NBATCH.LE.10)
     *WRITE (IO,1015) NBATCH,RANDOM
      CALL    MSOUR
      IF (ITERS)              195,195, 55
 55   CALL    OUTPT(1)
      IF(NMEM.LE.0)           GO  TO  170
C *****   BEGIN NEW HISTORY   *****************************************
 60   CALL    GETNT(NMEM)
      IRGIN   = 1
      IF (.NOT. PLFLG .OR. NBATCH.GT.3 )  GO TO 61
      IST     = 0
      WRITE (IPLOT)  IST,X,Y,Z
      IST     = 1
   61 CONTINUE
      NMEM    = NMEM - 1
      NALB    = 0
      NGPQT   = NGPQT1
      IF(NMEM.GE.NSLOSS)              GO  TO  65
C ** ERROR SOURCE LOSS
      WRITE(IO,910)  NSLOSS
  910 FORMAT('0  SOURCE PARTICLE STORE',I5,' LOSSES. ERROR IN MOSRAD')
CRC   CALL  EXIT
 65   IF (WATE) 70,165,70
 70   IF (ABS(WATE)-WTLAST)  71, 71, 72
 71   IF (IG-NGPQT2)          72,165,165
 72   IF (IG-NGPQT)           90, 90, 75
 75   IF(IG-NGPQT2)          160,160, 80
 80   IF(IG-NGPQT3)           85, 85,160
 85   NGPQT   = NGPQT3
 90   IGO     = IG
      UOLD    = U
      VOLD    = V
      WOLD    = W
      OLDWT   = WATE
      XOLD    = X
      YOLD    = Y
      ZOLD    = Z
      BLZON   = BLZNT
      MEDOLD  = NMED
      OLDAGE  = AGE
      IF(NTSTW.GT.0)   CALL TESTW
      IF(WATE)                100,95,100
 95   NDEAD(1) = NDEAD(1)+1
      DEADWT(1) = DEADWT(1)+OLDWT
C   R R KILL
      GO TO 165
 100   IF (ABS(WATE)-WTLAST) 1001,1001,1002
 1001  IF (IG-NGPQT2)         1002, 95, 95
 1002 CONTINUE
C     WRITE(6,800)  IG,IGO,XOLD,YOLD,ZOLD,X,Y,Z,OLDWT,WATE
       CALL     NXTCOL
      IF (.NOT.  PLFLG .OR. NBATCH.GT.3 )   GO TO 1003
      WRITE (IPLOT)  IST,X,Y,Z
 1003 CONTINUE
C     WRITE(6,801)  IG,IGO,XOLD,YOLD,ZOLD,X,Y,Z,OLDWT,WATE
      IF (NREG-MXREG)          102,102,101
 101  WRITE (IO,1016) NREG,MXREG
      CALL EXIT
 102  IF (ICUT.LE.0..OR.AGE.LT.TCUT)          GO TO 110
```

```
      NDEAD(4) = NDEAD(4) +1
      DEADWT(4) = DEADWT(4)+OLDWT
C  AGE KILL
      NPSCL(10) = NPSCL(10) + 1
C **  CALL BANKR(12)  FOR TIME-KILL ANALYSIS
      GO TO 165
 110  IF(WATE)                     120,115,120
 115  NDEAD(2) = NDEAD(2)+1
      DEADWT(2) = DEADWT(2)+OLDWT
C ** ESCAPE ******
      GO TO 165
 120   IF (ABS(WATE)-WTLAST)  121,121,122
 121   IF (IG-NGPQT2)         122,115,115
 122   IF (NALB)              130,130,125
 125  ISCT   = LOCNSC + 2*NGPREG + (NREG-1)*NMTG + IG
      NTS(ISCT) = NTS(ISCT) + 1
      ISCT   = ISCT + NGPREG
      WTS(ISCT) = WTS(ISCT) + WATE
C ***  CALLS RELCOL (TRACK LENGTH) *****
      CALL   BANKR(2)
CRC   CALL   BANKR(11)
      CALL   ALBDO (IG,U,V,W,WATE,NMED,NREG,
     1              BMU,ALBD,PALB,ALBTN,ALBTY,ALBTG,MEDIUM,
     2              IANGL,IANGL1,NTGRP,NGRP,NMTRX,MEDAM,NCOMB)
      NPSCL(6) = NPSCL(6) + 1
CRC   CALL   BANKR(11)
      GO   TO   65
 130  CALL   GTMED(NMED,IMED)
C     WRITE(6,810)
      IF (MFISTP)                140,140,135
 135  CALL   FPROB
 140  IF (NCOMB)                 155,155,145
 145  IF(WTS(LOCFSN+(2*MEDIA+IMED-1)*NMTG+IG))  155,155,150
 150  CALL   GPROB
C
 155  ISCT   = LOCNSC + (NREG-1)*NMTG + IG
      NTS(ISCT) = NTS(ISCT) + 1
      ISCT   = ISCT + NGPREG
      WTS(ISCT) = WTS(ISCT) + WATE
      ISCT   = LOCNSC + 8*NGPREG + IMED
      NTS(ISCT) = NTS(ISCT) + 1
C ***   CALLS RELCOL (TRACK LENGTH) *****
      CALL   BANKR(2)
C ***   CALLS COLISN  ****
      CALL COLISN( IG,U,V,W,WATE,NMED,NREG)
CCC   WRITE(6,820)
C *
C ***  STORE IN SOURCE LOSS TO COLISN POINTS.
      IF(NSLOSS.LE.0)                          GO  TO  158
      L1     = LNGSTR+NREG-1
      IF(NTS(L1).LE.0)                         GO  TO  158
      NTS(L1) = NTS(L1) - 1
      WATED  = WATE
      IGD    = IG
      AGED   = AGE
      NAMED  = NAME
      NAMEXD = NAMEX
      WATE   = WTSTRT
      AGE    = AGSTRT
      NAME   = NSLOSS
      NAMEX  = NSLOSS
      L2     = LGS +(NREG-1)*NMTG
      R      = FLTRNF(X)
      DO  156  I=1,NMTG
      IF(R-WTS(L2+I-1))       157,157,156
  156 CONTINUE
      I      = NMTG
  157 IG     = I
      CALL  STORNT(NSLOSS)
      NPSCL(1) = NPSCL(1) + 1
      CALL  BANKR(1)
C **    CALLS  SDATA
      NSLOSS = NSLOSS - 1
      WATE   = WATED
      IG     = IGD
      AGE    = AGED
      NAME   = NAMED
      NAMEX  = NAMEXD
  158 CONTINUE
```

```
C
      IRGIN  = 0
C ****  CALLS RELCOL (POINT DETECTOR) ****
      CALL    BANKR(14)
      NPSCL(5) = NPSCL(5) + 1
C ****  FLIGHT DIRECTION BIASING (NFDBS > 0) ******
      IF(NFDBS.GT.0)       CALL FDBS(U,V,W,WATE)
      GO  TO  65
C
 160  NDEAD(3) = NDEAD(3)+1
      DEADWT(3) = DEADWT(3)+WATE
      NPSCL(9) = NPSCL(9) + 1
C *** CALL    BANKR(9)  FOR E-CUT ANALYSIS
C  ENERGY CUTOFF
 165  IF (NMEM)                     170,170,60
C ***** END OF HISTORY   *********************************************
 170  CALL BANKR(-3)
CRC   IF (PLFLG .AND. NBATCH.LE.3 )  CALL  PLOTA (NBATCH,NSTRT)
C ***    CALLS  NBATCH
      CALL     OUTPT(2)
 180  ITERS  = ITERS - 1
      IF(NESP2.GT.0)              WRITE(NESP2)  ENDMK,(DUMMY(1),I=1,7)
      IF(NBATCH.LE.10)
     *CALL     CLOCKY(IXTRA)
      IF(ITERS)                     195,195,184
 184  CALL     ITIME(ITNEW)
      TIMIT1 = ITNEW-ITOLD
      TIMIT2 = ITMAX-ITNEW
      LIMIT  = TIMIT2-1.3*TIMIT1-0.01
      ITOLD  = ITNEW
      IF(LIMIT)                     195,195,185
 185  IF(NSOUR)                     40,40,190
 190  ITSTR  = 1
C ***** END OF BATCH     *********************************************
      GO  TO  40
C ***    CALLS  NRUN
 195  NITS    = NBATCH
      CALL     BANKR(-4)
      NNXT    = NBATCH + NNBAT + 1
      CALL     RNDOUT(RANDOM)
      WRITE (10,1017) NNXT,RANDOM
      WRITE(10,1018) IFX1,IFX2,IFX3,IFX4
      NQUIT   = NQUIT-1
      INDX    = -1
C     CALL     TIMER(INDX,XTRA)
C     WRITE (10,1030) NITS,(XTRA(I),I=1,INDX)
C     CALL     TIMER(-2,XTRA)
C     CALL     CLOCK(IXTRA)
      CALL     CLOCKY(IXTRA)
C  END OF NITS BATCHES
      IF (NQUIT)                200,200,25
 200  CALL     OUTPT(3)
C ***** END OF RUN   ***************************************************
C     FTIME   = ICLOCK(0) - MXT
C     FTIME   = FTIME/6000.
C     WRITE(10,1040) FTIME
C     CALL     CLOCK(IXTRA)
      CALL     CLOCKY(IXTRA)
CRC   IF (PLFLG)     CALL PLOT (0.0,0.0,999)
      GO  TO  10
      RETURN
  800 FORMAT(1H0,'ENTER NXTCOL',2I5,8E13.5)
  801 FORMAT(1H0,'PASS NXTCOL ',2I5,8E13.5)
  810 FORMAT(1H ,'PASS  GTMED')
  820 FORMAT(1H ,'PASS  COLISN')
 1010 FORMAT (29H0TIME REQUIRED FOR INPUT WAS ,10A4)
 1011 FORMAT (4H0***,32X,15HINITIAL RANDOM=,Z8 )
 1015 FORMAT (15H0***START BATCH ,I4,25X,7HRANDOM=,Z8 /)
 1016 FORMAT  (6H0NREG=,I5,8H, MXREG=,I5,81H, MXREG ON CARD I MUST BE GE
     1 TO THE NUMBER OF REGIONS DESCRIBED IN GEOMETRY INPUT)
 1017 FORMAT (21H0***START NEXT BATCH=,I5,25X,7HRANDOM=,Z8 /)
 1018 FORMAT('  CALLED OF UNCOLL',I10,' UNCOLL TOTAL FLUXST',I10,/,
     1        '  CALLED OF RLCOLL',I10,' RLCOLL TOTAL FLUXST',I10)
 1030 FORMAT (32H0TIME REQUIRED FOR THE PRECEDING,I4,13H BATCHES WAS ,10
     1A4)
 1040 FORMAT (37H0TOTAL CPU TIME FOR THIS PROBLEM WAS ,F6.2,9H MINUTES.)
      END
```

```
      SUBROUTINE MSOUR                                                  00000100
      COMMON /NUTRON/ NAME,NAMEX,IG,IGO,NMED,MEDOLD,NREG,U,V,W,UOLD,VOLD 00000200
     1 ,WOLD,X,Y,Z,XOLD,YOLD,ZOLD,WATE,OLDWT,WTBC,IBLZN,IBLZO,AGE,OLDAGE 00000300
      COMMON /FISBNK/ MFISTP,NFISBN,NFISH,FTOTL,FWATE,WATEF             00000400
      COMMON /APOLLO/ AGSTRT,DDF,DEADWT(5),ETA,ETATH,ETAUSD,UINP,VINP,  00000500
     1 WINP,WTSTRT,XSTRT,YSTRT,ZSTRT,TCUT,XTRA(10),                     00000600
     2   IO,II,MEDIA,IADJM,ISBIAS,ISOUR,ITERS,ITIME,ITSTR,LOCWTS,LOCFWL, 00000700
     3 LOCEPR,LOCNSC,LOCFSN,MAXGP,MAXTIM,MEDALB,MGPREG,MXREG,NALB,      00000800
     4 NDEAD(5),NEWNM,NGEOM,NGPQT1,NGPQT2,NGPQT3,NGPQTG,NGPQTN,NITS,    00000900
     5 NKCALC,NKILL,NLAST,NMEM,NMGP,NMOST,NMTG,NOLEAK,NORMF,NPAST,      00001000
     6 NPSCL(13),NQUIT,NSIGL,NSOUR,NSPLT,NSTRT,NXTRA(10)                00001100
      COMMON /GEOMC/ XTWOG,YTWOG,ZTWOG,XONEG,YONEG,ZONEG,ETAG,ETAUSG,   00001200
     1 IBLZON,IBLDUM,MARKG,NMEDG,NREGG                                  00001300
      COMMON /ALBMED/ MALBD,MATRAL(5),MEDIAN(5),MEDN                    00001400
      COMMON /JDB1   / NTAPE,NNRAT,JWRTE,NESP1,NESP2                    00001500
      COMMON /SPECTR/ NGPFS,DFF,NSORCE,NEMIS,NSPEC,ETOP,EBOT,XO,YO,ZO,  00001510
     1 XL,XR,YL,YR,ZL,ZR,UVWINP(3),IMAX1,IMAX,JMAX,FE(100),DE(100),     00001520
     2 DFLUX(100),E(100),DEG(100),ENG(100),ANGDIS(100),JDIREC           00001530
      COMMON /SOURC / LGSR,LGS,LNGSTR,LSPINT,NSLOSS                     00001600
      COMMON    WTS(1)                                                  00001700
      DIMENSION NTS(1)                                                  00001800
      EQUIVALENCE (WTS(1),NTS(1))                                       00001900
      DOUBLE PRECISION                                                  00002000
     *       XTWOG,YTWOG,ZTWOG,XONEG,YONEG,ZONEG,ETAG,ETAUSG            00002100
     *        ,XDUM,YDUM,ZDUM                                           00002200
      DATA XDUM,YDUM,ZDUM /0.0D0,0.0D0,0.0D0/                           00002300
      DATA LPC /0/                                                      00002400
      UOLD=0.                                                           00002500
      VOLD=0.                                                           00002600
      WOLD=0.                                                           00002700
      ETATH=0.                                                          00002800
      XOLD=0.                                                           00002900
      YOLD=0.                                                           00003000
      ZOLD=0.                                                           00003100
      IBLZO = 0                                                         00003200
      OLDWT=WTSTRT                                                      00003300
      ETA=0.                                                            00003400
      IGO=0                                                             00003500
      MEDOLD=0.                                                         00003600
      OLDAGE=0.                                                         00003700
C                                                                       00003800
      DO  100  IR=1,MXREG                                               00003900
      NTS(LNGSTR+IR-1) = 0                                              00004000
  100 CONTINUE                                                          00004100
      DO  110  N=1,NMEM                                                 00004200
      R = FLTRNF(X)                                                     00004300
      DO  120  IR=1,MXREG                                               00004400
      IF(R-WTS(LGSR+IR-1))    125,125,120                               00004500
  120 CONTINUE                                                          00004600
      IR = MXREG                                                        00004700
  125 NREG = IR                                                         00004800
      L1 = LNGSTR+NREG-1                                                00004900
      NTS(L1) = NTS(L1) + 1                                             00005000
  110 CONTINUE                                                          00005100
C                                                                       00005200
      IF(LPC.NE.0)                      GO  TO  115                     00005300
      WRITE (6,1000)                                                    00005310
      CALL  SOINP                                                       00005320
  115 CONTINUE                                                          00005350
      LPC    = 1                                                        00005400
      N      = NMEM                                                     00005500
      NCNT   = 0                                                        00005600
   10 CONTINUE                                                          00005700
      IF(ITSTR)15,20,15                                                 00005800
 15   CALL GETNT(N)                                                     00005900
      GO TO 25                                                          00006000
 20   WATE=WTSTRT                                                       00006100
      AGE=AGSTRT                                                        00006200
      NAMEX=N                                                           00006300
   25 CONTINUE                                                          00006400
C ..   SOURCE GEOM. (X,Y,Z)                                              00006500
      R = FLTRNF(X)                                                     00006600
      XSTRT = R*(XR-XL) + XL                                            00006700
      R = FLTRNF(X)                                                     00006800
      YSTRT = R*(YR-YL) + YL                                            00006900
      R = FLTRNF(X)                                                     00007110
      ZSTRT = R*(ZR-ZL) + ZL                                            00007120
      X      = XSTRT                                                    00007132
      Y      = YSTRT                                                    00007133
      Z      = ZSTRT                                                    00007134
```

```
  130 CONTINUE
      XDUM = X
      YDUM = Y
      ZDUM = Z
      CALL LOOKZ(XDUM,YDUM,ZDUM)
      IF(NMEDG.EQ.MEDALB)                   GO TO    25
      IF(MALBD.EQ.0)                        GO  TO   27
      DO   26   M=1,MALBD
      IF(NMEDG.EQ.MATRAL(M))                GO  TO   25
   26 CONTINUE
   27 CONTINUE
C
      IF(NTS(LNGSTR+NREGG-1).GT.0)          GO  TO   28
      NCNT  = NCNT + 1
      IF(NCNT.LE.150)                       GO  TO   25
      DO   140   I=1,MXREG
      IF(NTS(LNGSTR+I-1).LE.0)            GO   TO   140
      LSP1     = LSPINT + 4*(I-1)
      IF(NTS(LSP1).EQ.0)                  GO   TO   140
      X         = WTS(LSP1+1)
      Y         = WTS(LSP1+2)
      Z         = WTS(LSP1+3)
      XDUM     = X
      YDUM     = Y
      ZDUM     = Z
      CALL  LOOKZ (XDUM,YDUM,ZDUM)
      GO  TO  29
  140 CONTINUE
CRC   IF(ITERS.NE.NITS)                     GO   TO   55
      WRITE(6,9010)  N
      L1        = LNGSTR
      L1E       = L1 +MXREG-1
      WRITE(6,9020) (NTS(L),L=L1,L1E)
      GO  TO  55
 9010 FORMAT(' POINT(X,Y,Z) OF SOURCE REGION TABLE IS NOT FOUND.
     1  ,5X,'SOURCE LOSSES',I4,'. THESE ARE CHANGE TO COLISN POINTS.')
 9020 FORMAT(5X,10I5)
   28 CONTINUE
      LSP1     = LSPINT + 4*(NREGG-1)
      NTS(LSP1)     = 1
      WTS(LSP1+1) = X
      WTS(LSP1+2) = Y
      WTS(LSP1+3) = Z
   29 CONTINUE
      NCNT     = 0
      L1        = LNGSTR+NREGG-1
      NTS(L1) = NTS(L1) - 1
C
C **     ISOTROPIC EMISSION
  170 R         = FLTRNF(X)
      U         = 2.0*R-1.0
      ROW       = SQRT(1.0-U*U)
      R         = FLTRNF(X)
      FAI       = 3.1415926*(2.0*R-1.0)
      V         = ROW*COS(FAI)
      W         = ROW*SIN(FAI)
C
      WATE      = 1.0
C
      L2        = LGS + (NREGG-1)*NMTG
      R         = FLTRNF(X)
      DO  180  I=1,NMTG
      IF(R-WTS(L2+I-1))      185,185,180
  180 CONTINUE
      I         = NMTG
  185 IG        = I
C
      IBLZN   = IBLZON
      NREG    = NREGG
      NMED    = NMEDG
      NAME=N
      IF(ITERS.EQ.NITS)   WRITE (6,1010) N,IG,NMED,NREG,U,V,W,X,Y,Z
C      WRITE(6,1020) NAME,NMED,NREG,IBLZN,XDUM,YDUM,ZDUM
       IF (ABS(U)+ABS(V)+ABS(W))35,35,30
 30    U1=U
       V1=V
       W1=W
      GO TO 40
 35   CALL GTISO(U1,V1,W1)
```

```
 40   U=U1
      V=V1
      W=W1
      IF(ISOUR)50,50,45
 45   IG=ISOUR
 50   CALL STORNT(N)
      NPSCL(1) = NPSCL(1) +1
      CALL BANKR(1)
C ***   CALLS  SDATA
      N      = N - 1
      IF(N.GT.0)                            GO  TO  10
 55   CONTINUE
      NSLOSS = N
      NEWNM  = NMEM
 60   FTOTL  = 0.0
      FWATE  = 0.0
      NFISH  = 0
      RETURN
C
 1000 FORMAT(1H ,'** SOURCE**  N IG NMED NREG',
     1          7X,'U',14X,'V',14X,'W',14X,'X',14X,'Y',14X,'Z',/  )
 1010 FORMAT(11X,4I5,1P6E15.5)
 1020 FORMAT(1H ,'** PASS LOOKZ ** NAME NMED NREG IBLZN    XDUM        YD
     1UM       ZDUM'/18X,4I6,3E13.3)
      END


      SUBROUTINE SOINP
      COMMON /SPECTR/ NGPFS,DFF,NSORCE,NEMIS,NSPEC,ETOP,EBOT,X0,Y0,Z0,
     1 XL,XR,YL,YR,ZL,ZR,UVWINP(3),IMAX1,IMAX,JMAX,FE(100),DE(100),
     2 DFLUX(100),E(100),DEG(100),ENG(100),ANGDIS(100),JDIREC
      COMMON /JOMIN2/ XPBD,XMBD,YPBD,YMBD,ZPBD,ZMBD,NOX,NOY,NOZ,
     1 NOXY,NOXYZ
      DOUBLE PRECISION
     *        XPBD,XMBD,YPBD,YMBD,ZPBD,ZMBD
C
      XL = XMBD
      XR = XPBD
      YL = YMBD
      YR = YPBD
      ZL = ZMBD
      ZR = ZPBD
      RETURN
      END
```

A.3 Sample Input Data

A.3.1 One-Dimensional Problem

```
    1                                                                   00000100
     0     0     0    42    42     0                                    00000200
ANISN SAMPLE DATA    (NEUTRON)                                          00000300
15¥¥  8306       0     5     8     2     1     0     2    13     0      00000400
          42     4     5    46    30     0   240   252     0     0      00000500
           1     0     9   200     3     1     2     1     1     1      00000600
           0     1     0     1     1     0                              00000700
16**  2Z 1.0-4 1.42089 1.0+9 2Z 0.03333 0.0 0.5 2.0 4 3Z 1              00000800
17**  1R1   F0   T                                                      00000900
3**   F1.0-3      T                                                     00001000
1**   F1.0                                                              00001100
4** 910 30 1150 100                                                     00001200
5**   F1.0                                                              00001300
 6*            0.0         0.0604938 2R0.0453704 2R0.0604938 2R0.045370400001400
   0.0604938   0.0         0.0453704   0.0462962 2R0.0453704   0.046296200001500
   0.0453704   0.0       4R0.0453704   0.0       2R0.0604938            00001600
 7*             -.975900   -.9511897   -.7867958    .5773503    .218217900001700
   +.2182179   +.5773503   +.7867958   +.9511897    .8164965   -.786795800001800
   -.5773503   -.2182179   +.2182179   +.5773503   +.7867958   -.617213400001900
   -.5773503   -.2182179   +.2182179   +.5773503   -.3086067   -.218217900002000
   +.2182179                                                            00002100
8¥¥ 10R1 3R2                                                            00002200
9¥¥ 241 247                                                             00002300
10¥¥ 41241 246 1Q6 41247 252 2Q6                                        00002400
11¥¥  6Z 4155 60                                                        00002500
      6Z 4I91 96 4I19 24                                                00002600
12**  6Z 6R8.476-2                                                      00002700
      6Z 6R4.005-5 6R1.001-5                                            00002800
19¥¥  F5                                                                00002900
22¥¥  241 247                                                           00003000
23¥¥  F1                                                                00003100
27¥¥  2  3  4  45   1                                                   00003200
28¥¥  4011  42                                                          00003300
     T        T                                                         00003400
STOP                                                                    00003500
```

```
ACT4 SAMPLE DATA.    CASE (ANISN)                                       00000100
          2G          2Y          2Y       2000Y       4000Y       8000Y00000200
          2Y                                                            00000300
    42    13     1     2     5    54     6     0     0     0     0      00000400
     2     0     0     0     0     0     0     0     0                  00000500
     2    -2     2     0     1     1    -1     0                        00000600
     5     8     8     1     1                                          00000700
    -1                                                                  00000800
 440.0         4.520E+16 0.1592      5.0         0.0         0.0        00000900
         30S          1M          1H          1D          1G          1Y00001000
 9¥¥   101     0                                                        00001100
10¥¥  4R26   101                                                        00001200
11¥¥  26054 26056 26057 26058                                           00001300
      26                                                                00001400
12**  0.058   0.918   0.0215   2.9-3  8.476-2                           00001500
   T                                                                    00001600
GAMMA                                                                   00001700
     1     4     0                                                      00001800
END                                                                     00001900
```

```
    1                                                                   00000100
    0    0    0   54   54    0                                          00000200
ANISN SAMPLE DATA.  (GAMMA)                                             00000300
15¥¥  8306       0     5     8     2     1     0     2    13     0      00000400
          54     4     5    58    30     0   240   252     0     0      00000500
           1     0     0   200     3     1     2     1     1     1      00000600
           0     1     0     1     1     0                              00000700
16**  2Z 1.0-4 1.42089 1.0+9 2Z 0.0 0.0 0.5 2.0-4 3Z 1                  00000800
17**                                                                    00000900
3**   F1.0-3      T                                                     00001000
1**   F1.0                                                              00001100
4** 9I0 30 1150 100                                                     00001200
5**   F1.0                                                              00001300
 6*            0.0         0.0604938 2R0.0453704 2R0.0604938 2R0.045370400001400
   0.0604938   0.0         0.0453704   0.0462962 2R0.0453704   0.046296200001500
   0.0453704   0.0       4R0.0453704   0.0       2R0.0604938            00001600
 7*            -.975900    -.9511897   -.7867958    .5773503   -.218217900001700
   +.2182179   +.5773503   +.7867958   +.9511897    .8164965    .786795800001800
   -.5773503   -.2182179   +.2182179   +.5773503   +.7867958   -.617213400001900
   -.5773503   -.2182179   +.2182179   +.5773503   -.3086067   -.218217900002000
   +.2182179                                                            00002100
8¥¥ 10R1 3R2                                                            00002200
9¥¥ 241 247                                                             00002300
10¥¥ 4I241 246 1Q6 4I247 252 2Q6                                        00002400
11¥¥  6Z 4I55 60                                                        00002500
      6Z 4I91 96 4I19 24                                                00002600
12**  6Z 6R8.476-2                                                      00002700
      6Z 6R4.005-5 6R1.001-5                                            00002800
19¥¥  F5                                                                00002900
22¥¥  241 247                                                           00003000
23¥¥  F1                                                                00003100
27¥¥   2 3 4 57 1                                                       00003200
28¥¥   52I1 54                                                          00003300
    T        T                                                          00003400
STOP                                                                    00003500
```

```
APPLE-2 SAMPLE DATA.    CASE-(ANISN)                                    00000100
FLUX    1                                                               00000200
  1  0                                                                  00000300
CROS    1                                                               00000400
  1  1  1  1                                                            00000500
10¥¥  1                                                                 00000600
11¥¥  1                                                                 00000700
12** F1 T                                                               00000800
RCAL    1                                                               00000900
  1  1  1  1  0.0508                                                    00001000
 9¥¥ F1                                                                 00001100
22¥¥  1                                                                 00001200
23¥¥ F1 T                                                               00001300
1DAY                                                                    00001400
RPLT    1                                                               00001500
  1                                                                     00001600
 15.0        20.0                                                       00001700
  AFTER SHUTDOWN DOSE RATE                                              00001800
DISTANCE FROM THE PLASMA AXIS (CM)                                      00001900
      DOSE RATE ( REM/HOUR)                                             00002000
SPEC    1                                                               00002100
  2  1  1-54  0  2                                                      00002200
  3  8                                                                  00002300
 15.0        20.0                                                       00002400
 GAMMA   ENERGY SPECTRA                                                 00002500
    GAMMA   ENERGY (EV)                                                 00002600
  GAMMA   FLUX PER UNIT LETHARGY                                        00002700
IRON    AIR                                                             00002800
END     0                                                               00002900
```

A.3.2 Two-Dimensional Problem

```
  DOT3.5 SAMPLE DATA (NEUTRON)
 0
61¥¥      0      3      2     13     10     42      4      5     46     20
          0      0    168      1     48      1      1      0      1      1
          1     30     30      3      0      2      0      0      0      0
          0      0      0      0      1      0      0      0      0      0
          3     -2      0      0      0      0      0      0      0      0
          2      1      1      0      0      0      0      0      0      8
          0
62¥¥      2      3      4     14     15      9     10     11     12     13
          8 60000      0      0
63**      1.0         1.0-3   0.          0.   14Z     T
7**  -0.27900      -0.18343     1M1    -0.60442      -0.52553      -0.18343
     1M2         -0.85077      -0.79667      -0.52553      -0.18343      1M3
     -0.98303      -0.96029      -0.79667  -0.52553      -0.18343        1M4
     1Q24    3R-0.96029  5R-0.79667  7R-0.52553  9R-0.18343  3R0.96029
     5R0.79667     7R0.52553     9R0.18343 T
6**  0.0      0.025307  1N2      0.035623      0.019972      1N2      0.0
     0.035623      0.016252      0.026552         1N4   0.025307      0.019972
     0.026552      0.018840     1N4      1Q24    T
17**      1.0   12Z   9Q13 T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
17**       F0.0   T
 3**       F0    T
 1**       F0
 5**       F1
2**    9I0.0   30.0
4**    9I0.0   30.0   1I50.0   100.0
8¥¥    10R1   3R2   9Q13
10¥¥   2I161    164 1Q4             2I165    168  2Q4
11¥¥   4Z   2I37   40    4Z   2I61   64  2I13   16
12**   4Z   4R8.476-2    4Z   4R4.005-5   4R1.001-5
9¥¥    -161   -165
19¥¥   -161   -165
20¥¥   F1
  T      T
```

```
ACT4 SAMPLE DATA.   CASE-(DOT)                                          00011100
          2G          2Y          2Y        2000Y       4000Y       8000Y00011200
          2Y                                                            00011300
    42    13    10     2     5    54     1     0     0     0     0      00011400
     1     0     0     0     0     0     0     0     0                  00011500
     2    -2     2     0    -1    -1    -1     0                        00011600
     1    12    12     5     5                                          00011700
    -1                                                                  00011800
 440.0        4.5200E+16   1.0       0.0         0.0         0.0        00011900
          1D                                                            00012000
 9¥¥   101     0                                                        00012100
10¥¥  4R26   101                                                        00012200
11¥¥  26054 26056 26057 26058                                           00012300
      26                                                                00012400
12**  0.058   0.918   0.0215   2.9-3  8.476-2                           00012500
  T                                                                     00012600
GAMMA                                                                   00012700
     1     1     0                                                      00012800
END                                                                     00012900
```

```
   DOT3.5 SAMPLE DATA (GAMMA)                                           00022100
  0                                                                     00022200
 61¥¥      0     3     2    13    10    54     4     5    58    20      00022300
           0     0   168     1    48     1     1     0     1     1      00022400
           1    10    10     3     0     2     0     0     0     0      00022500
           0     0     0     0     5     0     0     0     0     0      00022600
           3    -2     0     0     0     0     0     0     0     0      00022700
           2     1     1     0     0     0     0     0     0     8   Z  00022800
 62¥¥      2     3     4    14    15     9    10    11    12    13      00022900
           8 60000     0     0                                          00023000
 63**      0.0       1.0-3   0.        0.   14Z    T                     00023100
7**  -0.27900     -0.18343    1M1   -0.60442    -0.52553    -0.18343    00023200
     1M2      -0.85077    -0.79667    -0.52553    -0.18343    1M3       00023300
     -0.98303     -0.96029    -0.79667  -0.52553    -0.18343     1M4    00023400
     1Q24   3R-0.96029  5R-0.79667  7R-0.52553  9R-0.18343  3R0.96029   00023500
     5R0.79667    7R0.52553   9R0.18343 T                               00023600
6**  0.0    0.025307  1N2    0.035623    0.019972    1N2    0.0         00023700
     0.035623    0.016252    0.026552      1N4  0.025307   0.019972     00023800
     0.026552    0.018840    1N4   1Q24   T                             00023900
 3**      F0   T                                                        00024000
 1**      F0                                                            00024100
 5**      F1                                                            00024200
 2**                                                                    00024300
   9I0.0  30.0                                                          00024400
 4**                                                                    00024500
   9I0.0  30.0  1I50.0  100.0                                           00024600
8¥¥                                                                     00024700
10R1   3R2                                                              00024800
10R1   3R2                                                              00024900
10R1   3R2                                                              00025000
10R1   3R2                                                              00025100
10R1   3R2                                                              00025200
10R1   3R2                                                              00025300
10R1   3R2                                                              00025400
10R1   3R2                                                              00025500
10R1   3R2                                                              00025600
10R1   3R2                                                              00025700
 10¥¥                                                                   00025800
 2I161   164 1Q4         2I165   168 2Q4                                00025900
 11¥¥                                                                   00026000
 4Z         2I37     40                                                 00026100
 4Z         2I61     64 2I13     16                                     00026200
 12**                                                                   00026300
 4Z         4R8.476-2                                                   00026400
 4Z         4R4.005-5   4R1.001-5                                       00026500
  9¥¥                                                                   00026600
 -161  -165                                                             00026700
  19¥¥                                                                  00026800
 -161  -165                                                             00026900
  20¥¥  F1                                                              00027000
  T     T                                                               00027100
```

```
APPLE-2 SAMPLE DATA.  ( DOT3.5 )  GAMMA DOSE RATE.                      00015100
FLUX    1                                                               00015200
  2  0                                                                  00015300
CROS    1                                                               00015400
  1  1  1  1                                                            00015500
10¥¥  1                                                                 00015600
11¥¥  1                                                                 00015700
12** F1 T                                                               00015800
RCAL    1                                                               00015900
  1  1  1  1  0.0508                                                    00016000
 9¥¥ F1                                                                 00016100
22¥¥  1                                                                 00016200
23¥¥ F1 T                                                               00016300
SAMPLE                                                                  00016400
RPLT    1                                                               00016500
  2  5Z                                                                 00016600
 15.0       20.0                                                        00016700
  SHUTDOWN DOSE RATE (Z=15CM)                                           00016800
DISTANCE FROM THE PLASMA AXIS (CM)                                      00016900
      DOSE RATE ( REM/HOUR)                                             00017000
RPLT    1                                                               00017100
  3  1                                                                  00017200
 -1  1-10  0  0  0    0.0       90.0        1.0    +10  15.0        30.000017300
   SHUTDOWN DOSE RATE                                                   00017400
SPEC    1                                                               00017500
  2  1  1-54  0  2                                                      00017600
  1  1                                                                  00017700
  3 12                                                                  00017800
 15.0       20.0                                                        00017900
 GAMMA   ENERGY SPECTRA                                                 00018000
    GAMMA   ENERGY (EV)                                                 00018100
  GAMMA   FLUX PER UNIT LETHARGY                                        00018200
IRON    AIR                                                             00018300
END     0                                                               00018400
```

A.3.3 Three-Dimensional Problem

```
 MORSE -GG SAMPLE DATA. (NEUTRON)                                       00054400
  200  300 9000   42    0   42   42    0    4    0    0   10    0  250  00054500
    0    1    0   1.0      0.001     10000.0   2.2   +5  1.0  -8     0  00054600
 1.5000 +7 1.372  +7 1.2549 +7 1.1478 +7 1.0500 +7 9.3140 +6 8.261  +6  00054700
 7.328  +6 6.5000 +6 5.7570 +6 5.0990 +6 4.5160 +6 4.0000 +6 3.1620 +6  00054800
 2.5000 +6 1.8710 +6 1.4000 +6 1.0580 +6 8.0000 +5 5.6600 +5 4.0000 +5  00054900
 2.8300 +5 2.0000 +5 1.4100 +5 1.0000 +5 4.6500 +4 2.1500 +4 1.0000 +4  00055000
 4.6500 +3 2.1500 +3 1.0000 +3 4.6500 +2 2.1500 +2 1.0000 +2 4.6500 +1  00055100
 2.1500 +1 1.0000 +1 4.6500 +0 2.1500 +0 1.0000 +0 4.6500 -1 2.1500 -1  00055200
7C7F6D03                                                                00055300
    0    1    0    0    0    9   42                                     00055400
                   1    1    9  10.0     1.0    -4 1.0    -3 0.0        00055500
   -1                                                                   00055600
    1     MALE                                                          00055700
X-ZONE         -100.0,     100.0                                        00055800
Y-ZONE         -100.0,     100.0                                        00055900
Z-ZONE          -16.0,      16.0                                        00056000
ZONE      1    1    1                                                   00056100
X-BLOC         -100.0,     100.0                                        00056200
Y-BLOC         -100.0,     100.0                                        00056300
Z-BLOC          -16.0,      16.0                                        00056400
BLOC      1    1    1                                                   00056500
MEDI            1,    3,   10,    1,    2,    1,    2,    3,    4       00056600
SURF            1,    2,    3,    4,    5,    6,    7,    8,    9,   10,00056700
   11,   12,   13                                                       00056800
SECT01             -1 -1              1                                 00056900
SECT03              1 -1                    1                           00057000
SECT10                 1 -1                                             00057100
SECT01                -1    -1                                          00057200
SECT02                -1     1 -1                                       00057300
SECT01                -1        1 -1                                    00057400
SECT02                -1           1 -1                                 00057500
SECT03              1 -1                 -1                             00057600
SECT04                -1                  1 -1                          00057700
REGI            1,    2,   10,    4,    5,    6,    7,    8,    9       00057800
SURF            1,    2,    3,    4,    5,    6,    7,    8,    9,   10,00057900
   11,   12,   13                                                       00058000
SECT01             -1 -1              1                                 00058100
SECT02              1 -1                    1                           00058200
SECT10                 1 -1                                             00058300
SECT04                -1    -1                                          00058400
SECT05                -1     1 -1                                       00058500
SECT06                -1        1 -1                                    00058600
SECT07                -1           1 -1                                 00058700
SECT08              1 -1                 -1                             00058800
SECT09                -1                  1 -1                          00058900
   13                                                                   00059000
 1.0      X      -100.0        ¥                                        00059100
 1.0      X       100.0        ¥                                        00059200
 1.0      Y      -100.0        ¥                                        00059300
 1.0      Y       100.0        ¥                                        00059400
 1.0      XSQ     1.0     YSQ      -900.0      ¥                        00059500
 1.0      ZSQ    -225.0        ¥                                        00059600
 1.0      ZSQ    -256.0        ¥                                        00059700
 1.0      XSQ     1.0     YSQ       -36.0      ¥                        00059800
 1.0      XSQ     1.0     YSQ      -144.0      ¥                        00059900
 1.0      XSQ     1.0     YSQ      -324.0      ¥                        00060000
 1.0      XSQ     1.0     YSQ      -576.0      ¥                        00060100
 1.0      XSQ     1.0     YSQ     -2809.0      ¥                        00060200
 1.0      XSQ     1.0     YSQ     -5776.0      ¥                        00060300
   CROSS SECTION.                                                       00060400
   42   42    0    0   42   45    4    4    2    4    6    3    1       00060500
    0    0    0    0    0    0   -1    0    0    0    0    1            00060600
    1   -1 1.0                                                          00060700
    2   -1 1.0                                                          00060800
    3   -2 1.0                                                          00060900
    4   -2 1.0                                                          00061000
```

```
 DETECTER AND SOURCE INPUT SET.                                         00065100
   0   42   42     1     1     1     3     1     8     0     0          00065200
 0.0       0.0         0.0                                              00065300
    TOTAL FLUX                                                          00065400
   NEUTRON FLUX                                                         00065500
1.0        1.0        1.0        1.0        1.0        1.0        1.0   00065600
1.0        1.0        1.0        1.0        1.0        1.0        1.0   00065700
1.0        1.0        1.0        1.0        1.0        1.0        1.0   00065800
1.0        1.0        1.0        1.0        1.0        1.0        1.0   00065900
1.0        1.0        1.0        1.0        1.0        1.0        1.0   00066000
1.0        1.0        1.0        1.0        1.0        1.0        1.0   00066100
    FLUX                                                                00066200
    1    2    3    4    5    6    7    8    9   10   11   12   13   14  00066300
   15   16   17   18   19   20   21   22   23   24   25   26   27   28  00066400
   29   30   31   32   33   34   35   36   37   38   39   40   41   42  00066500
3.05349+4 6.55626+5 2.4000 +5 3.39300+3 1.01790+4 1.69650+4 2.37510+4  00066600
1.79919+5 2.79633+5                                                     00066700
              4    2    3  1.5  E+7  1.372E+7    1                      00066800
          0.0        0.0        0.0                                     00066900
          0.0        3.0        0.0        0.0       -15.0      15.0    00067000
                                                                        00067100
   1                                                                    00067200
1.41  E+7 1.0                                                           00067300
END                                                                     00067400
****  TOPIC PLANE DATA.
  -120.0  -120.0   0.0    120.0  -120.0   0.0   -120.0   120.0     0.0  00067500
0.001                                                                   00067600
  -120.0   0.0  -120.0    120.0   0.0   -120.0  -120.0     0.0   120.0  00067700
0.001                                                                   00067800
   0.0  -120.0  -120.0    0.0   120.0   -120.0     0.0  -120.0   120.0  00067900
0.01                                                                    00068000
```

```
ACT4 SAMPLE DATA.  CASE-(MORSE )                                        00048800
        2G          2Y          2Y        2000Y        4000Y        8000Y00048900
        2Y                                                              00049000
   42    9    1    2    5   54    1    0    0    0    0                00049100
    7    0    0    0    0    0    0    0    0                          00049200
    2   -2    2    0   -1   -1   -1    0                                00049300
    1   10   10    5    5                                               00049400
   -1                                                                   00049500
 440.0        4.5200E+16   1.0        0.0         0.0         0.0       00049600
        1D                                                              00049700
 8¥¥   1  2  2  1  1  1  1  2  2  T                                     00049800
 9¥¥   101     0                                                        00049900
10¥¥  4R26   101                                                        00050000
11¥¥  26054 26056 26057 26058                                           00050100
      26                                                                00050200
12**  0.058    0.918    0.0215    2.9-3  8.476-2                        00050300
  T                                                                     00050400
GAMMA                                                                   00050500
    1     1     0                                                       00050600
END                                                                     00050700
```

```
 MORSE-GG SAMPLE DATA. (GAMMA)                                          00021900
  200  300 9000   54    0   54   54    0    4    0    0   10    0  130  00022000
    0    1    0  1.0       0.001     10000.0   2.2   +5 1.0    -8    0  00022100
 3.0000 +6 2.7000 +6 2.5000 +6 2.3000 +6 2.1000 +6 2.0000 +6 1.900  +6  00022200
 1.8000 +6 1.7000 +6 1.6000 +6 1.5000 +6 1.4000 +6 1.3000 +6 1.2000 +6  00022300
 1.1000 +6 1.0000 +6 9.0000 +5 8.1000 +5 7.3000 +5 6.6000 +5 6.0000 +5  00022400
 5.5000 +5 5.0000 +5 4.5000 +5 4.0000 +5 3.6000 +5 3.3000 +5 3.0000 +5  00022500
 2.7000 +5 2.5000 +5 2.3000 +5 2.1000 +5 2.0000 +5 1.9000 +5 1.8000 +5  00022600
 1.7000 +5 1.6000 +5 1.5000 +5 1.4000 +5 1.3000 +5 1.2000 +5 1.1000 +5  00022700
 1.0000 +5 9.0000 +4 8.1000 +4 7.3000 +4 6.6000 +4 6.0000 +4 5.5000 +4  00022800
 5.0000 +4 4.5000 +4 4.0000 +4 3.6000 +4 3.3000 +4                      00022900
7C7F6003                                                                00023000
    0    1    0    0    0    9   54                                     00023100
                   1    1    9  10.0     1.0    -3 1.0    -2 0.0        00023200
   -1                                                                   00023300
    1     MALE                                                          00023400
X-ZONE         -100.0,     100.0                                        00023500
Y-ZONE         -100.0,     100.0                                        00023600
Z-ZONE          -16.0,      16.0                                        00023700
ZONE      1    1    1                                                   00023800
X-BLOC         -100.0,     100.0                                        00023900
Y-BLOC         -100.0,     100.0                                        00024000
Z-BLOC          -16.0,      16.0                                        00024100
BLOC      1    1    1                                                   00024200
MEDI            1,    3,   10,    1,    2,    1,    2,    3,    4       00024300
SURF            1,    2,    3,    4,    5,    6,    7,    8,    9,   10,00024400
   11,   12,   13                                                       00024500
SECT01             -1 -1              1                                 00024600
SECT03              1 -1                    1                           00024700
SECT10                 1 -1                                             00024800
SECT01                -1    -1                                          00024900
SECT02                -1     1 -1                                       00025000
SECT01                -1        1 -1                                    00025100
SECT02                -1           1 -1                                 00025200
SECT03              1 -1                -1                              00025300
SECT04                -1                 1 -1                           00025400
REGI            1,    2,   10,    4,    5,    6,    7,    8,    9       00025500
SURF            1,    2,    3,    4,    5,    6,    7,    8,    9,   10,00025600
   11,   12,   13                                                       00025700
SECT01             -1 -1              1                                 00025800
SECT02              1 -1                    1                           00025900
SECT10                 1 -1                                             00026000
SECT04                -1    -1                                          00026100
SECT05                -1     1 -1                                       00026200
SECT06                -1        1 -1                                    00026300
SECT07                -1           1 -1                                 00026400
SECT08              1 -1                -1                              00026500
SECT09                -1                 1 -1                           00026600
   13                                                                   00026700
 1.0      X      -100.0        ¥                                        00026800
 1.0      X       100.0        ¥                                        00026900
 1.0      Y      -100.0        ¥                                        00027000
 1.0      Y       100.0        ¥                                        00027100
 1.0      XSQ     1.0     YSQ      -900.0      ¥                        00027200
 1.0      ZSQ    -225.0        ¥                                        00027300
 1.0      ZSQ    -256.0        ¥                                        00027400
 1.0      XSQ     1.0     YSQ       -36.0      ¥                        00027500
 1.0      XSQ     1.0     YSQ      -144.0      ¥                        00027600
 1.0      XSQ     1.0     YSQ      -324.0      ¥                        00027700
 1.0      XSQ     1.0     YSQ      -576.0      ¥                        00027800
 1.0      XSQ     1.0     YSQ      -2809.0     ¥                        00027900
 1.0      XSQ     1.0     YSQ      -5776.0     ¥                        00028000
  CROSS SECTION.                                                        00028100
   54   54    0    0   54   57    4    4    2    4    6    3    0       00028200
    0    0    0    0    0    0   -1    0    0    0    0    1            00028300
    1   -1 1.0                                                          00028400
    2   -1 1.0                                                          00028500
    3   -2 1.0                                                          00028600
    4   -2 1.0                                                          00028700
  DETECTER AND SOURCE INPUT SET.                                        00028800
    0   54   54    1    1    1    3    1    8    0    0                 00028900
  0.0       0.0       0.0                                               00029000
```

```
                                                                      00032900
    TOTAL FLUX                                                        00033000
 SHUTDOWN DOSE RATE (MREM/HOUR)                                       00033000
0.13266-3 0.13612-3 0.12570-3 0.11531-3 0.10746-3 0.10232-3 0.97182-4 00033100
0.91994-4 0.86807-4 0.81605-4 0.76397-4 0.71168-4 0.65913-4 0.60626-4 00033200
0.55299-4 0.49927-4 0.44770-4 0.40115-4 0.35973-4 0.32356-4 0.29278-4 00033300
0.26468-4 0.23648-4 0.20820-4 0.18269-4 0.16288-4 0.14595-4 0.12909-4 00033400
0.11513-4 0.10405-4 0.93080-5 0.84939-5 0.79561-5 0.74239-5 0.68973-5 00033500
0.63776-5 0.58663-5 0.53647-5 0.48750-5 0.43997-5 0.39426-5 0.35085-5 00033600
0.31047-5 0.27578-5 0.24894-5 0.22983-5 0.21809-5 0.21296-5 0.21408-5 00033700
0.22251-5 0.24143-5 0.26973-5 0.30287-5 0.34423-5                     00033800
    FLUX                                                              00033900
   1    2    3    4    5    6    7    8    9   10   11   12   13   14 00034000
  15   16   17   18   19   20   21   22   23   24   25   26   27   28 00034100
  29   30   31   32   33   34   35   36   37   38   39   40   41   42 00034200
  43   44   45   46   47   48   49   50   51   52   53   54           00034300
3.05349+4 6.55626+5 2.4000 +5 3.39300+3 1.01790+4 1.69650+4 2.37510+4 00034400
1.79919+5 2.79633+5                                                   00034500
```

A.4 Sample Output Data

A.4.1 ACT4 Output for One-Dimensional Problem

```
                               ACT4 INPUT DATA CARD IMAGE LIST
      ----*----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8
   1  ACT4 SAMPLE DATA,    CASE-(ANISN)                                       00000100
   2            2G          2Y          2Y       2000Y       4000Y       8000Y00000200
   3            2Y                                                            00000300
   4      42    13     1     2     5    54     6     0     0     0     0      00000400
   5       2     0     0     0     0     0     0     0     0                  00000500
   6       2    -2     2     0     1    -1    -1     0                        00000600
   7       5     8     8     1     1                                          00000700
   8      -1                                                                  00000800
   9   440.0         4.520E+16 0.1592      5.0         0.0         0.0        00000900
  10           30S          1M          1H          1D          1G          1Y00001000
  11   9¥¥   101     0                                                        00001100
  12  10¥¥  4R26   101                                                        00001200
  13  11¥¥  26054 26056 26057 26058                                           00001300
  14        26                                                                00001400
  15  12**  0.058   0.918   0.0215  2.9-3  8.476-2                            00001500
  16    T                                                                     00001600
  17  GAMMA                                                                   00001700
  18       1     4     0                                                      00001800
  19  END                                                                     00001900
      ----*----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8

                                         I N P U T   D A T A   L I S T
                                    TIME  INTERVAL           = 2.00000000     G
                                    LINE  TIME               = 2.00000000     Y
                                    SCHEDULE  :---
                                        SHORT  POWER ON      = 2.00000000     Y
                                               CYCLE         = 2000.00000     Y
                                        LONG   POWER ON      = 4000.00000     Y
                                               CYCLE         = 8000.00000     Y
                                    OUTPUT  TIMING  AFTER  SHUTDOWN   :---
                                               (1)             2.00000000     Y

                                               (2)            0.0

                                               (3)            0.0

                                               (4)            0.0

                                               (5)            0.0

                                               (6)            0.0
  NO OF NEUTRON ENERGY GROUPS.       42             NO OF RADIAL MESH POINT.           13
  NO OF AXIAL  MESH POINT.            1             NO OF ZONE.                         2
  NO OF MIXING TABLE LENGTH.          5             NO OF GAMMA ENERGY GROUPS.         54
  NO OF OUTPUT TIMES.                 6                   IMATX                         0
  NO OF TRANSMUTATION RATE.           0             NO OF C-MAT ITERATION.             10

 SLAB/CYL/SPER/X Y/R-Z/R-T/3-D        2             IHALV (SHORT LIFE CONST.)           6
  FIRST RADIAL MESH POINT.            1             LAST  RADIAL MESH POINT.           13
  FIRST AXIAL  MESH POINT.            1             LAST  AXIAL  MESH POINT.            1
  RADIAL MESH INTERVAL.               1             AXIAL  MESH INTERVAL.               1
  TIME   MESH INTERVAL.               1
OPTION PARAMATER                   EXECUTE       PRINT
  INDUCED ACTIVITY                   YES           YES
  DECAY    HEAT                      YES           YES
  GAMMA RAY SOURCE                   YES           YES
  TRANSMUTATION RATE                 NO            NO
  ACTIVATION CHAIN TABLE DATA        -             NO
  GAMMA RAY CROSS SECTION DATA       -             NO
  GAMMA RAY EMITTED DATA             -             NO
  A-MAT & CMAT FORT DEBUGING         -             NO


   R     Z     PRINTED BY MESH
   1        0   0        0   0
   2        0   0        0   0
   3        0   0        0   0
   4        0   0        0   0
   5        8   8        1   1

   POWER  (MW THERMAL  )       4.4000E+02            PPFLUX (NORM. FACTOR)       4.5200E+16
   RR     (TORUS R    )        1.5920E-01            DTINTV (2**IHALV/DT)        1.2168E-05
   VAR    (USED C-MAT.)        1.0000E+00            PREC   (USED C-MAT.)        1.0000E-06
                                   OUTPUT  TIMING  AFTER  SHUTDOWN   :---
                                              (1)            30.0000000     S
                                              (2)            1.00000000     M
                                              (3)            1.00000000     H
                                              (4)            1.00000000     D
                                              (5)            1.00000000     G
                                              (6)            1.00000000     Y

    9¥ ARRAY     2 ENTRIES READ
   10¥ ARRAY     5 ENTRIES READ
   11¥ ARRAY     5 ENTRIES READ
   12* ARRAY     5 ENTRIES READ
```

```
   ONE DIMENSIONAL GEOMETRICAL DATA (ANISN)
NO          R              R-MID          VOLUME          ZONE
  1    0.0             1.50000E+00    2.82823E+01           1
  2    3.00000E+00     4.50000E+00    8.48470E+01           1
  3    6.00000E+00     7.50000E+00    1.41412E+02           1
  4    9.00000E+00     1.05000E+01    1.97976E+02           1
  5    1.20000E+01     1.35000E+01    2.54541E+02           1
  6    1.50000E+01     1.65000E+01    3.11106E+02           1
  7    1.80000E+01     1.95000E+01    3.67670E+02           1
  8    2.10000E+01     2.25000E+01    4.24235E+02           1
  9    2.40000E+01     2.55000E+01    4.80800E+02           1
 10    2.70000E+01     2.85000E+01    5.37365E+02           1
 11    3.00000E+01     4.00000E+01    5.02797E+03           2
 12    5.00000E+01     6.25000E+01    9.82026E+03           2
 13    7.50000E+01     8.75000E+01    1.37484E+04           2
 14    1.00000E+02

 ***TOTAL NEUTRON FLUX PRINTED *****
               R MESH-  1      R MESH-  2      R MESH-  3      R MESH-  4      R MESH-  5      R MESH-  6      R MESH-  7      R MESH-  8
1   1.00 MON     1.61307D+21     1.10752D+21     8.55173D+20     6.79725D+20     5.38814D+20     4.20430D+20     3.17209D+20     2.25662D+20
2   1.00 YEAR    1.93568D+22     1.32903D+22     1.02621D+22     8.15670D+21     6.46576D+21     5.04516D+21     3.80651D+21     2.70794D+21
3   2.00 YEAR    3.87136D+22     2.65806D+22     2.05242D+22     1.63134D+22     1.29315D+22     1.00903D+22     7.61303D+21     5.41588D+21
               R MESH-  9      R MESH- 10      R MESH- 11      R MESH- 12      R MESH- 13      R MESH-
1   1.00 MON     1.43735D+20     6.71764D+19     1.96219D+19     1.23869D+19     8.67544D+18
2   1.00 YEAR    1.72482D+21     8.06116D+20     2.35463D+20     1.48643D+20     1.04105D+20
3   2.00 YEAR    3.44963D+21     1.61223D+21     4.70926D+20     2.97285D+20     2.08211D+20

       ATOMIC DENSITY MIXING TABLE                                                MAT,L/ZONE
    MIXURE       COMPORNENT   NO.DENSITY  ABUNDANCE                                  101
  1     26        26054                    5.8000E-02                                  0
  2     26        26056                    9.1800E-01
  3     26        26057                    2.1500E-02
  4     26        26058                    2.9000E-03
  5    101           26          8.4760E-02

       ATOMIC DENSITY AND RATIO DATA BY ZONE
                   ZONE- 1        ZONE- 2       ZONE-
     DENSITY      8.47598E+22   0.0
   ISOTOPES       //     RATIO BY ZONE
   1  26054            0.05800       0.0
   2  26056            0.91800       0.0
   3  26057            0.02150       0.0
   4  26058            0.00290       0.0

    ACT CHAIN-TBL LOCATION SIZE
  KIAMAX=    15          NXQMAX=   21
  KCSMAX=    31          NXPMAX=   52
  KACPMX=    72
ACT CROSS SECTION FE54N3N  IN ALL ZERO
ACT CROSS SECTION FE54ND   IN ALL ZERO
ACT CROSS SECTION FE54NNA  IN ALL ZERO
ACT CROSS SECTION FE54NHE3 IN ALL ZERO
ACT CROSS SECTION FE56N3N  IN ALL ZERO
ACT CROSS SECTION FE56ND   IN ALL ZERO
ACT CROSS SECTION FE56NNA  IN ALL ZERO
ACT CROSS SECTION FE57N2N  IN ALL ZERO
ACT CROSS SECTION FE57N3N  IN ALL ZERO
ACT CROSS SECTION FE57ND   IN ALL ZERO
ACT CROSS SECTION FE58N2N   NOT FOUND
       GAMMA SOURCE OUTPUT TIMMING AFTER SHUTDOWN
    AT TIME   12ST NO.    4 SHUTDOWN           86400. SEC.
                                                    *** WRITTEN BY UNIT   20 ***
   ***  DELAYED GAMMA-RAY YIELD DATA TABLES ***             TIME INTERVAL (DTINTV) =     1.21682E-05
                 NUCLIDE 10K   HALF LIFE   NMPC
 1ALL-  0                0   0    0.0
                                              NOT NMPC TBL.

 2FE - 55           26055   0    8.18048E-09
                                                 3.00000E-08

 3MN - 54           25054   1    2.56969E-08
                                                 1.00000E-09

 4CR - 51           24051   1    2.89624E-07
                                                 8.00000E-08

 5FE - 53SHORT      26053   5    1.35752E-03
                                              NOT NMPC TBL.

 6FE -153SHORT      26153   5    4.60259E-03
                                              NOT NMPC TBL.

 7MN - 53           25053   0    5.87289E-15
                                              NOT NMPC TBL.

 8FE - 52SHORT      26052   7    2.32679E-05
                                              NOT NMPC TBL.

 9MN -152SHORT      25152   5    5.47512E-04
                                              NOT NMPC TBL.

10MN - 52           25052  19    1.43491E-06
                                                 5.00000E-09

11MN - 56SHORT      25056   8    7.46575E-05
                                                 2.00000E-08

12MN   57SHORT      25057  14    7.50162E-03
                                              NOT NMPC TBL.

13FE   59           26059   5    1.80040E-07
                                                 2.00000E-09

14MN - 58SHORT      25058  29    1.06149E-02
                                              NOT NMPC TBL.

15CR - 55SHORT      24055   1    3.28196E-03
                                              NOT NMPC TBL.
```

```
           GAMMA-ENERGY    EV
     1   0.30000E+07 -    0.27000E+07
     2   0.27000E+07 -    0.25000E+07
     3   0.25000E+07 -    0.23000E+07
     4   0.23000E+07 -    0.21000E+07
     5   0.21000E+07 -    0.20000E+07
     6   0.20000E+07 -    0.19000E+07
     7   0.19000E+07 -    0.18000E+07
     8   0.18000E+07 -    0.17000E+07
     9   0.17000E+07 -    0.16000E+07
    10   0.16000E+07 -    0.15000E+07
    11   0.15000E+07 -    0.14000E+07
    12   0.14000E+07 -    0.13000E+07
    13   0.13000E+07 -    0.12000E+07
    14   0.12000E+07      0.11000E+07
    15   0.11000E+07 -    0.10000E+07
    16   0.10000E+07 -    0.90000E+06
    17   0.90000E+06 -    0.81000E+06
    18   0.81000E+06 -    0.73000E+06
    19   0.73000E+06 -    0.66000E+06
    20   0.66000E+06 -    0.60000E+06
    21   0.60000E+06 -    0.55000E+06
    22   0.55000E+06 -    0.50000E+06
    23   0.50000E+06 -    0.45000E+06
    24   0.45000E+06 -    0.40000E+06
    25   0.40000E+06 -    0.36000E+06
    26   0.36000E+06 -    0.33000E+06
    27   0.33000E+06 -    0.30000E+06
    28   0.30000E+06 -    0.27000E+06
    29   0.27000E+06 -    0.25000E+06
    30   0.25000E+06 -    0.23000E+06
    31   0.23000E+06 -    0.21000E+06
    32   0.21000E+06 -    0.20000E+06
    33   0.20000E+06 -    0.19000E+06
    34   0.19000E+06 -    0.18000E+06
    35   0.18000E+06 -    0.17000E+06
    36   0.17000E+06 -    0.16000E+06
    37   0.16000E+06 -    0.15000E+06
    38   0.15000E+06 -    0.14000E+06
    39   0.14000E+06 -    0.13000E+06
    40   0.13000E+06 -    0.12000E+06
    41   0.12000E+06 -    0.11000E+06
    42   0.11000E+06 -    0.10000E+06
    43   0.10000E+06 -    0.90000E+05
    44   0.90000E+05      0.81000E+05
    45   0.81000E+05 -    0.73000E+05
    46   0.73000E+05 -    0.66000E+05
    47   0.66000E+05 -    0.60000E+05
    48   0.60000E+05 -    0.55000E+05
    49   0.55000E+05      0.50000E+05
    50   0.50000E+05 -    0.45000E+05
    51   0.45000E+05 -    0.40000E+05
    52   0.40000E+05 -    0.36000E+05
    53   0.36000E+05 -    0.33000E+05
    54   0.33000E+05 -    0.30000E+05
 LOCATION REQUESTED ---- 250000
 LOCATION USED      ----   9454
 LOCATION UNUSED    ---- 240546
 ELAPSED  TIME     1.4390SEC.

     INDUCED ACTIVITY          AT TIME 12
                                                     AT MESH (  8,  1)   (CURIES / CC)
                                                                                       SHORT LIFE LIMIT =    15.823HOUR
                ALL-  0          FE - 55          MN - 54          CR  51           FE - 53 SHORT  FE -153 SHORT  MN - 53          FE - 52 SHORT
 HALF LIFE       0.0   SEC        2.685 YEAR      10.257 MON        3.957 WEEK       8.510 MIN      2.510 MIN  ********* YEAR     8.275 HOUR
  0.0  SEC     3.793750E-01   2.107021E-01   2.789663E-02   6.696541E-03   3.704280E-04   2.172532E-04   2.621647E-09   0.0
 30.00 SEC     3.786425E-01   2.107021E-01   2.789661E-02   6.696481E-03   2.998307E-04   1.892343E-04   2.621643E-09   0.0
  1.00 MIN     3.780513E-01   2.107019E-01   2.789659E-02   6.696425E-03   2.928365E-04   1.648289E-04   2.621643E-09   0.0
  1.00 HOUR    3.482370E-01   2.106959E-01   2.789405E-02   6.689563E-03   2.794304E-06   1.383593E-11   2.621646E-09   0.0
  1.00 DAY     2.547353E-01   2.105533E-01   2.783477E-02   6.531049E-03   4.269724E-55   0.0            2.621646E-09   0.0
  1.00 MON     2.415038E-01   2.062175E-01   2.607373E-02   3.126579E-03   0.0            0.0            2.621646E-09   0.0
  1.00 YEAR    1.751943E-01   1.627619E-01   1.239847E-02   7.185827E-07   0.0            0.0            2.621641E-09   0.0
 INTGR D ST    6.684406E+06   5.885079E+06   6.274200E+05   5.808573E+04   6.478405E-01   2.970583E-01   8.273262E-02   0.0
               MN -152 SHORT  MN - 52        MN - 56 SHORT  MN - 57 SHORT  FE - 59        MN - 58 SHORT  CR - 55 SHORT
 HALF LIFE      21.100 MIN     5.591 DAY       2.579 HOUR      1.540 MIN       1.464 MON      1.088 MIN      3.520 MIN        8.275 HOUR
  0.0  SEC     2.253026E-05   3.478299E-06   1.219162E-01   1.653793E-03   9.771567E-03   8.818170E-05   3.665820E-05
 30.00 SEC     2.216322E-05   3.477134E-06   1.216434E-01   1.370516E-03   9.771518E-03   6.413265E-05   3.322084E-05
  1.00 MIN     2.180215E-05   3.476999E-06   1.213712E-01   1.054402E-03   9.771466E-03   4.664231E-05   3.010580E-05
  1.00 HOUR    3.138731E-06   3.460236E-06   9.318316E-02   3.090287E-15   9.765238E-03   2.236037E-21   2.709932E-10
  1.00 DAY     6.433816E-26   3.072734E-06   1.926130E-04   0.0            9.620748E-03   0.0            0.0
  1.00 MON     0.0            7.990042E-08   0.0            0.0            6.086111E-03   0.0            0.0
  1.00 YEAR    0.0            7.508610E-26   0.0            0.0            3.330190E-05   0.0            0.0
 INTGR D ST    1.747482E-01   5.447724E+00   4.494109E+03   1.901914E+00   1.093224E+05   8.421850E-02   5.424887E-02
PLOT OF CURVE
          Y MIN IS 10**-4.      NUMBER OF NUCLIDE       9
```

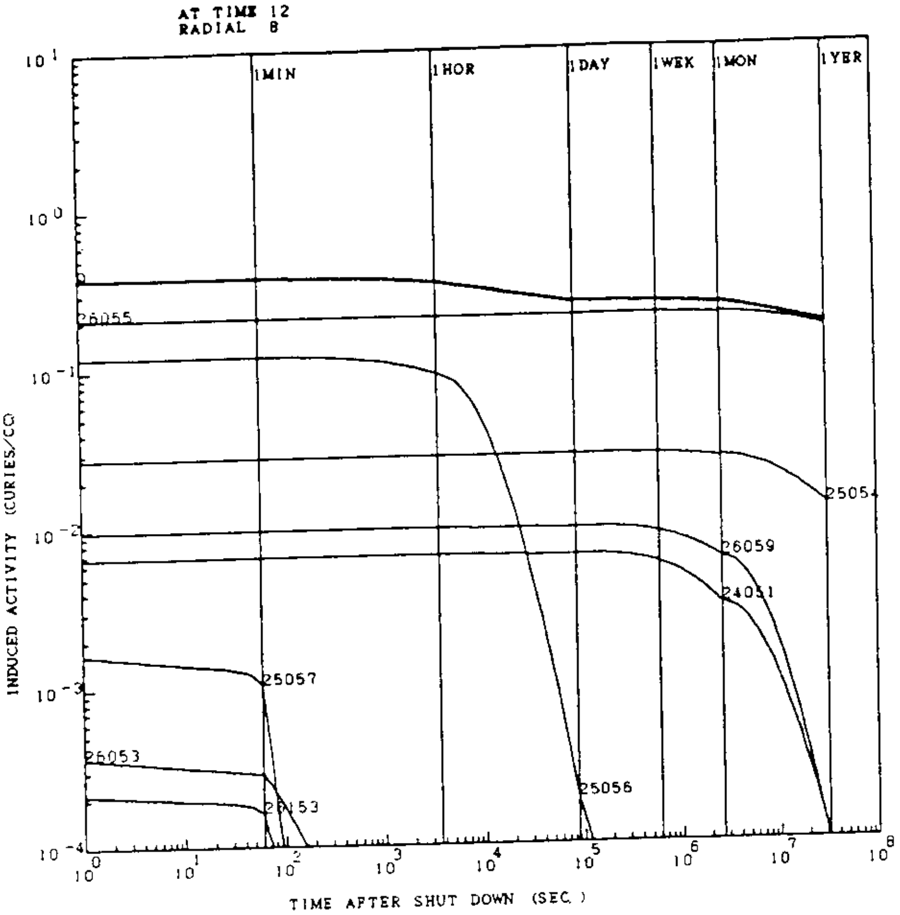
```
    DECAY HEAT                  AT TIME 12
                                              AT MESH (  8,  1)    (WATT    / CC)
                                                                                           SHORT LIFE LIMIT =    15.823HOUR
                                                                    FE - 53 SHORT  FE -153 SHORT  MN - 53          FE - 52 SHORT
                  ALL-   0         FE - 55         MN - 54        CR - 51          8.510 MIN      2.510 MIN   ********** YEAR    8.275 HOUR
   HALF LIFE       0.0   SEC        2.685 YEAR      10.257 MON      3.957 WEEK     7.070517E-06   3.908650E-06   0.0             0.0
   0.0   SEC     1.891112E-03   0.0             1.380516E-04   1.295663E-06   5.723002E-06   3.404555E-06   0.0             0.0
  30.00 SEC      1.883465E-03   0.0             1.380515E-04   1.295652E-06   5.589493E-06   2.965473E-06   0.0             0.0
   1.00 MIN      1.877560E-03   0.0             1.380514E-04   1.295642E-06   5.333608E-08   2.489252E-13   0.0             0.0
   1.00 HOUR     1.479954E-03   0.0             1.380389E-04   1.294314E-06   8.149802E-57   0.0            0.0             0.0
   1.00 DAY      7.160057E-04   0.0             1.377455E-04   1.263644E-06   0.0            0.0            0.0             0.0
   1.00 MON      1.766511E-04   0.0             1.290307E-04   6.049384E-07   0.0            0.0            0.0             0.0
   1.00 YEAR     6.161346E-05   0.0             6.135610E-05   1.390332E-10   1.236561E-02   5.344443E-03   0.0             0.0
  INTGR D ST     4.021786E+03   0.0             3.104904E+03   1.123857E+01
                 MN -152 SHORT  MN - 52         MN - 56 SHORT  MN - 57 SHORT  FE - 59        MN - 58 SHORT  CR - 55 SHORT
   HALF LIFE      21.100 MIN      5.591 DAY      2.579 HOUR      1.540 MIN      1.464 MON      1.088 MIN      3.520 MIN        8.275 HOUR
   0.0   SEC     3.238043E-07   7.209184E-08   1.655085E-03   7.924994E-06   7.548321E-05   1.735629E-06   1.617962E-07
  30.00 SEC      3.185292E-07   7.206768E-08   1.651381E-03   6.327927E-06   7.548276E-05   1.262287E-06   1.466250E-07
   1.00 MIN      3.133399E-07   7.206484E-08   1.647688E-03   5.052704E-06   7.548237E-05   9.180396E-07   1.328763E-07
   1.00 HOUR     4.510976E-08   7.171741E-08   1.265016E-03   1.480860E-17   7.543426E-05   4.401079E-23   1.196067E-12
   1.00 DAY      9.246673E-28   6.368606E-08   2.614832E-06   0.0            7.431812E-05   0.0            0.0
   1.00 MON      0.0            1.656032E-09   0.0            0.0            4.701383E-05   0.0            0.0
   1.00 YEAR     0.0            1.556249E-27   0.0            0.0            2.572497E-07   0.0            0.0
  INTGR D ST     2.511477E-03   1.129104E-01   6.101015E+01   9.113975E-03   8.444905E+02   1.657634E-03   2.394351E-04
 PLOT OF CURVE
       Y MIN IS 10**-6.     NUMBER OF NUCLIDE       9

    DECAY  GAMMA  SOURCE        AT TIME 12
                                              AT MESH (  8,  1)    (GAM RAY INTENSITY / ENERGY GROUPS. / CC)
                 GROUP-   1     GROUP-   2     GROUP-   3     GROUP-   4     GROUP-   5     GROUP-   6     GROUP-   7     GROUP-   8
   0.0   SEC     2.351496E+07   7.430214E+07   1.084375E+06   6.538066E+08   4.867977E+03   4.375700E+01   1.230078E+09   3.667551E+05
  30.00 SEC      2.307990E+07   7.412406E+07   9.390819E+05   6.513388E+08   3.540379E+03   4.374236E+01   1.227325E+09   2.875072E+05
   1.00 MIN      2.298787E+07   7.394965E+07   8.140108E+05   6.497846E+08   2.574841E+03   4.374065E+01   1.224580E+09   2.268546E+05
   1.00 HOUR     1.644705E+07   5.675731E+07   6.664801E-02   4.956925E+08   1.234382E-13   4.352975E+01   9.401746E+08   2.521313E+02
   1.00 DAY      3.396576E+04   1.173193E+05   0.0            1.024532E+06   0.0            3.865500E+01   1.943374E+06   5.168098E-18
   1.00 MON      0.0            0.0            0.0            0.0            0.0            1.005147E+00   0.0            0.0
   1.00 YEAR     0.0            0.0            0.0            0.0            0.0            9.445832E-19   0.0            0.0
 -INTGR D ST     7.959984E+11   2.737376E+12   1.467098E+09   2.391396E+13   4.649199E+06   6.853237E+07   4.534345E+13   4.201324E+08
                 GROUP-   9     GROUP- 10      GROUP- 11      GROUP- 12      GROUP- 13      GROUP- 14      GROUP- 15      GROUP- 16
   0.0   SEC     7.587509E+05   1.607237E+04   9.558352E+05   8.789144E+06   1.622087E+08   3.196489E+04   2.111652E+08   2.385614E+05
  30.00 SEC      5.814149E+05   1.177962E+04   9.402871E+05   7.394591E+06   1.620974E+08   2.324738E+04   2.102754E+08   2.113136E+05
   1.00 MIN      4.560921E+05   8.649117E+03   9.255836E+05   6.251311E+06   1.620028E+08   1.690732E+04   2.095004E+08   1.905807E+05
   1.00 HOUR     5.921108E+02   3.739980E-03   2.421561E+05   6.491496E+03   1.606204E+08   8.105386E-13   2.041424E+08   1.210434E+05
   1.00 DAY      5.343486E+01   0.0            1.136917E+05   5.764141E+03   1.548584E+08   0.0            2.011217E+08   1.074881E+05
   1.00 MON      1.389468E+00   0.0            7.956316E+03   1.498852E+02   9.795613E+07   0.0            1.272307E+08   2.795016E+03
   1.00 YEAR     1.305748E-18   0.0            2.778186E-15   1.408540E-16   5.359942E+05   0.0            6.961761E+05   2.626607E-15
  INTGR D ST     9.404360E+08   1.561552E+07   2.079273E+11   2.147716E+10   1.759720E+15   3.052827E+07   2.285395E+15   1.906927E+11
                 GROUP  17      GROUP- 18      GROUP- 19      GROUP- 20      GROUP- 21      GROUP- 22      GROUP- 23      GROUP- 24
   0.0   SEC     5.495353E+09   1.158273E+05   1.053724E+07   1.829608E+04   2.362558E+05   2.870034E+07   6.905544E+05   0.0
  30.00 SEC      5.484495E+09   1.157885E+05   8.988802E+06   1.358328E+04   1.886449E+05   2.352326E+07   5.022261E+05   0.0
   1.00 MIN      5.473894E+09   1.157840E+05   7.678741E+06   1.015598E+04   1.506287E+05   2.296750E+07   3.652583E+05   0.0
   1.00 HOUR     4.440900E+09   1.152257E+05   5.047671E-01   1.011427E+03   4.414691E-07   5.168924E+05   1.751049E-11   0.0
   1.00 DAY      1.036936E+09   1.023220E+05   0.0            8.981602E+02   0.0            7.641181E+04   0.0            0.0
   1.00 MON      9.647281E+08   2.660683E+03   0.0            2.335489E+01   0.0            1.986940E+03   0.0            0.0
   1.00 YEAR     4.587433E+08   2.500367E-15   0.0            2.194767E-17   0.0            1.867219E-15   0.0            0.0
  INTGR D ST     2.337895E+16   1.814092E+11   1.384050E+10   1.608872E+09   2.717018E+08   1.952660E+11   6.595192E+08   0.0
                 GROUP- 25      GROUP- 26      GROUP- 27      GROUP- 28      GROUP- 29      GROUP- 30      GROUP- 31      GROUP- 32
   0.0   SEC     5.952227E+06   2.007273E+06   2.527274E+07   0.0            0.0            1.005968E+05   0.0            9.780978E+01
  30.00 SEC      4.818358E+06   1.799733E+06   2.527253E+07   0.0            0.0            8.032431E+04   0.0            9.777704E+01
   1.00 MIN      4.680244E+06   1.634017E+06   2.527230E+07   0.0            0.0            6.413715E+04   0.0            9.777322E+01
   1.00 HOUR     4.572155E+04   9.768023E+05   2.524638E+07   0.0            0.0            1.879759E-07   0.0            9.730183E+01
   1.00 DAY      3.092397E+02   9.622269E+05   2.464816E+07   0.0            0.0            0.0            0.0            8.640530E+01
   1.00 MON      8.041180E+00   6.080317E+05   1.179970E+07   0.0            0.0            0.0            0.0            2.246799E+00
   1.00 YEAR     7.556667E-18   3.326860E+03   2.711930E+03   0.0            0.0            0.0            0.0            2.111421E-18
  INTGR D ST     1.093290E+10   1.092447E+13   2.192154E+14   0.0            0.0            1.156897E+08   0.0            1.531900E+08
                 GROUP- 33      GROUP- 34      GROUP- 35      GROUP- 36      GROUP- 37      GROUP- 38      GROUP- 39      GROUP- 40
   0.0   SEC     9.617188E+06   0.0            0.0            0.0            0.0            3.145469E+06   8.762452E+05   6.302603E+06
  30.00 SEC      9.617131E+06   0.0            0.0            0.0            0.0            3.145452E+06   6.996621E+05   5.032486E+06
   1.00 MIN      9.617081E+06   0.0            0.0            0.0            0.0            3.145435E+06   5.586646E+05   4.018326E+06
   1.00 HOUR     9.610951E+06   0.0            0.0            0.0            0.0            3.143430E+06   1.637357E-06   1.177708E-05
   1.00 DAY      9.468745E+06   0.0            0.0            0.0            0.0            3.096919E+06   0.0            0.0
   1.00 MON      5.989952E+06   0.0            0.0            0.0            0.0            1.959118E+06   0.0            0.0
   1.00 YEAR     3.277574E+04   0.0            0.0            0.0            0.0            1.071988E+04   0.0            0.0
  INTGR D ST     1.075952E+14   0.0            0.0            0.0            0.0            3.519088E+13   1.007711E+09   7.248191E+09
                 GROUP- 41      GROUP- 42      GROUP- 43      GROUP- 44      GROUP- 45      GROUP- 46      GROUP- 47      GROUP- 48
   0.0   SEC     0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
  30.00 SEC      0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
   1.00 MIN      0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
   1.00 HOUR     0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
   1.00 DAY      0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
   1.00 MON      0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
   1.00 YEAR     0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
  INTGR D ST     0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
                 GROUP  49      GROUP- 50      GROUP  51      GROUP- 52      GROUP- 53      GROUP- 54      GROUP-
   0.0   SEC     0.0            0.0            0.0            0.0            0.0            0.0
  30.00 SEC      0.0            0.0            0.0            0.0            0.0            0.0
   1.00 MIN      0.0            0.0            0.0            0.0            0.0            0.0
   1.00 HOUR     0.0            0.0            0.0            0.0            0.0            0.0
   1.00 DAY      0.0            0.0            0.0            0.0            0.0            0.0
   1.00 MON      0.0            0.0            0.0            0.0            0.0            0.0
   1.00 YEAR     0.0            0.0            0.0            0.0            0.0            0.0
  INTGR D ST     0.0            0.0            0.0            0.0            0.0            0.0
```

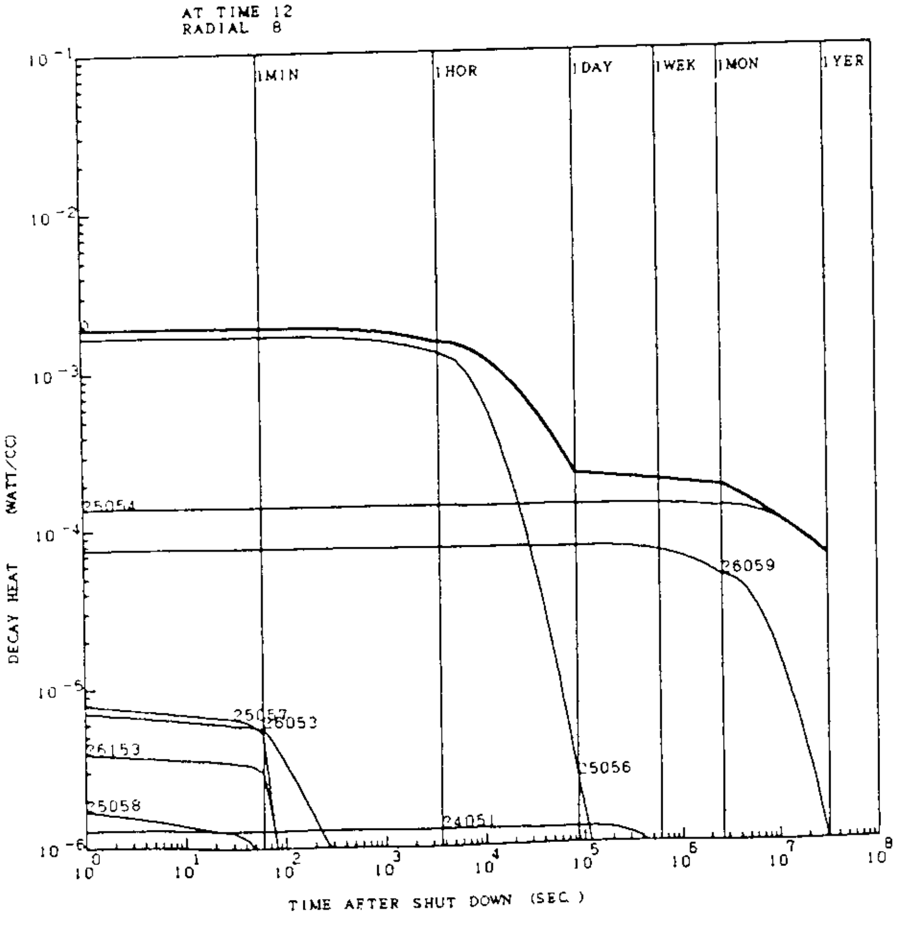
```
     DECAY  GAMMA  SOURCE       AT TIME 12
                                               AT MESH (  8,   1)    (GAM RAY INTENSITY / ENERGY GROUPS. / CC)
                                                                                                      AFTER SHUTDOWN    5
              GROUP-  1      GROUP-  2      GROUP-  3    . GROUP-  4      GROUP-  5      GROUP-  6      GROUP-  7      GROUP-  8
MN - 52        0.0            0.0            0.0            0.0            0.0            3.865500E+01   0.0            0.0
MN - 56SHO     3.396576E+04   1.173193E+05   0.0            1.024532E+06   0.0            0.0            1.943374E+06   0.0
              GROUP-  9      GROUP- 10      GROUP- 11      GROUP- 12      GROUP- 13      GROUP- 14      GROUP- 15      GROUP- 16
MN - 52        5.343486E+01   0.0            1.136912E+05   5.764141E+03   5.218422E+03   0.0            7.958385E+01   1.074881E+05
MN - 56SHO     0.0            0.0            0.0            0.0            7.116699E+03   0.0            0.0            0.0
FE   59        0.0            0.0            0.0            0.0            1.548460E+08   0.0            2.011217E+08   0.0
              GROUP- 17      GROUP- 18      GROUP- 19      GROUP- 20      GROUP- 21      GROUP- 22      GROUP- 23      GROUP- 24
MN   54        1.079886E+09   0.0            0.0            0.0            0.0            0.0            0.0            0.0
MN - 52        3.774546E+03   1.023220E+05   0.0            8.981602E+02   0.0            7.641181E+04   0.0            0.0
MN - 56SHO     7.046150E+06   0.0            0.0            0.0            0.0            0.0            0.0            0.0
              GROUP- 25      GROUP- 26      GROUP- 27      GROUP- 28      GROUP- 29      GROUP- 30      GROUP- 31      GROUP- 32
CR   51        0.0            0.0            2.464816E+07   0.0            0.0            0.0            0.0            0.0
MN - 52        3.092397E+02   1.114174E+03   0.0            0.0            0.0            0.0            0.0            8.640530E+01
FE - 59        0.0            9.611129E+05   0.0            0.0            0.0            0.0            0.0            0.0
              GROUP- 33      GROUP- 34      GROUP- 35      GROUP- 36      GROUP- 37      GROUP- 38      GROUP- 39      GROUP- 40
FE - 59        9.468745E+06   0.0            0.0            0.0            0.0            3.096919E+06   0.0            0.0

     INDUCED ACTIVITY           AT TIME 12
                                               OVER ALL        (CURIES / MW-TH)
                                                                                           SHORT LIFE LIMIT =    15.823HOUR
              ALL-  0        FE - 55        MN - 54        CR - 51        FE - 53 SHORT  FE -153 SHORT  MN - 53        FE - 52 SHORT
  HALF LIFE     0.0   SEC      2.685 YEAR    10.257 MON      3.957 WEEK     8.510 MIN      2.510 MIN  ********** YEAR    8.275 HOUR
  0.0  SEC     1.877599E+01   9.408357E+00   1.392572E+00   4.790708E-01   2.649623E-02   1.553980E-02   1.817823E-07   0.0
 30.00 SEC     1.873125E+01   9.408357E+00   1.392571E+00   4.790665E-01   2.144651E-02   1.353564E-02   1.817820E-07   0.0
  1.00 MIN     1.869576E+01   9.408357E+00   1.397571E+00   4.790624E-01   2.094620E-02   1.178997E-02   1.817820E-07   0.0
  1.00 HOUR    1.691441E+01   9.408088E+00   1.392442E+00   4.785714E-01   1.998725E-04   9.896630E-10   1.817822E-07   0.0
  1.00 DAY     1.135190E+01   9.401716E+00   1.389482E+00   4.672313E-01   3.054075E-53   0.0            1.817822E-07   0.0
  1.00 MON     1.078512E+01   9.208128E+00   1.301574E+00   2.236754E-01   0.0            0.0            1.817822E-07   0.0
  1.00 YEAR    7.886975E+00   7.267722E+00   6.189206E-01   5.140741E-05   0.0            0.0            1.817818E-07   0.0
 INTGR D ST    2.994565E+08   2.627834E+08   3.132014E+07   4.155451E+06   4.633911E+01   2.124817E+01   5.736596E+00   0.0
              MN -152 SHORT  MN - 52        MN - 56 SHORT  MN - 57 SHORT  FE - 59        MN - 58 SHORT  CR - 55 SHORT
  HALF LIFE     21.100 MIN      5.591 DAY      2.579 HOUR     1.540 MIN      1.464 MON      1.088 MIN      3.520 MIN      8.275 HOUR
  0.0  SEC     1.538194E-03   2.375692E-04   7.263513E+00   9.802514E-02   8.307040E-02   5.214658E-03   2.359314E-03
 30.00 SEC     1.513132E-03   2.374895E-04   7.247263E+00   7.827085E-02   8.306998E-02   3.792511E-03   2.138087E-03
  1.00 MIN     1.488484E-03   2.374804E-04   7.231049E+00   6.249753E-02   8.306950E-02   2.758210E-03   1.937605E-03
  1.00 HOUR    2.142885E-04   2.363354E-04   5.551655E+00   1.831704E-13   8.301657E-02   1.322290E-19   1.744104E-08
  1.00 DAY     4.392516E-24   2.098688E-04   1.147546E-02   0.0            8.178818E-02   0.0            0.0
  1.00 MON     0.0            5.457217E-06   0.0            0.0            5.173941E-02   0.0            0.0
  1.00 YEAR    0.0            5.128399E-24   0.0            0.0            2.831069E-04   0.0            0.0
 INTGR D ST    1.193047E+01   3.720811E+02   2.677492E+05   1.127321E+02   9.293744E+05   4.980289E+00   3.491446E+00
PLOT OF CURVE
       Y MIN IS 10**-2.     NUMBER OF NUCLIDE       9

     DECAY HEAT                 AT TIME 12
                                               OVER ALL        (MW-TH / PF MW-TH)
                                                                                           SHORT LIFE LIMIT =    15.823HOUR
              ALL    0       FE   55        MN - 54        CR - 51        FE - 53 SHORT  FE -153 SHORT  MN - 53        FE - 52 SHORT
  HALF LIFE     0.0   SEC      2.685 YEAR    10.257 MON      3.957 WEEK     8.510 MIN      2.510 MIN  ********** YEAR    8.275 HOUR
  0.0  SEC     1.076269E-07   0.0            6.891398E-09   9.269174E-11   5.057443E-10   2.795795E-10   0.0            0.0
 30.00 SEC     1.071500E-07   0.0            6.891394E-09   9.269088E-11   4.093583E-10   2.435223E-10   0.0            0.0
  1.00 MIN     1.067917E-07   0.0            6.891387E-09   9.269011E-11   3.998089E-10   2.121159E-10   0.0            0.0
  1.00 HOUR    8.300310E-08   0.0            6.890751E-09   9.259511E-11   3.815046E-12   1.780523E-17   0.0            0.0
  1.00 DAY     7.758430E-09   0.0            6.876107E-09   9.040101E-11   5.879437E-61   0.0            0.0            0.0
  1.00 MON     6.884132E-09   0.0            6.441073E-09   4.327722E-11   0.0            0.0            0.0            0.0
  1.00 YEAR    3.065036E-09   0.0            3.062840E-09   9.946423E-15   0.0            0.0            0.0            0.0
 INTGR D ST    1.666209E-01   0.0            1.549934E-01   8.040064E-04   8.844937E-07   3.822803E-07   0.0            0.0
              MN -152 SHORT  MN - 52        MN - 56 SHORT  MN - 57 SHORT  FE - 59        MN - 58 SHORT  CR - 55 SHORT
  HALF LIFE     21.100 MIN      5.591 DAY      2.579 HOUR     1.540 MIN      1.464 MON      1.088 MIN      3.520 MIN      8.275 HOUR
  0.0  SEC     2.210686E-11   4.923898E-12   9.860617E-08   4.697360E-10   6.416994E-10   1.026376E-10   1.041316E-11
 30.00 SEC     2.174667E-11   4.922248E-12   9.838561E-08   3.750735E-10   6.416958E-10   7.464611E-11   9.436745E-12
  1.00 MIN     2.139243E-11   4.922058E-12   9.816546E-08   2.994873E-10   6.416923E-10   5.428841E-11   8.551890E-12
  1.00 HOUR    3.079745E-12   4.898324E-12   7.536676E-08   8.777531E-22   6.412832E-10   7.602602E-27   7.697845E-17
  1.00 DAY     6.317903E-32   4.349775E-12   1.557859E-10   0.0            6.317944E-10   0.0            0.0
  1.00 MON     0.0            1.131072E-13   0.0            0.0            3.996747E-10   0.0            0.0
  1.00 YEAR    0.0            1.062920E-31   0.0            0.0            2.186935E-12   0.0            0.0
 INTGR D ST    1.714643E-07   7.711817E-06   3.634851E-03   5.402132E-07   7.179197E-03   9.802403E-08   1.540997E-08
```

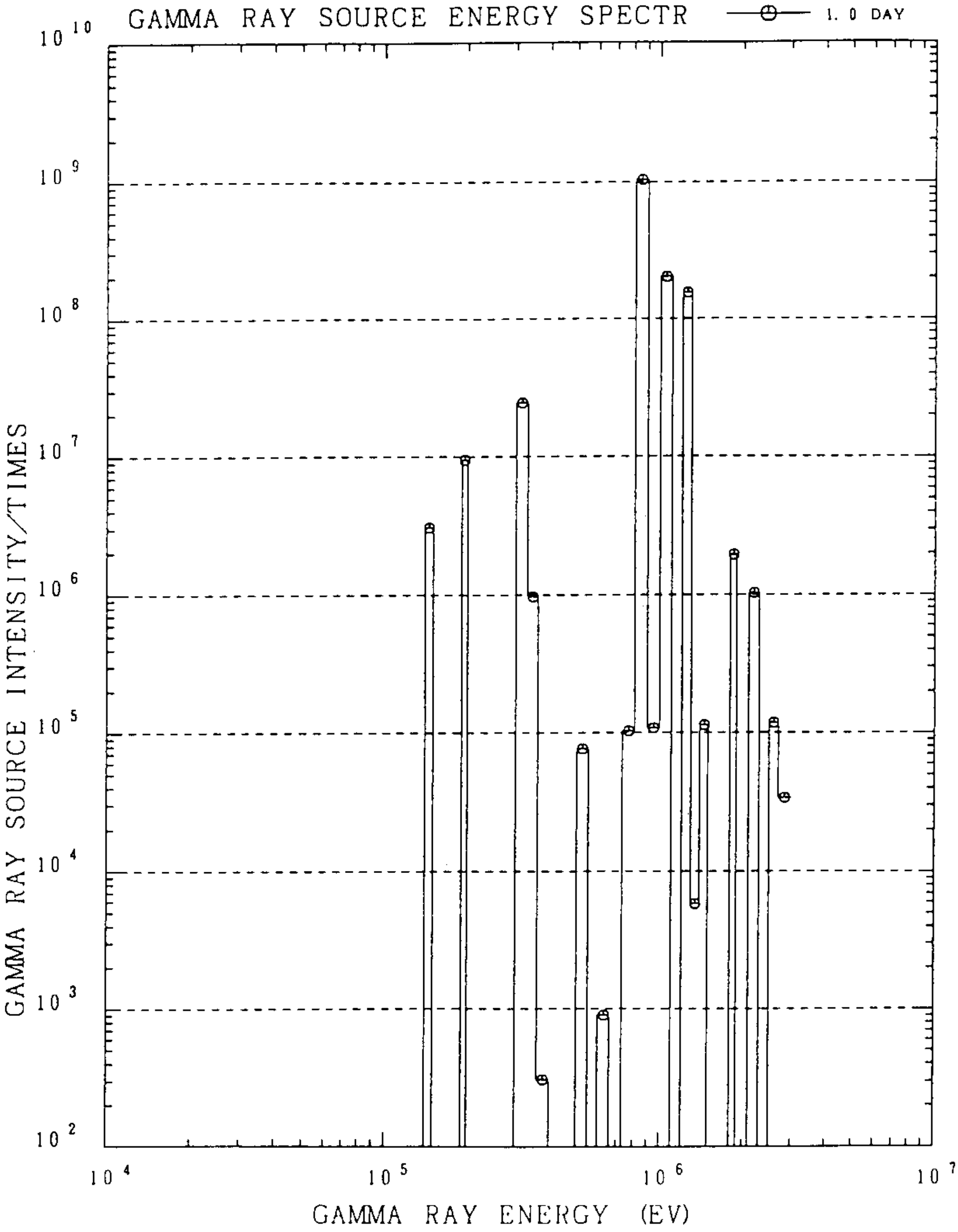
```
  DECAY  GAMMA  SOURCE        AT TIME 12
                                           OVER ALL        (GAM RAY INTENSITY / ENERGY GROUPS.)
             GROUP-  1      GROUP-  2      GROUP-  3      GROUP-  4      GROUP-  5      GROUP-  6      GROUP-  7      GROUP-  8
 0.0  SEC    6.268473E+11   1.947767E+12   3.392162E+10   1.716686E+13   1.266628E+08   1.314993E+06   3.224556E+13   1.012098E+10
30.00 SEC    6.134575E+11   1.943102E+12   2.940514E+10   1.709688E+13   9.211917E+07   1.314552E+06   3.217343E+13   7.984907E+09
 1.00 MIN    6.108491E+11   1.938531E+12   2.550983E+10   1.705561E+13   6.699624E+07   1.314501E+06   3.210146E+13   6.342279E+09
 1.00 HOUR   4.317262E+11   1.487851E+12   2.097584E+03   1.299442E+13   3.711811E-09   1.308163E+06   2.464597E+13   7.573995E+06
 1.00 DAY    8.903854E+08   3.075437E+09   0.0            2.685730E+10   0.0            1.161665E+06   5.094406E+10   1.552485E-13
 1.00 MON    0.0            0.0            0.0            0.0            0.0            3.020679E+04   0.0            0.0
 1.00 YEAR   0.0            0.0            0.0            0.0            0.0            2.838671E-14   0.0            0.0
INTGR D ST   2.088474E+16   7.175824E+16   4.597618E+13   6.269356E+17   1.209700E+11   2.059544E+12   1.188644E+18   1.176771E+13
             GROUP-  9      GROUP- 10      GROUP- 11      GROUP- 12      GROUP- 13      GROUP- 14      GROUP- 15      GROUP- 16
 0.0  SEC    2.014736E+10   4.193592E+08   2.868291E+10   2.666740E+11   7.176096E+11   8.317125E+08   9.809588E+11   6.701900E+09
30.00 SEC    1.545579E+10   3.075548E+08   2.822449E+10   2.254929E+11   7.146015E+11   6.048868E+08   9.529893E+11   5.991961E+09
 1.00 MIN    1.218443E+10   2.260014E+08   2.778914E+10   1.914813E+11   7.122859E+11   4.399209E+08   9.286268E+11   5.451842E+09
 1.00 HOUR   1.854976E+07   1.059097E+02   7.275905E+09   1.950847E+08   6.783376E+11   2.108989E-08   7.636091E+11   3.637618E+09
 1.00 DAY    1.605832E+06   0.0            3.416664E+09   1.732248E+08   5.795512E+11   0.0            7.523066E+11   3.230250E+09
 1.00 MON    4.175645E+04   0.0            8.884350E+07   4.504365E+06   3.664177E+11   0.0            4.759093E+11   8.399616E+07
 1.00 YEAR   3.924046E-14   0.0            8.349034E-11   4.232959E-12   7.004908E+09   0.0            2.604076E+09   7.893509E-11
INTGR D ST   2.554751E+13   4.080300E+11   6.248546E+15   6.519385E+14   6.586284E+18   7.943320E+11   8.548870E+18   5.730221E+15
             GROUP- 17      GROUP- 18      GROUP- 19      GROUP- 20      GROUP- 21      GROUP- 22      GROUP- 23      GROUP- 24
 0.0  SEC    1.396695E+14   3.480864E+09   3.175521E+11   4.801562E+08   6.161576E+09   9.001930E+11   1.796795E+10   0.0
30.00 SEC    1.393851E+14   3.479696E+09   2.716562E+11   3.575299E+08   4.919878E+09   7.374625E+11   1.306770E+10   0.0
 1.00 MIN    1.391074E+14   3.479563E+09   2.326757E+11   2.683525E+08   3.928412E+09   7.201298E+11   9.503855E+09   0.0
 1.00 HOUR   1.120287E+14   3.462786E+09   1.588627E+04   3.039557E+07   1.151355E-02   1.581875E+10   4.556165E-07   0.0
 1.00 DAY    2.280559E+13   3.074997E+09   0.0            2.699163E+07   0.0            2.296339E+09   0.0            0.0
 1.00 MON    2.118962E+13   7.995914E+07   0.0            7.018636E+05   0.0            5.971168E+07   0.0            0.0
 1.00 YEAR   1.007603E+13   7.514128E-11   0.0            6.595736E-13   0.0            5.611384E-11   0.0            0.0
INTGR D ST   5.142016E+20   5.451731E+15   4.194011E+14   4.828347E+13   7.086010E+12   5.934309E+15   1.716039E+13   0.0
             GROUP- 25      GROUP- 26      GROUP- 27      GROUP- 28      GROUP- 29      GROUP- 30      GROUP- 31      GROUP- 32
 0.0  SEC    1.863329E+11   3.054748E+10   7.955257E+11   0.0            0.0            2.623577E+09   0.0            2.939395E+06
30.00 SEC    1.508448E+11   2.513492E+10   7.955186E+11   0.0            0.0            2.094866E+09   0.0            2.938409E+06
 1.00 MIN    1.466557E+11   2.081313E+10   7.955118E+11   0.0            0.0            1.672703E+09   0.0            2.938297E+06
 1.00 HOUR   1.435687E+09   3.686782E+09   7.946965E+11   0.0            0.0            4.902430E-03   0.0            2.924130E+06
 1.00 DAY    9.293323E+06   3.628566E+09   7.758656E+11   0.0            0.0            0.0            0.0            2.596663E+06
 1.00 MON    2.416542E+05   2.275128E+09   3.714264E+11   0.0            0.0            0.0            0.0            6.752100E+04
 1.00 YEAR   2.270937E-13   1.244426E+07   8.536506E+07   0.0            0.0            0.0            0.0            6.345261E-14
INTGR D ST   3.420268E+14   4.094182E+16   6.900376E+18   0.0            0.0            3.017198E+12   0.0            4.603685E+12
             GROUP- 33      GROUP- 34      GROUP- 35      GROUP- 36      GROUP- 37      GROUP- 38      GROUP- 39      GROUP- 40
 0.0  SEC    3.597348E+10   0.0            0.0            0.0            0.0            1.176576E+10   2.285256E+10   1.643723E+11
30.00 SEC    3.597328E+10   0.0            0.0            0.0            0.0            1.176569E+10   1.824725E+10   1.312476E+11
 1.00 MIN    3.597309E+10   0.0            0.0            0.0            0.0            1.176562E+10   1.457002E+10   1.047983E+11
 1.00 HOUR   3.595016E+10   0.0            0.0            0.0            0.0            1.175813E+10   4.270244E-02   3.071473E-01
 1.00 DAY    3.541822E+10   0.0            0.0            0.0            0.0            1.158415E+10   0.0            0.0
 1.00 MON    2.240564E+10   0.0            0.0            0.0            0.0            7.328158E+09   0.0            0.0
 1.00 YEAR   1.225990E+08   0.0            0.0            0.0            0.0            4.009813E+07   0.0            0.0
INTGR D ST   4.074636E+17   0.0            0.0            0.0            0.0            1.316328E+17   2.628119E+13   1.890337E+14
             GROUP- 41      GROUP- 42      GROUP- 43      GROUP- 44      GROUP- 45      GROUP- 46      GROUP- 47      GROUP- 48
 0.0  SEC    0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
30.00 SEC    0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
 1.00 MIN    0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
 1.00 HOUR   0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
 1.00 DAY    0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
 1.00 MON    0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
 1.00 YEAR   0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
INTGR D ST   0.0            0.0            0.0            0.0            0.0            0.0            0.0            0.0
             GROUP- 49      GROUP- 50      GROUP- 51      GROUP- 52      GROUP- 53      GROUP- 54      GROUP-
 0.0  SEC    0.0            0.0            0.0            0.0            0.0            0.0
30.00 SEC    0.0            0.0            0.0            0.0            0.0            0.0
 1.00 MIN    0.0            0.0            0.0            0.0            0.0            0.0
 1.00 HOUR   0.0            0.0            0.0            0.0            0.0            0.0
 1.00 DAY    0.0            0.0            0.0            0.0            0.0            0.0
 1.00 MON    0.0            0.0            0.0            0.0            0.0            0.0
 1.00 YEAR   0.0            0.0            0.0            0.0            0.0            0.0
INTGR D ST   0.0            0.0            0.0            0.0            0.0            0.0
```

```
     DECAY  GAMMA  SOURCE      AT TIME 12
                                            OVER ALL      (GAM RAY INTENSITY / ENERGY GROUPS.)
                                                                                                   AFTER SHUTDOWN    5
            GROUP-  1     GROUP-  2     GROUP-  3     GROUP-  4     GROUP-  5     GROUP-  6     GROUP-  7     GROUP-  8
MN - 52      0.0           0.0           0.0           0.0           0.0           1.161665E+06  0.0           0.0
MN - 56SHO   8.903854E+08  3.075437E+09  0.0           2.685730E+10  0.0           0.0           5.094406E+10  0.0
            GROUP   9     GROUP- 10     GROUP- 11     GROUP- 12     GROUP- 13     GROUP- 14     GROUP- 15     GROUP- 16
MN - 52      1.605832E+06  0.0           3.416664E+09  1.732248E+08  1.568248E+08  0.0           2.391667E+06  3.230250E+09
MN - 56SHO   0.0           0.0           0.0           0.0           1.865588E+08  0.0           0.0           0.0
FE - 59      0.0           0.0           0.0           0.0           5.792078E+11  0.0           7.523043E+11  0.0
            GROUP- 17     GROUP- 18     GROUP- 19     GROUP- 20     GROUP- 21     GROUP- 22     GROUP- 23     GROUP- 24
MN - 54      2.262079E+13  0.0           0.0           0.0           0.0           0.0           0.0           0.0
MN - 52      1.134332E+08  3.074997E+09  0.0           2.699163E+07  0.0           2.296339E+09  0.0           0.0
MN - 56SHO   1.847093E+11  0.0           0.0           0.0           0.0           0.0           0.0           0.0
            GROUP- 25     GROUP- 26     GROUP- 27     GROUP- 28     GROUP- 29     GROUP- 30     GROUP- 31     GROUP- 32
CR - 51      0.0           0.0           7.758656E+11  0.0           0.0           0.0           0.0           0.0
MN - 52      9.293323E+06  3.348328E+07  0.0           0.0           0.0           0.0           0.0           2.596663E+06
FE - 59      0.0           3.595083E+09  0.0           0.0           0.0           0.0           0.0           0.0
            GROUP- 33     GROUP- 34     GROUP- 35     GROUP- 36     GROUP- 37     GROUP- 38     GROUP- 39     GROUP- 40
FE - 59      3.541822E+10  0.0           0.0           0.0           0.0           1.158415E+10  0.0           0.0


     BIOLOGICAL HAZARD POTENTIAL (B.H.P)          <KM**3 AIR / KW>
 SHUT DOWN  AT TIME- 12    AT TIME-
  0.0  SEC    2.116928E+03
 30.00 SEC    2.116114E+03
  1.00 MIN    2.115302E+03
  1.00 HOUR   2.031164E+03
  1.00 DAY    1.750220E+03
  1.00 MON    1.637176E+03
  1.00 YEAR   8.613164E+02
  ELAPSED  TIME     7.2740SEC.
DELAYED GAMMA RAY SOURCE  ( 13,  1), 54G     WRITTEN BY LOGICAL FILE NO. 17
    SHUTDOWN TIME NO.  5
*************************************************
***************<  DECAY HEAT  >******************
*************************************************

   IRMAX       13
   JZMAX        1
   NZONE        2
   IGM          1

      Z-MESH  POINT  IS     1
 R-MSH  ZONE  RADIAL         BETA           B & G
    1     1   0.0            2.29061E-04    3.24368E-02
    2     1   3.00000E+00    7.14591E-05    9.03576E-03
    3     1   6.00000E+00    3.95948E-05    4.02864E-03
    4     1   9.00000E+00    2.52354E-05    1.94192E-03
    5     1   1.20000E+01    1.82896E-05    1.05977E-03
    6     1   1.50000E+01    1.36424E-05    6.06613E-04
    7     1   1.80000E+01    1.00993E-05    3.56127E-04
    8     1   2.10000E+01    7.12598E-06    2.16006E-04
    9     1   2.40000E+01    4.46171E-06    1.25796E-04
   10     1   2.70000E+01    1.96530E-06    6.34877E-05
   11     2   3.00000E+01    0.0            0.0
   12     2   5.00000E+01    0.0            0.0
   13     2   7.50000E+01    0.0            0.0
GAMMA RAY SOURCE COPY END WRITTEN BY LOGICAL UNIT 17     EBSDIC TYPE READ IN 17*
   NEXT STEP CALC. IN ANISN FOR GAMMA RAY TRANSPORT
                                *** THIDA SYSTEM STEP NO.2 (ACT4) PROCESSING END***
 LOCATION REQUESTED ---- 250000
 LOCATION USED      ----   9726
 LOCATION UNUSED    ---- 240274
```

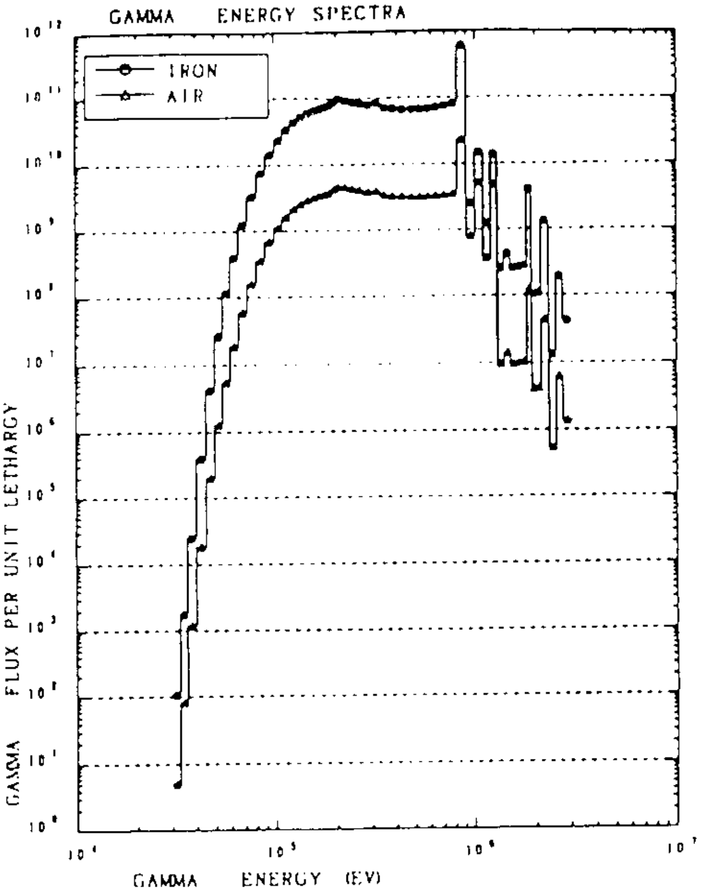
A.4.2 Plotter Output by ACT4

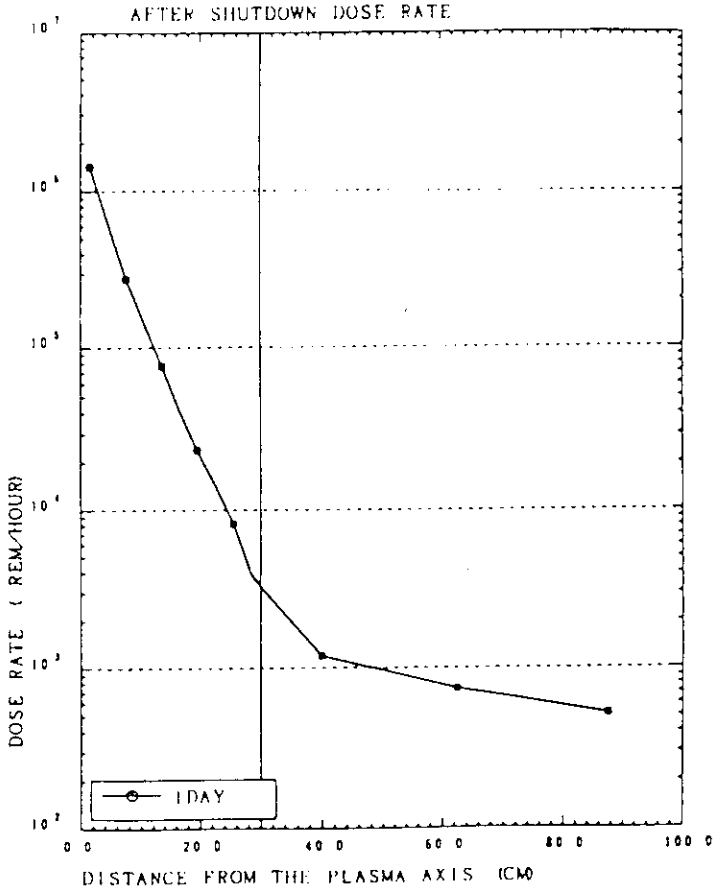





GAMMA RAY SOURCE ENERGY SPECTR
1. 0 DAY
GAMMA RAY SOURCE INTENSITY/TIMES
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{4}
10^{5}
10^{6}
10^{7}
GAMMA RAY ENERGY (EV)

A.4.3 Plotter Output by APPLE-2





A.5 Job Control Language (JCL)

A.5.1 One-Dimensional Problem

```
//JCLG JOB                                                              00000100
// EXEC JCLG                                                            00000200
//SYSIN DD DATA,DLM='++'                                                00000300
// JUSER 04392372,YA.SEKI,0017.01                                       00000400
  T.5W.2C.4I.5P.0  SRP                                                  00000500
  OPTP PASSWORD    ,MSGCLASS=X                                          00000600
//**********************************************************************00000700
//*   ANISN  COMPUTER SYSTEM               J2372.THIDA3PK.DATA(ANIRUN)  *00000800
//*   LOGICAL FILE                                                      *00000900
//*      FT09 ; WRITED OF CROSS SECTION WEIGHTING FOR HORSE             *00001000
//*      FT10 ; WRITED OF SCALAR  FLUX FOR APPLE OR THIDA OR ETC.       *00001100
//*      FT11 ; WRITED OF ANGULAR FLUX FOR APPLE  OR ETC.               *00001200
//*      FT50 ; WRITED OF KERMA FACTER FOR APPLE                        *00001300
//**********************************************************************00001400
// EXEC  FORT77,SO='J2372.ANISNTSS',Q='.FORT',A='ELM(FINPR2,SUMARY)'     00001500
// EXEC  LKEDIT77,LM='J2372.ANISN85'                                    00001600
// EXEC GO                                                              00001700
//FT06F001  DD  DCB=(BLKSIZE=137)                                       00001900
//  EXPAND  DISKTO,DDN=FT04F001,DSN='J2372.GICX40'                      00002000
//FT01F001 DD DISP=(,DELETE),DSN=&&FT01,                                00002100
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,                 00002200
// SPACE=(TRK,(400,50))                                                 00002300
//FT02F001 DD DISP=(,DELETE),DSN=&&FT02,                                00002400
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,                 00002500
// SPACE=(TRK,(100,50))                                                 00002600
//FT03F001 DD DISP=(,DELETE),DSN=&&FT03,                                00002700
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,                 00002800
// SPACE=(TRK,(100,50))                                                 00002900
//FT08F001 DD DISP=(,DELETE),DSN=&&FT08,                                00003000
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,                 00003100
// SPACE=(TRK,(100,50))                                                 00003200
//FT09F001 DD DISP=(,DELETE),DSN=&&FT09,                                00003210
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,                 00003220
// SPACE=(TRK,(100,50))                                                 00003230
//FT10F001 DD DISP=(,CATLG,DELETE),DSN=J2372.ANIFLX1.DATA,              00003600
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=D0010C,               00003700
// SPACE=(TRK,(50,20),RLSE)                                             00003800
//FT11F001 DD DISP=(,DELETE),DSN=&&FT11,                                00005100
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,                 00005200
// SPACE=(TRK,(100,50))                                                 00005300
//FT14F001 DD DISP=(,DELETE),DSN=&&FT14,                                00005310
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,                 00005320
// SPACE=(TRK,(100,50))                                                 00005330
//FT20F001 DD DISP=(,DELETE),DSN=&&FT20,                                00005400
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,                 00005500
// SPACE=(TRK,(100,50))                                                 00005600
//FT50F001 DD DISP=(,DELETE),DSN=&&FT50,                                00005610
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,                 00005620
// SPACE=(TRK,(100,50))                                                 00005630
//  EXPAND  DISKTO,DDN=SYSIN,DSN='J2372.THIDA3PK',Q='.DATA(ANIDATA)'    00005700
++                                                                      00005800
//                                                                      00005900
```

```
//JCLG  JOB
// EXEC  JCLG
//SYSIN  DD  DATA,DLM='++'
// JUSER  16632372,YA.SEKI,0017.01
   C.3I.4T.4W.4          GRP SRP
   OPTP PASSWORD=    ,MSGCLASS=X,NOTIFY=J2372
//**********************************************************************
//*  THIDA PROGRAM PAKAGE CODE.    J2372.THIDA3PK.DATA(THIDAJCL)       *
//*    STEP - 2 (ACT4)                                                 *
//*      INDUCED ACTIVITY, DECAY HEAT, AND GAMMA-RAY SOURCE            *
//*       FT04(SCALAR FLUX) TO FT17(DECAY GAMMA-RAY SOURCE)            *
//*    STEP - 3 (ANISN)                                                *
//*      GAMMA-RAY TRANSPORT.                                          *
//*       FT17(DECAY GAMMA-RAY SOURCE) TO FT10(GAMMA-RAY FLUX)         *
//*    STEP - 4 (APPLE)                                                *
//*      DOSE RATE AND ENERGY SPECTR PLOTTING                          *
//*       FT10(GAMMA-RAY FLUX) AND FT01(CONVERSION FACTOR)             *
//**********************************************************************
// EXEC  FORT77,SO=J2372.ACT45,Q='.FORT',
//       A='ELM(QIADH,SOURCE)',B=NOPRINT
// EXEC  LKEDIT77,LM=J2372.ACT45,A='LREP(JMF,JMP)'
// EXEC  GO
//FT06F001  DD  DCB=(BLKSIZE=137)
//  EXPAND  DISK,DDN=FT01F001
//  EXPAND  DISK,DDN=FT02F001
//  EXPAND  DISK,DDN=FT20F001
//  EXPAND  GRNLP,SYSOUT=E
//FT17F001  DD  DSN=J2372.aGS1.DATA,DISP=(NEW,CATLG,DELETE),
//  DCB=(RECFM=FB,LRECL=80,BLKSIZE=3200),UNIT=TSSWK,
//  SPACE=(TRK,(20,10),RLSE)
//  EXPAND  DISKTO,DDN=FT04F001,DSN='J2372.aTANIFLN',Q='.DATA'
//  EXPAND  DISKTO,DDN=FT08F001,DSN='J2372.CHAINLIB',Q='.DATA(CH82)'
//  EXPAND  DISKTO,DDN=FT09F001,DSN='J2372.CROSSLIB',Q='.DATA(CR82)'
//  EXPAND  DISKTO,DDN=FT10F001,DSN='J2372.GAMMALIB',Q='.DATA(GAM82)'
//  EXPAND  DISKTO,DDN=SYSIN,DSN='J2372.THIDA3PK',Q='.DATA(ANIACT)'
//**********************************************************************
//*          THIDA PROGRAM PAKAGE CODE.                                *
//*              ANISN -- GAMMA-RAY TRANSPORT.                         *
//**********************************************************************
//ANISNG EXEC FORT77,SO='J2372.THIDA2',
//       Q='.FORT',A='ELM(FIDAS)',B=NOPRINT
//FORT2 EXEC FORT77,SO='J2372.ANISNTSS',A='ELM(S814,FINPR2,SUMARY)',
//    DISP=MOD,B=NOPRINT,Q='.FORT'
//LINK2  EXEC  LKEDIT77,LM='J2372.ANISN85',A='LREP(JMF,JMP)'
//RUN2  EXEC  GO
//FT06F001  DD  DCB=(BLKSIZE=137)
//  EXPAND  DISKTO,DDN=FT04F001,DSN='J2372.GROUPIN'
//FT01F001  DD DISP=(,DELETE),DSN=&&FT01,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(400,50))
//FT02F001  DD DISP=(,DELETE),DSN=&&FT02,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT03F001  DD DISP=(,DELETE),DSN=&&FT03,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(400,50))
//FT08F001  DD DISP=(,DELETE),DSN=&&FT08,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT09F001  DD DISP=(,DELETE),DSN=&&FT09,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(400,50))
```

```
//FT10F001  DD DISP=(,CATLG,DELETE),DSN=J2372.@GF1.DATA,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=TSSWK,
// SPACE=(TRK,(10,5),RLSE)
//FT11F001  DD DISP=(,DELETE),DSN=&&FT11,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT14F001  DD DISP=(,DELETE),DSN=&&FT14,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT20F001  DD DISP=(,DELETE),DSN=&&FT20,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//  EXPAND  DISKTO,DDN=FT17F001,DSN='J2372.@GS1',Q='.DATA'
//  EXPAND  DISKTO,DDN=SYSIN,DSN='J2372.THIDA3PK',Q='.DATA(ANIDATA2)'
//**********************************************************************
//*  DOSE RATE PLOTING. INPUT FLUX FOR AFTER THE THIDA GAMMA TRANSPORT *
//* CALCULATIONS (1D-SN). INPUT CROSS SECTION FOR THE DOSE RATE CONVER-*
//* SION FACTOR (54 GROUPS).                                           *
//**********************************************************************
//GO   EXEC LMGO,LM='J2372.APPLEPNL'
//  EXPAND  DISK,DDN=FT21F001
//  EXPAND  DISK,DDN=FT23F001
//  EXPAND  DISK,DDN=FT24F001
//  EXPAND  DISK,DDN=FT27F001
//  EXPAND  GRNLP,SYSOUT=E
//  EXPAND  DISKTO,DDN=FT10F001,DSN='J2372.@GF1',Q='.DATA'
/*  EXPAND  DISKPSO,DDN=FT10F001,DSN=TAGFIN
//  EXPAND  DISKTO,DDN=FT01F001,DSN='J2372.APPLE',Q='.DATA(GFLXDOSE)'
//  EXPAND  DISKTO,DDN=SYSIN,DSN='J2372.THIDA3PK',Q='.DATA(ANIAPL)'
++
//
```

A.5.2 Two-Dimensional Problem

```
//JCLG JOB
// EXEC JCLG
//SYSIN DD DATA,DLM='++'
// JUSER   04392372,YA.SEKI,0017.01
   T.5   C.3 W.3 I.4  SRP
   OPTP PASSWORD=    ,MSGCLASS=X
//  EXEC  FORT77,SO='J2372.DOT35JCL',Q='.CNTL',A='ELM(GICX40DT)'
//  EXEC  LKED77
//  EXEC  GO
//  EXPAND  DISKTO,DDN=FT01F001,DSN='J2372.GICX40'
//FT02F001 DD DISP=(NEW,PASS),DSN=&&GICX,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(900,500))
//SYSIN      DD  *
  2  3 42  1
/*
//**********************************************************************
//*  DOT3.5 NEUTRON CALC.        J2372.THIDA3PK.DATA(DOTRUN)           *
//*     FT05 : READ  OF SUMPLE INPUT DATA CARDS.                       *
//*     FT08 : READ  OF GICX40 CROSS SECTION.                          *
//*     FT09 : WRITE OF FLUX FOR RESTART.                              *
//*     FT11 : WRITE OF ANGULAR FLUX FOR DOMINO.                       *
//*     FT18 : READ  OF FLUX GEUSS FOR REATART.                        *
//**********************************************************************
//  EXEC FORT77,SO='J2372.DOT35',Q='.FORT',A='ELM(OUTER,TPSAVE)'
//  EXEC FORT77,SO='J2372.DOT35',Q='.FORT',A='ELM(TPXF)',DISP=MOD
//  EXEC FORT77,SO='J2372.DOT35',Q='.FORT',A='ELM(ACTVTY)',DISP=MOD
//  EXEC LKEDIT77,LM='J2372.DOT35',A='LREP(JMF,JMP)'
//  EXEC GO
//FT06F001  DD  DCB=(BLKSIZE=137)
//FT01F001 DD DISP=(,DELETE),DSN=&&FT01,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT02F001 DD DISP=(,DELETE),DSN=&&FT02,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(300,100))
//FT03F001 DD DISP=(,DELETE),DSN=&&FT03,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(300,100))
//FT04F001 DD DISP=(,DELETE),DSN=&&FT04,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(300,100))
//FT08F001 DD DISP=(OLD,DELETE),DSN=&&GICX,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(900,500))
//FT09F001 DD DISP=(,CATLG,DELETE),DSN=J2372.DOTFLXN.DATA,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=D0010,
// SPACE=(TRK,(20,10),RLSE)
//FT10F001 DD DISP=(,DELETE),DSN=&&FT10,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT11F001 DD DISP=(,DELETE),DSN=&&FT11,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT12F001 DD DISP=(,DELETE),DSN=&&FT12,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT13F001 DD DISP=(,DELETE),DSN=&&FT13,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT14F001 DD DISP=(,DELETE),DSN=&&FT14,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT15F001 DD DISP=(,DELETE),DSN=&&FT15,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT20F001 DD DISP=(,DELETE),DSN=&&FT20,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT21F001 DD DISP=(,DELETE),DSN=&&FT21,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT50F001 DD DISP=(,DELETE),DSN=&&FT50,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
```

```
// EXPAND DISKTO,DDN=SYSIN,DSN='J2372.THIDA3PK',Q='.DATA(DOTDATA1)'     00019000
++                                                                      00019100
//                                                                      00019200
```

```
//JCLG JOB                                                              00032800
// EXEC JCLG                                                            00032900
//SYSIN DD DATA,DLM='++'                                                00033000
// JUSER   04392372,YA.SEKI,0017.01                                     00033100
   T.3  C.5  W.1  I.5     MTU                                           00033200
   OPTP PASSWORD=    ,MSGCLASS=D                                        00033300
//********************************************************************/ 00033400
//** DOT-THIDA CALCULATIONAL JOB CONTROL LIST.(THIDA2PK.DATA(DOTTHIDA)/ 00033500
//**                FT17 IS SHUTDOWN GAMMA-RAY SOURCE.               */ 00033600
//********************************************************************/ 00033700
//ACTF  EXEC  FORT77                                                    00033800
      COMMON  NLFT,D(200000)                                            00033900
      NLFT   = 200000                                                   00034000
      CALL  CLEAR(D,1,NLFT)                                             00034100
      CALL  CNTRL                                                       00034200
      STOP                                                              00034300
      END                                                               00034400
//ACTL  EXEC  LKEDIT77,LM='J2372.ACT45',GRLIB=PNL                       00034500
//ACTG  EXEC  GO                                                        00034600
//FT06F001  DD  DCB=(BLKSIZE=137)                                       00034700
//  EXPAND  TPDISK,DDN=FT01F001,DSN=FT01,SPC='30,10',                   00034800
//   RECFM=VBS,RSIZE=19064,BSIZE=19068                                  00034900
//  EXPAND  TPDISK,DDN=FT02F001,DSN=FT02,SPC='400,200',                 00035000
//   RECFM=VBS,RSIZE=19064,BSIZE=19068                                  00035100
//  EXPAND  TPDISK,DDN=FT20F001,DSN=FT20,SPC='400,200',                 00035200
//   RECFM=VBS,RSIZE=19064,BSIZE=19068                                  00035300
//FT17F001  DD  DISP=(NEW,PASS),DSN=&&SOUR,SPACE=(TRK,(300,100),RLSE),  00035400
//  DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10                 00035500
//FT18F001  DD  DISP=(,DELETE),DSN=&&FT09,SPACE=(TRK,(300,100)),        00035600
//  DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10                 00035700
//  EXPAND TAPE,DDN=FT04F001,DSN='J2372.DOTFLX1.DATA',MTV=021357,POS=4, 00035800
//      MTU=MT62,DEN=4                                                  00035900
//  EXPAND  DISKTO,DDN=FT08F001,DSN='J2372.CHAINLIB',Q='.DATA(CH82)'    00036000
//  EXPAND  DISKTO,DDN=FT09F001,DSN='J2372.CROSSLIB',Q='.DATA(CR82)'    00036100
//  EXPAND  DISKTO,DDN=FT10F001,DSN='J2372.GAMMALIB',Q='.DATA(GAM82)'   00036200
//  EXPAND  DISKTO,DDN=SYSIN,DSN='J2372.THIDA2PK',Q='.DATA(DOTACT)'     00036300
//**********************************************************************00036400
//****   GAMMA-RAY CROSS SECTION EDITER FOR DOT CALCULATIONS. ******    00036500
//**********************************************************************00036600
//  EXEC  FORT77,SO='J2372.DOT35JCL',Q='.CNTL',A='ELM(G81XS40)'         00036700
//  EXEC  LKED77                                                        00036800
//  EXEC  GO                                                            00036900
//  EXPAND  DISKTO,DDN=FT01F001,DSN='J2372.GROUPIN'                     00037000
//FT02F001 DD DISP=(NEW,PASS),DSN=&&GICX,                               00037100
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,                 00037200
// SPACE=(TRK,(300,100))                                                00037300
//SYSIN     DD  *                                                       00037400
  2  3 54                                                               00037500
/*                                                                      00037600
//**********************************************************************00037700
//*        DOT3.5  GAMMA CALC.                                         *00037800
//*    FT05 : READ  OF SUMPLE INPUT DATA CARDS.                        *00037900
//*    FT08 : READ  OF GICX40 CROSS SECTION.                           *00038000
//*    FT09 : WRITE OF FLUX FOR RESTART.                               *00038100
//*    FT11 : WRITE OF ANGULAR FLUX FOR DOMINO.                        *00038200
//*    FT18 : READ  OF FLUX GEUSS FOR REATART.                         *00038300
//**********************************************************************00038400
//  EXEC  FORT77,SO='J2372.DOT35',A='ELM(OUTER,TPSAVE,TPXF)',Q='.FORT'  00038500
//  EXEC  FORT77,SO='J2372.DOT35',A='ELM(ALOCAT)',Q=.'FORT',DISP=MOD    00038600
//  EXEC  LKEDIT77,LM='J2372.DOT35'                                     00038700
//  EXEC  GO                                                            00038800
//FT06F001  DD  DCB=(BLKSIZE=137)                                       00038900
//FT01F001 DD DISP=(,DELETE),DSN=&&FT01,                                00039000
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,                 00039100
// SPACE=(TRK,(100,50))                                                 00039200
//FT02F001 DD DISP=(,DELETE),DSN=&&FT02,                                00039300
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,                 00039400
// SPACE=(TRK,(300,100))                                                00039500
//FT03F001 DD DISP=(,DELETE),DSN=&&FT03,                                00039600
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,                 00039700
// SPACE=(TRK,(300,100))                                                00039800
```

```
//FT04F001 DD DISP=(,DELETE),DSN=&&FT04,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(300,100))
//FT08F001 DD DISP=(OLD,DELETE),DSN=&&GICX,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(300,100))
// EXPAND SLTAPE,DDN=FT09F001,DSN='J2372.DOTFLX2.DATA',MTV=001558,
//    POS=4,RECFM=VBS,RSIZE=13024,BSIZE=13028,MTU=MT62,DEN=4
//FT10F001 DD DISP=(,DELETE),DSN=&&FT10,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT11F001 DD DISP=(,DELETE),DSN=&&FT11,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT12F001 DD DISP=(,DELETE),DSN=&&FT12,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT13F001 DD DISP=(,DELETE),DSN=&&FT13,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT14F001 DD DISP=(OLD,DELETE),DSN=&&SOUR,SPACE=(TRK,(300,100)),
//  DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10
//FT15F001 DD DISP=(,DELETE),DSN=&&FT15,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT20F001 DD DISP=(,DELETE),DSN=&&FT20,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT21F001 DD DISP=(,DELETE),DSN=&&FT21,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT50F001 DD DISP=(,DELETE),DSN=&&FT21,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
// EXPAND DISKTO,DDN=SYSIN,DSN='J2372.THIDA2PK',Q='.DATA(DOTDATA2)'
++
//
```

```
//JCLG JOB
// EXEC JCLG
//SYSIN DD DATA,DLM='++'
// JUSER   04392372,YA.SEKI,0017.01
   T.1  C.5 W.0 I.2 P.0  GRP
   OPTP PASSWORD=   ,MSGCLASS=D
//**********************************************************************
//*   APPLE-2 DOSE RATE PLOTTING.   J2372.THIDA2PK.DATA(APPLE)          *
//*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*
//  EXEC  FORT77
      COMMON  D(200000)
      LIMM=200000
      CALL CLEAR(0.0,D,LIMM)
      CALL APPLE(LIMM)
      STOP
      END
//  EXEC  LKEDIT77,LM='J2372.APPLEPNL',GRLIB=PNL,A='LREP(JMF,JMP)'
//  EXEC  GO
//FT06F001  DD  DCB=(BLKSIZE=137)
//FT21F001 DD DISP=(,DELETE),DSN=&&FT21,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(400,50))
//FT23F001 DD DISP=(,DELETE),DSN=&&FT23,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT24F001 DD DISP=(,DELETE),DSN=&&FT24,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//FT27F001 DD DISP=(,DELETE),DSN=&&FT27,
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=WK10,
// SPACE=(TRK,(100,50))
//  EXPAND  DISKTO,DDN=FT10F001,DSN='J2372.DOT4FLX1'
/* EXPAND  TAPE,DDN=FT10F001,DSN='J2372.DOTFLX1.DATA',MTV=021357,
/*    POS=4,MTU=MT62,DEN=4
//  EXPAND  GRNLP,SYSOUT=E
//  EXPAND  DISKTO,DDN=FT01F001,DSN='J2372.APPLE',Q='.DATA(GFLXDOSE)'
/*  EXPAND  DISKTO,DDN=FT01F001,DSN='J2372.APPLE',Q='.DATA(XS135)'
/*  EXPAND  DISKTO,DDN=FT01F001,DSN='J2372.GICXKRMA'
//  EXPAND  DISKTO,DDN=SYSIN,DSN='J2372.THIDA2PK',Q='.DATA(DOTAPLG)'
++
//
```

A.5.3 Three-Dimensional Problem

```
//JCLG  JOB                                                              00000100
// EXEC  JCLG                                                            00000200
//SYSIN  DD  DATA,DLM='++'                                               00000300
// JUSER  16632372,YA.SEKI,0017.01,MORSEI                                00000400
    T.4  C.5  I.4  W.2   SRP                                             00000500
  OPTP  PASSWORD=   ,MSGCLASS=X                                          00000600
//********************************************************************** 00000700
//*    THIDA NEUTRON FLUX CALCULATION FOR 3-D NEUTRONICS ANALISYS.     * 00000800
//*      PROGRAM CODE USE TO MORSE-I. (3-D MONTE CALRO CALC.)          * 00000900
//*      NEUTRON FLUX FILE ON FT10F001. (EDIT OF NRUN)                 * 00001000
//*         JCL FILE ---    J2372.THIDA2PK.DATA(MORSEN2)               * 00001100
//********************************************************************** 00001200
/*  EXEC  FORT77,SO='J2372.MORSEI',A='ELM(JNPUT,XSEC)'                   00001400
//  EXEC  FORT77,SO='J2372.ALBMCD',A='ELM(NRUNSP)',Q='.FORT'             00001300
//  EXEC  FORT77,SO='J2372.SOURCES',A='ELM(SOURCE)',Q='.FORT',DISP=MOD   00001500
//  EXEC  LKEDIT77,LM='J2372.MORSEI',GRLIB=PNL,A='LREP(JMF,JMP)'         00001600
//  EXEC  GO                                                             00001700
//FT06F001  DD  DCB=(BLKSIZE=137)                                        00001800
//  EXPAND    DISK,DDN=FT09F001                                          00001900
//FT10F001 DD DISP=(NEW,CATLG,DELETE),DSN=J2372.@TMORFLN.DATA,           00002300
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=D0010C,                00002400
// SPACE=(TRK,(30,10),RLSE)                                              00002500
//  EXPAND  DISKTO,DDN=FT14F001,DSN='J2372.@TXS42'                       00002600
/*  EXPAND  DISKTO,DDN=FT20F001,DSN='J2372.DTPOWER1'                     00002700
//  EXPAND    DISK,DDN=FT51F001                                          00002800
//  EXPAND  DISKTO,DDN=SYSIN,DSN='J2372.THIDA2PK',Q='.DATA(MORDATAN)'    00002900
++                                                                       00003000
//                                                                       00003200
```

```
//JCLG  JOB                                                              00000100
// EXEC  JCLG                                                            00000200
//SYSIN  DD  DATA,DLM='++'                                               00000300
// JUSER  16632372,YA.SEKI,0017.100                                      00000400
   C.4I.4T.2W.0    GRP SRP                                               00000500
   OPTP PASSWORD=     ,MSGCLASS=X                                        00000600
//***********************************************************************00000700
//*  THIDA PROGRAM PAKAGE CODE.    J2372.THIDA3PK.DATA(MORSEACT)        *00000800
//*   STEP - 2 (ACT4)                                                   *00000900
//*     INDUCED ACTIVITY, DECAY HEAT, AND GAMMA-RAY SOURCE              *00001000
//*      FT04(SCALAR FLUX) TO FT17(DECAY GAMMA-RAY SOURCE)              *00001100
//***********************************************************************00001200
// EXEC  LMGO,LM='J2372.ACT45NEW'                                        00001510
//FT06F001  DD  DCB=(BLKSIZE=137)                                        00001600
//  EXPAND  DISK,DDN=FT01F001                                            00001700
//  EXPAND  DISK,DDN=FT02F001                                            00001800
//  EXPAND  DISK,DDN=FT20F001                                            00001900
//  EXPAND  DISK,DDN=FT18F001                                            00002000
//  EXPAND  GRNLP,SYSOUT=E                                               00002100
//FT17F001 DD DISP=(NEW,CATLG,DELETE),DSN=J2372.@TMORGS.DATA,            00002200
// DCB=(RECFM=VBS,LRECL=19064,BLKSIZE=19068),UNIT=D0010C,                00002300
// SPACE=(TRK,(30,10),RLSE)                                              00002310
//  EXPAND  DISKTO,DDN=FT04F001,DSN='J2372.@TMORFLN'                     00002400
//  EXPAND  DISKTO,DDN=FT08F001,DSN='J2372.CHAINLIB',Q='.DATA(CH82)'     00002500
//  EXPAND  DISKTO,DDN=FT09F001,DSN='J2372.CROSSLIB',Q='.DATA(CR82)'     00002600
//  EXPAND  DISKTO,DDN=FT10F001,DSN='J2372.GAMMALIB',Q='.DATA(GAM82)'    00002700
//  EXPAND  DISKTO,DDN=SYSIN,DSN='J2372.THIDA2PK',Q='.DATA(MORACT)'      00002800
++                                                                       00002900
//                                                                       00003000
```

```
//JCLG  JOB
// EXEC  JCLG
//SYSIN  DD  DATA,DLM='++'
// JUSER  04392372,YA.SEKI,0017.01
   T.4  C.6  I.3  W.2
 OPTP  PASSWORD=    ,MSGCLASS=D
//*********************************************************************
//*    THIDA GAMMA-RAY FLUX CALCULATION FOR 3-D NEUTRONICS ANALISYS.  *
//*      SHUTDOWN GAMMA-RAY FLUX FILE ON FT10F001. (EDIT OF NRUN)     *
//*         JCL FILE ---    J2372.THIDA3PK.DATA(MORSEG2)              *
//*********************************************************************
//  EXEC  FORT77,SO='J2372.MTHIDA',Q='.FORT',A='ELM(*)',DISP=MOD
//  EXEC  FORT77,SO='J2372.ALBMCD',Q='.FORT',A='ELM(NRUNSP)',DISP=MOD
//  EXEC  FORT77,SO='J2372.MORSEI',Q='.FORT',A='ELM(JNPUT)',DISP=MOD
//  EXEC  LKEDIT77,LM='J2372.MORSEI',A='LREP(JNF,JMP)'
//  EXEC  GO
//FT06F001  DD  DCB=(BLKSIZE=137)
//  EXPAND    DISK,DDN=FT09F001
//  EXPAND    DISK,DDN=FT10F001
//  EXPAND  DISKTO,DDN=FT14F001,DSN='J2372.THIDXS54'
//  EXPAND  DISKTO,DDN=FT17F001,DSN='J2372.MORACTS'
//  EXPAND    DISK,DDN=FT51F001
//  EXPAND  DISKTO,DDN=SYSIN,DSN='J2372.THIDA3PK',Q='.DATA(MORDATAG)'
++
//
```