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**Biological Dose and Radiological Activity
from Nuclear Reactor or Nuclear Weapon
Fission Products**

R. O. Chester

MASTER

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BIOLOGICAL DOSE AND RADIOLOGICAL ACTIVITY
FROM NUCLEAR REACTOR OR NUCLEAR WEAPON
FISSION PRODUCTS

R. O. Chester

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DECEMBER 1974

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BIOLOGICAL DOSE AND RADIOLOGICAL ACTIVITY
FROM NUCLEAR REACTOR OR NUCLEAR WEAPON FISSION PRODUCTS

R. O. Chester

ABSTRACT

This report describes the use of a computer code, YIELDS, that performs rapid, accurate calculation of dose and activity from the fission products in a nuclear reactor core or from a nuclear weapon. For example, if a dispersal model is assumed, calculations can be made of contaminated area, dose from inhaled or ingested fission products to each part of a biological system, or dose from external fission products, from a dispersed reactor core, or nuclear weapon fallout. Individual beta and gamma ray energies for each isotope are included, permitting detailed calculation of biological dose or other functions of these energies vs time. The calculation method facilitates the handling of complicated radiological decay chains coupled with multisection biological systems. The option of sorting the output by isotopes or chemical species is available.

INTRODUCTION

This report discusses a computer code written primarily to describe the aftereffects of a nuclear power reactor core meltdown. The code also is used to calculate the effects of nuclear fission weapon fallout.

Time-dependent dose and activity from each isotope in the fission-product decay chains were the original objectives. However, this method applies equally well to actinide decay chains, as will be illustrated in an example. It became necessary to add the details of multisection biological systems for accurate dose calculations. The resultant computational method can utilize a different multisection biological system for each isotope in the radiological decay chain.

Alpha, beta, and gamma ray energies have separate calculation procedures for absorption and dose determination. Hence, effects of one or more of the different emissions present can be singled out of the calculations. Standard options permit calculation of activity vs time, total energy released vs time, dose or dose rate in a single or multisection biological system vs time, and gamma ray dose rate one meter above a uniformly contaminated smooth plane.

USE OF THE CODE, YIELDS

Normal Use

For a reactor, the core is assumed to have three sections and one section is refueled every 16 months. Reactor shutdown is assumed to occur just before refueling. Activity is output vs time after shutdown. For reactor fission-product activity that is released from the immediate core area, either a single "puff-type" release or a continuous release can be included in the calculations.

For both the reactor and the weapon, three basic types of calculation can be made: (1) activity in curies, (2) an energy-activity product, or (3) an energy-activity product integrated over time. Changing an input parameter will produce an output in curies, MeV-curies, lifetime dose in rems to an organ weighing a specified number of grams, gamma-ray dose rate 1 meter above plane in $(\text{rem/hr}) \cdot \text{ft}^2$, or another energy-curie product where the average energy per disintegration for fission-product isotopes is an input parameter.

Further, a complicated biological system can be specified for each isotope so that a more accurate dose to a biological system can be calculated than with the radiological half-life alone.

Non-Standard Use

The reactor refueling schedule can be easily modified. The type of core can be changed and even a single section with continuous reprocessing can be used. The buildup of fission products in the core during reactor operation can also be included in the output.

The routines that calculate the average beta ray energy and the attenuation coefficients for gamma rays are accessible to modify the energy-activity calculations.

Fission products have provision for sorting by chemical species but the atomic weight is also available and can be used to sort isotopes.

Decay chains other than those for fission products can be supplied, as long as the basic equations to be solved are the same. The fissionable material is assumed to be ^{235}U but this assumption can be changed by changing the fission yields for each decay chain.

Detailed instruction for all these changes are also discussed in Appendix A.

Examples of Normal Use

Seven examples are listed below. The output from the examples are plotted in Figs. 1 through 9. A list of the input cards for these examples is in Appendix B.

Example 1: Activity

Activity in curies vs time for the fission products in a 1000-MWe (3440-MWt) Boiling Water Reactor core after reactor shutdown and a 1-megaton nuclear weapon after detonation are presented in Fig. 1.

The printed output from the calculations for this example contains a complete list of the fission-product isotopes and their individual activity vs time in addition to the total activity.

Example 2: Total Energy Release

MeV-curies from beta ray and gamma ray energies vs time after shutdown for the fission products of the reactor in Example 1 are plotted in Fig. 2.

This example gives the average rate of beta and gamma ray energy release by fission products in the reactor core. The results for all the fission products in the core are given as well as the results for the fission products whose oxides have a volatility less than that of uranium oxide. These fission products are the most likely to remain in the vicinity of the core during a core meltdown. The rate of energy production in megawatts is given on a second abscissa.

Example 3: Lifetime Thyroid Dose

The lifetime thyroid dose from the ingestion of radioiodine produced by the reactor in Example 1 is plotted in Fig. 3. The dose is a function of time elapsed after shutdown before ingestion. The contribution to the total dose by each isotope is also plotted. A 138-day biological half-life for iodine was assumed in the calculation.

Fig. 1. Gross activity vs time.

Fig. 2. Beta and gamma energy in fission products after shutdown for 1000 MWe BWR.

Fig. 3. Lifetime dose to adult thyroid vs time of ingestion.

ORNL-DWG 74-5780R

Fig. 4. Gamma dose rate at 1 meter above smooth plane, 1-megaton weapon fission products.

5×10^{13}

ORNL-DWG 74-6536R

Fig. 5. Dose to lungs, r, volatile, insoluble fission products from reactor core meltdown 1000 MWe BWR. Multiply by fraction of core ingested.

Fig. 6. Inhaled whole-body dose from fission products in 1000-MWe BWR core vs time after shutdown. Multiply graph by fraction of core retained in lungs.

ORNL-DMC 74-6939

RADIOLOGICAL DECAY CHAIN

BIOLOGICAL SYSTEM

SIMPLIFIED BIOLOGICAL SYSTEM

Fig. 7. Radiological decay chain and multisection biological system for example 7.

Fig. 8. Dose during chronic inhalation exposure to ^{241}Pu .

Fig. 9. Dose after acute inhalation exposure to ^{241}Pu .

The curves in Fig. 3 must be multiplied by the fraction of the reactor core ingested to give the dose to a single adult thyroid. For example, assume 10^6 curies of mixed iodine isotopes are released from the reactor containment. This is about 10^{-9} of the core inventory. By the time the radioactive material has been moved by atmospheric processes to the boundary of the plant area, it may be spread over a volume a half-mile in diameter. Assuming a breathing rate of 3.3×10^{-4} m³/sec, a 1/2-hour exposure, and that 1/5 of the ingested iodine collects in the thyroid, the dose to the individual thyroid is

$$10^{-6} \times \frac{1}{(0.5 \times 1.6 \times 10^3)} \times 3.3 \times 10^{-4} \times \frac{3.6 \times 10^3}{2} \times \frac{1}{5} \times \text{curve in Fig. 3.}$$

If ingestion takes place from 2 to 2-1/2 hours after shutdown, the lifetime thyroid dose is about $2.3 \times 10^{-15} \times 0.85 \times 10^{11} = 0.20$ rem.

Example 4: Gamma Ray Dose Above a Contaminated Plane

The gamma ray dose rate, in (rem/hr)·ft², 1 meter above a smooth plane is plotted in Fig. 4. All the fission products except the rare gases from detonation of a 1-megaton nuclear weapon are assumed distributed on the plane in one curve. A second curve gives the dose rate from just the fission products, Mo, Tc, Te, I, Cs, Ba, and La.

The plotted results must be divided by the number of square feet over which the fission products are spread. For example, an airburst, 1-megaton weapon detonated in Asia might deposit 1/50 of the weapon's total activity over an area of 1000 miles by 1500 miles in North America. In this case, the curves in Fig. 4 must be multiplied by

$$\frac{1}{50} \times \frac{1}{1000 \times 1500} \times \frac{1}{5280 \times 5280} = 4.8 \times 10^{-16}$$

At two weeks the dose rate from all but the rare gas fission products would then be $4.8 \times 10^{-16} \times 0.56 \times 10^{11} = 2.7 \times 10^{-5}$ rem/hr. Some measurements of trans-Pacific fallout two weeks after detonation indicate the deposited isotopes are primarily Mo, Rb, Te, I, Cs, Ba, and La. This mixture is used to give the results plotted in curve 2. At two weeks the calculated dose rate is $4.8 \times 10^{-16} \times 0.49 \times 10^{11} = 2.4 \times 10^{-5}$ rem/hr.

An inspection of the detailed output for this example shows the difference is due primarily to the isotopes ^{95}Zr , ^{95}Nb , and ^{103}Ru .

Example 5: Lifetime Lung Dose

Figure 5 presents the lifetime lung dose in rems from Te and Ru, if they are released continuously from the containment of the reactor in Example 1. These fission products have oxides that are more volatile than uranium oxide but relatively insoluble in lung fluids. The results are plotted as a function of time elapsed after shutdown before ingestion and time elapsed after shutdown before release of the fission products from containment. These calculations assume that, before release, the fission products decay according to their individual decay chains. Therefore, the release at different times will contain different amounts of each isotope. The net effect is that the overall decay and biological effects of each release will be different.

The curves in Fig. 5 must be multiplied by the fraction of the core that is ingested. If the oxides are in an airborne aerosol, roughly $1/4$ of the inhaled aerosol is retained in the lungs and, of the retained material, approximately $2/3$ is deposited on nonciliated lung surfaces. The clearance half-life for these surfaces is about 500 days. The weight of the lungs is assumed to be about 1 kg. Assume 10^{-4} of the core inventory leaks out of the reactor containment per day. Assume, further, a $1/2$ -hr exposure to the airborne radioactivity and a breathing rate of $3.3 \times 10^{-4} \text{ m}^3/\text{sec}$. Further, assume that as the fission products leak out of the reactor containment they occupy a volume with an average diameter of 0.1 mile and one day later the diameter is about 2 miles. Then the 'ingested as released' curve in Fig. 5 should be multiplied by

$$\frac{10^{-4}}{24} \times \frac{1}{2} \times \frac{1}{4} \times \frac{2}{3} \times \frac{3.3 \times 10^{-4}}{(0.1 \times 1.6 \times 10^3)^2} \times \frac{3.6 \times 10^3}{2} = 5.0 \times 10^{-14}$$

As a result, ingestion at 1 day after shutdown as the fission products are released from the reactor containment gives a lifetime dose to the lungs of $2.45 \times 10^{13} \times 5.0 \times 10^{-14} = 1.2 \text{ rems}$. If the fission products are ingested one day after they are released, the 'ingested one day after

release' curve applies and should be multiplied by $5.0 \times 10^{-14} \times \left(\frac{0.1}{2}\right)^3 = 6.2 \times 10^{-18}$. Thus the first fission products to be released, if ingested one day later, will give a dose to the lungs of about $6.2 \times 10^{-18} \times 2.63 \times 10^{13} = 1.6 \times 10^{-4}$ rem.

Example 6: Whole-Body Dose

The whole-body dose, in rems, from inhalation of all the fission products except the rare gases released by the reactor in Example 1 is plotted in Fig. 6. The biological half-lives of the elements are:

Se - 11 days	Mo - 1,100 days	Cs - 70 days
Br - 8 days	Pd - 1,100 days	Ba - 65 days
Rb - 45 days	Tc - 1 day	La - 1,100 days
Sr - 13,000 days	Rh - 1,100 days	Ce - 1,100 days
Y - 1,100 days	Sn - 1,100 days	Pr - 1,100 days
Ru - 1,100 days	Sb - 1,100 days	Nd - 1,100 days
Zr - 1,100 days	Te - 1,100 days	Pm - 1,100 days
Nb - 1,100 days	I - 138 days	Sa - 1,100 days

These curves also must be multiplied by the fraction of the reactor core ingested. The same general considerations to calculate the fraction of core ingested would apply as in Example 3. Under those conditions, the whole-body dose would be $2 \times 10^{-15} \times 0.9 \times 10^{12} = 2 \times 10^{-3}$ rem.

Example 7: Dose to a Multisection Biosystem

The lifetime dose to the bone, liver, and lungs from the acute and chronic inhalation of ^{241}Pu in the insoluble oxide form is plotted in Figs. 8 and 9. The inventory of ^{237}Np in the bone and total dose rate to the lungs is also plotted in Figs. 8 and 9. The radiological decay chain is similar to that used in the section entitled "Illustration of the Basic Method." Figure 7 shows the decay chain, and values for the constants are given in Table 1. The notation in Table 1 is that used in Eq. (11). For inhaled, insoluble particles like PuO_2 , whose size distribution is in the 0.1 to 10 μ range, a representation of the sections in the biological system is given in Fig. 7. The representation of the biological system for this particular problem can be further simplified by omitting short half-lived and uninvolved sections. This simplified representation is also given in Fig. 7 and the corresponding constants in Table 1.

Table 1. Radiological and Biological Constants^a

Radiological Half Lives				Radiological Constants			
Pu	13.2 yrs			$B_{2,1} = .999957$			
Am	46.2 yrs			$B_{3,1} = .000043$			
U	6.75 days			$B_{4,2} = 1.0$			
Np	2.2×10^6 yrs			$B_{4,3} = 1.0$			

Biological Half-Lives							
	Ciliated Lung	Unciliated Lung	G-I Tract	PLN	Liver	Bone	Kidney
Pu	1 day ^b	500 da ^b	27 hr ^b	1000 da ^b	82 yr	200 yr	88 yr
Am	1 day ^b	500 da ^b	27 hr ^b	1000 da ^b	9.5 yr	200 yr	75 yr
U	1 day ^b	500 da ^b	27 hr ^b	1000 da ^b	---	300 da	15 da
Np	1 day ^b	500 da ^b	27 hr ^b	1000 da ^b	150 yr	200 yr	175 yr

Constants for Biological System									
i(element)	$F_i^{5,3}$	$F_i^{6,5}$	$F_i^{7,5}$	$F_i^{8,5}$	$F_i^{3,1}$	$F_i^{3,2}$	$F_i^{4,2}$	$F_i^{5,2}$	$F_i^{5,4}$
1 (Pu)	3×10^{-5}	0.56 ^b	0.42 ^b	0.02	1.0 ^b	0.67 ^b	0.25	0.08 ^b	1.0 ^b
2 (Am)	1×10^{-4}	0.35	0.25	0.03	1.0 ^b	0.67 ^b	0.25	0.08 ^b	1.0 ^b
3 (U)	1×10^{-4}	--	0.11	0.065	1.0 ^b	0.67 ^b	0.25	0.08 ^b	1.0 ^b
4 (Np)	1×10^{-4}	0.05	0.45	0.03	1.0 ^b	0.67 ^b	0.25	0.08 ^b	1.0 ^b

Constants for Simplified Biological System							
i(element)	$F_i^{3,2}$	$F_i^{4,1}$	$F_i^{5,1}$	$F_i^{4,3}$	$F_i^{4,2}$	$F_i^{5,2}$	$F_i^{5,3}$
1 (Pu)	0.25	1.7×10^{-5}	1.2×10^{-5}	0.56	0.04	0.03	0.42
2 (Am)	0.25	3.5×10^{-6}	2.5×10^{-6}	0.35	0.12	0.08	0.25
3 (U)	0.25	--	1.1×10^{-5}	--	--	0.04	0.11
4 (Np)	0.25	5.0×10^{-6}	4.5×10^{-5}	0.05	0.02	0.15	0.45

^aUnless otherwise indicated, information in this table is taken from "Report of Committee II on Permissible Dose for Internal Radiation, 1959"; ICRP Publication 2, Pergamon, Oxford, 1959.

^bR. B. Fish, G. W. Keilholtz, W. S. Snyder, S. D. Swisher, "Calculation of Doses Due to Accidentally Released Plutonium from an IMPER," ORNL-NSIC-74 (1972), p. 98, p. 75-77.

Of the PuO_2 inhaled, either in an acute exposure or during chronic exposure, approximately 10% is retained on the ciliated lung surfaces and 15% on the unciliated lung surfaces. In the notation of Eq. (11), the non-zero R_i^L 's are $R_1^1 = 0.10$ and $R_1^2 = 0.15$.

CALCULATION METHOD

Basic Decay Chain

Discussion

The system of equations,

$$\frac{dN_i}{dt} = R_i + \sum_{j=1}^N B_{i,j} \lambda_j N_j, \quad i = 1, 2, \dots, N, \quad (1)$$

is solved subject to the boundary condition $N_i = A_i$, at $t = 0$, where

N_i = amount of the i -th member of the decay chain

t = time

A_i = amount of the i -th member of the decay chain at $t=0$

R_i = constant formation rate of N_i

λ_i = radioactive decay constant for N_i

$B_{i,j}$ = the fraction of N_j decays that produce an i -th member of the decay chain. $B_{i,i} \equiv -1$.

N = total number of members of the decay chain.

The solutions are

$$N_i = Y_{i,1} + (A_i - Y_{i,1}) e^{-\lambda_i t} + \sum_{\substack{j=2 \\ j \neq i+1}}^{N+1} Y_{i,j} (e^{-\lambda_{j-1} t} - e^{-\lambda_i t}) \quad (2)$$

$$i = 1, 2, \dots, N$$

Grouping the exponential terms as shown in Eq. (2) permits the greatest numerical accuracy when a decay chain contains decay constants that are very nearly equal or are greatly different.

The $Y_{i,j}$ are coefficients evaluated by the following procedure:

Form the matrix $\underline{\beta}$ whose elements are $\beta_{i,j} = r_{i,j} \lambda_j$. A column vector $\underline{R}$ is formed from the elements r_j . Then $\underline{K}$ is a column vector whose elements are $Y_{i,1}$, and

$$\underline{K} = -\underline{\beta}^{-1} \underline{R} \quad (3)$$

Substituting Eqs. (2) in Eqs. (1) gives

$$-\beta_{i,k} (A_k - K_k) = \lambda_k Y_{i,k+1} + \sum_{\substack{j=1 \\ j \neq k}}^N (\beta_{i,j} Y_{j,k+1} - \beta_{i,k} Y_{k,j+1}) \quad (4)$$

Arrange the N^2 number of quantities $-\beta_{i,k} (A_k - K_k)$ into a column vector, $\underline{D}$. Similarly, arrange the $Y_{i,j}$ for $i = 1, N$ and $j = 2, N+1$ into a column vector, $\underline{C}$.

For efficient, rapid calculation observe that, physically, if $\beta_{i,k} \neq 0$, then $\beta_{k,i}$ must equal 0. Also $Y_{i,i+1}$ is not used in Eqs. (2). Therefore, β can be rearranged so that $\beta_{i,j} = 0$ for $j > i$. Then only the $N(N-1)/2$ number of $Y_{i,j}$'s with $2 \leq j \leq i$ need be calculated. Equations (4) can be rewritten

$$-\beta_{i,k} (A_k - K_k) = (\lambda_k - \lambda_i) Y_{i,k+1} + \sum_{j=k+1}^{i-1} \beta_{i,j} Y_{j,k+1} - \beta_{i,k} \sum_{j=1}^{k-1} Y_{k,j+1} \quad (5)$$

for $i = 2, N$

and $k = 1, i-1$.

Equations (2) can be rewritten

$$N_i = Y_{i,1} + (A_i - Y_{i,1}) e^{-\lambda_i t} + \sum_{j=2}^i Y_{i,j} (e^{-\lambda_{j-1} t} - e^{-\lambda_i t}) \quad (6)$$

for $i = 2, N$.

The vectors, $\underline{C}$ and $\underline{D}$, can be written

$$C(j-1 + (i-2)(i-1)/2) = Y_{i,j} \quad (7)$$

$$D(j + (i-2)(i-1)/2) = -B_{i,j} (A_j - K_j) \quad (8)$$

The coefficients connecting the elements of $\underline{D}$ and $\underline{C}$ can then be arranged in a matrix, $\underline{E}$, such that

$$\underline{D} = \underline{E} \underline{C} \quad (9)$$

which can be rewritten

$$\underline{C} = \underline{E}^{-1} \underline{D} \quad (10)$$

Illustration of the Basic Method

For the four member decay chain shown below, the amount of each chain member as a function of time is desired.

A_1	$A_2 = 0$	$A_3 = 0$	$A_4 = 0$
$R_1 = 0$	R_2	$R_3 = 0$	$R_4 = 0$
λ_1	λ_2	λ_3	λ_4
$B_{41} = 0$	$B_{32} = 0$		

The solutions for the $Y_{i,1}$'s are obtained from Eq. (3).

$$\begin{pmatrix} Y_{1,1} \\ Y_{2,1} \\ Y_{3,1} \\ Y_{4,1} \end{pmatrix} = \begin{pmatrix} -\lambda_1 & 0 & 0 & 0 \\ B_{21}\lambda_1 & -\lambda_2 & 0 & 0 \\ B_{31}\lambda_1 & 0 & -\lambda_3 & 0 \\ 0 & B_{42}\lambda_2 & B_{43}\lambda_3 & -\lambda_4 \end{pmatrix}^{-1} \times \begin{pmatrix} 0 \\ R_2 \\ 0 \\ 0 \end{pmatrix}$$

or

$$Y_{1,i} = 0$$

$$Y_{2,1} = R_2 \lambda_2$$

$$Y_{3,1} = 0$$

$$Y_{4,1} = R_{4,2} \cdot R_2 / \lambda_4$$

The remaining $Y_{i,j}$'s are evaluated from Eqs. (5) and (10).

$$\begin{pmatrix} Y_{2,2} \\ Y_{3,2} \\ Y_{3,3} \\ Y_{4,2} \\ Y_{4,3} \\ Y_{4,4} \end{pmatrix} = \begin{pmatrix} \lambda_1 - \lambda_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & \lambda_1 - \lambda_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & \lambda_2 - \lambda_3 & 0 & 0 & 0 \\ R_{4,2}\lambda_2 & B_{4,3}\lambda_2 & 0 & \lambda_1 - \lambda_4 & 0 & 0 \\ -R_{4,2}\lambda_2 & 0 & B_{4,3}\lambda_3 & 0 & \lambda_2 - \lambda_4 & 0 \\ 0 & -B_{4,3}\lambda_3 & -B_{4,3}\lambda_3 & 0 & 0 & \lambda_3 - \lambda_4 \end{pmatrix}^{-1} \times \begin{pmatrix} -B_{2,1} A_1 \lambda_1 \\ -B_{3,1} A_1 \lambda_1 \\ 0 \\ -B_{4,1} A_1 \lambda_1 \\ B_{4,2} \lambda_2 Y_{2,1} \\ 0 \end{pmatrix}$$

Preprocessing removes the zero result $Y_{3,3}$, giving

$$\begin{pmatrix} Y_{2,2} \\ Y_{3,2} \\ Y_{4,2} \\ Y_{4,3} \\ Y_{4,4} \end{pmatrix} = \begin{pmatrix} \lambda_1 - \lambda_2 & 0 & 0 & 0 & 0 \\ 0 & \lambda_1 - \lambda_3 & 0 & 0 & 0 \\ R_{4,2}\lambda_2 & B_{4,3}\lambda_3 & \lambda_1 - \lambda_4 & 0 & 0 \\ -R_{4,2}\lambda_2 & 0 & 0 & \lambda_2 - \lambda_4 & 0 \\ 0 & -B_{4,3}\lambda_3 & 0 & 0 & \lambda_3 - \lambda_4 \end{pmatrix}^{-1} \times \begin{pmatrix} -B_{2,1} A_1 \lambda_1 \\ -B_{3,1} A_1 \lambda_1 \\ -B_{4,1} A_1 \lambda_1 \\ B_{4,2} \lambda_2 Y_{2,1} \\ 0 \end{pmatrix}$$

Rewriting the results

$$Y_{2,2} = -B_{2,1} A_1 \lambda_1 / (\lambda_1 - \lambda_2)$$

$$Y_{3,2} = -B_{3,1} A_1 \lambda_1 / (\lambda_1 - \lambda_3)$$

$$Y_{4,2} = -B_{4,1} A_1 \lambda_1 / (\lambda_1 - \lambda_4) + B_{4,2} \lambda_2 B_{2,1} A_1 \lambda_1 / (\lambda_1 - \lambda_2) (\lambda_1 - \lambda_4) + B_{4,3} \lambda_3 B_{3,1} A_1 \lambda_1 / (\lambda_1 - \lambda_3) (\lambda_1 - \lambda_4)$$

$$Y_{4,3} = B_{4,2} \lambda_2 Y_{2,1} / (\lambda_2 - \lambda_4) - B_{4,2} \lambda_2 B_{2,1} A_1 \lambda_1 / (\lambda_1 - \lambda_2) (\lambda_2 - \lambda_4)$$

$$Y_{4,4} = -B_{4,3} \lambda_3 B_{3,1} A_1 \lambda_1 / (\lambda_1 - \lambda_3) (\lambda_3 - \lambda_4)$$

Finally, the amount of each chain member is given by Eq. (2).

$$N_1 = A_1 e^{-\lambda_1 t}$$

$$N_2 = Y_{2,1} (1 - e^{-\lambda_2 t}) + Y_{2,2} (e^{-\lambda_1 t} - e^{-\lambda_2 t})$$

$$N_3 = Y_{3,1} (1 - e^{-\lambda_3 t}) + Y_{4,2} (e^{-\lambda_1 t} - e^{-\lambda_4 t}) + Y_{4,3} (e^{-\lambda_2 t} - e^{-\lambda_4 t}) + Y_{4,4} (e^{-\lambda_3 t} - e^{-\lambda_4 t})$$

Effects of a Biological System

Basic Equations

If the members of a radioactive decay chain are incorporated into a biological system, the system, through chemical and physical processes, removes each member of the decay chain from the system over a period of time. In many important cases, the elimination rates can be represented with biological half-lives, λB_i^M . In this case, Eqs. (1) can be rewritten:

$$S_i^L = R_i^L + \sum_{j=1}^{NRAD} B_{i,j} \lambda_j N_j^L + \sum_{M=1}^{NBIO} F_i^{L,M} \lambda B_i^M N_i^M, \quad (11)$$

for $i = 1, NRAD$
and $L = 1, NBIO$,

where

N_i^L is the amount of the i -th member of the decay chain that is in the L -th section of the biological system; $N_i^L = A_i^L$ at $t = 0$.

$B_{i,j}$ is the fraction of the j -th members of the decay chain that decays to produce an i -th member of the chain. $B_{i,i} = -1$.

$F_i^{L,M}$ is the fraction of the i -th member of the decay chain that is in the M -th section of the biological system that is moved via biological processes to the L -th biological section. $F_i^{L,L} = -1$.

λ_j is the radioactive decay constant for the j -th member of the decay chain.

λB_i^M is the biological half-life of the i -th chain member in the M -th biological section.

R_i^L is the constant formation rate of the i -th chain member in the L -th section of the biological system.

$NRAD$ is the number of members in the radiological decay chain.

$NBIO$ is the number of sections in the biological system.

Rewriting Eq. (11) gives

$$\dot{I}_q = S_q + \sum_{r=1}^{NTOT} \gamma_{q,r} T_r \quad q = 1, 2, \dots, NTOT \quad (12)$$

where

$$NTOT = NRAD \cdot NBIO$$

$$T_q = N_i^L$$

$$S_q = R_i^L$$

$$\gamma_{q,r} = B_{i,j} \cdot \lambda_j; \text{ or } F_i^{L,M} \cdot \lambda B_i^M$$

$$q = L + (i-1) \cdot NBIO$$

$$r = M + (j-1) \cdot NBIO$$

Equations (12) are the same as Eqs. (2) and can be solved in an identical manner.

Approximation

In many decay chains of interest all but one member of the chain has a short biological half-life. As a result, the chain can be approximated by one member with $A\theta$ equal to the amount of N that is initially ingested, or with $R = \frac{dN}{dt}$ from N at the times of ingestion for cronic ingestion. In this simplified case, the chain in the biological system has only one member

$$\frac{dN}{dt} = -(\lambda + \lambda B) N$$

The dose, in this case, is the integral

$$\text{lifetime dose} = C^L \bar{E} \int_{\text{ingestion}}^{\text{lifetime}} \lambda N dt \approx \frac{C^L \bar{E} \lambda}{(\lambda + \lambda B)} (A\theta - N_{\text{lifetime}} \int_{\text{ingestion}}^{\text{lifetime}} R dt), \quad (13)$$

where the notation is the same as in Eq. (19).

Computation time will be shortened if this approximation can be used. This approximation was used in examples 3, 5, and 6.

Use of Alpha, Beta, and Gamma Ray Energies

Alpha and Gamma Ray Energies

The average alpha, beta, and gamma ray energy released per radioactive decay of the i -th decay chain member is

$$\bar{E}_i = \sum_k F_{k,i} E_{k,i} \quad , \quad (14)$$

sum over all beta
rays and gamma rays

where $F_{k,i}$ is the fraction of disintegrations of the i -th chain member that produce a beta ray with average energy or an alpha or gamma ray with energy $E_{k,i}$.

The rate of energy release by the i -th member of a decay chain is then equal to $\bar{E}_i \lambda_i N_i$.

Input parameters for each decay chain are the $F_{k,i}$ and the beta ray endpoint energy or alpha or gamma ray energy, $E_{k,i}$.

Average Beta Energy

The average beta ray energy is calculated in subroutine AVEBET from the beta ray endpoint energy, E_{endpoint} , and the nuclear charge of the daughter, Z .

Following the method of Marinelli et al. (Rev. Mod. Phys., 19, 25 (1947))

$$W_B = \frac{\int_1^{W_0} N(W) W dW}{\int_1^{W_0} N(W) dW} \quad (15)$$

where

$$W_0 = \frac{E_{\text{endpoint}}}{M_0 c^2} + 1$$

$$W_B = \frac{E_{\text{ave}}}{M_0 c^2} + 1$$

and

$$N(W) = \frac{|M|^2}{T_0} F(Z, W) (W_0 - W)^2 (W^2 - 1)^{1/2} W \quad . \quad (16)$$

An approximate expression for the Coulomb correction factor, $F(Z, W)$, suggested by Hail (Phys. Rev. 79 745, (1950)), that is accurate to better than 1% is used.

$$F(Z, W) = \frac{4\pi(1+S)}{[(2S)!]^2} (2p_0)^{2S-2} (S^2 + \eta^2)^{S-1/2} \exp \left[2\eta \arctan \frac{S}{\eta} - 2S + \frac{S}{5(S^2 + \eta^2)} \right] \quad (17)$$

where

$$\begin{aligned} Z &= \text{charge of daughter nucleus} & c &= \text{vel. of light} \\ S &= \sqrt{1 - \left(\frac{Ze^2}{hc} \right)^2} & e &= \text{electronic charge} \\ p &= \frac{1}{c} \sqrt{(W-1)^2 + 2m c^2 (W-1)} & h &= \text{Planck constant} \\ o &= \frac{\text{nuclear radius}}{\frac{h}{mc}} = 1.2 A^{1/3} \times 10^{-3} \text{ cm} & m &= \text{electronic rest mass} \\ \eta &= \frac{Ze^2}{\left[\frac{h c^2 p}{(mc^2 + (W-1))} \right]} = \frac{Z e^2 (mc^2 + W-1)}{h c^2 p} \\ A &= \text{nuclear mass number} . \end{aligned}$$

Dose Calculations

Dose and dose rate to a biological system is calculated from the energy absorbed per unit weight of the system. The dose rate from the i -th decay chain member to the L -th biological section is just

$$\text{dose rate} = C^L \bar{E}_i^L \lambda_i N_i^L \quad (18)$$

where

$\bar{E}_i^L$ is the fraction of the average energy released when the i -th chain member decays and is absorbed in the L -th biological section.

C^L is the conversion factor for the L -th biological section that converts the results to the desired units.

Lifetime dose is given by

$$\text{lifetime dose} = C^L \frac{\overline{E}_i^L}{\int_{\text{ingestion time}}^{\text{lifetime}} \lambda_i N_i^L dt} \quad (19)$$

Four separate cases are handled by the program.

Case I: Total Energy Absorption

The dose or dose rate from ingested fission products is calculated assuming all the released alpha, beta, and gamma ray energy is absorbed in the biological section. The product, $\overline{E}_i^L \lambda_i N_i^L$, has the units MeV-curies for the entire reactor core or weapon. To convert this to an individual dose rate, the result must be multiplied by the fraction ingested and by C^L . C^L for alpha rays are multiplied by ten, the relative biological effectiveness, RBE, of alpha rays.

$$\frac{\text{rem}}{\text{hr}} = \text{MeV-curies} \times \text{fraction of core inventory or weapon ingested} \times C^L \quad (20)$$

$$C^L = 3.7 \times 10^{10} \frac{\text{disintegrations}}{\text{sec-curie}} \times 3600 \frac{\text{sec}}{\text{hr}} \times \frac{1}{6.2419 \times 10^5} \frac{\text{ergs}}{\text{MeV}} \times \frac{1}{93} \frac{\text{rad}}{\text{ergs/gm}} \times \frac{1}{\text{gms of biological section}} \times \text{RBE} \quad (21)$$

$$C^L = \frac{2.295 \times 10^6}{\text{gms of biological section}} \times \text{RBE} \quad (22)$$

Lifetime dose is calculated by integrating over the time from ingestion to the lifetime.

Case II: Gamma Ray Dose Above a Plane

The gamma ray dose rate at one meter above a uniformly contaminated smooth plane is calculated in units of $(\text{em/hr}) \cdot \text{ft}^2$.

For each gamma ray energy, an RBE of one is assumed and the following calculation is made:

$$\frac{\text{rem} \cdot \text{ft}^2}{\text{hr}} = 2.741 \times 10^3 \times \left(\frac{\sigma_{\text{absorption}}}{\rho_{\text{air}}} \right)_{\text{air}}^{\frac{\text{cm}^2}{\text{gm}}} E_{\text{MeV}} \times \frac{1}{2} \left[E_1 (\mu_0 H) + \frac{b}{\mu_0} e^{-\mu H} \right] \quad (23)$$

where

E_{MeV} is the gamma ray energy

$$E_1(x) = \int_x^{\infty} \frac{e^{-Z}}{Z} dZ$$

$$\frac{b}{\mu_0} = \left(\frac{\sigma_{\text{scattering}}}{\mu_{\text{absorption}}} \right)_{\text{air}}$$

μ_0 = total attenuation, cm^{-1} , in air

ρ_{air} = air density, $\frac{\text{gm}}{\text{cm}^3}$

H = 1 meter .

$$\frac{1}{2} \left[E_1(\mu_0 H) + \frac{b}{\mu_0} e^{-\mu_0 H} \right] = \int_{x=H}^{x=\infty} e^{-\mu x} (1 + bx) 2\pi x dx \frac{1}{4\pi x^2} \quad (24)$$

$e^{-\mu x}$ = attenuation

$1+bx$ = buildup factor

$2\pi x dx$ = contaminated area

$\frac{1}{4\pi x^2}$ = solid angle contribution

$$2.741 \times 10^3 = 3.7 \times 10^{10} \frac{\text{dis}}{\text{sec-curie}} \times \frac{1}{6.2419 \times 10^5} \frac{\text{ergs}}{\text{MeV}} \frac{1}{83.8} \frac{\text{rem}}{\text{ergs/gm}} \\ \times 3600 \frac{\text{sec}}{\text{hr}} \times 1.0765 \times 10^{-3} \frac{\text{ft}^2}{\text{cm}^2} .$$

To convert the results to $\frac{\text{rem-mi}}{\text{hr}}$, divide by $2.789 \times 10^7 \text{ ft}^2/\text{mi}^2$.

To obtain rem/hr from the $(\text{rem/ft}^2) \cdot \text{ft}^2$,

$$\frac{\text{rem}}{\text{hr}} = \frac{\text{rem} \cdot \text{ft}^2}{\text{hr}} \times \frac{1}{\text{ft}^2 \text{ contaminated}} \times \frac{\text{fraction of the core or weapon}}{\text{spread out on plane}} \quad (25)$$

Case III: Dose from Ingestion and Inhalation

The dose rate is calculated from the alpha, beta, and gamma ray energies, if all the beta ray energy and a fraction of the gamma ray energy is absorbed in biological section of specified weight. The gamma

ray energy fraction is calculated assuming absorption in a sphere of water with the same weight as the biological section. For each gamma ray energy, the following quantity is evaluated.

$$\frac{\text{rem}}{\text{hr}} = 2.524 \times 10^6 \left(\frac{\sigma_{\text{absorption}}}{\rho} \right)_{\text{air}} \frac{\text{cm}^2}{\text{gm}} E_{\text{MeV}} \left(\frac{\text{weight gm}}{4\pi} \right)^{1/3} \frac{(1 - e^{-Y})}{Y \cdot \text{wt} \cdot \text{gms}} \quad (26)$$

where

E_{MeV} = gamma ray energy in MeV

Weight gms = weight of biological section in gms

$Y = 1.1 \times \left(\frac{\mu_{\text{total atten.}}}{\rho} \right)_{\text{air}} \times \left(\frac{3 \text{ weight gms}}{4\pi} \right)^{1/3}$

$1 - e^{-Y}$ = approximate fraction of energy absorbed.

These equations use the approximate relationship

$$\left(\frac{\mu}{\rho} \right)_{\text{water}}^{\text{cm}^2/\text{gm}} = 1.1 \times \left(\frac{\mu}{\rho} \right)_{\text{air}}^{\text{cm}^2/\text{gm}} \quad (27)$$

Case IV: Optional Input

Any decay-rate-related quantity that can be included with input information can be incorporated into the calculations. This quantity is multiplied by curies for each member of the decay chain. An example input quantity is the average MeV released per disintegration. Another example is the (isotopic weight/mole) x the number of disintegrations/second/curie divided by the isotopic disintegration constant and the number of atoms per mole. The result of the final calculation will be grams of each isotope vs time.

Continuous Release of Fission Products

A calculation option is permitted that considers the fission products continuously released from the nuclear reactor containment after a core meltdown. Any biological half-life can be applied after release. This option makes it possible to calculate a downwind dose from a

continuous release of radioactive material even though the release rate and wind speed vary. A more detailed discussion of the use of this option is discussed elsewhere.¹

¹ R. O. Chester, Dose and Deposition from a Nuclear Reactor Core Meltdown, ORNL-4944, (1974).

APPENDIX A
NON-STANDARD USE OF THE CODE, YIELDS

APPENDIX A NON-STANDARD USE OF THE CODE, YIELDS

Reactor Refueling Schedule Change

In the main program, lines numbered 1030, 1040, 1050, 1300, 1310, 1320, and 1360 determine the refueling schedule. T1, T2, and T3 defined in lines 1030, 1040, and 1050 are the times elapsed in seconds before shutdown that each section was refueled. The inventory at shutdown for each section is calculated in lines 1300, 1310, and 1320. For example, line 1320 is

CALL SOLNCA (T3, 1, V, Y, A, MCHAIN, 2) .

The result of this calculation is the inventory in a reactor that has been operating T3 seconds is stored in array A(K,3). The K values depend on the decay chain but 3 is 1 plus the last argument in the call statement and A is the fifth argument.

Line 1360 adds the relative fractions of fission products produced by each of the core sections. In this particular core, each section produces one-third of the fission products.

Buildup of Fission Products During Operation

If the same refueling schedule is maintained and T is the elapsed time before reactor shutdown, replace the first argument in lines 1300, 1310, and 1320 with

$$\begin{aligned} T1 &= T + T3 \cdot G, \\ T2 &= T + T3 \cdot G, \text{ and} \\ T3 &= T + T3 \cdot G, \text{ respectively.} \end{aligned}$$

Where G is the smallest integer, including 0, that keeps all three arguments greater than zero. Output statements and an iterative procedure must be inserted. For example,

GO TO 2	1290
10 DO 110 IBLDUP = 1, NIT	1291
T = TIME (IBLDUP)	1292
G = AINT ((T-T1)/T3 + 1.)	1293
IF (T1.GT.T) G = 0	1294

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```

CALL SOLNCA (T1 - T + T3*G, 1, V, Y, A, NCHAIN, 0)1300
CALL SOLNCA (T2 - T + T3*G, 1, V, T, A, NCHAIN, 1)1310
CALL SOLNCA (T3 - T + T3*G, 1, V, Y, A, NCHAIN, 2)1320
      etc.
110 PRINT 1026, T, (AMTGR1 (K), K = 1, NCHAIN)      1371
1026 FORMAT (8 E 14.4)

```

Modifications of Beta and Gamma Ray Energy Calculations

Functions of beta and gamma calculations are performed in subroutine COEFCA. The average beta ray energy is calculated from the endpoint energy in line 840

$$16 \text{ EG}(K, I) = \text{AVEBET}(\text{EG}(K, I), ZD)$$

where

K indicates the k-th beta ray,

I indicates the i-th member of the decay chain,

ZD is the atomic charge of the beta decay daughter,

and the endpoint energy in MeV, $\text{EG}(K, I)$ is converted to the average energy by the function AVEBET.

Processing of the gamma energy is done in line 920 or line 930 by subroutines ABSN or SRCHAR. A detailed discussion of the use of these routines is given in the section entitled "Dose Calculations." The average energy released per decay chain member disintegration time C^L in Eq. (9) is stored in array SBB(K), $K = 1, NCHAIN$ and calculated in lines 1050 through 1140.

If an average energy or other quantity per decay chain member disintegration is read in with the decay chain data, it is stored in array ABB(K), $K = 1, NCHAIN$. Further processing statements should be inserted after line 740 and before line 750.

Calculation of energy-activity products is done in subroutine SOLNAR, lines 410, 420, 430, 450, 460, and 480. Modifications can be inserted as needed.

Use of the Atomic Weight

The atomic weight, IA, and atomic numbers, IZ(I), for each decay chain are stored in the COMMON labeled AANDZ. A check of atomic number is made before extensive calculations are performed. The check starts in line 1120 of the main routine. As a result, IZZEST is set equal to 1 or 0 if the current decay chain does or does not contain elements of interest. A check on atomic weight might also be done in conjunction with the atomic number check and IZZEST correspondingly altered.

Fissionable Material Other than ^{235}U

The only numbers in the decay chain data cards that would have to be changed are the fission yields in percent. It may be necessary to add a few additional decay chain specifications if their total fission yield is non-negligible.

Decay Chains for Induced Activity

Induced activity information must be obtained from other sources. In some cases, this additional information can be added to the calculations for a complete list of a chemical species. For example, in an operating reactor core, stable ^{133}Cs captures a neutron to form $^{134}\text{Cs}^*$ and ^{134}Cs . If the amount of ^{134}Cs is known at some time after shutdown, the amounts of $^{134}\text{Cs}^*$ and ^{134}Cs at shutdown can be estimated and the ^{134}Cs contribution to dose or energy related calculations can be made. The decay chain is specified

with fictitious fission yields to produce the observed quantities at shutdown.

APPENDIX B

INPUT CARDS

APPENDIX E

INPUT CARDS

Input Card Sequence

One card:

Contents: Operating level in thermal megawatts and the word REACTOR, or Fission yield in megatons and the word WEAPON

Variable names: THMPWR, REACWP

Format: E10.4, 1X, 1A4

Examples: 3440. REACTOR
1. WEAPON

One card:

Contents: Changes for the parameters IMUL~~OT~~, IGAMA, IRPT, LIFD~~OS~~

Variable names: (RDLIST(I), IRD(I), I=1, 4)

Format: 4(1A4, 3X, I1)

Examples: STD
LIFD~~OS~~=2IGAMA= 3

Parameter values:

STD	IMUL OT =1, IGAMA=1, IRPT=1, LIFD OS =0
IMUL OT =1 or 2	single or continuous release of fission products
IGAMA=0, 1, 3, or 4	Curies, MeV-curies, rems or rem/hr to a biological section, or rem/hr·ft ² one meter above a contaminated plane
IRPT=0 or 1	Minimal or detailed printed output
LIFD OS =0, 1, 2 or 3	Curies, MeV-curies, or rem/hr to a single biological section; Lifetime dose to a single biological section: dose rate in a multi-section biosystem, rem/hr; dose in a multi-section biosystem, rems

One card:

Contents: Weight of a single biosection in grams: This card is read only when IGAMA=3 and LIFD~~OS~~=0 or 1.

Variable name: GMS

Format: E10.4

Examples: 70000.
1000.

One card:

Contents: Specification of chronic or acute exposure of a
multisection biosystem to fission products

Variable name: CRAC

Format: 1A4

Examples: CRONIC
ACUTE

One or more cards:

Contents: A list of chemical species whose results are to be
summed: The list of atomic numbers is preceded
by the number of the list

Variable names: NILIST, (IZLIST(I), I=1, NILIST)

Format: 26I3

Examples: 1 53
6 34 37 38 39 55 56

One or more cards:

Contents: Biological half-life in days of each chemical species
in order as specified in the previous card. A zero
is interpreted as an infinite biological half-life.

Variable names: (TZLIST(I), I=1, NILIST)

Format: 82D.4

Examples: 138.
11. 45. 13000. 14000. 70. 65.

Four or more cards:

These cards describe the radiological decay chains and multisection
biological system and are discussed in detail in Appendix C.

One card:

Contents: Case title

Variable names: (TITLE(I), I=1, 18)

Format: 18A4

Examples: IODINE DOSE TO ADULT THYROID, R, REACTOR CORE MELT
R-FT*2/HR AT 1 METER ABOVE SMOOTH PLANE, 1 MT

One card:

Contents: Case separator=STOP for last case, otherwise
anything
Variable name: TITLE(1)
Format: 1A4
Examples: STOP
MORE

INPUT CARDS FOR EXAMPLES

INPUT CARD

EXPLANATION

EXAMPLE 1 CURVE 1

3440. REACTOR
IGAMA =0
26 34 35 36 37 38 39 40 41 42 43 44 45 46 50 51 52 53 54 55 56 57 58 59 60 61
62
DECAY CHAIN DATA (LISTED IN APPENDIX C)
REACTOR CURIES
MORE

THERMAL MEGAWATTS FOR OPERATING REACTOR
NON-STANDARD INPUT PARAMETERS
ATOMIC NUMBERS OF FISSION PRODUCTS USED
ATOMIC NUMBERS OF FISSION PRODUCT USED

CASE TITLE
ENDS EXAMPLE

EXAMPLE 1 CURVE 2

1. WEAPON
IGAPA =0
26 34 35 36 37 38 39 40 41 42 43 44 45 46 50 51 52 53 54 55 56 57 58 59 60 61
62
DECAY CHAIN DATA (LISTED IN APPENDIX C)
WEAPON CURIES
STOP

MEGATONS FISSION YIELD FOR WEAPON
NON-STANDARD INPUT PARAMETERS
ATOMIC NUMBERS OF FISSION PRODUCTS USED
ATOMIC NUMBERS OF FISSION PRODUCTS USED

CASE TITLE
ENDS EXAMPLE

EXAMPLE 2 CURVE 1

3440. REACTOR
STD
26 34 35 36 37 38 39 40 41 42 43 44 45 46 50 51 52 53 54 55 56 57 58 59 60 61
62
DECAY CHAIN DATA (LISTED IN APPENDIX C)
HT-CURIES, REACTOR
MORE

THERMAL MEGAWATTS FOR OPERATING REACTOR
STANDARD INPUT PARAMETERS REQUESTED
ATOMIC NUMBERS OF FISSION PRODUCTS USED
ATOMIC NUMBERS OF FISSION PRODUCTS USED

CASE TITLE
ENDS EXAMPLE

EXAMPLE 2 CURVE 2

3440. REACTOR
STD
8 39 40 41 42 43 44 45 62
DECAY CHAIN DATA (LISTED IN APPENDIX C)
HTV-CURIES, REACTOR REFRACTORY FISSION PRODUCTS
STOP

THERMAL MEGAWATTS FOR OPERATING REACTOR
STANDARD INPUT PARAMETERS REQUESTED
ATOMIC NUMBERS OF FISSION PRODUCTS USED

CASE TITLE
ENDS EXAMPLE

EXAMPLE 3 ALL CURVES

3440. REACTOR
IGAMA =3LIPDOS=1
20.
1 53
138.
DECAY CHAIN DATA (LISTED IN APPENDIX C)
IODINE DOSE TO ADULT THYROID, R
STOP

THERMAL MEGAWATTS FOR OPERATING REACTOR
NON-STANDARD INPUT PARAMETERS
GRAMS WEIGHT OF THYROID
ATOMIC NUMBERS OF FISSION PRODUCTS USED
BIOLOGICAL HALF-LIFE, DAYS

CASE TITLE
ENDS EXAMPLE

EXAMPLE 4 CURVE 1

1. WEAPON
 IGANA =4
 24 34 35 37 38 39 40 41 42 43 44 45 46 50 51 52 53 55 56 57 58 59 60 61 62
 DECAY CHAIN DATA (LISTED IN APPENDIX C)
 R-PT=2/HR AT 1 METER ABOVE SHOOTN PLANE FROM WEAPON
 MORE

MEGATONS FISSION YIELD FOR WEAPON
 NON-STANDARD INPUT PARAMETERS
 ATOMIC NUMBERS OF FISSION PRODUCTS USED
 CASE TITLE
 ENDS EXAMPLE

EXAMPLE 4
 CURVE 2

1. WEAPON
 IGANA =4
 7 42 43 52 53 55 56 57
 DECAY CHAIN DATA (LISTED IN APPENDIX C)
 R-PT=2/HR AT 1 METER ABOVE SHOOTN PLANE FROM WEAPON, SELECTED FISSION PRODUCTS
 STOP

MEGATONS FISSION YIELD FOR WEAPON
 NON-STANDARD INPUT PARAMETERS
 ATOMIC NUMBERS OF FISSION PRODUCTS USED
 CASE TITLE
 ENDS EXAMPLE

EXAMPLE 5
 ALL CURVES

3440. REACTOR
 INULOT=2IRPT =0IGANA =2LIPDOS=1
 1000.
 2 52 44 500 500.
 DECAY CHAIN DATA (LISTED IN APPENDIX C)
 LUNG DOSE, R/HR, FROM INHALED VOLATILE, SOLUBLE REACTOR FISSION PRODUCTS
 STOP

THERMAL MEGAWATTS FOR OPERATING REACTOR
 NON-STANDARD INPUT PARAMETERS
 GRAMS WEIGHT OF LUNGS
 ATOMIC NUMBERS OF FISSION PRODUCTS USED
 BIOLOGICAL HALF-LIVES, DAYS
 CASE TITLE
 ENDS EXAMPLE

EXAMPLE 6
 ALL CURVES

3440. REACTOR
 IGANA =3LIPDOS=1
 70000.
 9 35 40 41 57 58 59 60 61 62
 1100. 1100. 1100. 1100. 1100. 1100. 1100.
 1100.

THERMAL MEGAWATTS FOR OPERATING REACTOR
 NON-STANDARD INPUT PARAMETERS
 GRAMS WEIGHT OF WHOLE BODY
 ATOMIC NUMBERS OF FISSION PRODUCTS USED
 1100. BIOLOGICAL HALF-LIVES, DAYS

DECAY CHAIN DATA (LISTED IN APPENDIX C)
 WHOLE BODY DOSE INSOL, REP MULTIPLY RESULTS BY 0.15
 MORE

CASE TITLE
 ENDS SUBCASE
 THERMAL MEGAWATTS FOR OPERATING REACTOR
 NON-STANDARD INPUT PARAMETERS
 GRAMS WEIGHT OF WHOLE BODY
 ATOMIC NUMBERS OF FISSION PRODUCTS USED
 1100. BIOLOGICAL HALF-LIVES, DAYS

3440. REACTOR
 IGANA =3LIPDOS=1
 70000.
 7 42 44 45 46 50 51 52
 1100. 1100. 1100. 1100. 1100. 1100. 1100.
 DECAY CHAIN DATA (LISTED IN APPENDIX C)
 WHOLE BODY DOSE INSOL, VOL MULTIPLY RESULTS BY 0.15
 MORE

CASE TITLE
 ENDS SUBCASE
 THERMAL MEGAWATTS FOR OPERATING REACTOR
 NON-STANDARD INPUT PARAMETERS
 GRAMS WEIGHT OF WHOLE BODY
 ATOMIC NUMBERS OF FISSION PRODUCTS USED
 BIOLOGICAL HALF-LIVES, DAYS

3440. REACTOR
 IGANA =3LIPDOS=1
 70000.
 2 35 53
 8. 138.
 DECAY CHAIN DATA (LISTED IN APPENDIX C)
 WHOLE BODY DOSE HALOGENS
 MORE

CASE TITLE
 ENDS SUBCASE
 THERMAL MEGAWATTS FOR OPERATING REACTOR
 NON-STANDARD INPUT PARAMETERS

3440. REACTOR
 IGANA =3LIPDOS=1

70000.
7 42 44 45 46 50 51 52
1. 1. 1. 1. 1. 1.

DECAY CHAIN DATA (LISTED IN APPENDIX C)
WHOLE BODY DOSE INSOL, VOL MULTIPLY RESULTS BY 0.10
NONE

3440. REACTOR
IGANA =3LIPDOS=1
70030.

9 39 40 41 57 58 59 60 61 62
1. 1. 1. 1. 1. 1.

DECAY CHAIN DATA (LISTED IN APPENDIX C)
WHOLE BODY DOSE ISOL, REV MULTIPLY RESULTS BY 0.10
NONE

3440. REACTOR
IGANA =3LIPDOS=1
70000.

6 34 37 38 43 55 56
11. 45. 1.3E+8 1. 70. 65.

DECAY CHAIN DATA (LISTED IN APPENDIX C)
WHOLE BODY DOSE SOL, VOL MULTIPLY RESULTS BY .25
STOP

EXAMPLE 7
CURVES 1,2,3,4

1. WEAPON
LIPDOS=2IGANA =3
ACUTE

1 53
13.2-Y PG-241 46.2-YAN-241 6.75-D D-237 2.2-MY WP-237 LWR 90-DAY
1 100. 1.4.E-5 13.2 5
1 .1483 1. 46.2 5
1 .1175 1. 6.75 4
2 .00047 12.2P+6 5

6424 5 1000. 1000. 700. 1700. 7000.

1	4.E-3	4.910			
1	100.	.02			
2	84.	5.476	14.	5.433	
1	95.	.248			
3	53.	4.787	29.	4.767	3. 4.87
	CILIATED LUNG	UNCIL. LUNG	PLN	LIVER	BONE
1	.10	2.E-51.E-5		1. 4	
1	.15	.25 .04 .03		500. 4	
1		.56 .42		1000. 4	
1				83. 5	
2				200. 5	
1		4.E-53.E-5		1. 4	
1		.25 .12 .08		500. 4	
1		.35 .25		1000. 4	
1				9.5 5	
2				200. 5	
1		1.E-5		1. 4	
1		.25 .04		500. 4	
1		.11		1000. 4	
1				1. 4	

GRAMS WEIGHT OF WHOLE BODY
ATOMIC NUMBERS OF FISSION PRODUCTS USED
1. BIOLOGICAL HALF-LIVES, DAYS

CASE TITLE
ENDS SUBCASE
THERMAL MEGAWATTS FOR OPERATING REACTOR
NON-STANDARD INPUT PARAMETERS
GRAMS WEIGHT OF WHOLE BODY
ATOMIC NUMBERS OF FISSION PRODUCTS USED
1. BIOLOGICAL HALF-LIVES, DAYS

CASE TITLE
ENDS SUBCASE
THERMAL MEGAWATTS FOR OPERATING REACTOR
NON-STANDARD INPUT PARAMETERS
GRAMS WEIGHT OF WHOLE BODY
ATOMIC NUMBERS OF FISSION PRODUCTS USED
BIOLOGICAL HALF-LIVES, DAYS

CASE TITLE
ENDS EXAMPLE

DUMMY CARD TO INITIATE CALCULATIONS
NON-STANDARD INPUT PARAMETERS
TYPE OF BIOLOGICAL EXPOSURE
DUMMY CARD
TITLE FOR RADIOLOGICAL DECAY CHAIN
DECAY CHAIN DESCRIPTION

94959293 241
WEIGHTS OF BIOSYSTEM SECTIONS
ENERGIES OF EMISSIONS

TITLE FOR BIOSYSTEM
BIOSYSTEM DESCRIPTION FOR
RADIOLOGICAL CHAIN MEMBER 1

BIOSYSTEM DESCRIPTION FOR
RADIOLOGICAL CHAIN MEMBER 2

BIOSYSTEM DESCRIPTION FOR
RADIOLOGICAL CHAIN MEMBER 3

[illegible]

APPENDIX C
DETAILS OF DECAY CHAIN DATA

APPENDIX C
DETAILS OF DECAY CHAIN DATA

Standard Decay Chains for ^{235}U Fission

The input cards for the decay chain with atomic weight 89 are used as an example. A complete listing of the decay chain data follows this section. A pictorial description of the atomic weight 89 chain is given below.

Chain Member No.	1	2	3	4	5
^{235}U Fission Yield	4.59%	0	0.2%	0	not used in calculations
	^{89}Kr — 1.0 —→	^{89}Ro — 1.0 —→	^{89}Br — 0.9998 —→	$^{89}\text{Y}^*$ — 1.0 —→	^{89}Y
			0.0002		
Half-Life	3.2 min	15.4 min	51 days	16 sec	stable
ray MeV % decays		ray MeV % decays	ray MeV % decays	ray MeV % decays	
β 3.9 65		β 3.92 7.8	β 1.463 100	γ 0.915 99	
β 2.0 35		β 2.87 5			
		β 1.61 53			
		β 1.33 2			
		β 1.17 3			
		β 0.67 29			
		γ 1.05 75			
		γ 1.26 53			
		γ 0.663 15			
		γ 2.2 14			
		γ 2.59 13			
		γ 1.55 4			
		γ 2.75 3			
		γ 3.52 2			

The input cards for this chain are as follows:

	3.2-M KR-89	15.4-M RB-89	51-D SR-89	16-S Y-89*	Card No.1
1	4.59 1.			3.2 2	2
1	0.	1.		15.4 2	3
1	.20	.0002.9998		51. 4	4
2	0.	1.		16. 1	5
2321				36373839 89	6
2	65. 3.9	35. 2.			7
6	7.8 3.92	5. 2.97	53. 1.61	2. 1.33 3. 1.17 28. .67	8
8	75.0 1.0500	53.0 1.2600	15.0 .6630	14.0 2.2000 13.0 2.5900 4.0 1.5500	9
	3.0 2.7500	2.0 3.5200	. .		10
1	100. 1.463				11
1	99.0 .9150	. .	. .		12

64

Card Number 1 -- Decay Chain Title -- Format 18A11

<u>3.2-M KR-89</u>	<u>15.4-M RB-89</u>	<u>51-D SR-89</u>	<u>16-S Y-89*</u>
description of first member of decay chain	second member	third member	fourth member

To align output headings keep the description of each member of the decay chain less than 15 characters.

Cards Number 2, 3, 4, 5 -- Decay Chain Details -- Format I2, F8.3, 6F5.2, E10.3, I2

Each card refers to one member of the decay chain. I=1 refers to the first member, I=2 refers to the second member, etc.

I	an integer = 1 except for the card referring to the last member of the decay chain, where it is = 2.	fission yield, percent	B(2,I), fraction of decays of chain member number I that decay to chain member number 2.	B(3,I)	B(4,I)	B(5,I), not used in this chain's calculations but included for clarity.	radiological half-life	half-life units, 1-sec, 2-min, 3-hr, 4-days, 5-yrs
1	1	4.59	1.				3.2	2
2	1	0.	1.				15.4	2
3	1	.20		.0002	.9998		51.	4
4	2	0.			1.		16.	1

Card Number 6 -- Beta and Gamma Ray Indicators, Atomic Numbers and Weight -- Format 10I1, 5hX,
I2, 1X, 5I2, I3

an integer indicating whether beta or gamma rays are emitted when the first member of the chain decays.

an indicator for the second member of the chain = 0 for neither β or γ rays = 4 for α rays only.

an indicator for the third member of the chain = 1 for γ rays only = 5 for α & γ rays.

an indicator for the fourth member of the chain = 3 for both γ & β rays = 7 for α , β , & γ rays.

↓
2
↓
3
↓
2
↓
1

atomic number for chain member 1, 2, 3, 4

↓
36
↓
37
↓
38
↓
39
atomic weight for chain 89

Cards Number 7, 8, 9, 10, 11, 12 -- Alpha, beta, and gamma ray descriptions -- Format (I2, 6(E6.1,E7.4)/
(E8.1,E7.4,5(E6.1,E7.4))

25

the number of beta rays emitted by the first member of the decay chain

percent of decays emitting the first beta ray

energy of the first beta ray, MeV

percent of decays emitting the second beta ray

energy of the second beta ray, MeV

2	65.	3.9	35.	2.								
6	7.8	3.92	5.	2.87	53.	1.61	2.	1.33	3.	1.17	28.	.67
8	75.0	1.0500	53.0	1.2600	15.0	.6630	14.0	2.2000	13.0	2.5900	4.0	1.5500
	3.0	2.7500	2.0	3.5200	.	.	.	.	.	.	.	.
1	100.	1.463										
1	99.0	.9150										

the number of gamma rays emitted by the fourth member of the chain.

the number of beta rays emitted by the third member of the chain.

the number of gamma rays emitted by the second member of the chain.

the number of beta rays emitted by the second member of the chain.

Multisection Biosystem Data

When a multisection biosystem is to be used in the calculations, the biosystem specification must be made with each decay chain. Output is printed for each decay chain before proceeding to the next chain. The card order is as follows:

Cards 1 through 6: Radiological decay chain description as discussed in previous section in this Appendix.

Card 7:

Contents: Number and weight of the biosystem sections.

Variable names: $NRIO$, $(GRAMS(I), I=1, NRIO)$

Format: 15,6F7.4

Examples: 2 1000. 1000.
 5 1000. 1000. 700. 1700. 7000.

Cards 8 through 13: Alpha, beta, and gamma ray energies as described in cards 7 through 12 of the previous section in this Appendix.

Card 14:

Contents: The title for the biological output

Variable names: $(TITLEB(I), I=1, 18)$

Format: 18A4

Examples: CILIATED LUNG UNCIL. LUNG PLN LIVER BONE

Two or more cards:

Contents: Biological section description for the first member of the radiological decay chain. These cards have the same format as cards 2 through 5 of the previous section in this Appendix. The values of the constants are taken from Fig. 7.

Example:	1	.10	2.E-51.E-5	1. 1
	1	.15	.25 .04 .03	500. 1
	1		.57 .42	100. 1
	1			32. 5
	2			200. 5

Two or more cards:

Contents: Biological section description for the second member of the radiological decay chain. These cards have the same format as cards 2 through 5 of the previous section in this Appendix. The values of the constants are taken from Fig. 7.

Example:	1	4.E-53.E-5	1. 1
	1	.25 .12 .03	500. 1
	1	.35 .27	1000. 1
	1		9.5 5
	2		200. 5

Two or more cards:

Contents: Biological section description for the third member of the radiological decay chain. These cards have the same format as cards 2 through 5 of the previous section in this Appendix. The values of the constants are taken from Fig. 7.

Example:	1	1.E-5	1. 1
	1	.25 .04	500. 1
	1	.11	1000. 1
	1		1. 1
	2		300. 1

Two or more cards:

Contents: Biological section description for the fourth member of the radiological decay chain. These cards have the same format as cards 2 through 5 of the previous section in this Appendix. The values of the constants are taken from Fig. 7.

Example:	1	.5E-55.E-5	1. 1
	1	.25 .02 .15	500. 1
	1	.05 .45	1000. 1
	1		150. 5
	2		200. 5

Last card:

Contents: STOP
Format: 1A4

U-235 DECAY CHAIN DATA

[illegible]

4	25.	1.2	25.	2.25	25.	1.81	6.59						
4	12.5	5.23	12.5	4.4	37.0	.836	25.0	4.25	.	.	.	.	.
1	100.	.544											
2	19.0	.8630	5.1	2.5500	.	.8	.	.	.	.	.	.	.
	10-S KR-91		1.7-M RB-91		14-M RB-91		9.7-M SR-91		51-M Y-91*				
1	3.45	.5	.5				10. 1						
1	0.		1.				1.67 2						
1	0.		1.				14. 2						
1	2.36			.6	.4		9.7 3						
1	0.				1.		51. 2						
2	0.					1.	58. 4						
222313												39	3637373839 91
1	100.	3.6											
1	100.	4.6											
1	99.9	.1000	.	.	.	.	.	.					
5	33.	1.09	29.	1.36	27.	2.665	7.	.61	4.	2.03			
5	7.0	1.4130	30.0	1.0256	3.0	.9300	29.0	.7480	14.0	.6450	.	.	
1	99.9	.5512	.	.	.	.	.	.					
2	99.7	1.54	.3	.33			.	.					
1	.3	1.2080	.	.									
	3-S FR-92		5.3-S RB-92		2.7-M SR-92		3.6-M Y-92						
1	1.87	1.					3. 1						
1	0.		1.				5.3 1						
1	3.43		1.				2.7 3						
2					1.		3.6 3						
2233												36373839	92
1	100.	6.											
1	100.	6.5											
2	90.	.545	10.	1.5									
3	90.0	1.3700	4.1	.4400	3.5	.2300	.	.	.	.	.	.	.
3	9.	1.26	3.	1.75	8.	3.6							
5	9.0	1.4400	3.0	.2100	3.0	.2900	3.0	.4560	12.0	.9300	.	.	
	1.1-MY ZR-93		6-Y NB-93*										
1	6.45	1.					1.1E+06 5						
2			1.				6. 5						
20												40+1	93
2	75.	.063	25.	.034									
	16.5-M Y-94												
2	5.4	1.					16.5 2						
3												39	94
1	100.	5.											
8	1.0	.9200	2.0	1.1300	1.0	.5600	2.0	1.6500	3.0	1.9000	3.0	2.1300	
	3.0	2.8400	3.0	3.5300	.	.	.	.	.	.	.	.	
	65-D ZR-95		90-M NB-95*		35-D NB-95								
1	6.2	.02	.98				65. 4						
1	0.		1.				90. 3						
2	0.		1.				35. 4						
303												40+1+1	95
4	55.	.394	43.	.36	2.	.885	.4	1.13					
3	43.0	.7600	55.0	.7260	2.0	.2350	.	.	.	.	.		

2.6-M SM-130		33-M SM-130				2.6 2					
1	2.	1.					33. 2				
2			1.								
22									5051		130
1	100.	2.									
1	100.	5.									
23-M SM-131		30-M TE-131*		24-M TE-131		2.05-D I-131		12-D XE-131*			
1	2.6	.15	.85				23. 2				
1	.05		.20	.80			30. 3				
1	0.		1.				24. 2				
1	.2			.008	.992		8.05 4				
2	0.				1.		12. 4				
23331									5152525354131		
1	100.	1.1									
4	3.8	2.457	31.	.57	43.	.42	3.6	.215			
14	3.0	.2400	4.0	.2000	17.0	1.2700	5.0	1.0000	4.0	.0800	2.0 1.9200
	25.0	1.1400	8.0	.1000	8.0	.2070	3.0	.1620	40.0	.8400	16.0 .3350
	5.0	.9200	80.0	.7800							
4	40.	2.14	25.	1.68	5.	1.36	10.	1.15			
5	10.0	1.1300	5.0	.9200	80.0	.1650	20.0	.4540	5.0	.6000	
4	87.5	.606	9.3	.335	2.8	.25	.7	.812			
5	2.8	.1840	9.1	.6380	81.0	.3440	5.5	.2840	5.5	.0802	
1	99.9	.1640									
77-M TE-132		2.3M I-132									
1	4.38	1.					77. 3				
2	0.		1.				2.3 3				
33									5253		132
1	100.	.22									
2	99.9	.2330	99.9	.0520							
6	18.	2.14	21.	1.61	21.	.8	15.	1.04	12.	1.22	12. 1.49
14	99.9	.6730	1.8	1.5000	8.3	1.4000	6.5	.7200	2.2	.4600	1.3 .2400
	19.0	.9500	1.4	1.4500	17.0	.6500	19.0	.5200	82.0	.7750	9.0 .6470
	3.5	1.1400	5.2	.6200							
4.1-M SM-133		63-M TE-133*		2-M TE-133		20.8-M I-133		2.3-D XE-133*			
1	4.0	.72	.28				4.1 2				
1	1.02		1.				63. 2				
1	0.		1.				2. 2				
1	1.76			.024	.976		20.8 3				
1	0.				1.		2.3 4				
2	0.					1.	5.27 4				
023313									54 5152525354133		
1	100.	.4									
2	70.	1.3	17.	2.4							
10	20.7	.3090	5.7	.3870	50.0	.4320	22.0	.4680	35.0	.5570	18.0 .6320
	24.0	.6980	85.0	.7540	57.0	.9800	10.0	.9730			
2	94.	1.4	6.	.5							
6	99.9	.5300	2.0	.7100	14.0	.8700	1.0	1.0500	2.0	1.2400	5.0 1.3000
7											
1	20.0	.2330									
1	99.	.347									
1	40.0	.0810									
44-M TE-134		52.5-M I-134									
1	6.9	1.					44. 2				
2	.9		1.				52.5 2				
23									5253		134

1	100.	1.4											
6	23.	1.25	15.	1.49	7.5	1.60	9.5	1.81	12.	2.21	25.	2.41	
18	3.0	1.0700	2.0	.9400	9.5	1.1500	9.0	.5400	7.0	.3900	5.0	1.7900	
	4.5	1.0000	70.5	.8900	4.5	.8600	3.0	.1400	7.0	.4900	3.5	1.4600	
	18.0	.6100	3.0	.4300	15.0	1.0700	95.0	.8480	5.0	1.6200	6.0	.7700	
	6.7-H	1-135	15-M	XE-135*	9.2-H	XE-135	2.6-MV	CS-135					
1	6.1	.3	.7				6.7	3					
1	0.		1.				15.3	2					
1	2.03		1.				9.2	3					
2	4.38				1.		2.6E+06	5					
3132											53545455	135	
3	35.	.47	40.	1.	25.	1.4							
2	40.0	1.6900	25.0	1.2800	.	.	.	.	.	.	.	.	.
1	99.9	.5280	.	.	.	.	.	.	.	.	.	.	.
2	97.	.905	3.	.55	.	.	.	.	.	.	.	.	.
2	3.0	.6040	97.0	.2500	.	.	.	.	.	.	.	.	.
1	100.	.21											
	86-S	1-136											
2	3.1	1.					86.	1					
3											53	136	
5	6.	7.	15.	5.6	24.	4.37	6.	2.73	5.	4.16			
13	95.0	1.3200	11.0	2.6300	12.0	.2000	4.0	1.5500	8.0	2.8400	2.0	1.7200	
	19.0	.3900	5.0	1.9100	5.0	3.2000	7.0	2.2500	3.0	.7100	12.0	2.4000	
	6.0	1.0000	.	.	.	.	.	.	.	.	.	.	.
	24-S	1 137	3.9-M	XE 137	2.9-V	CS 137	2.57M	BA 137*					
1	6.5426	.94					24.	1					
1	0.		1.				3.9	2					
1	0.			.92	.08		29.	5					
2	0.			1.			2.57	2					
0221											53545556	137	
1	100.	3.5											
2	95.	.514	5.	1.18									
1	83.7	.6612	.	.	.	.							
	2.7-S	1-139	41-S	XE-139	9.5-M	CS-139	86-M	BA-139					
1	5.5	1.					2.7	1					
1	0.		1.				41.	1					
1	0.		1.				9.5	2					
2	1.05				1.		86.	2					
0223											53545556	139	
2	50.	3.5	50	4.6									
3	80.	4.	4.	3.4	16.	2.7							
3	72.	2.34	28.	2.17	.3	.91							
1	28.0	.1660	.	.	.	.	.	.	.	.	.	.	.
	16-S	XE-140	66-S	CS-140	12.8-D	BA-140	60.2-H	LA-140					
1	3.8	1.					16.	1					
1	0.		1.				66.	1					
1	2.64		1.				12.8	4					
2	0.				1.		60.2	3					
0233											54555657	140	
1	100.	6.5											
4	60.	1.02	25.	.48	10.	.6	5.	.89					
5	25.0	.5370	5.0	.4200	4.0	.3000	6.0	.1600	16.0	.0300	.	.	.
5	45.	1.38	10.	1.71	7.	2.20	26.	1.1	12.	.83			
4	90.0	1.6000	20.0	.4860	20.0	.8150	10.0	.3280					
	1.7-S	XE-141	18-M	BA-141	3.7-M	LA-141	33-D	CE-141					

1	1.34	1								1.7	1	
1	4.94		1.							18.	2	
1	.1			1.						3.7	3	
2	0.				1.					33.	4	
0232												54565758 141
1	100.	2.8										
2	98.	2.43	2.	1.06								
1	71.0	.1450	.	.	.	.	.	.	.	.	.	
2	70.	.435	30.	.58								
	6-M BA-142		75-M LA-142									
1	5.95	1.								6.	2	
2	0.		1.							75.	2	
01												5657 142
6	99.9	.6300	11.0	.8700	55.0	2.4000	30.0	2.2000	20.0	1.0000	15.0	2.9000
	18-M LA-143		33-M CE-143		13.7-D PR-143							
1	5.7	1.								18.	2	
1	0.		1.							33.	3	
2	0.			1.						13.7	4	
232												575859 143
1	100.	3.3										
5	40.	1.09	37.	1.38	12.	.52	6.	.22	5.	.72		
4	9.0	.7220	10.0	.6680	8.0	.3510	43.0	.2940	.	.	.	.
1	100.	.933										
	285-D CE-144		17.4-M PR-144									
1	5.67	1.								285.	4	
2	0.		1.							17.4	2	
33												5859 144
3	72.	.320	20.	.186	8.	.240						
2	2.0	.1340	1.0	.0800	.	.	.	.	.	.	.	.
3	97.7	2.98	1.3	2.29	1.	.8						
2	1.0	2.1800	1.3	.6910	.	.	.	.	.	.	.	.
	3-M CE-145		18-Y PR-145									
1	3.95	1.								3.	2	
2			1.							18.05		
20												5859 145
1	100.	2.										
	14-M CE-146		24.4-M PR-146									
1	3.07	1.								13.9	2	
2	0.		1.							24.4	2	
32												5859 146
1	100.	.7										
5	99.9	.3200	50.0	.2200	42.0	.1420	20.0	.1100	12.0	.2700	.	.
2	56.	3.7	44.	2.3								
	11.1-D ND-147		2.65-Y PM-147		.1-MMY SM-147.							
1	2.38	1.								11.1	4	
1			1.							2.65	5	
2				1.						1.3E+11	5	
230												606162 147
3	3.	.212	20.	.368	77.	.81						
1	100.	.225										
1	.01	.121										
	54-M PM-149											
2	1.13	1.								54.	3	
3												61 149
4	97.	1.07	3.	.784	.15	.47	.18	.19				

1	3.0	.2860	.	.	.	.	.	.	.	.	.
27.5-H PM-151 80-Y SM-151											
1	0.45	1.					27.5	3			
2	0.	1.					80.	3			
33									6162	151	
6	6.	.75	39.	.85	10.	1.03	5.	1.09	8.	1.12	11.
											1.2
10	3.3	.4450	21.0	.3400	6.4	.2750	3.1	.2400	6.3	.1770	2.1
	12.0	.1600	5.0	.1050	7.6	.1000	14.0	.0650	.	.	.
2	98.4	.0799	1.6	.0543					.	.	.
1	1.6	.0216	.	.	.	.	.	.	.	.	.
47-H SM-153											
2	.15	1.					47.	3			
3									62	153	
3	33.4	.641	45.6	.696	20.	.804			.	.	.
2	32.0	.0697	78.0	.1030	.	.	.	.	.	.	.
STOP											

APPENDIX D
COMPLETE LISTING OF YIELDS CODE

APPENDIX D

COMPLETE LISTING OF YIELDS CODE

```

SUBROUTINE AIDOU
COMMON /AANDZ/ IZ(6), IA
COMMON /ACTIV1/ ACTIV(6,100)
COMMON /AUXILL/ XI(6,7),B(6,6)
COMMON /CHAIN/ NCHAIN,NCOMBO,NBIO
COMMON /DOSEB1/ IORIGB,IRATEB
COMMON /DOSECA/ LIFDOS,INULOT,LIFBIO,ISORT
COMMON /EEESTD/ EEE
COMMON /EXTRA/ NIT,IPUNCH
COMMON /GNSHGT/ GNS,GRAMS(6)
COMMON /JUNK/ STORE(100),TITLE(18),OUTEN(18),A(6,100),TIME(100)
COMMON /JUNKB1/ TITLEB(18),AB(36,80)
COMMON /LABEL/ TUI(7,2),IORDER(16),EFF(6),THALFD(6)
COMMON /MEVCUR/ VFEEG(6),SDB(6),SDBBIO(6,6)
COMMON /ORIGIB/ AORIGB(36),YBIO(666),VB(36)
COMMON /ORIGIN/ ANTORI(6),VI(6,7),V(6)
COMMON /RATES/ R(6),ITIC(10)
COMMON /RBIOST/ RCON(36)
COMMON /REPEAT/ IRPT
COMMON /RESULT/ RESULT(6,200),DOSE(6,200)
COMMON /RPERMR/ NMR,ER(20),RHRCFT(20)
COMMON /SELEX/ IGAMA,IREAC,I TANK,I NEAP
COMMON /VALUES/ XI(6),FE(20,6),EG(20,6),KXX
COMMON /YSTEMP/ YS(6,6)
COMMON /ZLIST/ NILIST,IZLIST(60),IZTEST(6),TZLIST(60),PERCEN(60)
DOUBLE PRECISION ANTORI,V,V,R,B,RCON,AORIGB,YBIO,VB
I=1
RETURN
END

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AIDOU 10
AIDOU 20
AIDOU 30
AIDOU 40
AIDOU 50
AIDOU 60
AIDOU 70
AIDOU 80
AIDOU 90
AIDOU 100
AIDOU 110
AIDOU 120
AIDOU 130
AIDOU 140
AIDOU 150
AIDOU 160
AIDOU 170
AIDOU 180
AIDOU 190
AIDOU 200
AIDOU 210
AIDOU 220
AIDOU 230
AIDOU 240
AIDOU 250
AIDOU 260
AIDOU 270
AIDOU 280
AIDOU 290

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C PROGRAM YIELDS
COMMON /AUXILL/ XI(6,7),B(6,6)
COMMON /AANDZ/ IZ(6), IA
COMMON /ACTIV1/ ACTIV(6,100)
COMMON /CHAIN/ NCHAIN,NCOMBO,NBIO
COMMON /DOSEB1/ IORIGB,IRATEB
COMMON /DOSECA/ LIFDOS,INULOT,LIFBIO,ISORT
COMMON /EEESTD/ EEE
COMMON /EXTRA/ NIT,IPUNCH
COMMON /GNSHGT/ GNS,GRAMS(6)
COMMON /JUNK/ STORE(100),TITLE(18),OUTEN(18),A(6,100),TIME(100)
COMMON /ORIGIN/ ANTORI(6),VI(6,7),V(6)
COMMON /RATES/ R(6),ITIC(10)
COMMON /REPEAT/ IRPT
COMMON /RESULT/ RESULT(6,200),DOSE(6,200)
COMMON /SELEX/ IGAMA,IREAC,I TANK,I NEAP
COMMON /ZLIST/ NILIST,IZLIST(60),IZTEST(6),TZLIST(60),PERCEN(60)
DOUBLE PRECISION ANTORI,V,V,R,B
DIMENSION CHGLST(6),ADLIST(6),IA(6),JJ(20,6)
DIMENSION AA(6,40),AAA(40,40),AB(40,40)
DATA SSTOP/'STOP'/, REAC/'REAC'/, NEAP/'NEAP'/
DATA CRON/'CRON'/, ACUT/'ACUT'/

```

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100
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210
220

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DATA CHGLST/'STD ','IMUL','IGAM','IRPT','LIFD','' //
1 CONTINUE
C
CALL ZERDAR(TZLIST,60)
TLOG=LOG(2.1/8.64E-4)
U235=1.
READ 1020,THMPWR,REACHP
IF(REACHP.EQ.REAC) U235=8.433E-5*THMPWR/100.
IF(REACHP.EQ.WEAP) U235=3.912E-15*THMPWR/100.
C COMPENSATES FOR FISSION YIELD IN PER CENT
C U235=CURIES TO MAINTAIN POWER LEVEL, THMPWRW, IN MW
C OUTPUT IN MEV-CURIES MULT BY 5.929E-9 TO GET MWATTS
C
CALL ATOMM
CALL ZERDAR(AAA,1600)
CALL ZERDAR(ABG,1600)
PRINT 1001
READ 1002,(RDLIST(I),IRD(I),I=1,4)
C
C STANDARD PARAMETERS
C
IMULOT=1
IGAM=1
IRPT=1
LIFDOS=0
LIFBIO=1
C
DO 2 I=1,4
IF(RDLIST(I).EQ.CHGLST(1)) GO TO 2
IF(RDLIST(I).EQ.CHGLST(2)) IMULOT=IRD(I)
IF(RDLIST(I).EQ.CHGLST(3)) IGAM=IRD(I)
IF(RDLIST(I).EQ.CHGLST(4)) IRPT=IRD(I)
IF(RDLIST(I).EQ.CHGLST(5)) LIFDOS=IRD(I)
2 CONTINUE
IF(LIFDOS.GE.2) LIFBIO=2
IF(LIFDOS.GE.2) LIFDOS=LIFDOS-2
IF (LIFBIO.EQ.1.AND.IGAM.EQ.3) READ 1027, GMS
IGRIG=0
IRATEB=0
IF(LIFBIO.EQ.2) READ 1026,CAC
IF(CAC.EQ.CRON) IRATEB=1
IF(CAC.EQ.ACUT) IGRIG=1
READ 1003, NILIST, (IZLIST(I),I=1,NILIST)
IF (LIFBIO.EQ.1.AND.LIFDOS.EQ.1) READ 1027,(TZLIST(I),I=1,NILIST)
DO 3 I=1,NILIST
TZ=TZLIST(I)
IF(TZ.GT.0) TZLIST(I)=TLOG/TZ
IF(TZ.LE.0) TZLIST(I)=0
3 CONTINUE
CALL ZERDAR(STORE,100)
CALL ZERDAR(ACTIV,600)
CALL ZERDAR(RESULT,1200)
J=0
NIT=95
OT=10.0E-1
TIME(1)=60./OT

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230
240
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710
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860
870
880
890
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990
1000
1010
1020
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1040
1050
1060
1070
1080
1090
1100
1110
1120
1130

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	NIT=NIT+1	1140
	DO 4 I=1,NIT	1150
4	TIME(I)=TIMEIMOT	1160
	IFUNCH=0	1170
C		*****
	T=3.1536E+7	1190
	T3=4.*T	1200
	T1=T3/3.	1210
	T2=2.*T1	1220
5	CONTINUE	1230
	READ 1026,(TITLE(I),I=1,18)	1240
	IF(TITLE(I).EQ.OUTEND(1)) GO TO 19	1250
	IF(IRPT.EQ.1) PRINT 1004,(TITLE(I),I=1,18)	1260
	IF(REACMP.EQ.REAC) CALL COEFCA(NCHAIN,1,0,1)	1270
	IF(REACMP.EQ.WEAP) CALL COEFCA(NCHAIN,0,1,1)	1280
	CALL ZERDAR(IZTEST,6)	1290
	IZTEST=0	1300
	DO 8 K=1,NCHAIN	1310
	DO 7 L=1,NILIST	1320
	IF(IZ(K).NE.IZLIST(L)) GO TO 6	1330
	IZTEST(K)=L	1340
	IZTEST=1	1350
	GO TO 8	1360
6	CONTINUE	1370
7	CONTINUE	1380
8	CONTINUE	1390
	IF(IZTEST.EQ.0.AND.IRPT.EQ.1) PRINT 1005	1400
	IF(IZTEST.EQ.0.AND.LIFDOS.EQ.1) GO TO 5	1410
	IF(REACMP.EQ.REAC) GO TO 10	1420
	CALL SOLNCA(0,1,V,Y,A,NCHAIN,0)	1430
	CALL DERDAR(AMTOR I,6)	1440
	DO 9 K=1,NCHAIN	1450
9	AMTOR(K)=A(K,1)*U235	1460
	GO TO 12	1470
10	CALL SOLNCA(T1,1,V,Y,A,NCHAIN,0)	1480
	CALL SOLNCA(T2,1,V,Y,A,NCHAIN,1)	1490
	CALL SOLNCA(T3,1,V,Y,A,NCHAIN,2)	1500
	CALL DERDAR(AMTOR I,6)	1510
	J=J+1	1520
	DO 11 K=1,NCHAIN	1530
	AMTOR(K)=(A(K,1)+A(K,2)+A(K,3))*U235/3.	1540
11	CONTINUE	1550
12	CALL COEFCA(NCHAIN,0,2,0)	1560
	IF(TITLE(1).EQ.OUTEND(1)) GO TO 19	1570
	IF(IMULOT.EQ.2) GO TO 13	1580
	CALL SOLNAR(1,1)	1590
	GO TO 5	1600
13	CONTINUE	1610
	DO 14 IT=1,39	1620
14	CALL SOLNCA(TIME(IT),1,V,Y,A,NCHAIN,IT)	1630
	DO 15 K=1,NCHAIN	1640
	AA(K,1)=AMTOR(K)	1650
	DO 15 IT=2,40	1660
15	AA(K,IT)=A(K,IT)	1670
	DO 18 IT=1,40	1680
	DO 16 K=1,NCHAIN	1690

16	ANTON(K)=AA(K,IT)	1700
	CALL CDEFCA(NCHAM,0,2,0)	1710
	CALL ZERDAR(STORE,100)	1720
	CALL ZERDAR(RESULT,1200)	1730
	CALL SOLR,K(5,IT)	1740
	DO 17 L=IT,40	1750
	AAA(IT,L)=AAA(IT,L)+STORE(L)	1760
17	ADD(IT,L)=ADD(IT,L)+RESULT(L,L)	1770
18	CONTINUE	1780
	GO TO 5	1790
C		*****
C	OUTPUT SUM OF ACTIVITIES	*****
C		*****
19	CONTINUE	1830
	IF(INULOT.EQ.1) GO TO 23	1840
	DO 20 L=1,40	1850
20	ADD(L,L)=0	1860
	PRINT 1006, (TIME(IT),IT=1,9),((A3B(IT,L),IT=1,10),TIME(L),L=1,40)	1870
	DO 21 M=2,4	1880
	IT2=10*M	1890
	IT4=IT2-1	1900
	IT1=IT2-9	1910
	IT3=IT1-1	1920
21	PRINT 1007, (TIME(IT),IT=IT3,IT4),((ABB(IT,L),IT=IT1,IT2),TIME(L),	1930
	LL=1,40)	1931
	PRINT 1006, (TIME(IT),IT=1,9),((AAA(IT,L),IT=1,10),TIME(L),L=1,40)	1940
	DO 22 M=2,4	1950
	IT2=10*M	1960
	IT4=IT2-1	1970
	IT1=IT2-9	1980
	IT3=IT1-1	1990
22	PRINT 1007, (TIME(IT),IT=IT3,IT4),((AAA(IT,L),IT=IT1,IT2),TIME(L),	2000
	LL=1,40)	2001
	CALL SKALPR(ABB,1600,4)	2010
	PUNCH 1008,((ABB(I,J),J=1,40),I=1,40)	2020
	CALL SKALUN(ABB,1600,4)	2030
	CALL SKALPR(AAA,1600,4)	2040
	PUNCH 1008,((AAA(I,J),J=1,40),I=1,40)	2050
	CALL SKALUN(AAA,1600,4)	2060
23	CONTINUE	2070
	DO 24 I=1,NLIST	2080
	IF(TZLIST(I).NE.0) TZLIST(I)=TLOG/TZLIST(I)	2090
24	CONTINUE	2100
	IF(INULOT.EQ.2) GO TO 27	2110
	PRINT 1024, (STORE(K),TIME(K),K=1,NIT)	2120
	DO 26 K=1,NIT	2130
	IF(STORE(K).NE.0) GO TO 25	2140
	RESULT(I,K)=0	2150
	GO TO 26	2160
25	CONTINUE	2170
26	CONTINUE	2180
27	READ 1026, (TITLE(I),I=1,10)	2190
	IF(INULOT.NE.2) PRINT 1025, (RESULT(I,K),TIME(K),K=1,NIT)	2200
	PRINT 1023, (IZLIST(I),TZLIST(I),I=1,NLIST)	2210
	PRINT 1009, (TITLE(I),I=1,10)	2220
	IF(INULOT.EQ.1) PRINT 1010	2230

```

IF(INULOT.EQ.2) PRINT 1011
IF(ICAMA.EQ.0) PRINT 1012
IF(ICAMA.EQ.1) PRINT 1013
IF(ICAMA.EQ.2) PRINT 1014
IF(ICAMA.EQ.3) PRINT 1015,GMS
IF(ICAMA.EQ.4) PRINT 1016
IF(IRPT.EQ.0) PRINT 1017
IF(IRPT.EQ.1) PRINT 1018
IF(LIFBD.EQ.1.AND.LIFDOS.EQ.0) PRINT 1019
IF(LIFBD.EQ.1.AND.LIFDOS.EQ.1) PRINT 1020
IF(LIFBD.EQ.2.AND.LIFDOS.EQ.0) PRINT 1021
IF(LIFBD.EQ.2.AND.LIFDOS.EQ.1) PRINT 1022
READ 100% TITLE(1)
IF(TITLE(1).NE.SSTOP) GO TO 1
STOP 12121
1001 FORMAT('1')
1002 FORMAT(4I14,3X,1))
1003 FORMAT(2613)
1004 FORMAT(14X,18A4)
1005 FORMAT(' NO ELEMENTS FROM THE Z LIST ARE IN THIS DECAY CHAIN'
1/' '/' '/' ')
1006 FORMAT(
1 '1' 12X,'RELEASE'/' DECRY TIME TIME = 0 '9E11.4/5X,'0'5X,
210E11.4/(11E11.4))
1007 FORMAT(11X,'RELEASE TIME'/' DECRY TIME'10E11.4 /5X,'0'5X,
110E11.4/(11E11.4))
1008 FORMAT(16F5.0)
1009 FORMAT(' '18A4)
1010 FORMAT(' INULOT=1. SINGLE RELEASE AFTER SHUTDOWN')
1011 FORMAT(' INULOT=2. CONTINUOUS RELEASE AFTER SHUTDOWN')
1012 FORMAT(' ICAMA =0. OUTPUT IN CURIES. INPUT LONG DECK')
1013 FORMAT(' ICAMA =1. OUTPUT IN MEV-CURIES. INPUT LONG DECK')
1014 FORMAT(' ICAMA =2. OUTPUT IN MEV-CURIES. INPUT SHORT DECK')
1015 FORMAT(' ICAMA =3. OUTPUT IN R . INPUT LONG DECK'/' GMS ='
1E14.4)
1016 FORMAT(' ICAMA =4. OUTPUT IN R-FT**2/MR. INPUT LONG DECK')
1017 FORMAT(' IRPT =0. OMIT LABEL-LIST PRINT FOR EACH CHAIN')
1018 FORMAT(' IRPT =1. FULL PRINT OUTPUT')
1019 FORMAT(' LIFDOS=0. REGULAR CALCULATION')
1020 FORMAT(' LIFDOS=1. LIFETIME DOSE CALCULATION, MEV-CURIE-SEC')
1021 FORMAT(' LIFDOS=2. REGULAR CALCULATION, MULTISECTION BIOSYSTEM')
1022 FORMAT(' LIFDOS=3. LIFETIME DOSE CALCULATION, MULTISECTION BIOSYST
LEM')
1023 FORMAT(' INCLUDED ARE ELEMENTS WITH THE FOLLOWING Z AND HALF LIFE
1IN DAYS'/(4(I14,E14.4)))
1024 FORMAT(' TOTAL ACTIVITY '/' SEC MEV-CURIE
1S SEC MEV-CURIES SEC MEV-CURIES'/'
2 0 '5E14.4/(6E14.4))
1025 FORMAT(' FRACTIONAL ACTIVITY OF ELEMENTS IN ZLIST'/
1 84H SEC FRAC
2 SEC FRAC /14H
3 0 '5E14.4/(6E14.4))
1026 FORMAT(18A4)
1027 FORMAT(8E10.4)
1028 FORMAT(E10.4,IX,1A4)
END

```

```

SUBROUTINE BIOSEC(NRAD,NBIO,NCHAIN,V,BETA)
COMMON /BOSED1/ IORIG,IRATEB
COMMON /ORIGIB/ AORIG(34),Y(64),VB(34)
COMMON /RBIDST/ RCON(34)
DIMENSION V(1),BETA(1)
DIMENSION G(630),DIAG(34),BORY(34),BETAB(10),RB(64),BBIO(6,4)
DOUBLE PRECISION G,DIAG,RCON,BBIO,VB,AORIG,BETAB,RBIO,
DOUBLE PRECISION V,BETA
DATA IORIG,0/,IRATEB/1/
CALL DENDAR(G,630)
CALL DENDAR(RCON,34)
CALL DENDAR(RBIO,6)
CALL DENDAR(AORIG,34)
DO 5 I=1,NRAD
  I=I-1
  IF(I.GT.1) NBIOLD=NBIO
  IF(IORIG.EQ.1) CALL COEFIN(BBIO,VB,AORIG,BETAB,NBIO,4)
  IF(IRATEB.EQ.1) CALL COEFIN(BBIO,VB,RBIO,BETAB,NBIO,4)
  IF(I.GT.1.AND.NBIOLD.NE.NBIOLD) PRINT *,I,NBIOLD,NBIO,I
1001 FORMAT('ERROR IN BIOLOGICAL SYSTEM DESCRIPTION'/6X,'NUMBER OF STAGES'
  I=I+1
  IF(I.GT.1) NBIOLD=NBIO
  IADD=I1+NBIO
  IADD=I1*(I-2)/2
  N=I+L,NBIO
  K=IADD
  KADD=K*(K-1)/2
  G(K+KADD)=-V(I)-VB(I)
  DIAG(K)=-G(K+KADD)
  BORY(K)=-AORIG(I)
  RCON(K)=-RBIO(I)
  L=L-1
  LADD=L1*(L-2)/2
  IF(L.EQ.1) GO TO 2
  DO 1 N=L,1
    J=N+IADD
    G(J+KADD)=BETA(N+LADD)
    IF(I.EQ.1) GO TO 4
    DO 3 J=L,1
      N=(J-1)*NBIO+L
      G(N+KADD)=BETA(J+IADD)
    CONTINUE
    CONTINUE
    NCHAIN=NRAD+NBIO
    DO 6 K=L,NCHAIN
      IF(IORIG.NE.0) AORIG(K)=-BORY(K)
    6 VB(K)=DIAG(K)
    CALL DENDAR(V,630)
    DO 7 I=L,NCHAIN
      IF(RCON(I).EQ.0) GO TO 7
      CALL SLNTRI(RCON,G,V,NCHAIN)
    GO TO 8
    CONTINUE
    BORY(I)=BORY(I)+V(I)
    DO 10 I=2,NCHAIN
      I=I-1

```

```

0105 E 10
0105 E 20
0105 E 30
0105 E 40
0105 E 50
0105 E 60
0105 E 70
0105 E 80
0105 E 90
0105 100
0105 110
0105 120
0105 130
0105 140
0105 150
0105 160
0105 170
0105 180
0105 190
0105 200
0105 201
0105 210
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0105 390
0105 400
0105 410
0105 420
0105 430
0105 440
0105 450
0105 460
0105 470
0105 480
0105 490
0105 500
0105 510
0105 520
0105 530
0105 540

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      IADD=I*(I-2)/2
      DO 9 J=1,I
      IJ=J+IADD
      IJM=IJ+1
9      G(IJ)=G(IJM)
10     BORY(I)=BORY(I)+Y(I)
      CALL SOLNTR(G,V(NCHAIN+1),DIAG,BORY,NCHAIN)
      DO 11 I=2,NCHAIN
11     BORY(I)=Y(I)
      DO 12 I=2,NCHAIN
      IADD=I*(I-1)/2
      Y(IADD+1)=BORY(I)
      IBAD=IADD-I+NCHAIN
      DO 12 J=2,I
12     Y(J+IADD)=Y(J)+IBAD
      RETURN
      END

```

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BIOS 550
BIOS 560
BIOS 570
BIOS 580
BIOS 590
BIOS 600
BIOS 610
BIOS 620
BIOS 630
BIOS 640
BIOS 650
BIOS 660
BIOS 670
BIOS 680
BIOS 690
BIOS 700
BIOS 710

```

SUBROUTINE COEFC(NCHAIN,IRATE,IORIG,IREAD)

```

C
C IRATE, IORIG = 0 R.ANTORIG=0
C IRATE, IORIG = 1 R.ANTORIG READ IN
C IRATE, IORIG = 2 R.ANTORIG IN COMMON
C IREAD=0 OF NOT READ INPUT
C IREAD=1 READ INPUT
C
COMMON /AANDZ/ IZ(6),IA
COMMON /AUXILL/ XI(6,7),B(6,6)
COMMON /CHAIN/ NCTEMP,NCOMP,NBIO
COMMON /DOSEB1/ IORIG,BRATEB
COMMON /DOSECA/ LIFDOS,IMULOT,IFBIO,ISORT
COMMON /EEESTO/ EEE
COMMON /GMSMGT/ GMS,GRAMS(6)
COMMON /JUNK/ STOR(100),TITLE(18),OUTEN(18),A(6,100),TIME(100)
COMMON /JUNKB1/ TITLED(18),AB(36,80)
COMMON /LABEL/ TUN(7,2),IORDER(100),EFF(6),THALFD(6)
COMMON /MEVCUR/ VFEE(6),SBB(6),SBBB(6,6)
COMMON /ORIGIN/ ANTORI(6),VI(6,7),V(6)
COMMON /RATES/ R(6),ITIC(10)
COMMON /REPEAT/ IRPT
COMMON /RPERMR/ NRH,FR(20),RMRGFT(20)
COMMON /SELEK/ IGANA,IREAC,ITANK,THEAP
COMMON /VALUES/ KXI(6),FE(20,6),EG(20,6),KXX
COMMON /YSTEMP/ YSI(6,6)
COMMON /ZLIST/ NILIST,IZLIST(60),IZTEST(6),TZLIST(60),PERCEN(60)
DIMENSION VA(6),DI(49),NT(6),XSI(5),BETA(5)
DOUBLE PRECISION D,EIJ,VA,B,ANTORI,Y,V,R,TB,BETA,XS
IF(IORIG.NE.2) CALL DEROAC(ANTORI,6)
IF(IRATE.NE.2) CALL DEROAR(R,6)
IF(IREAD.EQ.0) GO TO 24
CALL ZERDAR(L,49)
CALL DEROAR(Y,42)
IF(IORIG.EQ.1) CALL COEFINB,V,ANTORI,BETA,NCHAIN,6)
IF(IRATE.EQ.1) CALL COEFINB,V,R,BETA,NCHAIN,6)
READ 1001,(ITIC(I),I=1,10),IZ(6),(IZ(I),I=1,5),IA
ISKIP=1

```

```

COEFC 10
*****
*****
*****
*****
*****
*****
*****
COEFC 90
COEF 100
COEF 110
COEF 120
COEF 130
COEF 140
COEF 150
COEF 160
COEF 170
COEF 180
COEF 190
COEF 200
COEF 210
COEF 220
COEF 230
COEF 240
COEF 250
COEF 260
COEF 270
COEF 280
COEF 290
COEF 300
COEF 310
COEF 320
COEF 330
COEF 340
COEF 350
COEF 360
COEF 370
COEF 380

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```

      ISKIP=0
      DO 2 I=1,NCHAIN
      DO 1 M=1,NLIST
      IF(I2(I).EQ.IZLIST(M)) GO TO 3
1     CONTINUE
2     CONTINUE
3     CONTINUE
      IF(ISKIP.EQ.1) GO TO 4
      IF(IRPT.NE.1) GO TO 4
      PRINT 1002,(TITLE(I),I=1,12)
      IF(IORIG.EQ.1) PRINT 1003,(APFOR(I),I=1,NCHAIN)
      IF(IRATE.EQ.1) PRINT 1003,(R      (I),I=1,NCHAIN)
      PRINT 1004,(V(I),I=1,NCHAIN)
4     CONTINUE
      IF(IGAMA.EQ.0) GO TO 5
5     CONTINUE
      CALL ZERDAR(EG,120)
      CALL ZERDAR(FE,120)
      CALL ZERDAR(KX,6)
      IF(IGAMA.NE.2) GO TO 7
      READ 1005,IA1,(SBB(K),K=1,NCHAIN)
      IF(IA.NE.1A1) STOP 10101
      DO 6 K=1,NCHAIN
6     VFEG(K)=SBB(K)*V(K)
      GO TO 23
7     CONTINUE
      CALL ZERDAR(SBBIO,36)
      IF(LIFBIO.EQ.2)
      IREAD 1005,NBIO,(GRAMS(I),I=1,NBIO)
C
C ITIC      01234567
C ALPHA     ....XXXX
C BETA       ..XX..XX
C GAMMA      .X.X.X.X
C
      DO 17 I=1,NCHAIN
      KMAX=0
      ITIC1=ITIC(I)+1
      GO TO (17,14,11,11,8,8,8,8),ITIC1
8     READ 1006,KMAX,(FE(K,I),EG(K,I),K=1,KMAX)
      DO 10 K=1,KMAX
      IF(IGAMA.EQ.4) EG(K,I)=0
      IF(IGAMA.EQ.3.AND.LIFBIO.EQ.1) EG(K,I)=EG(K,I)*2.134E+7/GPS
      IF(LIFBIO.EQ.1) GO TO 10
      DO 9 I8IO=1,NBIO
      GBIO=1.
      IF(IGAMA.EQ.3) GBIO=2.134E+7      /GRAMS(I8IO)
9     SBBIO(I8IO,I)=SBB(I8IO,I)+FE(K,I)*EG(K,I)*GBIO
10    CONTINUE
      KX(I)=KMAX
      GO TO (17,14,11,11,17,14,11,11),ITIC1
11   ZD=IZ(I)+1
      READ 1006,KXX,(FE(K+KMAX,I),EG(K+KMAX,I),K=1,KXX)
      DO 13 K=1,KXX
      ET=EG(K+KMAX,I)
      IF(IGAMA.EQ.4) EG(K+KMAX,I)=0
      COEF 390
      COEF 400
      COEF 410
      COEF 420
      COEF 430
      COEF 440
      COEF 450
      COEF 460
      COEF 470
      COEF 480
      COEF 490
      COEF 500
      COEF 510
      COEF 520
      COEF 530
      COEF 540
      COEF 550
      COEF 560
      COEF 570
      COEF 580
      COEF 590
      COEF 600
      COEF 610
      COEF 620
      COEF 630
      COEF 640
      COEF 650
      COEF 660
      COEF 661
      *****
      *****
      *****
      *****
      *****
      *****
      COEF 730
      COEF 740
      COEF 750
      COEF 760
      COEF 770
      COEF 780
      COEF 790
      COEF 800
      COEF 810
      COEF 820
      COEF 830
      COEF 840
      COEF 850
      COEF 860
      COEF 870
      COEF 880
      COEF 890
      COEF 900
      COEF 910
      COEF 920
      COEF 930

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```

      EG(K+KMAX,I)=AVEBET(ET,ZD)
      IF(ICAMA.EQ.3.AND.J.IFBD.EQ.1) E=(K+KMAX,I)=ET*2.134E+6/GMS
      IF(LIFBD.EQ.1) GO TO 13
      DO 12 IBD=1,NBD
      C8ID=1.
      IF(ICAMA.EQ.3) C8ID=2.134E+6 /GRANS(IBID)
12  S888ID(IBID,I)=S888ID(IBID,I)+FE(K+KMAX,I)*EG(K+KMAX,I) *C8ID
13  CONTINUE
      KX(I)=KX+KMAX
      KMAX=KX(I)
      GO TO (17,14,17, 14,17, 14,17, 14),ITIC1
14  READ 1006,KXX,(FE(K+KMAX,I),EG(K+KMAX,I),K=1,KXX)
      DO 16 K=1,KXX
      ET=EG(K+KMAX,I)
      IF(ICAMA.EQ.3.AND.J.IFBD.EQ.1) EG(K+KMAX,I)=ABS(ET,GRS)
      IF(ICAMA.EQ.4) CALL SRCVAR(1,NBN,2,MCFCT,EA,ET,EG(K+KMAX,I),IER)
      IF(LIFBD.EQ.1) GO TO 16
      DO 15 IBD=1,NBD
      IF(ICAMA.EQ.3) EG(K+KMAX,I)=ABS(ET,GRANS(IBID))
15  S888ID(IBID,I)=S888ID(IBID,I)+FE(K+KMAX,I)*EG(K+KMAX,I)
16  CONTINUE
      KX(I)=KX+KMAX
      KMAX=KX(I)
17  CONTINUE
      KXX=KX(I)
      DO 18 I=1,NCHAIN
      KXX=MAX(KX(I),KXX)
18  IF(IRPT.EQ.1) PRINT 1009,(KX(I),I=1,NCHAIN)
      IF(IRPT.EQ.1) PRINT 1013
      DO 19 I=1,KXX
      IF(IRPT.EQ.1.AND.ICAMA.LE.2) PRINT 1010,(EG(I,J),FE(I,J),J=1,NCHACOF
1IN)
      IF(IRPT.EQ.1.AND.ICAMA.GT.2) PRINT 1011,(EG(I,J),FE(I,J),J=1,NCHACOF
1IN)
19  CONTINUE
      DO 22 K=1,NCHAIN
      S8=0
      KMAX=KX(K)
      IF(KMAX.EQ.0) GO TO 21
      DO 20 KK=1,KMAX
      S8=S8+FE(KK,K)*EG(KK,K)
20  S88(K)=S8/100.
21  VFEEG(K)=S8*VIK/100.
22  PUNCH 1006,1A,(S88(K),K=1,NCHAIN)
      CONTINUE
      IF(IRPT.NE.1) GO TO 24
      PRINT 1007,(S88(K),K=1,NCHAIN)
      PRINT 1008,(VFEEG(K),K=1,NCHAIN)
      PRINT 1012
      IF(LIFBD.EQ.2) READ 1014,(TITLE3(I),I=1,18)
      IF(LIFBD.EQ.2) CALL BIOSEC(NCHAIN,NBID,NCOMBO,V,BETA)
24  CONTINUE
      CALL DERDAR(D,49)
      CALL DERDAR(Y,42)
      IF(IDRIG.EQ.0) CALL DERDAR(ANTORI,6)
      IF(IRATE.EQ.0) GO TO 28

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```

COEF 940
COEF 950
COEF 960
COEF 970
COEF 980
COEF 990
COE 1000
COE 1010
COE 1020
COE 1030
COE 1040
COE 1050
COE 1060
COE 1070
COE 1080
COE 1090
COE 1100
COE 1110
COE 1120
COE 1130
COE 1140
COE 1150
COE 1160
COE 1170
COE 1180
COE 1190
COE 1200
COE 1210
COE 1220
COE 1230
COE 1240
COE 1250
COE 1251
COE 1260
COE 1270
COE 1280
COE 1290
COE 1300
COE 1310
COE 1320
COE 1330
COE 1340
*****
COE 1360
COE 1370
COE 1380
COE 1390
COE 1400
COE 1410
COE 1420
COE 1430
COE 1440
COE 1450
COE 1460
COE 1470

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      DO 25 I=1,NCHAIN
      IADD=I*(I-1)/2
      DO 25 J=1,I
25    VA(J+IADD)=B(I,J)*VE(J)
      DO 26 I=1,NCHAIN
      IF(I.EQ.0) GO TO 27
26    CONTINUE
      GO TO 28
27    CALL SLNTRI(R,VA,Y,NCHAIN)
28    IF(NCHAIN.EQ.1) RETURN
      DO 29 J=1,NCHAIN
29    DI(J)=Y(J,1)-ANTORI(J)
      CALL SOLNTR(BETA,XS,V,D,NCHAIN)
      DO 31 I=1,NCHAIN
      IF(I.EQ.1) GO TO 31
      JEND=I-1
      IADD=JEND*(I-2)/2
      DO 30 J=1,JEND
30    Y(I,J+1)=XS(J+IADD)
31    Y(I,I+1)=ANTORI(I)-Y(I,1)
      RETURN
1001 FORMAT(10I1,5A12,1X,5I2,13)
1002 FORMAT(14X,18A4)
1003 FORMAT('14X,6(F10.4,' PCT')')
1004 FORMAT('14X,6(E12.4,'/S')')
1005 FORMAT(15,6F7.4)
1006 FORMAT(12,6(E6.1,E7.4)/(E8.1,E7.4,5(E6.1,E7.4)))
1007 FORMAT(' AV.NEV/DECAY' 6F14.4)
1008 FORMAT('7X,'NEV/SEC',6E14.4)
1009 FORMAT('END. OF GAMMA RAYS'17,5I14)
1010 FORMAT(14X,6(F7.4,F7.1))
1011 FORMAT(14X,12F7.1)
1012 FORMAT(1H0)
1013 FORMAT(16X,
1      1 83H NEV PERCENT NEV PERCENT NEV PERCENT NEV PERCENT
2EV PERCENT NEV PERCENT )
1014 FORMAT(18A4)
      END

      SUBROUTINE COEFIN(B,V,D,BETA,NCHAIN,NB)
      DIMENSION B(NB,NB),V(1),D(1),BETA(1),IZERO(6)
      DOUBLE PRECISION B,V,D,BETA,THALF,TLOG
      TLOG=DLOG(2.00)
      CALL D5XDR(V,6)
      DO I=1,6
1    READ 1001,IZERO(I),D(I),(B(J,I),J=2,6),87I,THALF,IHALF
      NCHAIN=I
      GO TO (4,2,3,4,5),IHALF
2    THALF=THALF*60.00
      GO TO 6
3    THALF=THALF*3600.00
      GO TO 6
4    THALF=THALF*86400.00
      GO TO 6
5    THALF=THALF*3.1536707
      GO TO 6

```

```

COE 1480
COE 1490
COE 1500
COE 1510
COE 1520
COE 1530
COE 1540
COE 1550
COE 1560
COE 1570
COE 1580
COE 1590
COE 1600
COE 1610
COE 1620
COE 1630
COE 1640
COE 1650
COE 1660
COE 1670
COE 1680
COE 1690
COE 1700
COE 1710
COE 1720
COE 1730
COE 1740
COE 1750
COE 1760
COE 1770
COE 1780
COE 1790
COE 1800
COE 1810
COE 1811
COE 1812
COE 1820
COE 1830
COEF 1 10
COEF 1 20
COEF 1 30
COEF 1 40
COEF 1 50
COEF 1 60
COEF 1 70
COEF 1 80
COEF 1 90
COEF 100
COEF 110
COEF 120
COEF 130
COEF 140
COEF 150
COEF 160
COEF 170

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6  V(I)=TLOG /THALF
   IF(IZERO(I).EQ.2) GO TO 8
7  CONTINUE
8  IZERO(I)=1
   B(1,1)=-1.00
   DO 9 I=2,NCHAIN
     B(1,I)=-1.00
9  B(1,I)=0
   CALL MATCK(0,BETA,V,NCHAIN)
   RETURN
1001 FORMAT(12,F8.3,6F5.2,E10.3,12)
    END

SUBROUTINE DEROA(A,N)
  DIMENSION A(1)
  DOUBLE PRECISION A
  DO 1 I=1,N
1  A(I)=0
  RETURN
  END

DOUBLE PRECISION FUNCTION EXAPR(U,F)
  DOUBLE PRECISION U,F,C1,C2
  DATA C1/1.00/,C2/2.00/
  EXAPR=UP(C1-UP(C1-UP(C1-U/F))/(F-C1))/(F-C2)
  RETURN
  END

SUBROUTINE MATCK(0,BD,V,N)
C
C   NXN MATRIX DIAGONALIZED, ASSIGNED K VALUE IN ROW ARRAY
C   DIAGONAL ELEMENTS ARE ASSUMED NON ZERO
C   DIMENSION B(6,6), BD(15), LD(6), ICOUNT(6), BNEW(6,6), V(1)
  DIMENSION B(6,6), BD(15), LD(6), ICOUNT(6), BNEW(6,6), V(1)
  DOUBLE PRECISION B, BD, BNEW, V
  DO 1 I=1,N
1  LD(I)=1
C   CHECK FOR N=1 OR N=2
  IF(N.EQ.1) RETURN
  IF(N.GT.2) GO TO 2
C CHECK 2X2 MATRIX
  IF(B(1,2).EQ.0) GO TO 10
  IF(B(1,2).NE.0.AND.B(2,1).NE.0) GO TO 11
  B(2,1)=B(1,2)
  B(1,2)=0.
  BD(1)=B(2,1)*V(1)
  GO TO 11
C CHECK IF MATRIX IS ALREADY DIAGONALIZED
2  DO 3 I=1,N
  DO 3 J=1,N
3  BNEW(I,J)=B(I,J)
  N1=N-1
  DO 4 I=1,N1
  IF(B(I,I).EQ.0) GO TO 5
  I1=I+1
  DO 4 J=I1,N
  IF(B(I,J).NE.0) GO TO 6

```

COEF 180
COEF 190
COEF 200
COEF 210
COEF 220
COEF 230
COEF 240
COEF 250
COEF 260
COEF 270
COEF 280
COEF 290

DEROA 10
DEROA 20
DEROA 30
DEROA 40
DEROA 50
DEROA 60
DEROA 70

10
20
30
40
50
60

MATCK 10

MATCK 40
MATCK 50
MATCK 60
MATCK 70

MATCK 90
MATCK 100

MATCK 120
MATCK 130
MATCK 140
MATCK 150
MATCK 160
MATCK 170

MATCK 190
MATCK 200
MATCK 210
MATCK 220
MATCK 230
MATCK 240
MATCK 250
MATCK 260
MATCK 270

4	CONTINUE	MATC 280
	GO TO 18	MATC 290
5	PRINT 1008	MATC 300
	GO TO 11	MATC 310
6	IF (B(I,I).EQ.0) GO TO 7	MATC 320
	PRINT 1001, I, J	MATC 330
	GO TO 11	MATC 340
C	REORDERING OF MATRIX	*****
7	DO 15 ND = 1, N	MATC 360
	DO 10 I = 1, ND	MATC 370
	ICOUNT = 0	MATC 380
	DO 8 J = ND, N	MATC 390
	IF (B(I,J).NE.0) ICOUNT = ICOUNT + 1	MATC 400
8	CONTINUE	MATC 410
	ICOUNT(I) = ICOUNT	MATC 420
	IF (ICOUNT .GT. 1) GO TO 10	MATC 430
	IF (I.EQ.ND) GO TO 15	MATC 440
	LT = LD(I)	MATC 450
	II = I - 1	MATC 460
	KSET = II + ND	MATC 470
	DO 9 KK = ND, II	MATC 480
	K = KSET - KK	MATC 490
9	LD(K+1) = LD(K)	MATC 500
	LD(ND) = LT	MATC 510
	GO TO 13	MATC 520
10	CONTINUE	MATC 530
11	PRINT 1002	MATC 540
	DO 12 I = 1, N	MATC 550
12	PRINT 1004, (BNEW(I,J), J=1, N)	MATC 560
	GO TO 20	MATC 570
13	DO 14 I = 1, N	MATC 580
	LDI = LD(I)	MATC 590
	DO 14 J = 1, N	MATC 600
14	B(I,J) = BNEW(LDI, LD(J))	MATC 610
15	CONTINUE	MATC 620
	PRINT 1006, (I, I = 1, N)	MATC 630
	PRINT 1007, (LD(I), I = 1, N)	MATC 640
	PRINT 1003	MATC 650
	DO 16 I = 1, N	MATC 660
16	PRINT 1004, (BNEW(I,J), J=1, N)	MATC 670
	PRINT 1005	MATC 680
	DO 17 I = 1, N	MATC 690
17	PRINT 1004, (B(I,J), J = 1, N)	MATC 700
C	END ARRAY	*****
18	DO 19 I = 2, N	MATC 720
	II = I - 1	MATC 730
	ITWO = (I-1) * (I-2) / 2	MATC 740
	DO 19 J = 1, II	MATC 750
	K = J + ITWO	MATC 760
19	BID(K) = B(I,J)*V(J)	MATC 770
20	RETURN	MATC 780
1001	FORMAT (' B(I,J) AND B(J,I) BOTH NOT ZERO, I, J =', 2I4)	MATC 790
1002	FORMAT (' ORIGINAL MATRIX CANNOT BE TRIANGULARIZED')	MATC 800
1003	FORMAT ('/' ORIGINAL MATRIX')	MATC 810
1004	FORMAT (1X, 12E10.2)	MATC 820
1005	FORMAT (' TRIANGULARIZED MATRIX')	MATC 830

```

1006 FORMAT (' CALCULATED ORDER CHANGED FROM INPUT ORDER'//
1' INPUT = ' (20(4))
1007 FORMAT (' VEM = ' (20(4))
1008 FORMAT (' DIAGONAL IS ZERO'//)
END

```

```

MATC 840
MATC 841
MATC 850
MATC 860
MATC 870

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```

SUBROUTINE SKALPR(A,N,J)
DIMENSION A(1)
AX=A(1)
DO 1 I=2,N
1 AX=AMAX1(AX,A(I))
IE=J-IFIX(ALOG10(AX)+1.)
EIE=10.**IE
DO 2 I=1,N
2 A(I)=A(I)*EIE
RETURN
ENTRY SKALUN
DO 3 I=1,N
3 A(I)=A(I)/EIE
PRINT 1001,IE
1001 FORMAT(' DIVIDE THE ABOVE TABLE BY 10.**'I6)
RETURN
END

```

```

SKALP 10
SKALP 20
SKALP 30
SKALP 40
SKALP 50
SKALP 60
SKALP 70
SKALP 80
SKALP 90
SKAL 100
SKAL 110
SKAL 120
SKAL 130
SKAL 140
SKAL 150
SKAL 160
SKAL 170

```

```

SUBROUTINE SLNTRI(Y,A,X,N)
DIMENSION Y(1),A(2),X(1)
DOUBLE PRECISION Y,A,X,S
CALL DENDAR(X,N)
IF(A(1).NE.0) X(1)=Y(1)/A(1)
IF(N.LE.1) RETURN
DO 2 I=2,N
1 I=I-1
IA=I+I/2
S=Y(I)
DO 1 J=1,II
1 S=S-A(I+IA)*X(J)
IF(A(I+IA).NE.0) X(I)=S/A(I+IA)
2 CONTINUE
RETURN
END

```

```

SLNTR 10
SLNTR 20
SLNTR 30
SLNTR 40
SLNTR 50
SLNTR 60
SLNTR 70
SLNTR 80
SLNTR 90
SLNT 100
SLNT 110
SLNT 120
SLNT 130
SLNT 140
SLNT 150
SLNT 160

```

```

SUBROUTINE SOLNAR(I SOLN,ISTORE)
COMMON /A AND Z/ IZ(6),IA
COMMON /ACTIVE/ ACTIVE(6,100)
COMMON /CHAIN/ NCHAIN,NCOMB,NBIO
COMMON /DOSEBI/ TORIG,IRATEB
COMMON /DOSECA/ LIFOOS,INULDT,LIFBIO,ISHORT
COMMON /EXTRA/ NYT,IPUNCH
COMMON /GHSWGT/ GHS,GRAN(6)
COMMON /JUNK/ STORE(100),TITLE(18),OUTEND(18),A(6,100),TIME(100)
COMMON /MEVCUR/ VFEEG(6),SBB(6),SBBBIO(6,6)
COMMON /JUNKBI/ TTTEB(18),AB(36,80)
COMMON /ORIGIB/ AORIG(36),YCOMBO(666),VB(36)
COMMON /ORIGIN/ AMTOR(16),V(6,7),V(6)
COMMON /RATES/ R(6),ITIC(10)
COMMON /REPEAT/ IRPT

```

```

SOLNA 10
SOLNA 20
SOLNA 30
SOLNA 40
SOLNA 50
SOLNA 60
SOLNA 70
SOLNA 80
SOLNA 90
SOLN 100
SOLN 110
SOLN 120
SOLN 130
SOLN 140
SOLN 150

```

COMMON /RESULT/RESULT(6,200),DOE(6,200)	SOLN 160
COMMON /SELEK/ IGANA,IREAC,ITAK,IMEAP	SOLN 170
COMMON /VALUES/KXI(6),FE(20,6),EG(20,6),KXX	SOLN 180
COMMON /ZLIST/ NLIST,IZLIST(40),IZTEST(6),TZLIST(60),PERCENT(60)	SOLN 190
DOUBLE PRECISION ANTORI,V,V,R,V3,ADRI(6),YCONDG,V8	SOLN 200
DIMENSION DOSEIN(6),V3(6),EN(16,6)	SOLN 210
NIT=NTT	SOLN 220
IF(DMLOT.EQ.2)NIT=40	SOLN 230
NIT=NIT+1	SOLN 240
DO 1 K=1,NCHAIN	SOLN 250
V3(K)=V(K)	SOLN 260
IF(IZTEST(K).EQ.0) GO TO 1	SOLN 270
V3(K)=V(K)+TZLIST(IZTEST(K))	SOLN 280
1 CONTINUE	SOLN 290
OK=1.258925	SOLN 300
OK=34.279333	SOLN 310
M=1	SOLN 320
IF(DMLOT.EQ.2) M=ISTORE	SOLN 330
ISOLL=ISOLL	SOLN 340
IF(ISOLL.EQ.5) ISOLL=1	SOLN 350
DO 4 IT=N,NIT	SOLN 360
TIMEIT=TIME(IT)	SOLN 370
C IF(ISOLL.EQ.5) TIMEIT=3.1536E+7*10.	*****
IF(LIFDOS.EQ.1) GO TO 3	SOLN 390
CALL SOLNCA(TIME IT ,1,V,V,A,NCHAIN,0)	SOLN 400
DO 2 K=1,NCHAIN	SOLN 410
2 A(K,IT+1)=A(K,1)/(V3(K)*3600.)	SOLN 420
3 IF(LIFDOS.EQ.0) CALL SOLNCA(TIME IT ,1,SOLL,V,V,A,NCHAIN,IT)	SOLN 430
DO 4 K=1,NCHAIN	SOLN 440
ACTIV(K,IT+1)=A(K,IT+1)	SOLN 450
IF(IGANA.EQ.0) AND 1 IFB(D.EQ.1) ACTIV(K,IT+1)=ACTIV(K,IT+1)*SB0(K)	SOLN 460
4 ACTIV(K,IT+1)=ACTIV(K,IT+1)*VK	SOLN 470
DO 6 K=1,NCHAIN	SOLN 480
A(K,M)=ANTORI(K)	SOLN 490
ACTIV(K,M)=A(K,M)*V(K)	SOLN 500
IF(IGANA.EQ.0) GO TO 5	SOLN 510
ACTIV(K,M)=ACTIV(K,M)*SB0(K)	SOLN 520
5 CONTINUE	SOLN 530
6 CONTINUE	SOLN 540
DO 7 K=1,NCHAIN	SOLN 550
STORE(M)=STORE(M)+ACTIV(K,M)	SOLN 560
IF(IZTEST(K).EQ.0) RESULT(1,M)=RESULT(1,M)+ACTIV(K,M)	SOLN 570
DO 7 IT=N,NIT	SOLN 580
STORE(IT+1)=STORE(IT+1)+ACTIV(K,IT+1)	SOLN 590
IF(IZTEST(K).EQ.0) RESULT(1,IT+1)=RESULT(1,IT+1)+ACTIV(K,IT+1)	SOLN 600
7 CONTINUE	SOLN 610
IF(IIRPT.EQ.0) GO TO 9	SOLN 620
PRINT 1001,(ACTIV(I,M),I=1,NCHAIN)	SOLN 630
DO 8 J=N,NIT	SOLN 640
L=J+1	SOLN 650
8 PRINT 1003,TIME(J),(ACTIV(I,L),I=1,NCHAIN)	SOLN 660
PRINT 1002	SOLN 670
9 CONTINUE	SOLN 680
IF(LIFDOS.EQ.2) RETURN	SOLN 690
T50=50.*3.1536E+7	SOLN 700
CALL ZEROD(AD,2800)	SOLN 710

DOUBLE PRECISION ANTORI,V,V,R,VB,EXAPRX,TNDEXP,ASUM,U,W,EU,EN	SOLN 150
DOUBLE PRECISION VOK,VBK,VBK .C1,C2,C4,C5,C6,CH	SOLN 160
DATA DEL/.000/.C1/1.00/.C2/2.00/.C4/4.00/.C5/5.00/.C6/6.00/.CH/	SOLN 170
1.500/	SOLN 171
DIMENSION V(6),A(36,80)	SOLN 180
NCHART1=NCHART+1	SOLN 190
DO 31 K=1,NCHART	SOLN 200
KADD=K+(K-1)/2	SOLN 210
K1=KADD+1	SOLN 220
U=V(K1)*T	SOLN 230
IF(U-DEL) 1, 15	SOLN 240
1 GO TO (2,3,4,2), ITYPE	SOLN 250
2 ASUM=ANTORI(K)+(V(K 1)-ANTORI(K1))*EXAPRX(U,C4)	SOLN 260
GO TO 5	SOLN 270
3 ASUM=(ANTORI(K)+(V(K 1)-ANTORI(K1))*EXAPRX(U,C5)/C2)*T	SOLN 280
GO TO 5	SOLN 290
4 ASUM=(ANTORI(K)+(V(K 1)-ANTORI(K1))*EXAPRX(U,C6)/C4)*T	SOLN 300
5 IF(NCHART1.EQ.1) GO TO 29	SOLN 310
DO 14 I=2,K	SOLN 320
K1=I+KADD	SOLN 330
IF(V(K 1).EQ.0) GO TO 14	SOLN 340
W=V(I1)-10*T	SOLN 350
IF(W-DEL) 6, 6, 7	SOLN 360
6 GO TO (8,9,10,8), ITYPE	SOLN 370
7 EN=DEXP(-W)	SOLN 380
GO TO (11,12,13,11), ITYPE	SOLN 390
8 ASUM=ASUM+V(K 1)*TNDEXP(U,W,C4)	SOLN 400
GO TO 14	SOLN 410
9 ASUM=ASUM+V(K 1)*TNDEXP(U,W,C5)*T/C2	SOLN 420
GO TO 14	SOLN 430
10 ASUM=ASUM+V(K 1)*TNDEXP(U,W,C6)*T/C4	SOLN 440
GO TO 14	SOLN 450
11 ASUM=ASUM+V(K 1)*((EN-C1)*EXAPRX(U,C4))	SOLN 460
GO TO 14	SOLN 470
12 ASUM=ASUM+V(K 1)*T*((C1-EN)/W-C1)*EXAPRX(U,C5)/C2	SOLN 480
GO TO 14	SOLN 490
13 ASUM=ASUM+V(K 1)*T*((C1-(C1-EN)/W)/W-C4)*EXAPRX(U,C6)/C4	SOLN 500
14 CONTINUE	SOLN 510
GO TO 29	SOLN 520
15 EN=DEXP(-U)	SOLN 530
GO TO (16,17,18,16), ITYPE	SOLN 540
16 ASUM=V(K 1)*(ANTORI(K)-V(K 1))*EU	SOLN 550
GO TO 19	SOLN 560
17 ASUM=V(K 1)*T*(ANTORI(K)-V(K 1))*T*(C1-EN)/U	SOLN 570
GO TO 19	SOLN 580
18 ASUM=V(K 1)*T/C2*(ANTORI(K)-V(K 1))*T*(C1-(C1-EN)/U)/U	SOLN 590
19 IF(NCHART1.EQ.1) GO TO 29	SOLN 600
DO 20 I=2,K	SOLN 610
K1=I+KADD	SOLN 620
IF(V(K 1).EQ.0) GO TO 20	SOLN 630
W=V(I1)-10*T	SOLN 640
IF(W-DEL) 20, 20, 21	SOLN 650
20 GO TO (22,23,24,22), ITYPE	SOLN 660
21 EN=DEXP(-W)	SOLN 670
GO TO (25,26,27,25), ITYPE	SOLN 680
22 ASUM=ASUM+V(K 1)*(C1-EXAPRX(U,C4)-EN)	SOLN 690

	GO TO 28	SOLN 700
23	ASUM=ASUM+Y(K 1)*T*(C1-EM)PRX(U,C5)/C2-(C1-EU)/U	SOLN 710
	GO TO 28	SOLN 720
74	ASUM=ASUM+Y(K 1)*T*(C1-EM)PRX(U,C6)/C6-(C1-(C1-EU)/U)/U	SOLN 730
	GO TO 28	SOLN 740
25	ASUM=ASUM+Y(K 1)*(EM-EU)	SOLN 750
	GO TO 28	SOLN 760
26	ASUM=ASUM+Y(K 1)*T*(C1-EM)/b-(C1-EU)/U	SOLN 770
	GO TO 28	SOLN 780
27	ASUM=ASUM+Y(K 1)*T*(C1-(C1-EU)/U)/U-(C1-(C1-EU)/U)/U	SOLN 790
28	CONTINUE	SOLN 800
29	IF(ITYPE.EQ.4) ASUM=ASUM/VB(K)	SOLN 810
30	A(K, IT+1)=ASUM	SOLN 820
	IF(ASUM.GE.0) GO TO 31	SOLN 830
	A(K, IT+1)=0	SOLN 840
	PRINT 1001,K,T,ASUM,W(K)	SOLN 850
31	CONTINUE	SOLN 860
	RETURN	SOLN 870
1001	FORMAT(' CALCULATION ERROR. SEQUENCE NUMBER 'I2,' TIME ='E14.4,'	SOLN 880
	RESULT ='E14.4,' DECAY CONSTANT ='E14.4)	SOLN 890
	END	SOLN 900
	SUBROUTINE SOLNCA(ITYPE,VB,P,A,NCHAI,NIT)	SOLN 10
	ITYPE =1 NIT)	*****
	ITYPE =2 / M(X) DX	*****
	10	*****
	ITYPE =3 (1/T)* / (/ M(X) DX) DU	*****
	10 10	*****
	ITYPE =4 NIT) THEN INTEGRATE WITH OIU TO INFINITE TIME	*****
	V(N,1) MUST = 0	*****
	COMMON /ORIGIN/ APTOR(6),V(6,7),V(6)	SOLN 140
	DOUBLE PRECISION APTOR(1,Y,V,R,W,E)XAPRX,TMODEXP,ASUM,U,W,EU,Ed	SOLN 150
	DOUBLE PRECISION VB(K),VB(K),MBK C1,C2,C4,C5,C6,CH	SOLN 160
	DATA DEL /.000/,C1/1.00/,C2/2.00/,C4/4.00/,C5/5.00/,C6/6.00/,CH/	SOLN 170
	1.500/	SOLN 171
	DATA DEL /.01/	SOLN 180
	DIMENSION VB(6),A(6,100)	SOLN 190
	NCHAI1=NCHAI+1	SOLN 200
	DO 30 K=1,NCHAI	SOLN 210
	U=V(K)*T	SOLN 220
	IF(U-DEL)1,1,15	SOLN 230
1	GO TO (2,3,4,21),ITYPE	SOLN 240
2	ASUM=ANTOR(K)+(Y(K,1)-ANTOR(K))*E XAPRX(U,C4)	SOLN 250
	GO TO 5	SOLN 260
3	ASUM=(ANTOR(K)+(Y(K,1)-ANTOR(K))*E XAPRX(U,C5)/C2)*T	SOLN 270
	GO TO 5	SOLN 280
4	ASUM=(ANTOR(K)+(Y(K,1)-ANTOR(K))*E XAPRX(U,C6)/C6)*T	SOLN 290
5	IF(NCHAI1.EQ.1) GO TO 25	SOLN 300
	DO 14 I=2,NCHAI1	SOLN 310
	IF(I.EQ.K+1)GO TO 14	SOLN 320
	W=V(I-1)*T	SOLN 330
	IF(W-DEL)6,6,7	SOLN 340

6	GO TO (8, 9, 10, 8), ITYPE	SOLN 350
7	EM=DEXP(-M)	SOLN 360
	GO TO (11, 12, 13, 11), ITYPE	SOLN 370
8	ASUM=ASUM+Y(K, I)*T*DEXP(U, M, C4)	SOLN 380
	GO TO 14	SOLN 390
9	ASUM=ASUM+Y(K, I)*T*DEXP(U, M, C5)*T/C2	SOLN 400
	GO TO 14	SOLN 410
10	ASUM=ASUM+Y(K, I)*T*DEXP(U, M, C6)*T/C6	SOLN 420
	GO TO 14	SOLN 430
11	ASUM=ASUM+Y(K, I)*(EM-C1+EXAPRX(U, C4))	SOLN 440
	GO TO 14	SOLN 450
12	ASUM=ASUM+Y(K, I)*T*((C1-EM)/M-C1+EXAPRX(U, C5)/C2)	SOLN 460
	GO TO 14	SOLN 470
13	ASUM=ASUM+Y(K, I)*T*((C1-(C1-EM)/M)/M-C4+EXAPRX(U, C6)/C6)	SOLN 480
14	CONTINUE	SOLN 490
	GO TO 29	SOLN 500
15	EU=DEXP(-U)	SOLN 510
	GO TO (16, 17, 18, 16), ITYPE	SOLN 520
16	ASUM=Y(K, I)+(ANTORI(K)-Y(K, I))*EU	SOLN 530
	GO TO 19	SOLN 540
17	ASUM=Y(K, I)*T+(ANTORI(K)-Y(K, I))*T*(C1-EU)/U	SOLN 550
	GO TO 19	SOLN 560
18	ASUM=Y(K, I)*T/C2+(ANTORI(K)-Y(K, I))*T*(C1-(C1-EU)/U)/U	SOLN 570
19	IF(NCHAM.EO.1) GO TO 29	SOLN 580
	DO 28 I=2, NCHAM	SOLN 590
	IF(I.EO.X+1) GO TO 28	SOLN 600
	M=Y(I-1)*T	SOLN 610
	IF(M-DEL) 20, 20, 21	SOLN 620
20	GO TO (22, 23, 24, 22), ITYPE	SOLN 630
21	EM=DEXP(-M)	SOLN 640
	GO TO (25, 26, 27, 25), ITYPE	SOLN 650
22	ASUM=ASUM+Y(K, I)*(C1-EXAPRX(M, C4)-EU)	SOLN 660
	GO TO 28	SOLN 670
23	ASUM=ASUM+Y(K, I)*T*(C1-EXAPRX(M, C5)/C2-(C1-EU)/U)	SOLN 680
	GO TO 28	SOLN 690
24	ASUM=ASUM+Y(K, I)*T*(C1-EXAPRX(M, C6)/C6-(C1-(C1-EU)/U)/U)	SOLN 700
	GO TO 28	SOLN 710
25	ASUM=ASUM+Y(K, I)*(EM-EU)	SOLN 720
	GO TO 28	SOLN 730
26	ASUM=ASUM+Y(K, I)*T*(C1-EM)/M-(C1-EU)/U	SOLN 740
	GO TO 28	SOLN 750
27	ASUM=ASUM+Y(K, I)*T*((C1-(C1-EM)/M)/M-(C1-(C1-EU)/U)/U)	SOLN 760
28	CONTINUE	SOLN 770
29	IF(ITYPE.EO.4) ASUM=ASUM/VB(K)	SOLN 780
	IF(ASUM.LT.0) CALL ERROR	SOLN 790
30	A(K, IT+1)=ASUM	SOLN 800
	RETURN	SOLN 810
	END	SOLN 820
SUBROUTINE SOLNTR(B, X, V, C, N)		SOLNT 10
DIMENSION B(1), X(1), V(1), C(1)		SOLNT 20
DOUBLE PRECISION B, X, V, C		SOLNT 30
CALL DERRAR(X, (N-1)*N/2)		SOLNT 40
DO 5 I=2, N		SOLNT 50
I=I-1		SOLNT 60
I=I-2		SOLNT 70

```

IADD= I1*I2/2
IADD1= IADD+1
DO 5 K=1, I1
  K2=K-1
  IK=K+IADD
  KSTART=K1*(K-2)/2
  SUM=C( K )
  IF(K.LE.1) GO TO 2
  L1=KSTART+1
  L2=KSTART+K1
  DO 1 L=L1,L2
1    SUM=SUM+X(L)
2    SUM=B(IK)*SUM
  IF(I.LE.X+1) GO TO 4
  DO 3 J=K, I2
    JADD=J*(J-1)/2
3    SUM=SUM-B(J+IADD)*Y(K+JADD)
4    VKVI=V(K)-V(I)
    IF(VKVI.NE.0) X(IK)=SUM/VKVI
5  CONTINUE
  RETURN
  END

SUBROUTINE SRCHA(I1,I2,X,Y,YFIX,XU,IU)
  DIMENSION X(1),Y(1)
  I2=I2-1
  IU=11
  IF(I2)7,7,1
1  IF(I1)7,7,2
2  IF(Y(I1)-Y(I2))3,7,10
3  DO 4 I=I1,I21
    IF(YFIX-Y(I))5,9,4
4  IU=I
  I=I21
  IF(YFIX.NE.Y(I2)) GO TO 5
  I=I2
  GO TO 9
5  IF(Y(I) .LE.0) GO TO 8
  IF(Y(I+1).LE.0) GO TO 8
  IF(X(I+1).LE.0) GO TO 8
  IF(X(I) .LE.0) GO TO 8
  IF(YFIX .LE.0) GO TO 8
  IF(ABS(1.-X(I+1)/X(I)).GE.1.E-5) GO TO 6
  IF(I.LE.11) GO TO 9
  I=I-1
  IU=I
  GO TO 5
6  XU=VINT(IU,X,Y,YFIX)
7  RETURN
8  XU=VLNT(IU,X,Y,YFIX)
  RETURN
9  IU=I
  XU=X(I)
  GO TO 7
10 DO 11 I=I1,I21
    IF(YFIX-Y(I))11,9,5

```

SOLNT 80
 SOLNT 90
 SOLN 100
 SOLN 110
 SOLN 120
 SOLN 130
 SOLN 140
 SOLN 150
 SOLN 160
 SOLN 170
 SOLN 180
 SOLN 190
 SOLN 200
 SOLN 210
 SOLN 220
 SOLN 230
 SOLN 240
 SOLN 250
 SOLN 260
 SOLN 270
 SOLN 280
 SOLN 290

SRCHA 10
 SRCHA 20
 SRCHA 30
 SRCHA 40
 SRCHA 50
 SRCHA 60
 SRCHA 70
 SRCHA 80
 SRCHA 90
 SRCH 100
 SRCH 110
 SRCH 120
 SRCH 130
 SRCH 140
 SRCH 150
 SRCH 160
 SRCH 170
 SRCH 180
 SRCH 190
 SRCH 200
 SRCH 210
 SRCH 220
 SRCH 230
 SRCH 240
 SRCH 250
 SRCH 260
 SRCH 270
 SRCH 280
 SRCH 290
 SRCH 300
 SRCH 310
 SRCH 320
 SRCH 330

1

```

      FUNCTION ABSN(E,GHS)
C  E= GAMMA ENERGY, MEV
C  ABSORPTION IN WATER SPHERE (PAIR)/CURIE
C  GAMMA RAY ABSN IN WATER
      COMMON /ABSNCF/ NEA,EA(16),UAP(16)
      COMMON /BILDUP/ NEG,EG(19),BF(19),PAIR
      COMMON /DIRDOS/ NEE,EE(18),UDP(18)
      DATA PI/3.14159265/
      CALL SACHAR(1,NEA,UAP,EA,E,AU,IAU)
      CALL SACHAR(1,10,UDP,EE,E,RU,IRU)
      CALL SACHAR(1,19,BF,EG,E,SL,ISL)
      R=(GHS*.75/PI)**(1./3.)
      Y=R**1.1
      EY=EXP(-Y)
      F=1.-Y/2.
      IF(Y.GT..05) F=R*(1.-EY)/Y*GHS
      F=F*2524000./PAU*E
      ABSN=F
      RETURN
      END
      BLOCK DATA
      COMMON /ABSNCF/ NEA,EA(16),UAP(16)
      COMMON /BILDUP/ NEG,EG(19),BF(19),PAIR
      COMMON /DIRDOS/ NEE,EE(18),UDP(18)
      COMMON /SPERRR/ YRH,ER(20),RHRCFT(20)
C  GAMMA COEFFICIENTS IN AIR, CM*2/GM
C  EA,EG,EE = GAMMA ENERGY, MEV
C  ER = GAMMA ENERGY, MEV
C  RHRCFT = (R/HR)/(CURIE * 1000) AT ONE METER ABOVE PLANE
C  UAP = TOTAL ATTENUATION
C  UAP = TOTAL ABSORPTION
C  BF = DISTANCE COEFFICIENT IN BUILDUP FACTOR
C  PAIR = AIR DENSITY, GM/CC
      DATA NEA/16/,EA/.01,.0315,.04,.05,.06,.07,.08,.1,.15,.3,.4,.5,.6,.
17.1,.10./,UAP/4.,.1,.0575,.0375,.0285,.025,.024,.024,.025,.024,.02
2,.03,.0295,.029,.027,.0152/
      DATA PAIR/.001293/
      DATA NEE/20/,ER/.01,.02,.03,.04,.05,.06,.07,.08,.09,.1,.15,.2,.3,
1.4,.5,.6,.7,.8,.9,9./,RHRCFT/30.92,27.38,18.73,17.45,18.79,19.67,
221.62,24.05,26.67,29.27,41.5,52.60,78.37,102.5,122.6,141.3,159.7,
3175.8,191.5,1090./
      DATA NEG/19/,EG/.01,.015,.02,.0225,.025,.03,.038,.05,.055,.06,.066
1,.07,.074,.08,.1,.15,.3,.4,.6./,BF/.212,.23,.255,.272,.3,.39,.565,.
281,.88,.93,.97,.98,.97,.95,.85,.6,.31,.15,.0108/
      DATA NEE/18/,EE/.01,.02,.025,.03,.035,.04,.05,.06,.08,.1,.15,.25,.
135,.6,1.,2.,4.,10./,UDP/4.,.075,.415,.315,.257,.225,.19,.176,.16.,
2151,.135,.115,.102,.081,.062,.0425,.03,.02/
      END
      FUNCTION AVEBET(E,Z)
C  E= END POINT ENERGY, MEV
C  NUCLEAR CHARGE OF DAUGHTER (36 TO 62)

```

```

DATA D/.02/
IF (E.LE.0) AVEDET=E/4.
IF (E.GT.0) AVEDET=EBETA(Z.E/.511)*.511
RETURN
END

```

```

WEDE 60
WEDE 70
WEDE 80
WEDE 90
WEDE 100

```

```

FUNCTION EBETA (ZJ,EO)

```

```

C
C EBETA = AVERAGE E/REE
C EO = MAX E/REE
C

```

```

COMMON /CHARGE/ ZJ,Z,ESS,ROM,EBED
IMAX=EO*100.-1.
MM=0.
ADEN=0.
W=1.
DW=.01
Z=ZJ*.0072976
ESS=SQRT(1.-Z**2)
ROM=((2.+ZJ*.006716**Z**2J)**(.33333))**.10720E-03
DO 3 W=1,IMAX
W=W+DW
F1=FZE(W)*(EO+1.-W)**2*SQRT(W*W-1.)*W
IF ((1/2)*2-I) L=2,1
1 F1=2.*F1
2 CONTINUE
MM=MM+F1*(W-1.)
3 ADEN=ADEN+F1
EBETA=MM/ADEN
EBED=EBETA/EO
RETURN
END

```

```

EBETA 10
*****
*****
*****
*****
EBETA 60
EBETA 70
EBETA 80
EBETA 90
EBETA 100
EBETA 110
EBETA 120
EBETA 130
EBETA 140
EBETA 150
EBETA 160
EBETA 170
EBETA 180
EBETA 190
EBETA 200
EBETA 210
EBETA 220
EBETA 230
EBETA 240
EBETA 250
EBETA 260

```

```

FUNCTION FZE(W)
COMMON /CHARGE/ ZJ,Z,ESS,ROM,EBED
S=SQRT(W*W-1.)
ETA=Z*W/S
E2=ESS*ESS+ETA*ETA
PHI=ATAN(ESS/ETA)
FZE=(12.566370*(1.+ESS)*(2.*SQRT(W**2+ESS**2)-2.*ESS-2.)*E2**((ESS-.5)*EXP(FZE)
12.*PHI*ETA-2.*ESS*ESS/(6.*F2)))/GAMMAF(2.+2.*ESS)**2
RETURN
END

```

```

FZE 10
FZE 20
FZE 30
FZE 40
FZE 50
FZE 60
FZE 70
FZE 71
FZE 80
FZE 90

```

```

FUNCTION GAMMAF(X)

```

```

1 IF (X) L=1,2
GAMMAF=0
RETURN
2 IF (X-1.) L=3,4
GAMMAF=1.
RETURN
4 IF (X-2.) L=5,6,7
GAMMAF=GAMMAF(1.+X)/X
RETURN
6 GAMMAF=GAMMAF(X)
RETURN

```

```

GAMMA 10
GAMMA 20
GAMMA 30
GAMMA 40
GAMMA 50
GAMMA 60
GAMMA 70
GAMMA 80
GAMMA 90
GAMMA 100
GAMMA 110
GAMMA 120

```

7	IU=X	GAMM 130
	UI=IU	GAMM 140
	UF=X-UI	GAMM 150
	IF(UF)8,8,9	GAMM 160
8	GAMMAF=GAMMAI(IU)	GAMM 170
	RETURN	GAMM 180
9	UI=UI-1	GAMM 190
	II=UII	GAMM 200
	S=GAMMAI(1.+UF)	GAMM 210
	DO 10 K=L,III	GAMM 220
	KK=K	GAMM 230
	T=UF+KK	GAMM 240
10	S=S+T	GAMM 250
	GAMMAF=S	GAMM 260
	RETURN	GAMM 270
	END	GAMM 280
	FUNCTION GAMMAI(IX)	GAMMA 10
	L=1	GAMMA 20
	J=IX-1	GAMMA 30
	DO 1 K=L,J	GAMMA 40
1	L=L+K	GAMMA 50
	GAMMAI=L	GAMMA 60
	RETURN	GAMMA 70
	END	GAMMA 80
	BLOCK DATA	10
	COMMON /GAMMAF/ GAMMAR(100)	20
	DATA GAMMAR/	30
	11.0000,0.99433,0.98884,C.98355,0.97844,0.97350,0.96874,0.96415,	31
	2.95973,0.95544,0.95135,0.94739,0.94359,0.93973,0.93642,0.93304,	0 32
	3.92980,0.92670,0.92373,C.92089,0.91817,0.91558,0.91311,0.91075,	0 33
	4.91852,0.90640,0.90440,0.90250,0.90072,0.89904,0.89747,0.89600,	0 34
	5.89464,0.89338,0.89222,0.89115,0.89018,0.88931,0.88854,0.88785,	0 35
	6.88726,0.88676,0.88636,0.88604,0.88580,0.88565,0.88560,0.88553,	0 36
	7.88575,0.88595,0.88623,0.88652,0.88704,0.88757,0.88818,0.88887,	0 37
	8.88964,0.89049,0.89142,0.89243,0.89352,0.89468,0.89592,0.89724,	0 38
	9.98374,0.98768,J.99171,C.99581/	39
	END	40
	FUNCTION GAMMAI(X)	GAMMA 10
	COMMON /GAMMAF/ GAMMAR(100)	GAMMA 20
	IF(X-1.)2,3,1	GAMMA 30
1	IF(X-2.)4,3,2	GAMMA 40
2	GAMMAI=0.	GAMMA 50
	GO TO 5	GAMMA 60
3	GAMMAI=1.	GAMMA 70
	GO TO 5	GAMMA 80
4	XV=X+100.	GAMMA 90
	IU=XV-100.	GAMM 100
	IX=XU	GAMM 110
	XI=IX	GAMM 120
	XX=XU-XI	GAMM 130
	G1=GAMMAR(IX+2)	GAMM 140
	G2=GAMMAR(IX+3)	GAMM 150
	G0=GAMMAR(IX+1)	GAMM 160

5 $G4 = 2 * G1 - (3 * G0 + G2) / 2.$
 $G5 = (G0 + G2 - 2 * G1) / 2.$
 $GAMMA = G0 + XX * (G4 + G5 * XX)$
 CONTINUE
 RETURN
 END

CARR 170
 CARR 180
 CARR 190
 CARR 200
 CARR 210
 CARR 220

BLOCK DATA
 COMMON /GAMMAF/ CARRAR(100)
 DATA CARRAR /
 11.0000, 0.99433, 0.98884, C.98355, 0.97844, 0.97350, 0.96874, 0.96415,
 2.95973, 0.95546, 0.95135, 0.94739, 0.94359, 0.93993, 0.93642, 0.93304, 0 31
 3.92980, 0.92670, 0.92373, 0.92088, 0.91817, 0.91558, 0.91311, 0.91075, 0 32
 4.91852, 0.90640, 0.90440, C.90250, 0.90072, 0.89904, 0.89747, 0.89600, 0 33
 5.89464, 0.89338, 0.89222, 0.89115, 0.89018, 0.88931, 0.88854, 0.88785, 0 34
 6.88726, 0.88676, 0.88636, 0.88604, 0.88580, 0.88565, 0.88560, 0.88563, 0 35
 7.88575, 0.88595, 0.88623, 0.88652, 0.88704, 0.88757, 0.88818, 0.88887, 0 36
 8.88964, 0.89049, 0.89142, 0.89243, 0.89352, 0.89468, 0.89592, 0.89724, 0 37
 9.98374, 0.98768, 0.99171, 0.99581/
 END 38
 40