LBL-12711

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

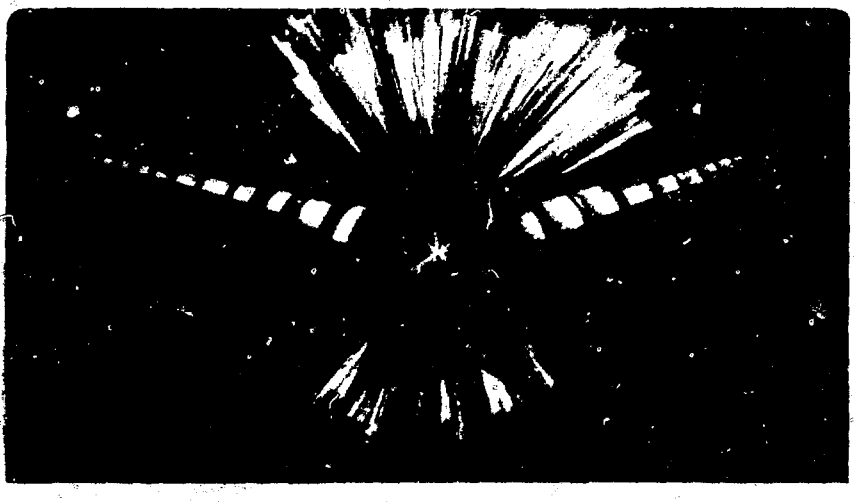
Accelerator & Fusion
Research Division

MASTER

ACDOS2: AN IMPROVED NEUTRON-INDUCED DOSE RATE CODE

Jean-Charles Lagache
(M.S. thesis)

June 1981



Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

LBL-12711

ACDOS2: AN IMPROVED NEUTRON-INDUCED DOSE RATE CODE

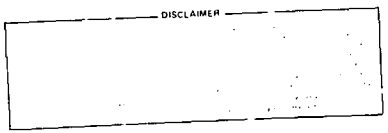
Jean-Charles Lagache

(M.S. Thesis)

Accelerator and Fusion Research Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

June, 1981

This work was supported by the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division of the U.S. Department of Energy under Contract No. W-7405-ENG-48.



CONTENTS

I. Introduction

Although it is generally recognized that activation problems will result from several of the large fusion devices now planned or under construction, it appears that such problems may have to be faced even before such devices operate. This consequence follows from the fact that neutral-beam design must necessarily precede applications by several years. A forthcoming upgrade program at LBL will require prolonged periods of testing of a deuterium 170-kev neutral beam, at 65A, with a 10% duty factor. Such a source can produce appreciable dose rates for personnel who must do maintenance work following a prolonged period of testing. To calculate the expected dose rate as a function of geometry, composition, and time after shutdown a computer code, ACDOS2, was written, which utilizes up-to-date libraries of cross-sections and radio-isotope decay data. ACDOS2 is in ANSI FORTRAN IV, in order to make it readily adaptable elsewhere.

The methodology for solving the overall problem is broken down into several steps. The first is that of determining the production of neutrons in the case of a neutral-beam injector. In practice, neutron production is not uniform but occurs during a succession of evenly spaced pulses of short time duration. During the pauses, no neutrons are produced. An effective steady neutron source term is generated by utilizing an appropriate

duty factor over the time duration of the test periods. The neutron production rate is then calculated on the basis of the energy and current of the accelerated beam.

With the unity-normalized average group fluxes assumed to be available from a previous calculation, the second step involves calculating the activities due to the activation of a target or of the walls, by the neutrons. First the flux weighted group cross-sections have to be computed by making use of a library containing microscopic cross-sections. Prerequisite to this calculation is the determination of a weighting flux for use in averaging cross-section data over the appropriate energy groups. This is accomplished by assuming a room-termperature Maxwell-Boltzmann distribution for the thermal region, a 1/E distribution for intermediate energies, and an exponential function for the source-neutron groups. Arbitrary constants in the weighting fluxes are determined by integral and/or boundary conditions on the known flux for the particular energy group in question. With the weighting flux a determinable function of energy, the required flux-weighted group cross-sections can be evaluated. The microscopic cross-section library contains up to ten different neutron reactions per target nuclide, at neutron energies up to 20 MeV. The calculation of the resultant activities given the neutron production rate, the flux weighted group cross-sections, the target nuclide mass and type, and the specific times after shutdown at which induced activities are desired, can then be performed. This is done by solving the pertinent ordinary

differential multigroup equations that describes the system undergoing activation and then algebraically modifying the standard solution to make it amenable to the injector test schedule.

The final step is a calculation of the dose rates as a function of time and geometry, given the previously calculated activities. This routine interrogates a decay library and extracts the necessary gamma ray energy and intensity information. The program treats radioactive daughters accurately. The user specifies the type of geometry to be used in the actual calculations (point, sphere, cylinder-on axis, cavity) and the strategy (non-absorbing source, absorbing source), in addition to the distance from the activated component, at which the dose rate is desired.

The code can handle from one to fifty neutron groups with up to thirty target nuclides. It has an option which allows the user to substitute a neutron source term other than that from a neutral-beam injector, and a further option which allows for the evaluation of the approximate fluxes in the walls, and thereby the dose-rate from the walls. The end result is then a code that is tailored to solve injector acti-vation problems, but contains enough versatility to be useful in solving a wide variety of general activation problems produced by neutrons of energy less than 20 MeV.

This report constitutes the user manual of ACDOS2, which is an improved version of ACDOS1.[1] Basically, ACDOS2 uses the same framework as ACDOS1 to calculate neutron induced activation and

corresponding dose rates as a function of geometry, composition and time after shutdown. Improvements have been made in the physical models and the versatility has been increased by the introduction of new options. Specifically, the radioactive daughters are now accurately treated, a fourth possible geometry (cavity) is supplied, both absorption and build-up in volumetric sources are taken into account, the dose due to the walls can be computed, and an option to indirectly couple a slowing-down code is provided.

The main part of the report deals with the different models and equations used by ACDOS2. Some sections (§ II, IV-a) are reproduced directly from the report on ACDOS1 [1]. A new user* will find enough information to run the code by just reading the Appendices which completely describe the input required for ACDOS2.

*ACDOS2 is available on magnetic tape. Address inquiries to: Head, Neutral Beam Development Group, Bldg. 4, Lawrence Berkeley Laboratory, Berkeley CA 94720.

II. Neutron Production Model

The first major step in solving the overall activation problem is to supply the average neutron source strength. Alternatively, ACDOS2 makes provision for the user to directly enter the average neutron source strength or to determine from data supplied by the user, the production of neutrons in the specific case of neutral-beam injectors.

In neutral-beam testing, neutron production is not uniform but occurs during an arbitrary succession of evenly spaced injector pulses of short time duration. The neutron production coincides with the injector pulses. Figure II-1 represents the duty factor (i.e. the fraction of time in which the injector is actually on) during the test periods. INSNPS is the instantaneous number of neutrons produced per second. T1 is the length of the test periods--typically a few hours. T2 is the length of time between test periods. N is the number of test periods, following the last of which, the activities are calculated. It is assumed throughout the activation calculations that T1 and T2 do not vary during operation of the injector.

The neutrons originate from two sources within the injector system: gaseous deuterium that leaks from the neutralizer and the ion-source, adsorbs on the surfaces of the neutral-beam calorimeter and the deflected-beam dump. A (d, n) reaction occurs as D^{o} and D^{+} impinge upon these surfaces. The reaction is:

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + ^{1}_{0}n + 3.27\ MeV$$

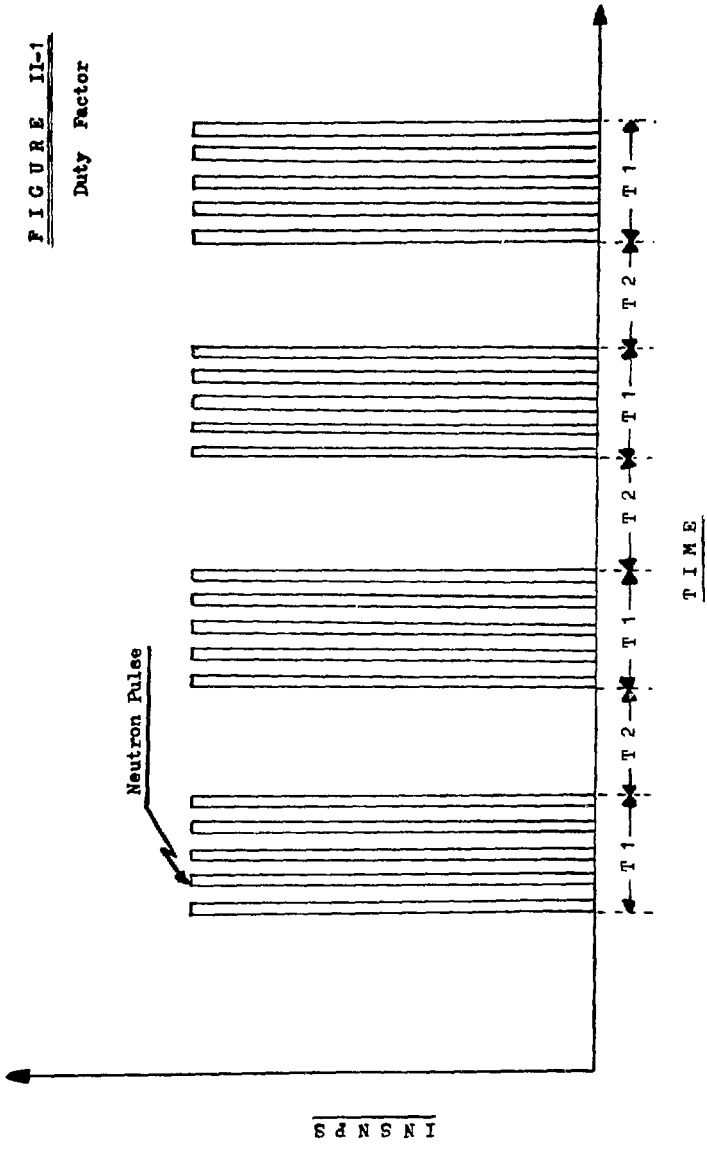


FIGURE II-1

Duty Factor

The calculation that determines the instantaneous number of neutrons produced per seconds is empirical in nature and based on data taken under accelerator test conditions.[2] The expression used is:

$$INSNPS = 8.64 \times 10^4 \left(\frac{neutron}{\mu coulomb}\right) \times A \times 10^6 \left(\frac{\mu coulomb}{second}\right) \times F \times CF \times DF$$

INSNPS: instantaneous number of neutrons produced per second.

A: current in Amperes

DF: duty factor during the test periods

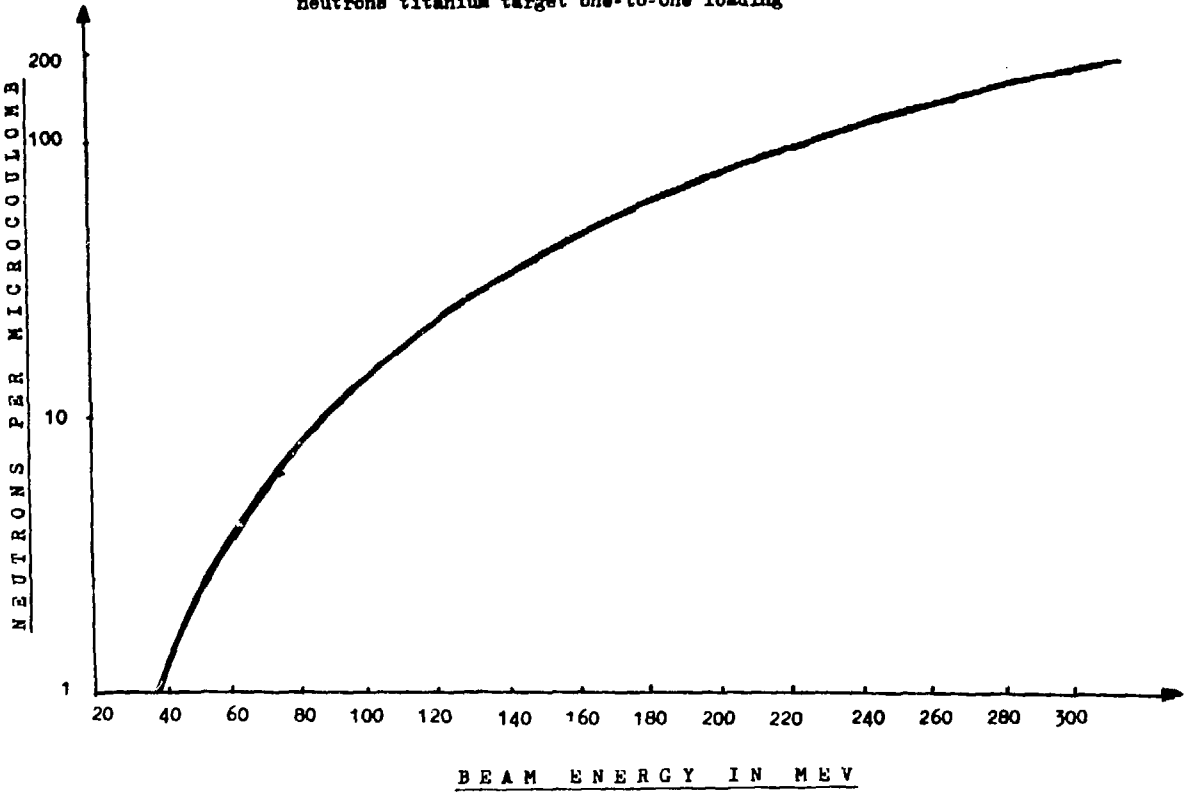
F: fraction of the beam which is monoatomic

CF: yield correction factor for voltages different from 150 kV.

The yield correction factor for voltages different than 150 kV, is taken from the thick-target yield curve[3] reproduced in Figure II-2. To facilitate the calculation of INSNPS during execution of the program, a power fit of the form $y=a^x$ was applied to the points read from the curve to determine an analytical expression for CF. Three different fits were used to insure a high coefficient of determination. These expressions are incorporated into ACDOS2 to calculate INSNPS.

FIGURE II-2

Theoretical thick target yield of
neutrons titanium target one-to-one loading



III. FLuxes

The mono-energetic source of neutrons produces a continuous spectrum by slowing-down in the shielding walls. The group fluxes in the test-cell are not calculated in ACDOS2, but rather are supplied from a previous calculation, with, for example, a Monte-Carlo code like MORSE or a transport code like ANISN. The output of such a calculation is coupled to ACDOS2 either from a tape or from the input data deck.

The coupling of ACDOS2 with a slowing-down code can then be done in two steps. First, the unity-normalized average group fluxes are computed by using the slowing down code, based on a unity source placed in the center of the test-cell. At the end of the slowing-down calculation, the space-independent fluxes inside the test cell are stored on a tape, starting with the higher energy-group flux and according to the format of ACDOS2 (E 10.3, 2X). Then, ACDOS2 is executed by reading the fluxes from the tape.

ACDOS2 provides for the calculation of the dose due to the activation of an object placed inside the test-cell or the dose due to the activation of the walls of the test-cell, which is approximated to be a hollow sphere. In this case, the fluxes in the walls are assumed to be the same as the fluxes in the test-cell, but corrected by a shape factor. This factor was calculated on the basis of one-group diffusion theory.

According to this model, the flux resulting from a point source placed in the center of a hollow sphere is constant inside a hollow sphere. This is due to the fact that the net current is zero at the inner radius. In the walls, the flux satisfies:

$$\nabla^2\phi + K^2\phi = 0$$

where: $$K^2 = 1/\lambda^2 = \Sigma_a/D$$

and also satisfies the boundary condition:

$$\phi(R + H) = 0$$

where R is the inner radius and H the thickness of the hollow sphere. The solution to this equation is:

$$\phi(r) = A \sinh[K(R + H - r)]/Kr$$

where A is a constant.

The average flux in the wall is then:

$$\langle\phi\rangle = \frac{\int_R^{R+H} \frac{A \sinh K(R+H-r)}{Kr} \, 4\pi r^2 dr}{4/3\pi[(R+H)^3 - R^3]}$$

or after integration:

$$\langle\phi\rangle = \frac{3A}{[K(R+H)]^3 - [KR]^3} [\sinh(KD) + KR \cosh(KD) - (KR+KD)]$$

Defining the shape factor FF by the ratio of the flux inside the hollow sphere to the average flux in the walls, we have:

$$FF = \frac{\langle\phi\rangle}{\phi(r=R)}$$

or

$$FF = \frac{3KR}{(KR+KH)^3 - (KR)^3} \left(1 - \frac{KR+KH}{\sinh(KH)} + \frac{KR \cosh(KH)}{\sinh(KH)}\right)$$

In ACDOS2, the dose due to the walls, can be computed approximately by multiplying the fluxes inside the test-cell, available from a previous calculation, by the shape factor FF.

IV. Activation

A. Weighting flux and flux weighted group cross-sections

In order to average cross-section data over the appropriate energy groups to acquire group cross-sections, a weighting flux is required. The flux-weighted group cross section can be evaluated from the expression:

$$\bar{\sigma} = \frac{\int_{\Delta E} \sigma(E)\phi(E)dE}{\int_{\Delta E} \phi(E)dE}$$

The weighting fluxes were determined by assuming that the thermal region could be represented by a Maxwell-Boltzmann distribution with kT = 0.025 eV, the intermediate energies by a function proportional to 1/E, and the fast groups by an exponential function. All energy dependences are thus determined, except for arbitrary constants.

The decision to use these energy dependences came in part from the predictions of slowing-down theory plus the results of a Monte-Carlo calculation involving a neutral beam injector surrounded by thick concrete walls. The group fluxes calculated[4] for this case are given in Table IV-1. To verify the above assumptions, column 3 (neutrons/cm^2.eV.source neutron) was plotted as a function of the arithmetic average of the group boundaries found in column 2 for groups 1 through 19 (figure IV-1).

Inspection of the curve suggests a 1/E type of behavior for groups 4 through 19 since a quantity that varies as a constant

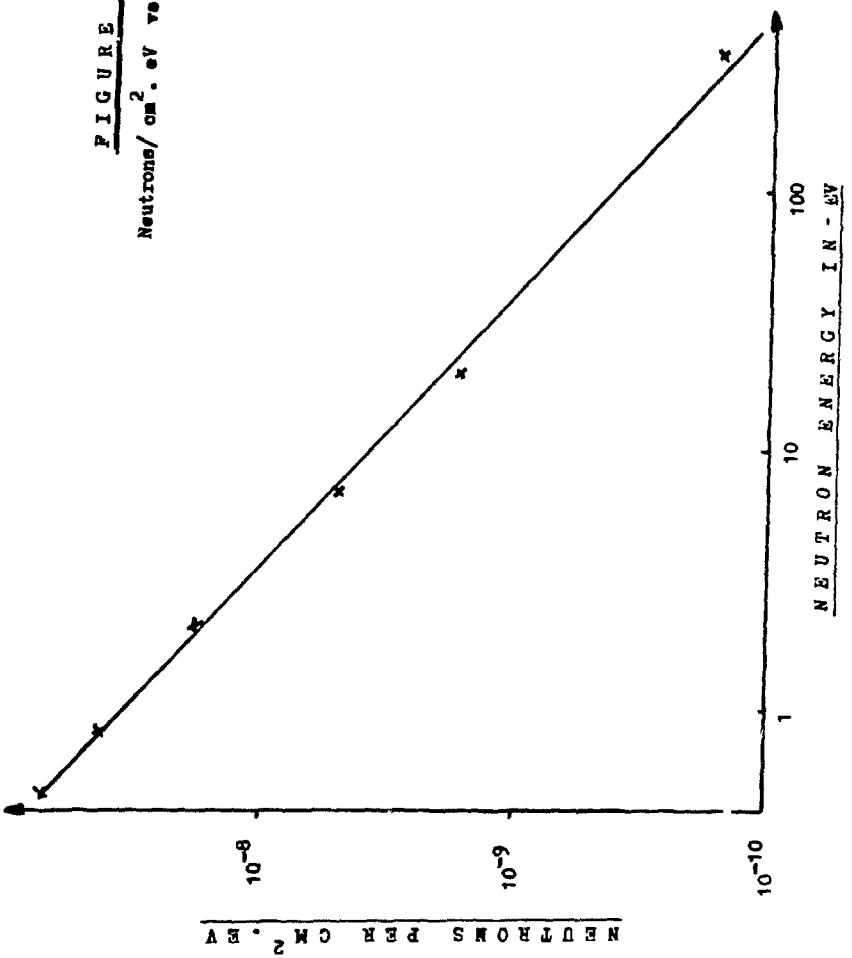
T A B L E IV-1

Group Fluxes Inside the Test Cell

GROUP	ENERGY INTERVAL (eV)	NEUTRONS cm^2 .eV SOURCE NEUTRON	NEUTRONS cm^2 .SOURCE NEUTRON
1	2.385E+6 2.307E+6	1.013E-10	7.901E-6
2	2.307E+6 1.827E+6	2.879E-13	1.382E-7
3	1.827E+6 1.108E+6	1.959E-13	8.333E-8
4	1.108E+6 5.502E+5	1.896E-13	1.058E-7
5	5.502E+5 1.576E+5	3.510E-13	1.378E-7
6	1.576E+5 1.111E+5	6.111E-13	2.842E-8
7	1.111E+5 5.248E+4	8.172E-13	4.790E-8
8	5.248E+4 2.479E+4	1.394E-12	3.860E-8
9	2.479E+4 2.188E+4	2.550E-12	7.420E-9
10	2.188E+4 1.033E+4	3.049E-12	3.522E-8
11	1.033E+4 3.355E+3	6.552E-12	4.570E-8
12	3.355E+3 1.234E+3	1.896E-11	4.021E-8
13	1.234E+3 5.829E+2	4.673E-11	3.043E-8
14	5.829E+2 1.013E+2	1.502E-11	7.234E-8
15	1.013E+2 2.902E+1	6.481E-10	4.684E-8
16	2.902E+1 1.068E+1	1.642E-09	3.011E-8
17	1.068E+1 3.059E+0	5.184E-09	3.951E-8
18	3.059E+0 1.125E+0	1.787E-08	3.456E-8
19	1.125E+0 4.140E-1	4.327E-08	3.076E-8
20	4.140E-1 1.000E-5	2.002E-06	8.288E-7

FIGURE IV-1

Neutrons/ cm^2 . eV vs Neutron energy



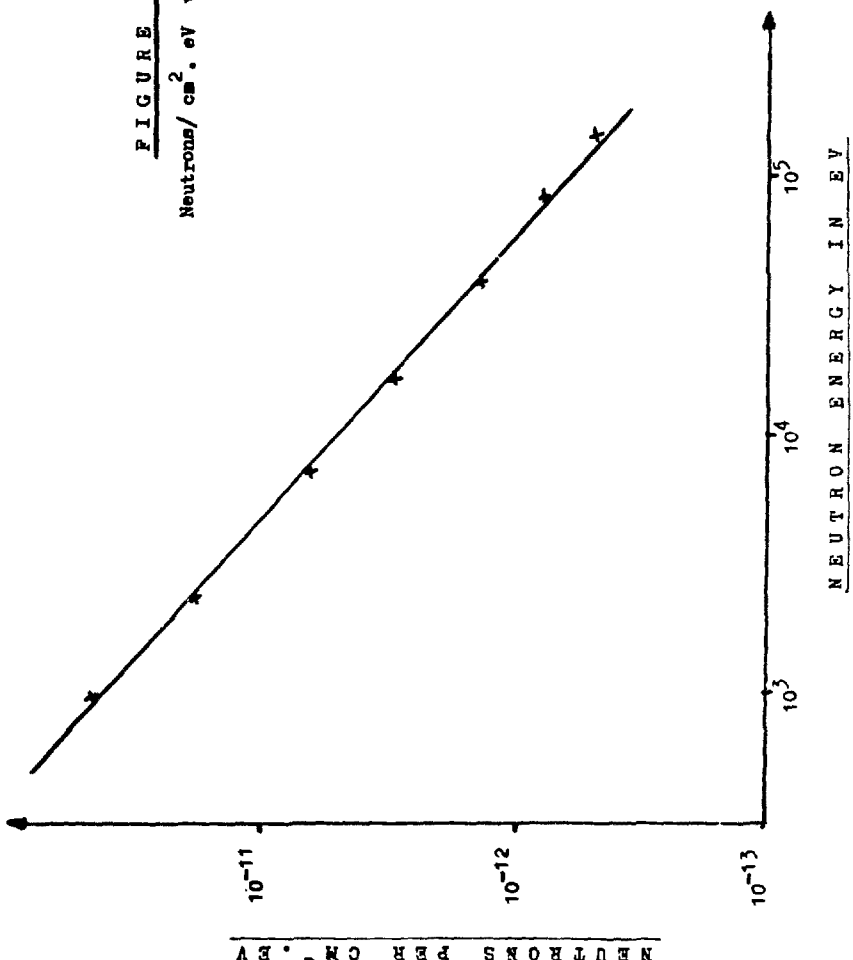
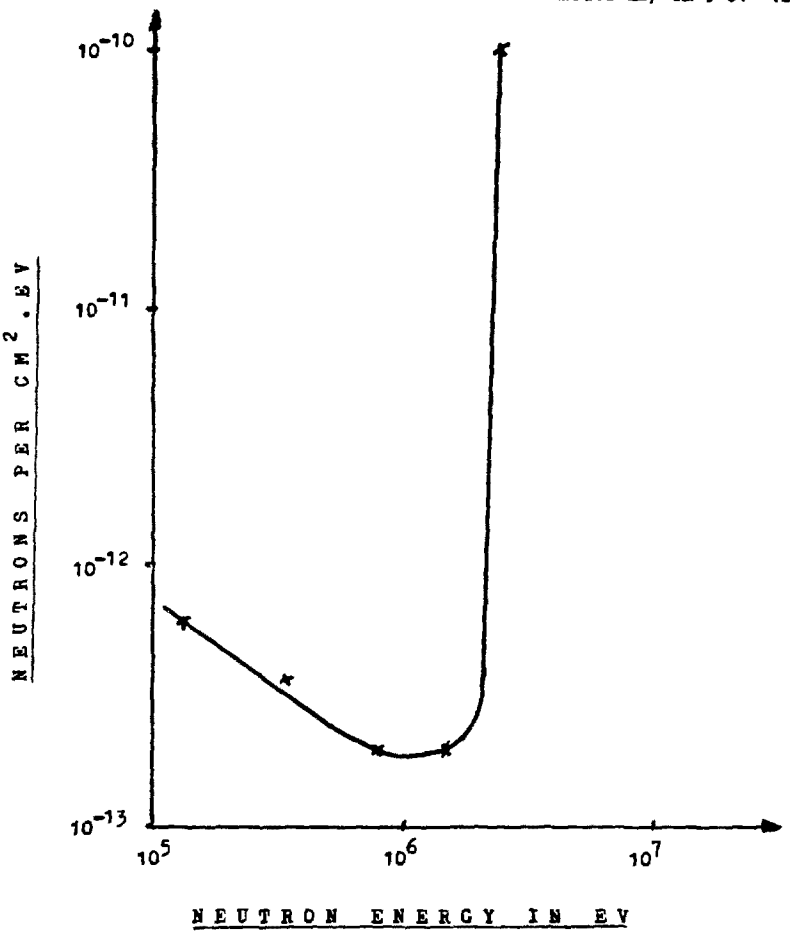


FIGURE IV-1 (Cont.)

Neutrons/ cm^2. eV vs Neutron energy

FIGURE IV-1 (Cont.)

Neutrons/ cm^2. eV vs Neutron energy



over E will plot as a straight line on log-log paper and will have a slope of -1. Calculation of the slope at various points along the line did reveal a slope close to -1. At higher energies, above 2 x 10^4 eV, the curve departs somewhat more from 1/E behavior and finally reaches a region just below fast energies where the curve is neither 1/E nor exponential. Even though this region just below the exponential part of the curve deviates from 1/E behavior, it is assumed, for ease of calculations, that it does behave as 1/E.

Since neutrons are "born" with a narrow group of discrete energies in the injector, as contrasted with a fission spectrum in a reactor, one would intuitively expect the fast region to appear more as a "spike" than as a continuous distribution. The graph definitely illustrates this behavior and for this reason the assumption of an exponential form for the fast groups appears justified. As stated previously, the Maxwell-Boltzmann distribution is used for describing the thermal region.

At this point, the forms of the equations for describing the weighting flux are known except for arbitrary constants. To evaluate the constants, each analytic expression for the weighting flux is integrated over the appropriate energy group and set equal to the numerical value of the corresponding group quantities in column 4 of table IV-1, which are normalized total group fluxes. For example, for the thermal region, group 20:

$$\int_{10^{-5}}^{4.14\times10^{-1}} C\sqrt{E}\, e^{-\frac{E}{0.025}}\, dE = 8.288 \times 10^{-7}$$

therefore:

$$C = 2.36 \times 10^{-4}$$

For an intermediate neutron group, group 17:

$$\int_{3.059}^{10.68} C/E\, dE = 3.951 \times 10^{-8}$$

therefore:

$$C = 3.16 \times 10^{-8}$$

The determination of the constants associated with fast groups, however, is somewhat more involved. Since the assumed form for the fast exponential is

$$\phi(E) = A\, e^{\frac{E_1-E_2}{B}}$$

where E_1 and E_2 are known and E_2 is the highest energy of that group, two equations are required to evaluate the two constants. One equation results from the usual integral condition that

$$\int_{E_1}^{E_2} A\, e^{\frac{E_1-E_2}{B}}\, dE = \text{total flux for that group}$$

while the other condition results from a continuity of flux requirement at the boundary of the two groups, namely:

$$C/E_1 = A\, e^{\frac{E_1-E_2}{B}}$$

where C is known constant from the integral condition placed on the last 1/E group. The analysis is then always performed, starting with the lowest energy group. With two equations and two unknowns, the constants can be determined by solving the resultant trancendental equations. If there is another fast

group, the same method is applied. One equation results from the required integral condition on that group, and a second equation results from a continuity of flux requirement at the boundary with the preceeding group.

The result of this method is that the first exponential group is always matched to the last 1/E group, and any additional fast groups are always matched to the preceeding fast groups. In the case of only two groups, one thermal and one fast, a match is required at the boundary between the groups to allow evaluation of the two constants in the assumed exponential function following the Maxwellian.

Only one equation is required to evaluate 1/E groups as there is only one constant to be evaluated. Since 1/E constants are calculated solely from the integral condition placed on the equation for that group, discontinuities sometimes result in the flux at the group boundary between two adjacent 1/E or between the thermal and the first 1/E group. This is not a serious problem because the discontinuities are not significantly large. The important consideration is that the integral of the weighting-flux function over the group be equal to the total flux for that group so that the correct averaging of the flux over that same interval is maintained.

Table IV-2 shows the results of this approach to the weighting flux function determination. The integral of these functions over their proper energy range always results in the numerical value of the total flux for that group, as it should. A plot of the data in Table IV-2 (groups 1-19) is shown in Figure IV-2.

TABLE IV-2

Weighting Fluxes

GROUP	ENERGY INTERVAL (eV)	EQUATION $\phi(X)$ (neutrons/cm^2 ,source neutron)
1	2.385E+6 2.307E+6	7.07E-10*EXP((X-2.385E6)/11184)
2	2.307E+6 1.827E+6	6.62E-13*EXP((X-2.307E6)/2.42E6)
3	1.827E+6 1.108E+6	1.666E-7*(1/X)
4	1.108E+6 5.502E+5	1.511E-7*(1/X)
5	5.502E+5 1.576E+5	1.102E-7*(1/X)
6	1.576E+5 1.111E+5	8.129E-8*(1/X)
7	1.111E+5 5.248E+4	6.387E-8*(1/X)
8	5.248E+4 2.479E+4	5.147E-8*(1/X)
9	2.479E+4 2.188E+4	5.942E-8*(1/X)
10	2.188E+4 1.033E+4	4.693E-8*(1/X)
11	1.033E+4 3.355E+3	4.064E-8*(1/X)
12	3.355E+3 1.234E+3	4.020E-8*(1/X)
13	1.234E+3 5.829E+2	4.057E-8*(1/X)
14	5.829E+2 1.013E+2	4.134E-8*(1/X)
15	1.013E+2 2.902E+1	3.747E-8*(1/X)
16	2.902E+1 1.068E+1	3.012E-8*(1/X)
17	1.068E+1 3.059E+0	3.160E-8*(1/X)
18	3.059E+0 1.125E+0	3.455E-8*(1/X)
19	1.125E+0 4.140E-1	3.077E-8*(1/X)
20	4.140E-1 1.00E-5	$2.36E\text{-}4*(X)^{1/2}$ *EXP(-X/0.025)

FIGURE IV-2

Weighting Flux

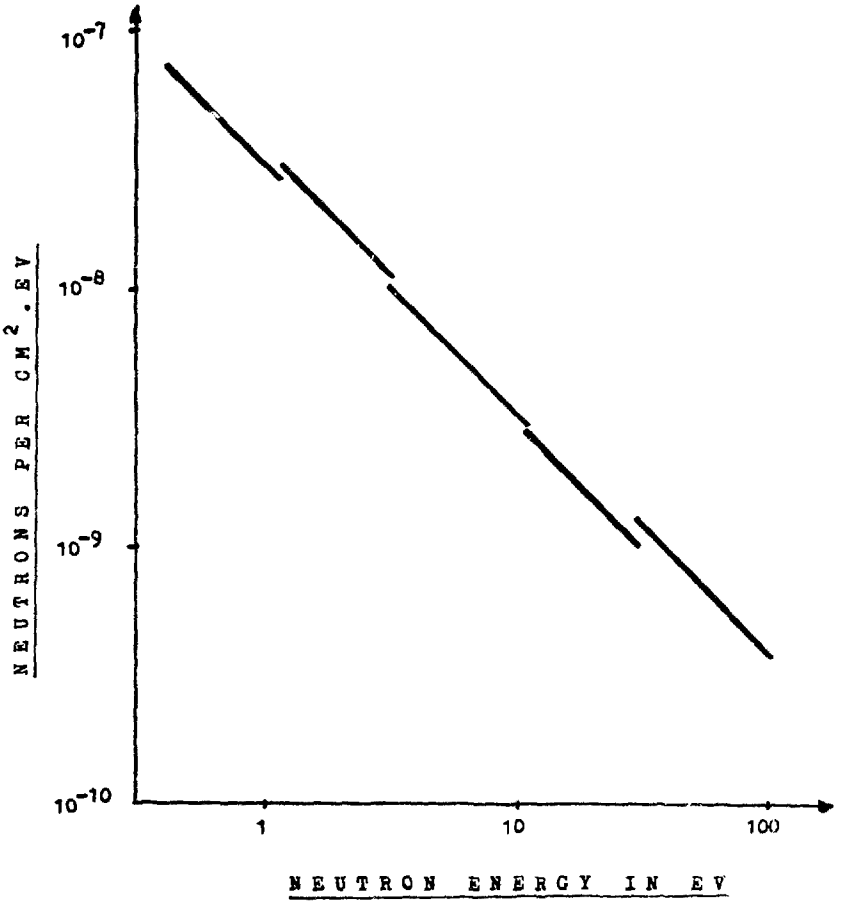
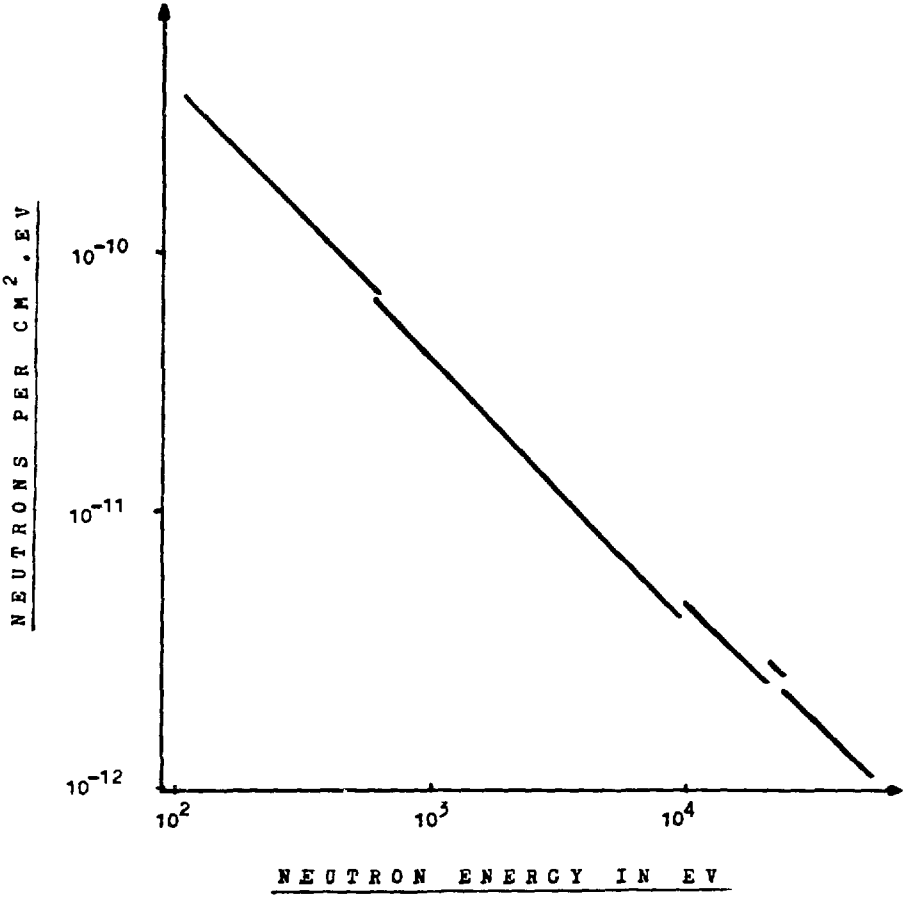


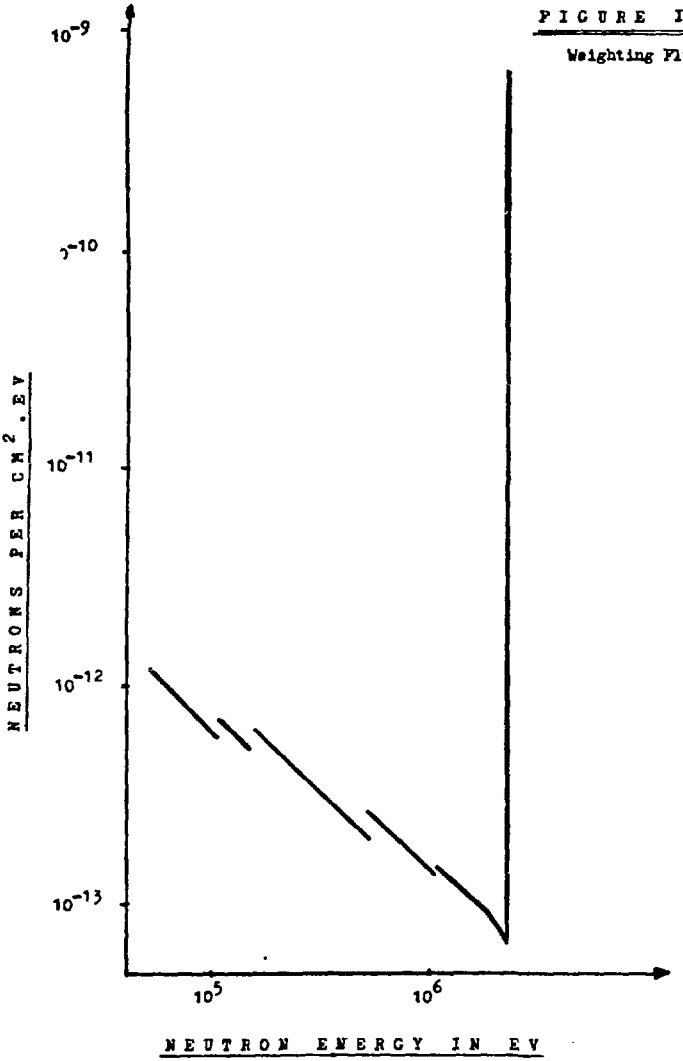
FIGURE IV-2 (Cont.)

Weighting Flux



PICTURE IV-2 (Cont.)

Weighting Flux



As previously mentioned, slight flux discontinuities at boundaries between 1/E group exist. Note that the discontinuities are greater in the region just below the two fast groups. This is not surprising since that region deviates somewhat from 1/E but was assumed to be 1/E in weighting flux calculations. Comparison of Figure IV-1 with Figure IV-2 shows a close resemblance as is desired.

With the weighting flux function know for each group, the flux weighted group cross-section can be calculated from the expression:

$$\bar{\sigma} = \frac{\int_{\Delta E} \sigma(E)\phi(E)\, dE}{\int_{\Delta E} \phi(E)\, dE}$$

where $\phi(E)$ is the previously determined weighting flux function. In the calculation of the activation, the cross-section information for the target nuclide is read from the ACTLMFE library which is a subset (without fission cross-sections) of the ACTL library.[5] The data consist of two numbers, an energy in MeV and an associated cross-section for that energy in barns.

To calculate $\bar{\sigma}$, ACDOS2 first merges the group boundary values into the energy-cross-section pair data and performs a linear interpolation to calculate the cross-section at the group-boundaries.[6] The result is two arrays, one with energy values and the other with cross-section values. There is always a one to one correspondence. If GP(J) is an arbitrary group boundary which initially had no cross-section value associated with it. The value is obtained by a linear interpolation using the first value on each side of the group boundary assuming that

cross-sections are linearly interpolable in energy. For two arbitrary cross-sections, $\sigma(I)$ and $\sigma(I+1)$ whose values lie within the group boundaries GP(J) and GP(J+1), an analytical expression is found for the line connecting them, using the common two point formula:

$$\sigma(E) - \sigma(I) = \frac{\sigma(I+1)-\sigma(I)}{E(I+1)-E(I)} [E - E(I)]$$

so that $\sigma(E)$ for $E(I) \leq E \leq E(I+1)$

$$\sigma(E) = \sigma(I) + \frac{\sigma(I+1)-\sigma(I)}{E(I+1)-e(I)} [E - E(I)]$$

Now that an analytical expression exists for $\sigma(E)$ and $\phi(E)$, the product of these two functions is numerically integrated between E(I) and E(I+1) and the value kept as a running sum. This process is continued, point by point, until the upper boundary is reached. The particular form of $\phi(E)$ used, depends upon the energy range in which the specific group boundaries lie. For example, in the Monte-Carlo calculation involving a neutral beam injector surrounded by thick concrete walls, for the thermal region, where

$$GP(J) = 10^{-5} \text{ eV} \quad \text{and} \quad GP(J+1) = 0.414 \text{ eV}$$

from Table IV-2, we have:

$$\phi(E) = 2.36 \times 10^{-4} \times \sqrt{E} \times e^{-\frac{E}{0.025}}$$

so that the expression for $\sigma(E) \times \phi(E)$ is:

$$\left\{\sigma(I) + \frac{\sigma(I+1)-\sigma(I)}{E(I+1)-E(I)} [E-E(I)]\right\} \times \left\{2.36 \times 10^{-4} \times \sqrt{E} \times e^{-\frac{E}{0.025}}\right\}$$

where E is in eV.

It is this expression that is numerically integrated between each thermal E(I) and E(I+1).

When all numerical integrations are completed for a specific group, the running sum is divided by the total flux for that group. The quotient is the desired quantity, the flux weighted group cross section for that group. This entire process is repeated until all energy groups have been addressed. Several test cases have been run to acquire results for comparison with another averaging program which originated at LLNL.[6] The values obtained by this method are remarkably close to those obtained by the LLNL code for fast and intermediate neutron groups. For the thermal region, however, the above-mentioned procedure produced better results than the LLNL code.

Two further comments are in order considering the method of averaging cross-sections. First, for the case of nuclear reactions which are threshold oriented, a zero is substituted for each group cross-section whose energy range is below the threshold energy. Calculations begin only when the energy at which a cross-section value was measured, equals or exceeds the threshold energy. Typically, that first cross section value is located somewhere within the group boundaries at which the calculations begin. The contribution to that particular group cross section comes solely from evaluation of the pertinent quantities for energies greater than or equal to the first cross-section value and less than or equal to the first encountered group boundary. This is shown in figure IV-3. In this example, the reaction has a threshold located between the arbitrary group boundaries, GP(J+3) and GP(J+4). The group cross section for group (J+3)

results strictly from the evaluation of the pertinent quantities from the threshold value, Tv, to the first encountered group boundary, GP(J+4). Even if there is only one cross-section value located in group (J+3), the calculation proceeds since there is a cross section value associated with GP(J+4) as a result of the initial merging of group boundary energies into the energy-cross-section data. In any case, however, zeros are substituted for group cross-sections in group J through J+2 in accordance with the above discussion.

The second comment concerns the calculation of the thermal group cross section. Since no provision is made for interpolating cross section values at the first group boundary, averaging calculations begin at the first encountered cross section value above the energy of the first group boundary. As a result a very small portion of the Maxwellian, generally below 0.0001 eV, is not accounted for. However, the resultant error is insignificant, since the contribution from this part of the Maxwellian is exceedingly small.

B. Activation

The differential equations describing the activation of target nuclides T giving radioactive product nuclides P which decay into daughter nuclides D are:[10]

$$\frac{dP(t)}{dt} = \sigma_T \phi T - \lambda_P P(t)$$

$$\frac{dD(t)}{dt} = \lambda_P P(t) - \lambda_D D(t)$$

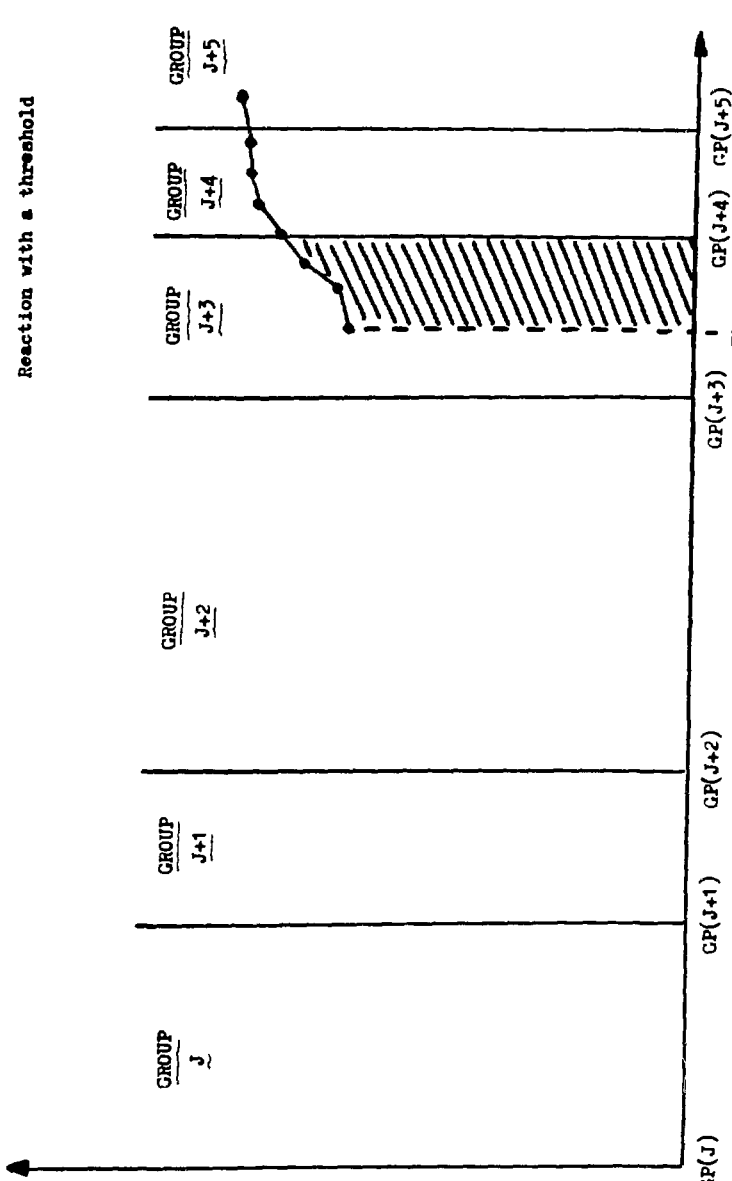


FIGURE IV-3

Reaction with a threshold

where:

*T(t) is the number of atoms of the target nuclide

*P(t) is the number of atoms of the product nuclide

*D(t) is the number of atoms of the daughter nuclide

*λ_P is the decay constant of nuclide P

*λ_D is the decay constant of nuclide D

*σ_T is the group activation cross section for nuclide T

*ϕ is the group neutron flux.

The solutions are:[10]

$$P(t) = \frac{\sigma_T \phi T}{\lambda_P} \left(1 - e^{-\lambda_P t}\right)$$

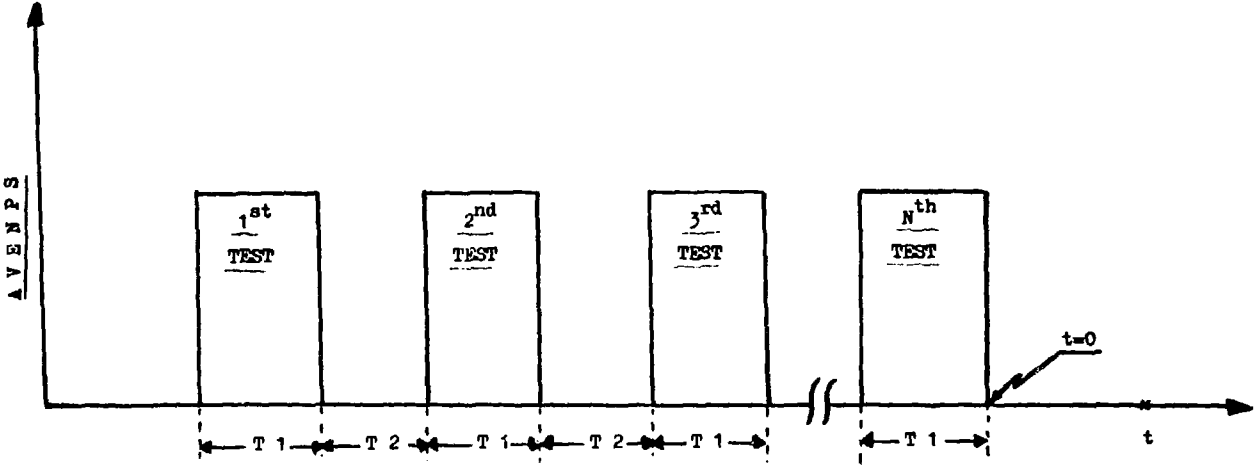
$$D(t) = \frac{\sigma_T \phi T}{\lambda_D} \left(1 - \frac{\lambda_D e^{-\lambda_P t} - \lambda_P e^{-\lambda_D t}}{\lambda_D - \lambda_P}\right)$$

These are the basic solutions that are used in subsequent activation calculations. These basic forms, however, must be algebraically modified to take into account pauses of length T_2 in the injector test schedule as shown in Figure IV-4.

Acording to this figure, let T1 be the time length of one test, T2 the time length of one pause, N the total number of tests, t=0 the time at which shutdown occurs and t, an arbitrarily selected time after shutdown where activities are required. It is desired to calculate the amount of an activated nuclide at t=0 due to an arbitrary neutron testing history. The method of approach is to calculate the amount at t=0 due to each test prior t=0. The total amount at t=0 will then be the sum of the contributions from each test.

FIGURE IV-4

Modified Neutron Pulses



The contribution at t = 0 of the i'th test will be:

$$\underline{P}_i = \frac{\sigma_T \phi T}{\lambda_P} \cdot \left(1 - e^{-\lambda_P T_1}\right) \cdot e^{-(N-i)(T_1+T_2)\lambda_P}$$

and

$$D_i = \frac{\sigma_T \phi T}{\lambda_D} \cdot \left(1 - \frac{\lambda_D e^{-\lambda_P T_1} - \lambda_P e^{-\lambda_D T_1}}{\lambda_D - \lambda_P}\right) \cdot e^{-(N-i)(T_1+T_2)\lambda_P}$$

Then for some arbitrary time t after shutdown, the amount of nuclide $\underline{P}$ will be given by:

$$\underline{P}(t) = \frac{\sigma_T \phi T}{\lambda_P} \cdot \left(1 - e^{-\lambda_P T_1}\right) \cdot \left(\sum_{i=1}^{N} e^{-(N-i)(T_1+T_2)\lambda_P}\right) e^{-\lambda_P t}$$

and the amount of nuclide D by:

$$D(t) = \frac{\sigma_T \phi T}{\lambda_D} \cdot \left(1 - \frac{\lambda_D e^{-\lambda_P T_1} - \lambda_P e^{-\lambda_D T_1}}{\lambda_D - \lambda_P}\right)$$

$$\left(\sum_{i=1}^{N} e^{-(N-i)(T_1+T_2)\lambda_D}\right) e^{-\lambda_P t}$$

These expressions, however, represent only one group of neutrons. To generalize the relations for up to energy groups, the above calculations of the amounts of nuclides must be done for each group, that is:

$$\underline{P}(t) = \left(\sum_{k=1}^{n} \frac{\sigma_{Tk} \phi_k T}{\lambda_P}\right) \left(1 - e^{-\lambda_P T_1}\right) \left(\sum_{i=1}^{N} e^{-(N-i)(T_1+T_2)\lambda_P}\right) e^{-\lambda_P t}$$

and

$$D(t) = \left(\sum_{k=1}^{n} \frac{\sigma_{Tk}\phi_k T}{\lambda_D}\right)\left(1 - \frac{\lambda_D e^{-\lambda_P T_1} - \lambda_P e^{-\lambda_D T_1}}{\lambda_D - \lambda_P}\right)$$

$$\left(\sum_{i=1}^{N} e^{-(N-i)(T_1+T_2)\lambda_D}\right) e^{-\lambda_P D}$$

For the general case of the reaction:

$$n + T \xrightarrow{\sigma_T \phi} \underline{P} \xrightarrow{\lambda_P} D \xrightarrow{\lambda_D} \ldots$$

the specific activities of the product nuclide and the daughter D in becquerels, t seconds after shutdown will be:

$$\lambda_P \underline{P}(t) = \left(\sum_{k=1}^{n} \sigma_{Tk}\phi_k T\right)\left(1 - e^{-\lambda_P T_1}\right)\left(\sum_{i=1}^{N} e^{-(N-i)(T_1+T_2)\lambda_P}\right) e^{-\lambda_P t} \quad (1)$$

and:

$$\lambda_D D(t) = \left(\sum_{k=1}^{n} \sigma_{Tk}\phi_k T\right)\left(1 - \frac{\lambda_D e^{-\lambda_P T_1} - \lambda_P e^{-\lambda_D T_1}}{\lambda_D - \lambda_P}\right)$$

$$\left(\sum_{i=1}^{N} e^{-(N-i)(T_1+T_2)\lambda_D}\right) e^{-t\lambda_D} \quad (2)$$

Equation is used in ACDOS2 for calculating the activity due to the product nuclides. Then, the activity of the daughters, if any, is computed from Equation 2.

V. Dose-rate calculation

The final step is to calculate dose rates as a function of geometry and time after shutdown.

A. Source

Using the previously calculated total activities as part of the input information, ACDOS2 first reads a decay library, a shortened version of LEVDEC, which is a sublet of ENSL[7] (See Appendix 1), for the energy and multiplicity associated with each gamma ray produced by a specific activated nuclide. A search for radioactive daughters is also made. During the interrogation of the library, ACDOS2 checks the mode of decay of the radioactive products and daughters. If the mode of decay is γ, β^+ or β^- decay, the reaction is considered. If not, the reaction is skipped and interrogation continues. Secondly, when the decay is a β^+ desintegration, two annihilation γ of 0.511 MeV each are automatically included in the dose rate calculation, with the appropriate multiplicities. The case of the same product nuclide created from two different target nuclides is allowed for in the LEVDEC-read algorithm (see Appendix 1). Any daughter of a radioactive daughter is assumed to be stable.

Next, the code calculates an effective photon flux that yields an absorbed dose of 2.5 mrem/h in soft tissue for any

gamma ray or annihilation quantum read from the decay library. The latter calculation was accomplished by first fitting thirteen curves to the data[8] shown in Table V-1. Twelve of the curves are of the form ax^b and one of the form ae^{bx}. A large number of curves were chosen so as to accurately reproduce the data over a wide energy range. As a result, all coefficients of determination arising from the curve fitting process are in excess of 0.99. Table V-2 shows the result of the curve fittings. The appropriate equation for calculating the effective particle flux, FLUXE, is chosen according to the value of E, the energy of a particular gamma ray, as read from the decay library.

The source strength divided by the flux per unit dose rate can then be computed in $cm^2 \cdot$ mrem/h as follow

$$So = \frac{MULT \times 2.5 \times ACT}{FLUXE}$$

where MULT is the multiplicity of the gamma ray, FLUXE is the effective particle flux corresponding to a dose rate of 2.5 mrem/h in soft tissue, ACT is the previously calculated activity in Bq .

For a volumetric source of volume VOLU, the volumetric gamma ray source strength divided by the flux per unit dose rate is then:

$$SOU = \frac{So}{VOLU} = \frac{MULT \times 2.5 \times ACT}{FLUXE \times VOLU}$$

E(MeV)	DOSE RATE OF 2.5 MREM/H CORRESPONDS TO Ø QUANTA/ CM^2 .SEC
0.010	956
0.015	2310
0.020	4320
0.030	9980
0.040	17400
0.050	23100
0.060	25200
0.080	23200
0.100	18600
0.150	10800
0.300	5020
0.400	3660
0.500	2920
0.600	2440
0.800	1880
1.000	1550
1.250	1330
1.500	1130
2.000	912
3.000	686
4.000	559
5.000	460
6.000	420
8.000	339
10.000	284

TABLE V-1

Effective Photon Fluxes

T A B L E V-2

Curve Fittings of FLUXE .

ENERGY INTERVAL (MeV)	PARTICLE FLUX EQUATION FLUXE(X)
0.010 0.020	21495330.64*(X**2.17594470)
0.020 0.040	11460233.22*(X**2.0136022)
0.040 0.050	1036918.975*(X**1.2698653)
0.050 0.060	96497.38032*(X**0.4772399)
0.060 0.080	11225.12221*(X**(-0.2874410))
0.080 0.150	55482.78326*EXP(X*(-10.9132069))
0.150 0.400	1330.569205*(X**(-1.1036085))
0.400 0.600	1462.198966*(X**(-1.0004513))
0.600 1.000	1546.997798*(X**(-0.8891058))
1.000 1.500	1549.091320*(X**(-0.7797676))
1.500 3.000	1508.205757*(X**(-0.7188784))
3.000 6.000	1488.362190*(X**(-0.7051622))
6.000 10.000	1656.852874*(X**(-0.7649757))

B. Geometry

The second consideration is that of geometry. ACDOS2 provides four possible geometries (point source, sphere, cylinder, hollow sphere) and two possible strategies (non absorbing source, absorbing source) using the following formulae.

Non-absorbing Source

Point source

The point source approximation gives the following dose rate:

$$DSR = \frac{S}{4\ D^2} = \frac{MULT \times 2.5 \times ACT}{FLUXE \times 4 \times D^2}$$

where the variables are the same as previously defined and D is the radial distance to the point where the dose rate is desired.

Spherical source

Outside a non-absorbing sphere the dose rate is given by[8]:

$$DSR = \frac{SOU}{(R+D)}(2R(R+D)-(D^2-2RD)\ln(\frac{2R+D}{D})$$

where R is the radius of the sphere, D is the distance from the surface of the sphere to the observer.

Cylindrical source

On the axis of a cylinder of radius R and height H, at a distance D from one end, the dose rate is:[8]

$$DSR = \frac{SOU}{4}((D+H)(\ln(1+\frac{R^2}{(1+D)^2})+\frac{2R}{H+D}\arctan(\frac{H+D}{R}))$$

$$-D(\ln(1+\frac{R^2}{D^2})+\frac{2R}{D}\arctan(\frac{D}{R})))$$

Hollow sphere

At the center of a hollow sphere of inner radius R and thickness D the dose rate is:

$$DSR = SOU \times H$$

Self-absorbing source

Analytical formulae independent of the nature of the nuclide were developed for computing the constants needed in self-absorption calculations. Therefore, self-absorption for every gamma ray energy, read from the decay library, can be calculated without having to know the emitter nuclide species .

The mass attenuation factor AMU can be computed as a function of the gamma ray energy E in MeV, by using:

$$AMU = 0.0488\ E^{-0.4633}$$

Table V-3 shows that this formula is conservative, since it gives a somewhat smaller value than the experimenta' values found for any nuclide.

The attenuation factor MU in cm^{-1} is then given by:

$$MU = \frac{AMU \times TMASS}{VOLU}$$

where TMASS is the total mass of the target and VOLU its volume, assuming that these values are consistent with the density of the material.

The build-up factor B can be calculated by using a Taylor expansion

$$B = A\, e^{-\alpha_1 \mu t} + (1-A)\, e^{-\alpha_2 \mu t}$$

which later will enable an integration of this factor over the geometry.

TABLE V-3

Mass Attenuation Coefficient (cm^2/g)

	Gamma ray Energy (MeV)							
	0.15	0.3	0.5	1.0	1.5	2.0	5.0	10.0
Analytical function	.1175	.0852	.0673	.0488	.0404	.0354	.0232	.0168
H	.2650	.2120	.1730	.1260	.1030	.0876	.0510	.0321
Be	.1190	.0945	.0773	.0565	.0459	.0394	.0234	.0161
C	.1340	.1060	.0870	.0636	.0518	.0444	.0270	.0194
Al	.1340	.1030	.0840	.0614	.0500	.0432	.0282	.0229
Cu	.2060	.1080	.0820	.0585	.0476	.0418	.0316	.0305
Pb	1.840	.3560	.1450	.0684	.0512	.0457	.0426	.0489
Concrete	.1390	.1070	.0870	.0635	.0517	.0445	.0287	.0229

The coefficient A is estimated by using:

$A = 44.1 - 10.2 \times E$ if $E \leq 3$ MeV

$A = 16.2 - 0.9 \times E$ if $3 < E \leq 8$ MeV

$A = 29 - 2.5 \times E$ if $8 < E \leq 10$ MeV

$A = 4$ if $E > 10$ MeV

Table V-4 shows that this formulation is conservative since the calculated A is larger than the experimental values for all the nuclides.

The coefficient α_1 is computed according to the following formula:

$\alpha_1 = 0.063 \times E - 0.182$ if $E \leq 2$ MeV

$\alpha_1 = -0.02 \times E - 0.015$ if $2 < E \leq 8$ MeV

$\alpha_1 = -0.0085 \times E - 0.107$ if $E < 8$ MeV

This expression is conservative, since the calculated values of $-\alpha_1$ are larger than the experiment ones (Table V-5).

The coefficient α_2 is calculated by using:

$\alpha_2 = -0.032 \times E + 0.048$ if $E \leq 1$ MeV

$\alpha_2 = -0.001 \times E + 0.017$ if $1 < E \leq 2$ MeV

$\alpha_2 = 0.012 \times E - 0.009$ if $2 < E \leq 4$ MeV

$\alpha_2 = 0.00125 \times E + 0.034$ if $4 < E \leq 8$ MeV

$\alpha_2 = 0.012 \times E - 0.052$ if $E > 8$ MeV

Table V-6 shows that this analytical form can be applied conservatively to a great number of nuclides, since the calculated values are bigger than the experimental values.

TABLE V-4

Parameter A of the Taylor Expansion of the Build-up Factor

	Gamma Ray Energy (MeV)							
	0.5	1	2	3	4	6	8	10
Analytical function	39.000	33.900	23.700	13.500	12.600	10.800	9.000	4.000
Al	38.911	28.782	16.981	10.583	7.526	5.713	4.716	3.999
Fe	31.379	24.957	17.622	13.218	9.624	5.867	3.243	1.747
Sn	11.440	11.426	8.783	5.400	3.496	2.005	1.100	0.708
Pb	1.677	2.984	5.421	5.580	3.897	0.926	0.368	0.311
Concrete	38.225	25.507	18.089	13.640	11.460	10.780	8.972	4.015

TABLE V-5

Parameter $-\alpha_1$ of the Taylor expansion of the Build-up factor

	Gamma Ray Energy (MeV)							
	0.5	1	2	3	4	6	8	10
Analytical Function	0.1505	0.1190	0.0560	0.075	0.095	0.1350	0.1750	0.1920
Al	0.1002	0.0682	0.0459	0.0407	0.0397	0.0393	0.0384	0.0390
Fe	0.0684	0.0609	0.0463	0.0443	0.0470	0.0615	0.0750	0.0990
Sn	0.0180	0.0427	0.0535	0.0744	0.0952	0.1373	0.1729	0.1920
Pb	0.0308	0.0350	0.0348	0.0542	0.0847	0.1786	0.2370	0.2402
Concrete	0.1482	0.0723	0.0425	0.0320	0.0260	0.0152	0.0130	0.0288

TABLE V-6

Parameter α_2 of the Taylor expansion of the Build-up Factor

	Gamma Ray Energy (MeV)							
	0.5	1	2	3	4	6	8	10
Analytical function	0.0320	0.0160	0.0150	0.0270	0.0390	0.0415	0.0440	0.0680
Al	-0.0631	-0.0297	0.0027	0.0251	0.0386	0.0435	0.0443	0.0413
Fe	-0.0374	-0.0246	-0.0053	-0.0009	0.0018	-0.0019	0.0212	0.0663
Sn	0.0319	0.0160	0.0150	0.0208	0.0260	-0.0150	-0.0179	0.0155
Pb	0.3094	0.1349	0.0438	0.0061	-0.0238	-0.0464	-0.0586	-0.0278
Concrete	-0.1058	-0.0184	0.0085	0.0202	0.0245	0.0293	0.0298	0.0684

The next task concerns the geometry and the calculation of the self-absorption over the entire volume of the source.

Spherical source.

The dose rate at a distance D outside a spherical volume source of radius R can be represented by the expression:[8]

$$DSR = \frac{SOU \times B \times R}{\pi} . G\ (p\ ,\ MU \times R)$$

where $p = \frac{D + R}{R}$ and the function $G(p, MU \times R)$ can be approximated by the following analytical formula:

$$G(p, MU \times R) = \exp - ((0.342 \times MU \times R + 2.07322) \times \ln p + \text{Min} (60 \times MU \times R - 0.144 , 46.37 \times MU \times R - 0.035 , 28.78 \times MU \times R + 0.3168 , 14.55 \times MU \times R - 0.144,, 8.17 \times MU \times R + 1.3966 , 4.72 \times MU \times R + 1.742))$$

where D and R are in centimeters.

Table V-7 shows the differences between this analytical form and an exact computer calculation of G.

Using the "buildup factor method"[8], the Taylor expansion of B:

$$B = A\, e^{-\alpha_1 \mu t} + (1-A)\, e^{-\alpha_2 \mu t}$$

can be combined with G to give:

$$DSR = \frac{SOU \times R}{\pi} (A \times G(p,(1+\alpha_1)xMUxR) + (1 - A) \times G(p,(1+\alpha_2)xMUxR)$$

Cylindrical source.

In the case of the calculation of the dose rate on the axis on the end of a cylinder, such a function as G for the

TABLE V-7

Comparison of G^8 tabulated and G analytical

		MU x R						
		0.4	0.8	2	4	8	10	15
p=1.25	Analytical	5.719E-1	4.497E-1	2.576E-1	1.446E-1	8.055E-2	6.828E-2	5.371E-2
	Tabulated	6.011E-1	4.732E-1	2.718E-1	1.528E-1	8.526E-2	7.244E-2	5.725E-2
p=1.5	Analytical	3.918E-1	3.080E-1	1.763E-1	9.884E-2	5.492E-2	4.650E-2	3.646E-2
	Tabulated	3.923E-1	3.082e-1	1.763E-1	9.869E-2	5.446E-2	4.598E-2	3.580E-2
p=2.0	Analytical	2.158E-1	1.695E-1	9.689E-2	5.423E-2	3.001E-2	2.536E-2	1.978E-2
	Tabulated	2.094E-1	1.642E-1	9.366E-2	5.255E-2	2.922E-2	2.474E-2	1.930E-2
p=3.0	Analytical	9.306E-2	7.304E-2	4.169E-2	2.327E-2	1.280E-2	1.079E-2	8.358E-3
	Tabulated	9.000E-2	7.045E-2	4.000E-2	2.233E-2	1.230E-2	1.036E-2	7.992E-3
p=5.0	Analytical	3.226E-2	2.529E-2	1.441E-2	8.011E-3	4.377E-3	3.679E-3	2.823E-3
	Tabulated	3.190E-2	2.495E-2	1.414E-2	7.857E-3	4.306E-3	3.625 -3	2.813E-3
p=10.0	Analytical	7.661E-3	5.999E-3	3.407E-3	1.886E-3	1.020E-3	8.540E-4	6.471E-4
	Tabulated	7.924E-3	6.197E-3	3.511E-3	1.947E-3	1.054E-3	8.807E-4	6.695E-4

spherical case, exists.[8] But since this function depends on four parameters, no simple analytical form could be found.

An approximate solution in the axial direction was obtained by substituting for the cylindrical colume source a truncated cone of the same height as the cylinder, H, and the apex of which is at the point where the dose rate is calculated.[9] The equations for the attenuation of radiation for a source in the form of a truncated cone can then be used. The upper limit of the dose rate will be found for a truncated cone of angle, at the apex

$$\theta = \theta_1 = \arctan\left(\frac{R}{D}\right)$$

(The small base of the conc is then the closest base of the cylinder) and the lower limit dose will be found for

$$\theta = \theta_2 = \arctan\left(\frac{R}{D+H}\right)$$

(The large base of the cone is then the farest base of the cylinder).

The most conservative attitude would be to use the expression yielding the upper limit of the dose rate. But such an attitude results in a gross overestimate, especially when comparing the dose rate from a sphere and a cylinder geometrically similar. As a result of such considerations, it was decided that a truncated cone should be used, which has an angle at the apex equal to:

$$\theta = \arctan\left(\frac{R}{D+H/3}\right)$$

If the height of the cylinder satisfies the relation:

$$H \leq 3/MU$$

then the dose rate is:[9]

$$DSR = \frac{B \times SOU}{2 \times MU} \left(1 - \cos\theta - E_2(MU \times H) + \cos\theta \times E_2\left(\frac{MU \times H}{\cos\theta}\right)\right)$$

where E_2 is the exponential integral function of the second kind and can be approximated by:[10]

$$E_2(X) = \exp(-X) \times (1/(X+2) + 1/(X+2)^3$$

Using the Taylor expansion of B in the "build-up factor method"[9] gives:

$$DSR = (SOU/2)x(A/(1+\alpha_1)xMU)x(1-COS\theta-E_2((1+\alpha_1)xMUxH)) + COS\theta xE_2((1+\alpha_1)xMUxH/COS\theta))+(1-A)/(1+\alpha_2)xMU) x (1-COS\theta-E_2((1+\alpha_2)xMUxH)+COS\theta xE_2((1+\alpha_2)xMUxH/COS\theta))$$

When the height of the cylinder satisfies the relation:

$$H > 3/MU$$

the contribution of radiation only from a partial cylinder of height:

$$H' = 3/MU$$

is taken into account, assuming that only the first three mean-free paths of cylinder material will contribute appreciably to the dose rate which then is:[9]

$$DSR = \frac{SOU \times B}{2 \times MU} (1 - COS\theta)$$

or using the "buildup factor method":

$$DSR = SOU \times (1 - COS\theta) \times (A/2xMUx(1+\alpha_1)) + (1-A)/(2xMUx(1+\alpha_2)))$$

Hollow sphere

The dose rate at the center of an absorbing sphere of radius R is:[9]

For an absorbing cavity of inner radius R and thickness H, the dose rate at the center is then:

$$DSR = \frac{B \times SOU}{MU}\left(1 - e^{-MU \times H}\right)$$

Using the "buildup factor" method this expression becomes:

$$DSR = SOU \times \left(\frac{A\left(1 - e^{-MU \times (1+\alpha_1) \times H}\right)}{(1+\alpha_1) \times MU} + \frac{(1-A) \times \left(1 - e^{-MU \times (1+\alpha_2) \times H}\right)}{(1+\alpha_2) \times MU}\right)$$

VI. Conclusion

The first application of ACDOS2 was to the dose-rate produced by the target calorimeter of a TFTR-upgraded neutral-beam injector (see Appendix 2). About 55 mrem/h, one hour after shutdown, were found at 10 cm from the furface of a calorimeter made of copper, and around 2 mrem/h for a calorimeter made of molybdenum. From the point of view of dose-rates to personnel, molybdenum is thus preferable to copper. Even though ACDOS2 is designed to be specific to the case of injectors, it can also be used for the calculation of the entire test cell as described by Asmiller et al.[11]

Some improvements are possible in the models used in ACDOS2. In particular, the temperature of the calorimeter should be taken into account in the calculation of the neutron-source strength. Secondly, tabulated functions, that are approximated by analytical functions, could be more accurately defined. Such changes, however, would not drastically improve the code since the actual tabulated data have been computed by analytic approximations to within 5%.

For some applications, hand calculations were performed to verify the accuracy of the results given by ACDOS2. For example, the dose at the center of the injector test cell due to the activation of the concrete walls (Appendix 2) comes almost entirely from one product- ^{28}Al. The hand calculation gave, at the time of shutdown for ^{28}Al, an activity of 1.02×10^{10} Bq to be compared

with 1.21 x 10^{10} Bq given by the code, and a dose-rate of 4.07 mrem/h by hand to be compared with 4.05 mrem/h by the code. In the case of a thin disk of copper, which is a special case of a cylinder, the dose-rate found by a hand computation also matched the one found by running the code. Additionally, the accuracy of ACDOS2 should be evaluated by running some benchmark problems whose results could be compared with other codes. In the future, dose-rate measurements obtained from the test facility at LBL will allow an experimental verification of ACDOS2 predictions.

Acknowledgments

I am indebted to Robert J. Howerton, of LLNL, who provided the ACTLMFE and LEVDEC libraries, and to Gregory S. Keney, who is the author of the ACDOS1 code.

This work was sponsored in part by the Office of Fusion Energy, U.S. Department of Energy, under Contract No. W-7405-ENG-48.

Appendix 1

Code description

- Subroutine description
- Subroutine level chart
- Input data description
- Output description
- Tape description
    - General structure
    - ACTLMFE description
    - LEVDEC description

Subroutine description

ACDOS2 is written in a structured form, using one executing program to call up a number of subroutines. Variably dimensioned arrays are used, where possible, to conserve memory. The name and purpose of each subroutine is discussed below.

1) INPUT: for entering all variable input data into computer memory. All data is printed out for user confirmation. Error tests are provided to check input data.

2) ARRAYIN: for entering all array data. Array data is printed for user confirmation.

3) SOURCE: given the current, voltage, beam fraction, and duty factor, calculates the instantaneous and average number of source neutrons produced per second during a test. This subroutine is bypassed if the user wishes to use his own source term.

4) GRFLUX: uses the calculated values of the average number of source neutrons produced per second during a test, or the user supplied source term, and calculated the average flux for each group by taking the product of the unity normalized total group flux and source neutron term.

5) WTFLUX: determines the constants for the assumed weighting flux functions by applying integral and/or group

boundary constraints to the pertinent equations. Also prints out the integrals of the weighting flux functions over their appropriate energy intervals for user verification.

6) ACTVAT: takes the following parameters and calculates activities according to the equation of section IV.

- number of tests
- time length of the tests
- time length of the pauses
- number of kilograms of a particular nuclide
- specific times after shutdown
- average group fluxes
- flux weighted group cross sections

The result of each activation calculation is printed so the user can determine what reaction is the most significant for a particular target nuclide. Moreover, two running sums are maintained in order to print out the total activity from the activation of a particular target nuclide and the total system activity.

ACTVAT calls the following subroutines.

*AVRAGE: determines an analytical expression for $\sigma(E)$ over a specific ΔE and numerically integrates the product of $\sigma(E)$ and $\phi(E)$, the weighting function, over the group energy interval. It then takes the sum

of the integrated products over the unity normalized total flux for the same group to calculate the flux weighted group cross sections.

*SMOOTH: first determines if the energy associated with the first energy-cross-section pair read from the ACTLMFE library is below the greatest group boundary. If not, the particular reaction is skipped and the next one considered. If so, the routine then merges the group boundary energies into the energy cross-section data read from the ACTLMFE library and linearly interpolates to find the value of the cross section at the group boundary.

*POSITN: positions the file marker in the ACTLMFE library.

*POSIT2: Same as POSITN

7) DOSRTE: using the previously calculated total activities, computes dose rates as a function of geometry and time after shutdown. The result of each dose-rate calculation is printed and two running sums of dose rate values are printed, one for a particular target nuclide and one for the system as a whole.

Since the CDC compilers do not permit the BACKSPACE command with formated tapes, the interrogation of the decay library performed in DOSRTE is somewhat complicated. In order to cope with the case of the same product nuclide created from two or

more different target nuclides, and with the search for radioactive daughters, alternative solutions to the use of BACKSPACE had to be found. The first case is handled by putting the product nuclides in increasing order and by checking, during the interrogation of the library, to see if the same product appears twice or more. For the search for radioactive daughters, the tape containing the library is rewound and the interrogation starts again from the top. Possible radioactive daughters are detected by checking the previously stored information on the parents. No grand-daughter's search is done.DOSRTE calls the following subroutines:

*CURVE: given the energy E of the gamma ray, calculates the effective particle flux that yields a unit absorbed dose in soft tissue, FLUXE.

*ADVAN: for positioning the file marker in the LEVDEC library

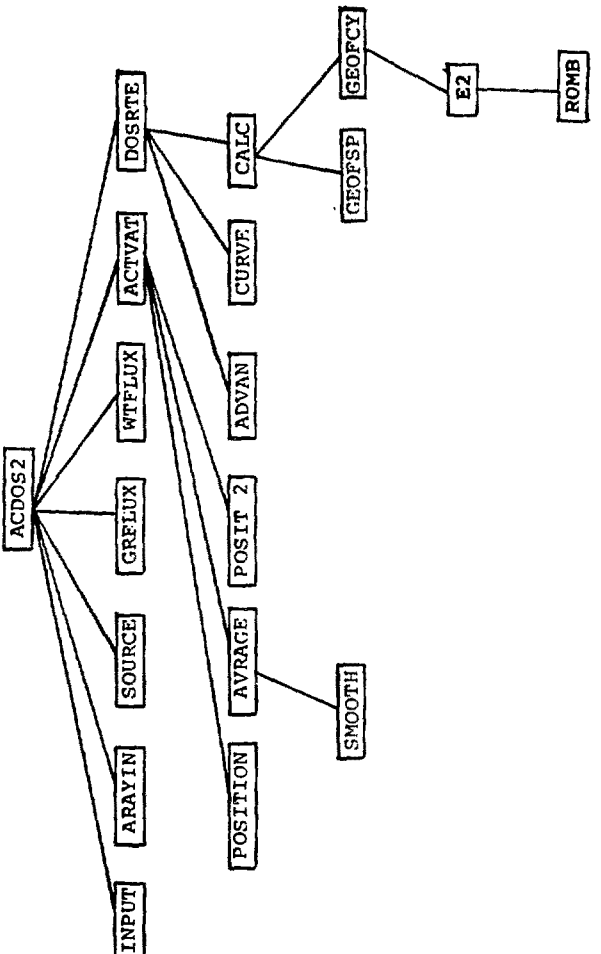
*CALC: calculated dose rates using one of the four geometries, given: FLUXE, activity in Bg, multiplicity of the gamma ray or annhiliation quantum, and proper dimensions.

CALC can call the following subroutines:

-GEOFSP: calculates the geometrical correction in the case of an absorbing sphere.

-GEOFCY: calculates the geometrical correction in the case of an absorbing cylinder by calling the subroutine E2 which estimates the exponential integral function of the second species using subroutine ROMB.

Subroutine level chart



Input data description

card #	Variable description	columns	format
1	OPTION: -if 0.000 ACDOS2 will calculate the average number of neutrons -any other value will be used as the average number of neutrons	1 to 14	E14.7
2	A current in amphere (only if OPTION=0.000	1 to 10	E10.3
	V voltage in kilovolts (only if OPTION=0.000)	13 to 22	E10.3
	F fraction of the beam which is monoatomic (only if OPTION=0.000)	25 to 34	E10.3
	DF duty factor (only if OPTION =0.000)	37 to 46	E10.3
	T1 time length of test in hours	49 to 58 (if OPTION=0) 1 to 10 (if OPTION≠0)	E10.3
	T2 time length of pauses in hours	61 to 70 (if OPTION=0) 13 to 22 (if OPTION≠0)	E10.3
	N number of tests	72 to 75 (if OPTION=0) 25 to 27 (if OPTION≠0)	I 3
3	NoEGPS number of energy groups (up to 50)	1 to 2	I2
4	NoPAS number of points after shutdown (up to 12)	1 to 2	I2
5	R radius of the sphere or of the cylinder or inner radius of the cavity (in m)	1 to 10	E10.3
	D distance from point source or surface of the sphere or the cylinder. Zero for inside a cavity (in m)	13 to 22	E10.3

	H height of the cylinder or thickness of the cavity (in m)	25 to 34	E10.3
	IGEOM 1 for point source 2 for outside a sphere 3 for a cylinder on the axis 4 for at the center of a cavity	37	I1
	ISAB 0 for non absorbing source 1 for absorbing source	38	I1
6	NONUCL number of target nuclides (up to 30)	1 to 2	I2
7	NF number of fast neutron groups	1 to 2	I2
8 & 9 if needed	STAFS (I) (I from 1 to NOEPAS) Times after shutdowns in hours (6 per card).	1 to 72	NOEPAS x (E10.3, 2x)
Above to as needed (NONUCL cards: one per target nuclide)	ZNAM 1(I) first part of the name of the Ith nuclide	1 to 10	A10
	ZNAM2(I) second part of the name of the Ith nuclide	11 to 20	A10
	IDNO(I) ID number (1000Z+A) of the Ith nuclide	22 to 26	I5
	MASS(I) number of kilograms of the Ith nuclide	27 to 36	E10.3
Above to as needed	GP(I) (I from 1 to NOEGPS + L) group boundaries in MeV in ascending order	1 to 72	(NOEGPS+1) x(E10.3, 2x)
One Above	IFLUX: option on the fluxes 0 fluxes read from input data deck 1 fluxes read from tape 8	1 to 2	I2
	IWALL option on the place of the activation 0 activation of an object inside the test cell. 1 activation of the wall	4 to 5	I2
	KWALL (only if IWALL=1) inverse of the relaxation length of the wall material in cm^{-1}.	6 to 15	E10.3

Above to as needed	BFLUX (I) (only if IFLUX=0) (I from 1 to NOEGPS) Unity normalized group fluxes in $cm^{-2} s^{-1}$.	1 to 72	NOEGPS x (E10.3, 2X

Output description

Prior to the execution of activation calculations, all input informations are printed out for user verification or recheck in case of abortion of the code. The following heading is used:

"THE FOLLOWING DATA HAVE BEEN ENTERED INTO MEMORY".

The results are then printed out under the following heading:

"THE FOLLOWING HAS BEEN CALCULATED BY ACDOS2".

The instantaneous and average number of neutrons produced per second are printed out. The integrals of the weighting flux functions over their appropriate energy intervals are printed out for user verification.

Calculated activities are printed out for each target nuclide under the two different headings:

```
TIME (H)                -                  -
TARGET PRODUCT     ACT (T1)    ...    ACT(T12)
   -     -             -                  -
```

and:

```
TIME (H)                -                  -
TARGET             ACT (T1)           ACT (T12)
   -                    -                  -
```

Calculated dose-rates are printed out in the same way including daughters. The first heading is:

TIME (H) - -

TARGET PRODUCT DSR (T1) DSR (T12)

- - - -

- - - -

PRODUCT DAUGHTER DSR (T1) DSR (T12)

The second heading giving the dose due to each target nuclide is:

TIME (H) - -

TARGET DSR (T1) DSR (T12)

The final heading announces the total dose:

TIME (H) - -

SYSTEM DSR(T1) DSR (T12)

- -

Tape description

General structure

ACDOS2 was put on a nine-track magnetic tape comprising two files:

1. /NAME/ACDOS2/ LIBS , XXXXX. containing the ACTLMFE and the condensed LEVDEC libraries.

2. /NAME/ACDOS2/SOURCE, XXXXX. containing the source listing (see Appendix 3)

- NAME is the name of the owner of the tape (optional when reading)
- XXXXX is the registration number of the tape

ACTLMFE description

The ACTMLFE library contains 20,177 lines. The format of the file is:

Record	Column	Variable	Format
1	1-6	ZA (1000Z+A)	I6
	7-13	IGNORE	7X
	14-24	TARGET MASS (amu)	E11.4
	25-35	IGNORE	11X
	36-46	LEVEL OF TARGET (MeV)	E11.4
	47	IGNORE	1X
	48-58	TARGET HALF-LIFE (S)	E11.4
2	1 -2	REACTION ID NUMBER	I2
	3-8	IGNORE	6X

	9-20	Q VALUE (MeV)	E12.4
	21-32	ZA OF PRODUCT	I6
	33-44	LEVEL OF PRODUCT (MeV)	E12.4
	45-56	PRODUCT HALF-LIFE (s)	E12.4
3	1-3	NUMBER OF ENERGY-CROSS-SECTION PAIRS(NP)	I3
3 et seq	1-66	EN(K), CS(K) (K=1,NP)	6(E11.4
After the last line of EN, CS pairs	72	REACTION SEPARATOR SENTINEL	71X, I1

The above pattern is repeated for each reaction. The last reaction is for ^{240}V (n, γ).

LEVDEC Description

LEVDEC is a decay-mode library based on the more detailed library ENSL. The format for each set is:

record	column	variable	format
first of each set	1-6	AZ (1000Z+A)	I6
	7-17	LEVEL	E11.4
	18-21	PARITY	F4.1
	22-26	SPIN	F .1
	27-37	HALF-LIFE (s)	E11.4
	38-41	NUMBER of DECAY MODE TO FOLLOW (NMODE)	I3
2nd and seq. records to NMODE	1-38	IGNORE	38X
	39-40	MODE OF DECAY	I2

41-47	ZA of DAUGHTER	I7
48-58	LEVEL of DAUGHTER	E11.4
59-69	PROBABILITY OF DECAY TO THAT LEVEL	E12.4

Twelve modes of decay are possible for each nuclide:

Decay identifier	Mode of decay
1	neutron
2	proton
3	deuteron
4	triton
5	He^3
6	α
7	γ
8	β^+
9	β^-
10	EC
18	unresolved EC + β^+
99	No decay-stable ground state

A shortened version of LEVDEC was obtained by deleting the stable nuclides (half-life bigger than 10^{50} s) and the nuclides with a very short half-life (smaller than 1 second) which are not taken into account in ACDOS2. For example, for hydrogen, LEVDEC gives:

```
1001 0.    1.0    .5    1.000E+SI 1
                                  99        0.0          0

1002 0.    1.0    .0    1.000E+51 1
                                  99        00           0

1003 0.    1.0    .5    .388E+09  1
                                  9 20030              .1E+ol
```

when the new version gives only:

```
1003 0.    1.0    .5     .388E+09  1
                                    9   2003 0.     .1E+01
```

Such a procedure allows for condensing LEVDEC from three files to one, which reduces the running time of ACDOS2.

Appendix 2

Sample Problems

1. Calorimeter of a TFTR-upgraded neutral beam injector: copper vs molybdinum.
2. TFTR neutral beam injector shielding walls.

Calorimeter of a TFTR-upgraded neutral beam injector

Copper

Assuming a spherical geometry the calorimeter is made of 372 kg of copper. From the "chart of nuclides", 9th edition, 1966:

Isotope	Atomic %	Weight%	Mass (kg)
Cu^{63}	69.1	68.45	117.36
Cu^{65}	30.9	31.55	254.64

Since the density of copper is 8.96 g/cm^3 the volume of the sphere is:

$$VOLU = \frac{372000}{8.96} = 4.15 \times 10^5 \text{ cm}^3$$

and its radius

$$R = (3xVOLU/4x\pi)^{1/3} = 21.48 \text{ cm}$$

The observer is standing at a distance D= 10 cm from the sphere. The fluxes, read from a tape, were provided by a Monte-Carlo calculation (MORSE) involving a neutral beam injector surrounded by thick concrete walls (Table IV-1).

The following parameters are used:

A	current (A)	65
V	voltage (kV)	170
F	beam fraction	0.5
DF	duty factor	0.1
T1	length of test (h)	8
T2	length of test (h)	16
N	number of test	7

NOEGPS	number of energy groups	20
NOPAS	number of points after shutdown	12
IGEOM	geometry designator	2
ISAB	strategy designator	1
NONUCL	number of nuclides	2
NF	number of fast groups	2
IFLUX	option on fluxes	1
IWALL	option on walls	0

Table A shows the input data deck and table B the output listing.

Molybdenum

Assuming the same conditions as for the copper case, the only parameters to be changed concern the sphere. Using 554 kg of molybdenum from the "chart of nuclides" 9th edition, 1966, we have:

Isotope	Atomic %	Weight %	Mass (kg)
Mo^{92}	14.8	14.24	78.91
Mo^{94}	9.1	8.93	49.45
Mo^{95}	15.9	15.75	87.24
Mo^{95}	16.7	16.75	92.80
Mo^{97}	9.5	9.63	53.34
Mo^{98}	24.4	24.67	136.69
Mo^{100}	9.6	10.03	55.57

Since the density of Molybdenum is 10.2 g/cm^3, the volume of the sphere is:

TABLE A

Input Data Deck for Copper

```
 0.0000000E+00
  .650E+02     .170E+03     .10CE+01     .010E+01     .80CF+01     .16CE+02     7
20
12
  .215E+00     .100F+00     .0CCE+00  21
 2
 2
  0.300E+1     0.100E+1     0.200E+1     0.300F+1     0.400F+1     0.500E+1
  0.600E+1     0.700E+1     0.800E+1     0.900E+1     1.000E+1     2.000E+1
           COPPER-65 29065 1.1735E+02
           COPPER-63 29063 2.5465E+02
1.000E-11    4.140E-07    1.125E-06    3.059E-06    1.068E-05    2.902E-05
1.013E-04    5.829E-04    1.234E-03    3.355E-03    1.033E-02    2.198E-02
2.479E-02    5.248E-02    1.111E-01    1.576E-01    5.502E-01    1.108E+00
1.827E+00    2.307E+00    2.385E+00
1  0
```

TABLE B

Output Listing for Copper

```
THE FOLLOWING DATA HAVE BEEN ENTERED INTO MERCK
**********************************************

AMPERES     KILO-VOLTS      REFERENCE(I)        DUTYFACTOR          T1          T2          M

.650E+02     .175E+03          .100E+01           .100E+00       .900E+01    .160E+02       7


NUMBER OF ENERGY GROUPS-NCEGPS          20

NUMBER OF TARGET NUCLIDES-NENUCL         2

NUMBER OF POINTS AFTER SHUTDOWN-NCPAS   12

ISAB=1

IGEOM=2

YOU ARE USING AN ABSORBING SOURCE

THIS SOURCE IS A SPHERE
ITS RADIUS IS R=  .715E+00 METERS
THE OBSERVER IS STANDING AT A DISTANCE D=  .100E+00 METERS FROM THE SURFACE OF THIS SPHERE

NUMBER OF GROUPS BOUNDARIES-NG          21

NUMBER OF FAST NEUTRON GROUPS-NF         7


SPECIFIC TIMES AFTER SHUTDOWN (HR)

TIME  1            0.
TIME  2            .100E+01
TIME  3            .200E+01
TIME  4            .300E+01
TIME  5            .400E+01
TIME  6            .500E+01
TIME  7            .600E+01
TIME  8            .700E+01
TIME  9            .800E+01
TIME 10            .900E+01
TIME 11            .100E+02
TIME 12            .200E+02

OPTION ON THE FLUXES-IFLX= 1
THE FLUXES WILL BE READ FROM TAPE 8

OPTION ON THE PART OF THE ROOM WHERE ACTIVATION
TAPES PLACE-IW=ALL= 0
ACTIVATION OF AN OBJECT PLACED INSIDE THE ROOM


UNIT NORMALIZED FLUXES INSIDE THE ROOM

GROUP  1            .755E-05
GROUP  2            .119E-04
GROUP  3            .837E-07
GROUP  4            .105E-06
```

GROUP 5	.1378E-06
GROUP 6	.2442E-07
GROUP 7	.4360E-07
GROUP 8	.7960E-07
GROUP 9	.1427E-07
GROUP 10	.2572E-07
GROUP 11	.4570E-07
GROUP 12	.4021E-07
GROUP 13	.3242E-07
GROUP 14	.7334E-07
GROUP 15	.8EE4E-07
GROUP 16	.3211E-07
GROUP 17	.3591E-07
GROUP 18	.3456E-07
GROUP 19	.3078E-07
GROUP 20	.62EBE-06

GROUP BOUNDARIES (MEV)

BOUNDARY	1	.2385E+01
BOUNDARY	2	.2107E+01
BOUNDARY	3	.1E77E+01
BOUNDARY	4	.11CBE+01
BOUNDARY	5	.5502E+00
BOUNDARY	6	.1576E+00
BOUNDARY	7	.1111E+00
BOUNDARY	8	.5248E-01
BOUNDARY	9	.2435E-01
BOUNDARY	10	.2186E-01
BOUNDARY	11	.1032E-01
BOUNDARY	12	.2356E-02
BOUNDARY	13	.1274E-03
BOUNDARY	14	.5828E-09
BOUNDARY	15	.1C17E-C3
BOUNDARY	16	.2502E-04
BOUNDARY	17	.1C6BE-06
BOUNDARY	18	.3C45E-09
BOUNDARY	19	.5125E-05
BOUNDARY	20	.4149E-06
BOUNDARY	21	.1CCCE-1C

NAME	ID-NUMBER	MASS(EV)
CCBREB-69	29CC2	.2EEE+C2
CCBREB-69	29CCE	.1E3E+C2

BLOCK IS NOW READY TO RUN
****

THE FOLLOWING HAS BEEN CALCULATED BY ACDES2
****

INSTANTANEOUS NUMBER OF NEUTRONS PRODUCED PER SECOND .7645E+12

AVERAGE NUMBER OF NEUTRONS PRODUCED PER SECOND .7645E+12

INTEGRALS OF THE FITTING FUNCTION OVER THE GROUP INTERVALS

GROUP	LOWER BOUNDARY	UPPER BOUNDARY	REQUIRED INTEGRAL	CALCULATED INTEGRAL
20	.100E-04	.414E+00	.829E-06	.829E-06
19	.414E+00	.111E+01	.309E-07	.308E-07
18	.111E+01	.302E+01	.346E-07	.346E-07
17	.302E+01	.107E+02	.295E-07	.295E-07
16	.107E+02	.290E+02	.303E-07	.303E-07
15	.290E+02	.101E+03	.468E-07	.468E-07
14	.101E+03	.577E+03	.722E-07	.722E-07
13	.577E+03	.172E+04	.304E-07	.304E-07
12	.123E+04	.226E+04	.402E-07	.402E-07
11	.226E+04	.103E+05	.457E-07	.457E-07
10	.183E+05	.235E+05	.352E-07	.352E-07
9	.719E+05	.248E+05	.342E-07	.342E-07
8	.749E+05	.525E+05	.386E-07	.386E-07
7	.525E+05	.111E+06	.479E-07	.479E-07
6	.111E+06	.149E+06	.284E-07	.284E-07
5	.149E+06	.550E+06	.138E-06	.138E-06
4	.550E+06	.111E+07	.106E-06	.106E-06
3	.111E+07	.183E+07	.833E-07	.833E-07
2	.193E+07	.231E+07	.139E-06	.139E-06
1	.231E+07	.239E+07	.790E-05	.790E-05

THE FOLLOWING OUTPUT DATA ARE CALCULATED ACTIVITIES IN BQ

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET PRODUCT	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
29063 29062	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29065 29064	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29063 29059	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29059 29267	.1745E+04	.1745E+04	.1745E+04	.1745E+04	.1745E+04	.1745E+04	.1745E+04	.1745E+04	.1745E+04	.1745E+04	.1745E+04	.1745E+04
29063 27064	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29063 27064	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29063 29064	.4234E+10	.4064E+10	.3903E+10	.3748E+10	.3598E+10	.3454E+10	.3316E+10	.3182E+10	.3055E+10	.2932E+10	.2815E+10	.1945E+10

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
29063	.4234E+10	.4064E+10	.3903E+10	.3748E+10	.3598E+10	.3454E+10	.3316E+10	.3182E+10	.3055E+10	.2932E+10	.2815E+10	.1945E+10

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET PRODUCT	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
29065 29064	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29065 29063	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29065 27064	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29065 27061	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

29065	280E5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29365	27062	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29065	27062	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29065	27066	.191E+10	.435E+06	.125E+02	.360E-01	.1041-04	.299E-08	.860E-12	.248E-15	.713E-19	.205E-22	.591E-26	.231E-61

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	ACTIT1)	ACTIT2)	ACTIT3)	ACTIT4)	ACTIT5)	ACTIT6)	ACTIT7)	ACTIT8)	ACTIT9)	ACTIT10)	ACTIT11)	ACTIT12)
29065	.191E+10	.435E+06	.125E+02	.360E-01	.1041-04	.299E-08	.860E-12	.248E-15	.713E-19	.205E-22	.591E-26	.231E-61

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
SYSTEM	ACTIT1)	ACTIT2)	ACTIT3)	ACTIT4)	ACTIT5)	ACTIT6)	ACTIT7)	ACTIT8)	ACTIT9)	ACTIT10)	ACTIT11)	ACTIT12)
	.519E+10	.404E+10	.383E+10	.363E+10	.344E+10	.326E+10	.309E+10	.292E+10	.277E+10	.262E+10	.248E+10	.145E+10

THE FOLLOWING OUTPUT DATA ARE CALCULATED DOSE RATES IN MREM/H

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET PRODUCT	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)	DSR(T9)	DSR(T10)	DSR(T11)	DSR(T12)
29063 27055	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29063 27056	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29063 27060	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29063 27062	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29063 29053	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29063 29062	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29063 29064	.591E+03	.522E+02	.495E+02	.469E+02	.444E+02	.421E+02	.398E+02	.377E+02	.358E+02	.339E+02	.321E+02	.187E+02
PRODUCT DAUGHTER	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)	DSR(T9)	DSR(T10)	DSR(T11)	DSR(T12)
29064 29064	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)	DSR(T9)	DSR(T10)	DSR(T11)	DSR(T12)
29063	.591E+03	.522E+02	.495E+02	.469E+02	.444E+02	.421E+02	.398E+02	.377E+02	.358E+02	.339E+02	.321E+02	.187E+02

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET PRODUCT	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)	DSR(T9)	DSR(T10)	DSR(T11)	DSR(T12)
29065 27061	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29065 27062	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29065 27062	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29065 29065	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29065 27065	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29065 27067	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29065 27064	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
29065 29066	.804E+01	.231E-02	.664E-06	.191E-09	.552E-13	.159E-16	.458E-20	.132E-23	.379E-27	.109E-30	.314E-34	.123E-69
PRODUCT DAUGHTER	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)	DSR(T9)	DSR(T10)	DSR(T11)	DSR(T12)
29066 29066	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)	DSR(T9)	DSR(T10)	DSR(T11)	DSR(T12)
29066	.804E+01	.231E-02	.664E-06	.191E-09	.552E-13	.159E-16	.458E-20	.132E-23	.379E-27	.109E-30	.314E-34	.123E-69

VOLU = 554000 / 10.2 = 5.43×10^5 cm^3

and its radius

R = $(3 \times VOLU / 4 \times \pi)^{1/3}$ = 23.49 cm

The only parameters changed compared with the previous calculation are:

NONUCL number of nuclides 7

R radius of the sphere 23.49 cm

and of course the target nuclides ID and mass.

Table C lists the input data deck and Table D shows the output listing.

Discussion of results

Thermal-neutron activation was found in both cases to produce the dominant dose rates. In the of the conper beam dump, the activation of ^{63}Cu to ^{64}Cu (12.7 h), which undergoes a β^+ decay producing two 0.511 MeV γ rays, constitues the main dose. In the case of the molybdenum beam dump, after an hour to allow the ^{101}Mo (14.6 mn) and its daughter ^{101}Tc to decay, ^{99}Mo (66.7 h) aa product of ^{98}Mo, becomes the principal dose-rate producer. However, the dose rate from the Mo dump is only about 5% of that from the Cu dump for the first 10 hours, even though the former is 30% larger volumetrically

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
SYSTEM	DSR(1)	DSR(2)	DSR(3)	DSR(4)	DSR(5)	DSR(6)	DSR(7)	DSR(8)	DSR(9)	DSR(10)	DSR(11)	DSR(12)
	[illegible]	[illegible]	.475E+02	.469E+02	.444E+02	.471E+02	.398E+02	.377E+02	.358E+02	.339E+02	.221E+02	.187E+02

TABLE C

Input Data Deck for Molibdenum

```
 0.000000E+00
  .650E+02     .170E+03     .100E+01     .010E+01     .900E+01     .165E+02     7
20
12
  .235E+00     .100E+00     .000E+00  21
 7
 2
  0.000E+1     0.100E+1     0.200E+1     0.300E+1     0.400E+1     0.500E+1
  0.600E+1     0.700E+1     0.800E+1     0.900E+1     1.000E+1     2.000E+1
     MOLYBDNUM-97     42097 53.340E+00
     MOLYBDNUM-95     42095 87.240E+00
     MOLYBDNUM-92     42092 78.900E+00
     MOLYBDNUM-94     42094 49.450E+00
     MOLYBDNUM-98     42098 13.669E+01
     MOLYBDNUM-96     42096 92.800E+00
     MOLYBDNUM-100    42100 55.570E+00
 1.000E-11    4.140E-07    1.125E-06    3.059E-06    1.068E-05    2.902E-05
 1.013E-04    5.823E-04    1.234E-03    3.355E-03    1.033E-02    2.188E-02
 2.479E-02    5.249E-02    1.111E-01    1.576E-01    5.562E-01    1.103E+00
 1.827E+00    2.307E+00    2.385E+00
 1  0
```

TABLE D

Output listing for Molibdenum

THE FOLLOWING DATA HAVE BEEN ENTERED INTO MEMORY
****

AMPERES	KILO-VOLTS	REAMFRACTION	DIVERGENCE	TI	T2	A
.250E+02	.170E+03	.100E+01	.100E+00	.A10E+01	.140E+02	7

NUMBER OF ENERGY GROUPS-NOEGPS 20

NUMBER OF TARGET NUCLIDES-NONUCL 7

NUMBER OF POINTS AFTER SHUTDOWN-NOPAS 12

ISAB=1

IGEOM=2

YOU ARE USING AN ABSORBING SOURCE

THIS SOURCE IS A SPHERE
IT'S RADIUS IS A= .2555+00 METERS
OBSERVER IS STANDING AT A DISTANCE D= .100E+00 METERS FROM THE SURFACE OF THIS SPHERE

NUMBER OF GROUPS BOUNDARIES-NG 21

NUMBER OF FAST NEUTRON GROUPS-NF 2

SPECIFIC TIMES AFTER SHUTDOWN (HR)

TIME 1	0.
TIME 2	.1CCE+01
TIME 3	.2CCE+01
TIME 4	.3CCE+01
TIME 5	.4CCE+01
TIME 6	.5CCE+01
TIME 7	.6CCE+01
TIME 8	.7CCE+01
TIME 9	.8CCE+01
TIME 10	.9CCE+01
TIME 11	.1CCE+02
TIME 12	.2CCE+02

REGION OF THE FLUXES-IFLUX= 1
THE FLUXES WILL BE READ FROM TAPE 8

IF IT IS THE CASE OF THE BEAM AFTER SATURATION,
THIS PLACE=(WALL= 1)
(ACTIVATION OF AN OBJECT PLACED INSIDE THE BEAM

UNIT NORMALIZED FLUXES INSIDE THE BEAM

GROUP 1	.25E1E-05
GROUP 2	.13B2E-04
GROUP 3	.8[illegible]E-04
GROUP 4	.3[illegible]E-03

GROUP 5	.137BE-06
GROUP 6	.2962E-07
GROUP 7	.43[illegible]E-07
GROUP 8	.2[illegible]E-07
GROUP 9	.74[illegible]E-07
GROUP 10	.[illegible]E-07
GROUP 11	.45[illegible]E-07
GROUP 12	.4[illegible]E-07
GROUP 13	.3[illegible]E-07
GROUP 14	.7[illegible]E-07
GROUP 15	.4[illegible]E-07
GROUP 16	.3[illegible]E-07
GROUP 17	.[illegible]E-07
GROUP 18	.[illegible]E-07
GROUP 19	.[illegible]E-07
GROUP 20	.E2[illegible]E-06

GROUP BOUNDARIES (NEV)

BOUNDARY	1	.2365E+01
BOUNDARY	2	.[illegible]
BOUNDARY	3	.[illegible]
BOUNDARY	4	.13[illegible]E+01
BOUNDARY	5	.550[illegible]+00
BOUNDARY	6	.[illegible]E+00
BOUNDARY	7	.1111E+00
BOUNDARY	8	.[illegible]E-01
BOUNDARY	9	.[illegible]E-01
BOUNDARY	10	.23[illegible]E-01
BOUNDARY	11	.1022E-01
BOUNDARY	12	.3355E-02
BOUNDARY	13	.1[illegible]E-02
BOUNDARY	14	.582[illegible]E-03
BOUNDARY	15	.1013E-03
BOUNDARY	16	.[illegible]E-04
BOUNDARY	17	.1[illegible]E-04
BOUNDARY	18	.[illegible]E-05
BOUNDARY	19	.[illegible]E-05
BOUNDARY	20	.[illegible]E-06
BOUNDARY	21	.1000E-10

NAME	ID-NUMBER	MASS(EV)
[illegible]	42092	.[illegible]
[illegible]	42094	.[illegible]
[illegible]	42095	.[illegible]
[illegible]	42096	.[illegible]
[illegible]	42097	.[illegible]
[illegible]	42098	.137[illegible]
[illegible]	42100	.[illegible]

ACOPS IS NOW READY TO RUN

****

THE FOLLOWING HAS BEEN CALCULATED BY ACTDS2
****

INSTANTANEOUS NUMBER OF NEUTRONS PRODUCED PER SECOND .7445E+13

AVERAGE NUMBER OF NEUTRONS PRODUCED PER SECOND .7445E+12

INTEGRALS OF THE FITTING FUNCTION OVER THE GROUP INTERVALS

GROUP	LOWER BOUNDARY	UPPER BOUNDARY	REQUIRED INTEGRAL	CALCULATED INTEGRAL
20	.100E-04	.414E+00	.829E-06	.829E-06
19	.414E+00	.113E+01	.305E-07	.305E-07
18	.113E+01	.306E+01	.346E-07	.346E-07
17	.130E+01	.107E+02	.395E-07	.395E-07
16	.107E+02	.290E+02	.301E-07	.301E-07
15	.290E+02	.101E+03	.448E-07	.448E-07
14	.101E+03	.583E+03	.773E-07	.773E-07
13	.583E+03	.123E+04	.304E-07	.304E-07
12	.123E+04	.336E+04	.402E-07	.402E-07
11	.336E+04	.103E+05	.457E-07	.457E-07
10	.103E+05	.219E+05	.352E-07	.352E-07
9	.219E+05	.248E+05	.742E-07	.742E-07
8	.248E+05	.525E+05	.386E-07	.386E-07
7	.525E+05	.111E+06	.479E-07	.479E-07
6	.111E+06	.150E+06	.244E-07	.244E-07
5	.150E+06	.550E+06	.138E-06	.138E-06
4	.550E+06	.111E+07	.106E-06	.106E-06
3	.111E+07	.183E+07	.833E-07	.833E-07
2	.183E+07	.223E+07	.138E-06	.138E-06
1	.223E+07	.229E+07	.790E-05	.790E-05

THE FOLLOWING OUTPUT DATA ARE CALCULATED ACTIVITIES IN BQ

TIME(H)	0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET PRODUCT	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
42092 42091	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42092 41092	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42092 41091	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42092 40090	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42092 40091	.148E+05	.148E+05	.148E+05	.148E+05	.148E+05	.148E+05	.148E+05	.148E+05	.148E+05	.148E+05	.148E+05	.148E+05

TIME(H)	0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET PRODUCT	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
42094 42093	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42094 42092	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42094 41094	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42094 41093	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42094 40091	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

42096	42055	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

	TIME(HR)	.0	.1000E+01	.2000E+01	.3000E+01	.4000E+01	.5000E+01	.6000E+01	.7000E+01	.8000E+01	.9000E+01	.1000E+02	.2000E+02
	TARGET	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
	42096	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

	TIME(HR)	.0	.1000E+01	.2000E+01	.3000E+01	.4000E+01	.5000E+01	.6000E+01	.7000E+01	.8000E+01	.9000E+01	.1000E+02	.2000E+02
TARGET	PRODUCT	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
42095	42055	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42095	42093	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42095	41095	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42095	41096	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42095	43092	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42095	42096	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

	TIME(HR)	.0	.1000E+01	.2000E+01	.3000E+01	.4000E+01	.5000E+01	.6000E+01	.7000E+01	.8000E+01	.9000E+01	.1000E+02	.2000E+02
	TARGET	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
	42095	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

	TIME(HR)	.0	.1000E+01	.2000E+01	.3000E+01	.4000E+01	.5000E+01	.6000E+01	.7000E+01	.8000E+01	.9000E+01	.1000E+02	.2000E+02
TARGET	PRODUCT	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
42096	42055	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42096	42056	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42096	41056	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42096	43093	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42096	42097	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

	TIME(HR)	.0	.1000E+01	.2000E+01	.3000E+01	.4000E+01	.5000E+01	.6000E+01	.7000E+01	.8000E+01	.9000E+01	.1000E+02	.2000E+02
	TARGET	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
	42096	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

	TIME(HR)	.0	.1000E+01	.2000E+01	.3000E+01	.4000E+01	.5000E+01	.6000E+01	.7000E+01	.8000E+01	.9000E+01	.1000E+02	.2000E+02
TARGET	PRODUCT	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
42097	42096	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42097	42055	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42097	41057	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42097	43094	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42097	42098	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

	TIME(HR)	.0	.1000E+01	.2000E+01	.3000E+01	.4000E+01	.5000E+01	.6000E+01	.7000E+01	.8000E+01	.9000E+01	.1000E+02	.2000E+02
	TARGET	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
	42097	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

	TIME(HR)	.0	.1000E+01	.2000E+01	.3000E+01	.4000E+01	.5000E+01	.6000E+01	.7000E+01	.8000E+01	.9000E+01	.1000E+02	.2000E+02
TARGET	PRODUCT	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
42098	42097	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42098	42056	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42098	41098	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42098	43095	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42098	42099	.1055+08	.1006+08	.957	.91	.86	.81	.77	.73	.691E+08	.654E+08	.621E+08	.589E+08	.559E+08	.530E+08

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
42099	.198E+09	.104E+09	.137E+08	.132E+08	.130E+08	.991E+07	.691E+07	.473E+07	.961E+06	.951E+05	.951E+04	.957E+03

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
42100	42099	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42100	42099	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42100	41100	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42100	40097	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42100	42101	.110E+09	.835E+07	.369E+06	.313E+05	.124E+04	.713E+02	.415E+01	.241E+00	.140E-01	.809E-03	.469E-04	.201E-16

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
42100	.110E+09	.835E+07	.369E+06	.313E+05	.124E+04	.713E+02	.415E+01	.241E+00	.140E-01	.809E-03	.469E-04	.201E-16

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
SYSTEM	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
	.219E+09	.111E+09	.136E+08	.132E+08	.131E+08	.100E+08	.991E+07	.981E+07	.971E+07	.961E+06	.951E+05	.957E+03

THE FOLLOWING OUTPUT DATA ARE CALCULATED DOSE RATES IN REM/HR

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)
42092	42099	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42092	41091	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42092	41092	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42092	42091	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42092	42093	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
PRODUCT	DOSE(REM/HR)	DOSE(REM/HR)	DOSE(REM/HR)	DOSE(REM/HR)	DOSE(REM/HR)	DOSE(REM/HR)	DOSE(REM/HR)	DOSE(REM/HR)	DOSE(REM/HR)	DOSE(REM/HR)	DOSE(REM/HR)	DOSE(REM/HR)	DOSE(REM/HR)

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)
42092	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)	DOSE(R)
42094	42091	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42094	41092	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42094	42094	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42094	42092	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42094	42093	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42094	42097	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

42094	42095	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
PRODUCT	DAUGHTER	DSRFIT1)	DSRFIT2)	DSRFIT3)	DSRFIT4)	DSRFIT5)	DSRFIT6)	DSRFIT7)	DSRFIT8)	DSRFIT9)	DSRFIT10)	DSRFIT11)	DSRFIT12)

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET		DSRFIT1)	DSRFIT2)	DSRFIT3)	DSRFIT4)	DSRFIT5)	DSRFIT6)	DSRFIT7)	DSRFIT8)	DSRFIT9)	DSRFIT10)	DSRFIT11)	DSRFIT12)
42094		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DSRFIT1)	DSRFIT2)	DSRFIT3)	DSRFIT4)	DSRFIT5)	DSRFIT6)	DSRFIT7)	DSRFIT8)	DSRFIT9)	DSRFIT10)	DSRFIT11)	DSRFIT12)
42095	40093	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42095	41094	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42095	41395	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42095	42093	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42095	42094	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42095	42096	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
PRODUCT	DAUGHTER	DSRFIT1)	DSRFIT2)	DSRFIT3)	DSRFIT4)	DSRFIT5)	DSRFIT6)	DSRFIT7)	DSRFIT8)	DSRFIT9)	DSRFIT10)	DSRFIT11)	DSRFIT12)

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET		DSRFIT1)	DSRFIT2)	DSRFIT3)	DSRFIT4)	DSRFIT5)	DSRFIT6)	DSRFIT7)	DSRFIT8)	DSRFIT9)	DSRFIT10)	DSRFIT11)	DSRFIT12)
42095		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DSRFIT1)	DSRFIT2)	DSRFIT3)	DSRFIT4)	DSRFIT5)	DSRFIT6)	DSRFIT7)	DSRFIT8)	DSRFIT9)	DSRFIT10)	DSRFIT11)	DSRFIT12)
42096	40093	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42096	41396	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42096	42094	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42096	42095	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42096	42097	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
PRODUCT	DAUGHTER	DSRFIT1)	DSRFIT2)	DSRFIT3)	DSRFIT4)	DSRFIT5)	DSRFIT6)	DSRFIT7)	DSRFIT8)	DSRFIT9)	DSRFIT10)	DSRFIT11)	DSRFIT12)

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET		DSRFIT1)	DSRFIT2)	DSRFIT3)	DSRFIT4)	DSRFIT5)	DSRFIT6)	DSRFIT7)	DSRFIT8)	DSRFIT9)	DSRFIT10)	DSRFIT11)	DSRFIT12)
42096		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DSRFIT1)	DSRFIT2)	DSRFIT3)	DSRFIT4)	DSRFIT5)	DSRFIT6)	DSRFIT7)	DSRFIT8)	DSRFIT9)	DSRFIT10)	DSRFIT11)	DSRFIT12)
42097	40094	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42097	41093	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42097	42095	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42097	42096	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42097	42097	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
PRODUCT	DAUGHTER	DSRFIT1)	DSRFIT2)	DSRFIT3)	DSRFIT4)	DSRFIT5)	DSRFIT6)	DSRFIT7)	DSRFIT8)	DSRFIT9)	DSRFIT10)	DSRFIT11)	DSRFIT12)

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET		DSRFIT1)	DSRFIT2)	DSRFIT3)	DSRFIT4)	DSRFIT5)	DSRFIT6)	DSRFIT7)	DSRFIT8)	DSRFIT9)	DSRFIT10)	DSRFIT11)	DSRFIT12)
42097		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DSRFIT1)	DSRFIT2)	DSRFIT3)	DSRFIT4)	DSRFIT5)	DSRFIT6)	DSRFIT7)	DSRFIT8)	DSRFIT9)	DSRFIT10)	DSRFIT11)	DSRFIT12)
42098	40095	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

42098	41099	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42098	42098	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42098	42098	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42098	42099	.154E+01	.153E+01	.151E+01	.149E+01	.148E+01	.146E+01	.145E+01	.143E+01	.142E+01	.140E+01	.139E+01	.125E+01
PRODUCT	DAUGHTER	DSRE(11)	DSRE(12)	DSRE(13)	DSRE(14)	DSRE(15)	DSRE(16)	DSRE(17)	DSRE(18)	DSRE(19)	DSRE(110)	DSRE(111)	DSRE(112)
42099	42097	.139E-06	.109E-06	.139E-06	.109E-06	.139E-06	.109E-06	.109E-06	.109E-06	.109E-06	.109E-06	.109E-06	.109E-06

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSRE(11)	DSRE(12)	DSRE(13)	DSRE(14)	DSRE(15)	DSRE(16)	DSRE(17)	DSRE(18)	DSRE(19)	DSRE(110)	DSRE(111)	DSRE(112)
42099	.154E+01	.153E+01	.151E+01	.149E+01	.148E+01	.146E+01	.145E+01	.143E+01	.142E+01	.140E+01	.139E+01	.125E+01

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DSRE(11)	DSRE(12)	DSRE(13)	DSRE(14)	DSRE(15)	DSRE(16)	DSRE(17)	DSRE(18)	DSRE(19)	DSRE(110)	DSRE(111)	DSRE(112)
42100	41100	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42100	42100	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42100	42098	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42100	42099	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
42100	42101	.495E+01	.247E+00	.166E-02	.208E-03	.555E-04	.224E-05	.[illegible]8E-06	.109E-07	.631E-09	.366E-10	.212E-11	.908E-24
PRODUCT	DAUGHTER	DSRE(11)	DSRE(12)	DSRE(13)	DSRE(14)	DSRE(15)	DSRE(16)	DSRE(17)	DSRE(18)	DSRE(19)	DSRE(110)	DSRE(111)	DSRE(112)
42101	42101	.247E+01	.123E+00	.773E-02	.620E-03	.220E-04	.120E-05	.658E-07	.358E-08	.196E-09	.107E-10	.583E-12	.137E-24

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSRE(11)	DSRE(12)	DSRE(13)	DSRE(14)	DSRE(15)	DSRE(16)	DSRE(17)	DSRE(18)	DSRE(19)	DSRE(110)	DSRE(111)	DSRE(112)
42100	.743E+01	.622E+00	.243E-01	.137E-02	.719E-04	.444E-05	.243E-06	.145E-07	.827E-09	.473E-10	.270E-11	.104E-23

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
SYSTEM	DSRE(11)	DSRE(12)	DSRE(13)	DSRE(14)	DSRE(15)	DSRE(16)	DSRE(17)	DSRE(18)	DSRE(19)	DSRE(110)	DSRE(111)	DSRE(112)
	.963E+01	.155E+01	.153E+01	.150E+01	.148E+01	.146E+01	.145E+01	.143E+01	.142E+01	.140E+01	.139E+01	.125E+01

TFTR neutral beam injector shielding walls

Assuming the test cell a spherical cavity, the inner radius can be determined by conserving the interior surface of the parallelipedic real cell (6.2 x 7.4 x 20.2 meters).

A = inside surface

= 2x 7.4 x 20.2 + 20.2 x 6.8 + 6.8 x 7.4

= 674.32 m^2

hence we have:

$$R = (A / (4x\pi))^{1/2} = 7.325 \text{ m}$$

The thickness used is the same as the one of the real cell:

H = 0.30 m

Assuming a concrete density of 2.6 g/cm^3 the total mass is

TMASS= 2.6 x VOLU

where VOLU = $4/3.\pi.((R+H)^3 - R^3) = 2.11 \times 10^8 \text{ m}^3$

then TMASS = 547 753 kg

distributed over the different elements as listed in Table E.

This time, the space-independent group-fluxes inside the test cell are inputed from the input data deck. The average group-fluxes in the walls are computed by setting: IWALL = 1 with KWALL= 0.1111 since for concrete $\lambda \sim 9$ cm. The input data deck is shown in Table F. Table G is the output listing. The dose is almost entirely dur to the 1.78 MeV gamma rays emitted by ^{28}Al, a product of ^{27}Al. Since the half-life of this product is short (134 s), after one hour, the dose-rate due to the activation of the walls is

TABLE E

Concrete Composition

ELEMENT	% IN CONCRETE	ISOTOPES	ATOMIC %	WEIGHT %	MASS (Kg)
H	16.3	^{1}H	99.985	99.97	89257.22
		^{2}H	0.015	0.03	26.78
O	54.5	^{16}O	99.759	99.73	297723.64
		^{17}O	0.037	0.04	116.44
		^{18}O	0.204	0.23	684.92
Al	2.1	^{27}Al	100.	100.	11503.00
Si	23.9	^{28}Si	92.27	91.92	120344.50
		^{29}Si	4.68	4.82	6307.01
		^{30}Si	3.05	3.26	4261.49
Ca	3.2	^{40}Ca	97.13	96.89	16981.50
		^{42}Ca	0.64	0.67	117.50
		^{43}Ca	0.15	0.16	28.20
		^{44}Ca	2.06	2.26	396.20
		^{48}Ca	0.02	0.02	4.20

TABLE F

Input Data Deck for Concrete

```
 0.0000000E+00
  .650E+02     .170E+03     .100E+01     .010E+01     .800E+01     .160E+02     7
20
12
 7.325E+00    0.000E+00    0.300E+00  41
14
 2
  0.000E+1     0.100E+1     0.200E+1     0.300E+1     0.400E+1     0.500E+1
  0.600E+1     0.700E+1     0.800E+1     0.900E+1     1.000E+1     2.000E+1
    HYDROGEN-1          1001 89.257E+03
    HYDROGEN-2          1002 26.780E+00
    OXYGEN-16           8016 29.772E+04
    OXYGEN-17           8017 11.644E+01
    OXYGEN-18           8018 68.492E+01
    ALUMINIUM-27       13027 11.503E+03
    SILICON-28         14028 12.034E+04
    SILICON-29         14029 63.070E+02
    SILICON-30         14030 42.615E+02
    CALCIUM-40         20040 16.982E+03
    CALCIUM-42         20042 11.750E+01
    CALCIUM-43         20043 28.200E+00
    CALCIUM-44         20044 39.620E+01
    CALCIUM-48         20048  4.200E+00
1.000E-11    4.140E-07    1.125E-06    3.059E-06    1.068E-05    2.902E-05
1.013E-04    5.829E-04    1.234E-03    3.355E-03    1.033E-02    2.188E-02
2.479E-02    5.248E-02    1.111E-01    1.576E-01    5.502E-01    1.10EE+00
1.827E+00    2.307E+00    2.385E+00
0  1  1.111E-01
 8.288E-7     3.076E-8     3.456E-8     3.951E-8     3.011E-8     4.684E-8
 7.234E-8     3.043E-8     4.021E-8     4.570E-8     3.522E-8     7.420E-9
 3.860E-8     4.790E-8     2.842E-8     1.378E-7     1.058E-7     8.333E-8
 1.382E-7     7.901E-6
```

TABLE G

Output Listing for Concrete

THE FOLLOWING DATA HAVE BEEN ENTERED INTO MEMORY
****

AMPERES	KILO-VOLTS	REMEMBRANCE	DUTY FACTOR	T1	T2	N
.650E+02	.170E+03	.137E+01	.100E+00	.400E+01	.160E+02	7

NUMBER OF ENERGY GROUPS-NOEGPS 20

NUMBER OF TARGET NUCLIDES-NONUCL 14

NUMBER OF POINTS AFTER SHUTDOWN-NOPSS 12

ISAD=1

IGEOM=4

YOU ARE USING AN ABSORBING SOURCE

THIS SOURCE IS A SPHERICAL CAVITY
ITS RADIUS IS R= .733E+01 METERS
ITS WIDTH IS W= .300E+00 METERS
THE OBSERVER IS AT THE CENTER OF THE CAVITY

NUMBER OF GROUPS REQUIRED-NG 21

NUMBER OF FAST NEUTRON GROUPS-NF 7

SPECIFIC TIMES AFTER SHUTDOWN (H)

TIME 1	0.
TIME 2	.100E+01
TIME 3	.200E+01
TIME 4	.300E+01
TIME 5	.400E+01
TIME 6	.500E+01
TIME 7	.600E+01
TIME 8	.700E+01
TIME 9	.800E+01
TIME 10	.900E+01
TIME 11	.100E+02
TIME 12	.200E+02

OPTION ON THE FLUXES-IFLUX= 0
THE FLUXES WILL BE READ FROM THE INPUT

OPTION ON THE PART OF THE ROOM AFTER ACTIVATION,
TAKES PLACE-IWALL= 1
ACTIVATION OF THE WALLS OF THE ROOM

AVERAGE UNIT NORMALIZED FLUXES IN THE WALLS (FWALL= .111E+00)

GROUP 1	.214[illegible]E-05
GROUP 2	.374[illegible]E-07
GROUP 3	.22[illegible]E-07

GROUP 4	.28666E-07
GROUP 5	.37337E-07
GROUP 6	.76599E-08
GROUP 7	.12597E-07
GROUP 8	.11644E-07
GROUP 9	.20108E-08
GROUP 10	.45542E-08
GROUP 11	.13776E-07
GROUP 12	.10895E-07
GROUP 13	.82448E-08
GROUP 14	.19905E-07
GROUP 15	.12698E-07
GROUP 16	.81787E-08
GROUP 17	.10705E-07
GROUP 18	.53626E-08
GROUP 19	.83336E-08
GROUP 20	.22945E-06

GROUP BOUNDARIES (MEV)

BOUNDARY	1	.23855E+01
BOUNDARY	2	.23037E+01
BOUNDARY	3	.19777E+01
BOUNDARY	4	.11088E+01
BOUNDARY	5	.55028E+00
BOUNDARY	6	.15368E+00
BOUNDARY	7	.11111E+00
BOUNDARY	8	.52485E-01
BOUNDARY	9	.24796E-01
BOUNDARY	10	.21788E-01
BOUNDARY	11	.10337E-01
BOUNDARY	12	.23554E-02
BOUNDARY	13	.12746E-02
BOUNDARY	14	.58289E-03
BOUNDARY	15	.10923E-03
BOUNDARY	16	.25026E-04
BOUNDARY	17	.10688E-04
BOUNDARY	18	.20597E-05
BOUNDARY	19	.11259E-05
BOUNDARY	20	.48148E-06
BOUNDARY	21	.10000E-10

NAME	ID-NUMBER	MASS(G)
HYDROGEN-1	1001	.99756+00
HYDROGEN-2	1002	.37456+00
OXYGEN-16	8016	.57756+00
OXYGEN-17	8017	.13756+00
OXYGEN-18	8018	.69756+00
ALUMINUM-27	13027	.11756+00
SILICON-28	14028	.19756+00
SILICON-29	14029	.47756+00
SILICON-30	14030	.34756+00
CALCIUM-40	20040	.17756+00
CALCIUM-42	20042	.11756+00
CALCIUM-43	20043	.29756+00
CALCIUM-44	20044	.39756+00
CALCIUM-48	20048	.42756+00

```
ACCOS IS NOW READY TO RUN.
**************************
```

THE FOLLOWING HAS BEEN CALCULATED BY ACCESS
****

INSTANTANEOUS NUMBER OF NEUTRONS PRODUCED PER SECOND .7645E+13

AVERAGE NUMBER OF NEUTRONS PRODUCED PER SECOND .7645E+12

INTEGRALS OF THE FITTING FUNCTION OVER THE GROUP INTERVALS
GROUP LOWER BOUNDARY LOWER BOUNDARY REQUIRED INTEGRAL CALCULATED INTEGRAL

20	.1005E-04	.4167E-01	.2227E-05	.2235E-05
19	.4167E-01	.1535E+01	.8233E-04	.8237E-04
18	.1535E+01	.3355E+01	.9365E-04	.9361E-04
17	.3355E+01	.5537E+01	.1035E-03	.1037E-03
16	.5537E+01	.2930E+02	.9161E-04	.9165E-04
15	.2930E+02	.1013E+03	.1227E-03	.1227E-03
14	.1013E+03	.5943E+03	.1196E-03	.1196E-03
13	.5943E+03	.1123E+04	.8746E-04	.8746E-04
12	.1123E+04	.3355E+04	.1099E-03	.1099E-03
11	.3355E+04	.1007E+05	.1224E-03	.1224E-03
10	.1007E+05	.2192E+05	.8546E-04	.8546E-04
9	.2192E+05	.2479E+05	.2011E-04	.2011E-04
8	.2479E+05	.5531E+05	.1056E-03	.1056E-03
7	.5531E+05	.1111E+06	.1370E-03	.1370E-03
6	.1111E+06	.1549E+06	.7709E-04	.7709E-04
5	.1549E+06	.4550E+06	.1733E-03	.1733E-03
4	.4551E+06	.1111E+07	.2497E-03	.2497E-03
3	.1111E+07	.1853E+07	.2761E-03	.2761E-03
2	.1853E+07	.2231E+07	.2746E-03	.2746E-03
1	.2231E+07	.2385E+07	.2134E-03	.2134E-03

THE FOLLOWING OUTPUT DATA ARE CALCULATED ACTIVITIES IN B2

TIME(HR)	.0	.1000E+01	.2000E+01	.3000E+01	.4000E+01	.5000E+01	.6000E+01	.7000E+01	.8000E+01	.9000E+01	.1000E+02	.2000E+02
TARGET PRODUCE	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
1001 1001	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
TIME(HR)	.0	.1000E+01	.2000E+01	.3000E+01	.4000E+01	.5000E+01	.6000E+01	.7000E+01	.8000E+01	.9000E+01	.1000E+02	.2000E+02
TARGET	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
1001	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)	.0	.1000E+01	.2000E+01	.3000E+01	.4000E+01	.5000E+01	.6000E+01	.7000E+01	.8000E+01	.9000E+01	.1000E+02	.2000E+02
TARGET PRODUCT	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
1001 1001	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03
TIME(HR)	.0	.1000E+01	.2000E+01	.3000E+01	.4000E+01	.5000E+01	.6000E+01	.7000E+01	.8000E+01	.9000E+01	.1000E+02	.2000E+02
TARGET	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
1002	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03	.4746E+03

TIME(HR)	.0	.1000E+01	.2000E+01	.3000E+01	.4000E+01	.5000E+01	.6000E+01	.7000E+01	.8000E+01	.9000E+01	.1000E+02	.2000E+02

TARGET	PRODUCT	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
8015	8015	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
8014	7015	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
8016	8015	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
8016	7015	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
8015	7015	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
8016	8015	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET		ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
8015		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

ATTENTION-TARGET NUCLIDE NUMBER 8017 DOES NOT EXIST IN DATA LIBRARY-THEREFORE-NO CONTRIBUTION FROM THIS NUCLIDE IN DOSE CALS.

ATTENTION-TARGET NUCLIDE NUMBER 8017 DOES NOT EXIST IN DATA LIBRARY-THEREFORE-NO CONTRIBUTION FROM THIS NUCLIDE IN DOSE CALS.

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
13027	13027	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13027	12027	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13027	12026	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13027	12025	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13027	11024	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13027	13029	.123E+11	.183E+02	.279E-05	.425E-13	.648E-21	.987E-29	.150E-36	.229E-44	.349E-52	.531E-60	.809E-68	.543-146
TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET		ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
13027		.123E+11	.183E+02	.279E-05	.425E-13	.648E-21	.987E-29	.150E-36	.229E-44	.349E-52	.531E-60	.809E-68	.543-146

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
14028	14027	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14028	13027	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14028	12026	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14028	12025	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14028	11025	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14028	14029	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET		ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
14028		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY	ACTIVITY
14029	14029	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14029	13029	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14029	12025	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

14029	13039	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14029	12026	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14029	14030	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	ACTIVITY1	ACTIVITY2	ACTIVITY3	ACTIVITY4	ACTIVITY5	ACTIVITY6	ACTIVITY7	ACTIVITY8	ACTIVITY9	ACTIVITY10	ACTIVITY11	ACTIVITY12
14029	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(H)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	ACTIVITY1	ACTIVITY2	ACTIVITY3	ACTIVITY4	ACTIVITY5	ACTIVITY6	ACTIVITY7	ACTIVITY8	ACTIVITY9	ACTIVITY10	ACTIVITY11	ACTIVITY12
14033	14025	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14033	14028	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14033	13029	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14033	12026	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14033	13030	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14033	12027	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14033	14031	.169E+10	.129E+10	.993E+09	.760E+09	.583E+09	.448E+09	.344E+09	.264E+09	.202E+09	.155E+09	.119E+09	.847E+07

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	ACTIVITY1	ACTIVITY2	ACTIVITY3	ACTIVITY4	ACTIVITY5	ACTIVITY6	ACTIVITY7	ACTIVITY8	ACTIVITY9	ACTIVITY10	ACTIVITY11	ACTIVITY12
14033	.169E+10	.129E+10	.993E+09	.760E+09	.583E+09	.448E+09	.344E+09	.264E+09	.202E+09	.155E+09	.119E+09	.847E+07

TIME(H)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	ACTIVITY1	ACTIVITY2	ACTIVITY3	ACTIVITY4	ACTIVITY5	ACTIVITY6	ACTIVITY7	ACTIVITY8	ACTIVITY9	ACTIVITY10	ACTIVITY11	ACTIVITY12
20040	20035	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20040	19035	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20040	18035	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20040	17040	.113E+00	.113E+00	.113E+00	.113E+00	.113E+00	.113E+00	.113E+00	.113E+00	.113E+00	.113E+00	.113E+00	.113E+00
20043	19039	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	18037	.792E+09	.791E+09	.791E+09	.790E+09	.789E+09	.789E+09	.788E+09	.788E+09	.787E+09	.786E+09	.786E+09	.779E+09
20043	23041	.120E+04	.120E+04	.120E+04	.120E+04	.120E+04	.120E+04	.120E+04	.120E+04	.120E+04	.120E+04	.120E+04	.120E+04

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	ACTIVITY1	ACTIVITY2	ACTIVITY3	ACTIVITY4	ACTIVITY5	ACTIVITY6	ACTIVITY7	ACTIVITY8	ACTIVITY9	ACTIVITY10	ACTIVITY11	ACTIVITY12
20040	.792E+09	.791E+09	.791E+09	.790E+09	.789E+09	.789E+09	.788E+09	.788E+09	.787E+09	.786E+09	.786E+09	.779E+09

TIME(H)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	ACTIVITY1	ACTIVITY2	ACTIVITY3	ACTIVITY4	ACTIVITY5	ACTIVITY6	ACTIVITY7	ACTIVITY8	ACTIVITY9	ACTIVITY10	ACTIVITY11	ACTIVITY12
20042	23041	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20042	19041	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20042	18038	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20042	17042	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20042	23039	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	23043	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	ACTIVITY1	ACTIVITY2	ACTIVITY3	ACTIVITY4	ACTIVITY5	ACTIVITY6	ACTIVITY7	ACTIVITY8	ACTIVITY9	ACTIVITY10	ACTIVITY11	ACTIVITY12
20042	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02

TARGET	PRODUCT	ACTIVITY1	ACTIVITY2	ACTIVITY3	ACTIVITY4	ACTIVITY5	ACTIVITY6	ACTIVITY7	ACTIVITY8	ACTIVITY9	ACTIVITY10	ACTIVITY11	ACTIVITY12
20043	20042	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	18039	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	17043	.122E+06	.119E+06	.115E+06	.112E+06	.109E+06	.105E+06	.102E+06	.986E+05	.956E+05	.926E+05	.898E+05	.869E+05
20043	17042	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20042	18040	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	23044	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	ACTIVITY1	ACTIVITY2	ACTIVITY3	ACTIVITY4	ACTIVITY5	ACTIVITY6	ACTIVITY7	ACTIVITY8	ACTIVITY9	ACTIVITY10	ACTIVITY11	ACTIVITY12
20043	.122E+06	.119E+06	.115E+06	.112E+06	.109E+06	.105E+06	.102E+06	.986E+05	.956E+05	.926E+05	.898E+05	.869E+05

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	ACTIVITY1	ACTIVITY2	ACTIVITY3	ACTIVITY4	ACTIVITY5	ACTIVITY6	ACTIVITY7	ACTIVITY8	ACTIVITY9	ACTIVITY10	ACTIVITY11	ACTIVITY12
23044	23043	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
23044	17044	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
23044	17043	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
23044	18041	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
23044	23045	.888E+07	.888E+07	.888E+07	.888E+07	.888E+07	.888E+07	.887E+07	.887E+07	.887E+07	.887E+07	.887E+07	.885E+07

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	ACTIVITY1	ACTIVITY2	ACTIVITY3	ACTIVITY4	ACTIVITY5	ACTIVITY6	ACTIVITY7	ACTIVITY8	ACTIVITY9	ACTIVITY10	ACTIVITY11	ACTIVITY12
20044	.888E+07	.888E+07	.888E+07	.888E+07	.888E+07	.888E+07	.887E+07	.887E+07	.887E+07	.887E+07	.887E+07	.885E+07

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	ACTIVITY1	ACTIVITY2	ACTIVITY3	ACTIVITY4	ACTIVITY5	ACTIVITY6	ACTIVITY7	ACTIVITY8	ACTIVITY9	ACTIVITY10	ACTIVITY11	ACTIVITY12
23048	23047	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20048	18048	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
23048	20049	.761E+07	.459E+05	.594E+03	.518E+01	.460E-01	.409E-03	.362E-05	.321E-07	.285E-09	.253E-11	.224E-13	.676E-14

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	ACTIVITY1	ACTIVITY2	ACTIVITY3	ACTIVITY4	ACTIVITY5	ACTIVITY6	ACTIVITY7	ACTIVITY8	ACTIVITY9	ACTIVITY10	ACTIVITY11	ACTIVITY12
20048	.761E+07	.459E+05	.594E+03	.518E+01	.460E-01	.409E-03	.362E-05	.321E-07	.285E-09	.253E-11	.224E-13	.676E-14

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
SYSTEM	ACTIVITY1	ACTIVITY2	ACTIVITY3	ACTIVITY4	ACTIVITY5	ACTIVITY6	ACTIVITY7	ACTIVITY8	ACTIVITY9	ACTIVITY10	ACTIVITY11	ACTIVITY12
	.145E+11	.707E+10	.135E+10	.131E+10	.127E+10	.123E+10	.119E+10	.116E+10	.112E+10	.109E+10	.106E+10	.103E+10

THE FOLLOWING OUTPUT DATA ARE CALCULATED RATES IN PPM/H

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DSRATE1	DSRATE2	DSRATE3	DSRATE4	DSRATE5	DSRATE6	DSRATE7	DSRATE8	DSRATE9	DSRATE10	DSRATE11	DSRATE12
1031	1002	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
PRODUCT DAUGHTER		DSRATE1	DSRATE2	DSRATE3	DSRATE4	DSRATE5	DSRATE6	DSRATE7	DSRATE8	DSRATE9	DSRATE10	DSRATE11	DSRATE12

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
1001	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET PRODUCT	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
1002 1001	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
PRODUCT DAUGHTER	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
1003 2003	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
1002	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET PRODUCT	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
5016 6012	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5016 5013	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5016 7015	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5015 7315	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5016 7014	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5016 5015	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
PRODUCT DAUGHTER	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
5016	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET PRODUCT	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
PRODUCT DAUGHTER	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
8017	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET PRODUCT	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
PRODUCT DAUGHTER	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
8018	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(H)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET PRODUCT	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)

13027	11024	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13027	12025	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13027	12026	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13027	13027	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13027	13028	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13027	13029	.405E+01	.617E-07	.640E-15	.143E-22	.218E-30	.332E-38	.506E-46	.770E-54	.117E-61	.179E-69	.272E-77	.183-155
PRODUCT	DAUGHTER	DSRETI)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
13028	14028	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
13027	.405E+01	.617E-07	.640E-15	.143E-22	.218E-30	.332E-38	.506E-46	.770E-54	.117E-61	.179E-69	.272E-77	.183-155

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
14028	12024	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14028	12025	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14028	13027	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14028	13028	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14028	14027	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14028	14028	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
PRODUCT	DAUGHTER	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
14028	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
14029	12025	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14029	12026	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14029	13028	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14029	13029	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14029	14028	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14029	14029	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
PRODUCT	DAUGHTER	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
14029	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
14030	12026	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14030	12027	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14030	13029	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14030	13030	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14030	14029	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14030	14030	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14031	14031	.412E-03	.216E-02	.262E-02	.744E-03	.143E-02	.130E-03	.942E-04	.644E-04	.496E-04	.381E-04	.292E-04	.708E-05
PRODUCT	DAUGHTER	DSRET1)	DSRET2)	DSRET3)	DSRET4)	DSRET5)	DSRET6)	DSRET7)	DSRET8)	DSRET9)	DSRET10)	DSRET11)	DSRET12)
14031	15031	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSP(I1)	DSP(I2)	DSP(I3)	DSP(I4)	DSP(I5)	DSP(I6)	DSP(I7)	DSP(I8)	DSP(I9)	DSP(I10)	DSP(I11)	DSP(I12)
14023	.412E-03	.314E-03	.243E-03	.189E-03	.147E-03	.111E-03	.862E-04	.664E-04	.496E-04	.371E-04	.252E-04	.208E-05

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DSP(I1)	DSP(I2)	DSP(I3)	DSP(I4)	DSP(I5)	DSP(I6)	DSP(I7)	DSP(I8)	DSP(I9)	DSP(I10)	DSP(I11)	DSP(I12)
20043	18078	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	19017	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	19038	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	19039	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	19040	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	20039	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	20041	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
PRODUCT DAUGHTER		DSP(I1)	DSP(I2)	DSP(I3)	DSP(I4)	DSP(I5)	DSP(I6)	DSP(I7)	DSP(I8)	DSP(I9)	DSP(I10)	DSP(I11)	DSP(I12)

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSP(I1)	DSP(I2)	DSP(I3)	DSP(I4)	DSP(I5)	DSP(I6)	DSP(I7)	DSP(I8)	DSP(I9)	DSP(I10)	DSP(I11)	DSP(I12)
20043	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DSP(I1)	DSP(I2)	DSP(I3)	DSP(I4)	DSP(I5)	DSP(I6)	DSP(I7)	DSP(I8)	DSP(I9)	DSP(I10)	DSP(I11)	DSP(I12)
20042	13039	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20042	19038	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20042	19041	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20042	19042	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20042	20041	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20042	20043	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
PRODUCT DAUGHTER		DSP(I1)	DSP(I2)	DSP(I3)	DSP(I4)	DSP(I5)	DSP(I6)	DSP(I7)	DSP(I8)	DSP(I9)	DSP(I10)	DSP(I11)	DSP(I12)

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSP(I1)	DSP(I2)	DSP(I3)	DSP(I4)	DSP(I5)	DSP(I6)	DSP(I7)	DSP(I8)	DSP(I9)	DSP(I10)	DSP(I11)	DSP(I12)
20042	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)		.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DSP(I1)	DSP(I2)	DSP(I3)	DSP(I4)	DSP(I5)	DSP(I6)	DSP(I7)	DSP(I8)	DSP(I9)	DSP(I10)	DSP(I11)	DSP(I12)
20043	19039	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	19040	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	19042	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	19043	.399E-04	.327E-04	.268E-04	.219E-04	.180E-04	.148E-04	.120E-04	.101E-04	.825E-05	.675E-05	.529E-05	.207E-04
20043	20039	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20043	20044	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
PRODUCT DAUGHTER		DSP(I1)	DSP(I2)	DSP(I3)	DSP(I4)	DSP(I5)	DSP(I6)	DSP(I7)	DSP(I8)	DSP(I9)	DSP(I10)	DSP(I11)	DSP(I12)
19043	20043	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSP(I1)	DSP(I2)	DSP(I3)	DSP(I4)	DSP(I5)	DSP(I6)	DSP(I7)	DSP(I8)	DSP(I9)	DSP(I10)	DSP(I11)	DSP(I12)
20043	.399E-04	.327E-04	.268E-04	.219E-04	.180E-04	.148E-04	.120E-04	.101E-04	.825E-05	.675E-05	.529E-05	.207E-04

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET PRODUCT	DSP(I1)	DSP(I2)	DSP(I3)	DSP(I4)	DSP(I5)	DSP(I6)	DSP(I7)	DSP(I8)	DSP(I9)	DSP(I10)	DSP(I11)	DSP(I12)

20044	18041	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20044	17043	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20044	19044	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20044	20043	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20044	20045	.154E-07	.154E-07	.153E-07	.153E-07	.143E-07	.153E-07	.153E-07	.143E-07	.143E-07	.143E-07	.153E-07	.153E-07
PRODUCT	DAUGHTER	DSR(I1)	DSR(I2)	DSR(I3)	DSR(I4)	DSR(I5)	DSR(I6)	DSR(I7)	DSR(I8)	DSR(I9)	DSR(I10)	DSR(I11)	DSR(I12)
20045	21045	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSR(I1)	DSR(I2)	DSR(I3)	DSR(I4)	DSR(I5)	DSR(I6)	DSR(I7)	DSR(I8)	DSR(I9)	DSR(I10)	DSR(I11)	DSR(I12)
20044	.154E-07	.154E-07	.153E-07	.153E-07	.153E-07	.153E-07	.153E-07	.153E-07	.153E-07	.153E-07	.153E-07	.153E-07

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	PRODUCT	DSR(I1)	DSR(I2)	DSR(I3)	DSR(I4)	DSR(I5)	DSR(I6)	DSR(I7)	DSR(I8)	DSR(I9)	DSR(I10)	DSR(I11)	DSR(I12)
20048	19048	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20048	20047	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20048	20049	.329E-02	.292E-04	.259E-06	.220E-08	.204E-10	.181E-12	.160E-14	.142E-16	.126E-18	.112E-20	.593E-22	.200E-43
PRODUCT	DAUGHTER	DSR(I1)	DSR(I2)	DSR(I3)	DSR(I4)	DSR(I5)	DSR(I6)	DSR(I7)	DSR(I8)	DSR(I9)	DSR(I10)	DSR(I11)	DSR(I12)
20049	21049	.151E-05	.726E-06	.350E-06	.169E-06	.814E-07	.393E-07	.189E-07	.913E-08	.440E-08	.212E-08	.102E-08	.695E-12

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
TARGET	DSR(I1)	DSR(I2)	DSR(I3)	DSR(I4)	DSR(I5)	DSR(I6)	DSR(I7)	DSR(I8)	DSR(I9)	DSR(I10)	DSR(I11)	DSR(I12)
20048	.329E-02	.292E-04	.259E-06	.232E-08	.814E-07	.393E-07	.189E-07	.913E-08	.440E-08	.212E-08	.102E-08	.695E-12

TIME(HR)	.0	.100E+01	.200E+01	.300E+01	.400E+01	.500E+01	.600E+01	.700E+01	.800E+01	.900E+01	.100E+02	.200E+02
SYSTEM	DSR(I1)	DSR(I2)	DSR(I3)	DSR(I4)	DSR(I5)	DSR(I6)	DSR(I7)	DSR(I8)	DSR(I9)	DSR(I10)	DSR(I11)	DSR(I12)
	.405E+01	.293E-01	.279E-03	.221E-03	.177E-03	.142E-03	.114E-03	.557E-04	.747E-04	.672E-04	.575E-04	.228E-04

3333333333.2333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.33
3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.33
3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.33
3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.3333333333.33

insignificant. In fact a more accurate calculation should take into account heavy elements which, even in small quantities in concrete, could significantly increase the dose.

```
      PROGRAM ACDOS2(INPUT,OUTPUT,TAPE5=INPUT,TAPE8,TAPE7,TAPE6=OUTPUT)
C
C
C
C     ****************************************************************
C     ****************************************************************
C     **                                                            **
C     **                                                            **
C     **                                                            **
C     **                          ACDOS2                            **
C     **                                                            **
C     **            A NEUTRON-INDUCED DOSE RATE CALCULATION CODE    **
C     **                                                            **
C     **              WRITTEN BY G S KENEY AND J-C LAGACHE          **
C     **                                                            **
C     **            AT THE UNIVERSITY OF CALIFORNIA BERKELEY        **
C     **                                                            **
C     **                                                            **
C     **                                                            **
C     ****************************************************************
C     ****************************************************************
C
C
C     ACDOS2 IS A STANDARD FORTRAN 4 CODE DEVELOPED FOR CALCULATING DOSE
C     RATES FROM NEUTRON ACTIVATION OF NEUTRAL-BEAM INJECTORS. SUFFICIENT
C     VERSATILITY HAS ALSO BEEN INCORPORATED INTO THE CODE TO MAKE IT
C     APPLICABLE TO A WIDE VARIETY OF GENERAL ACTIVATION PROBLEMS DUE TO
C     NEUTRONS OF ENERGY LESS THAN 20 MEV. FOR FURTHER INFORMATION
C     CONCERNING THIS PROGRAM, SEE LBL REPORT NO.12711 BY J-C LAGACHE.
C
C
C
C
C          VARIABLES AND ARRAYS ARE DEFINED AS BELOW
C
C          A               CURRENT IN AMPERES
C          ACT             ACTIVITY DUE TO ACTIVATION OF A PARTICULAR TARG
C                          ET NUCLIDE BY A SPECIFIC NEUTRON REACTION
C          AMU             MASS ATTENUATION COEFFICIENT
C          AVENPS          AVERAGE NUMBER OF NEUTRONS PRODUCED PER SECOND
C          BFA             COEFFICIENT A OF THE TAYLOR EXPANSION OF THE
C                          BUILT-UP FACTOR
C          BALPH1          COEFFICIENT ALPHA 1 OF THE TAYLOR EXPANSION
C                          OF THE BUILD-UP FACTOR
C          BALPH2          COEFFICIENT ALPHA 2 OF THE TAYLOR EXPANSION
C                          OF THE BUILT-UP FACTOR
C          EFLUX(I)        UNIT NORMALIZED FLUX
C          CF              NEUTRON YIELD CORRECTION FACTOR FOR VOLTAGES
C                          DIFFERENT FROM 150 KV
C          CONST(I)        CONSTANTS FOR WEIGHTING FUNCTIONS
C          CS(I)           CROSS SECTION VALUE
C          CS1(I)          CROSS SECTION VALUE
C          C               DISTANCE FROM POINT SOURCE OR SURFACE OF
C                          SPHERE OR CYLINDER
C          DF              DUTY-FACTOR
C          DIFF            DIFFERENCE BETWEEN THE LATEST REFINED GUESS AND
C                          THE PREVIOUS GUESS
C          DOSRAT          CALCULATED DOSERATE
C          DOSDAU(I)       DOSE DUE TO A DAUGHTER AT SHUTDOWN
C          DOSDGT(I)       DOSE DUE TO THE DAUGHTERS
C          DOSNUC(I)       DOSE DUE TO A GIVEN PRODUCT WITH ITS DAUGHTERS
```

```
C       DOSPRO(I)     DOSE DUE TO A PRODUCT AT SHUTDOWN
C       DOSPRC(I)     DOSE DUE TO A GIVEN PRODUCT ALONE
C       DOSSUM(I)     DOSE RATE DUE TO A PARTICULAR TARGET NUCLIDE
C                     FOR UP TO 12 DIFFERENT TIMES
C       DPVAR         VALUE OF DEPENDENT VARIABLE IN NUMERICAL
C                     INTEGRATIONS
C       E             ENERGY OF GAMMA RAY
C       EN(I)         ENERGY VALUE ASSOCIATED WITH A CROSS SECTION
C       E1(I)         ENERGY VALUE ASSOCIATED WITH A CROSS SECTION
C       F             BEAM FRACTION
C       FCONST(I)     EXPONENTIAL CONSTANTS FOR FAST NEUTRON GROUPS
C       FF            SHAPE FACTOR FOR THE FLUXES IN THE WALL
C       FLUXBC        WEIGHTING FLUX AT A GROUP BOUNDARY
C       FPRIME        EVALUATED VALUE OF THE DERIVATIVE OF THE
C                     TRANSCENDENTAL EQUATION FOR B
C       FXSUBI        EVALUATED VALUE OF THE TRANSCENDENTAL EQUATION
C                     FOR B
C                     ABSORBING CYLINDER
C       GFC           GEOMETRIC CORRECTION IN THE CASE OF  AN
C       GFS           GEOMETRIC CORRECTION IN THE CASE OF  AN
C                     ABSORBING SPHERE
C       GP            GROUP BOUNDARIES
C       GPFLUX(I)     FEW GROUP FLUXES-UP TO 50
C       GPXSEC(I)     FEW GROUP CROSS SECTIONS-UP TO 50
C       GUESSI        INITIAL GUESS FOR SOLVING TRANSCENDENTAL
C                     EQUATIONS
C       H             HEIGHT OF CYLINDER (M)
C       ICOUNT        NEUTRON GROUP COUNTER
C       ICP1          ICOUNT+1
C       ICP2          ICOUNT+2
C       IDNC(I)       5 DIGIT ID NUMBER OF TARGET NUCLIDE
C       IDLMB         DUMMY VARIABLE FOR ADVANCING DISK FILE RECORDS
C       IEPTH         COUNTER FOR INTERMEDIATE NEUTRON GROUPS
C       IFLUX         OPTION ON THE WAY TO INPUT THE FLUXES
C       IGEOM         DESIGNATES PROBLEM GEOMETRY
C       INSAPS        INSTANTANEOUS NUMBER OF NEUTRONS PRODUCED PER
C                     SECOND
C       IORDER(I)     HOLDING ARRAY FOR PRODUCT NUCLIDE ID NUMBERS
C       IPROD         PRODUCT NUCLIDE COUNTER
C       ISAB          OPTION ON THE ABSORPTION STRATEGY
C       ITAPE         READ VARIABLE FOR DISK FILE DATA
C       ITER          ITERATION COUNTER
C       IWALL         OPTION ON THE PLACE OF THE ACTIVATION
C       KWALL         INVERSE OF THE RELAXATION LENGTH OF THE WALL
C                     MATERIAL
C       MASS(I)       NUMBER OF KILOGRAMS OF A PARTICULAR NUCLIDE
C       MU            ATTENUATION COEFFICIENT
C       MULT          MULTIPLICITY OF GAMMA RAY
C       N             NUMBER OF TESTS
C       NEPTH         NUMBER OF INTERMEDIATE NEUTRON GROUPS
C       NE1(I)        NUMBER OF E1 C1 PAIRS
C       NF            NUMBER OF FAST NEUTRON GROUPS
C       NG            NUMBER OF GROUP BOUNDARIES-UP TO 51
C       NOEGPS        NUMBER OF ENERGY GROUPS-UP TO 50
C       NONUCL        NUMBER OF TARGET NUCLIDES-UP TO 30 PER RUN
C       NOPAS         NUMBER OF POINTS AFTER SHUTDOWN-UP TO 12
C       NOTORD(I)     HOLDING ARRAY FOR PRODUCT NUCLIDE NUMBERS THAT
C                     HAVE NOT BEEN RE-ARRANGED IN ASCENDING ORDER
C       NP            NUMBER OF ENERGY-CROSS-SECTION PAIRS
C       OPTION        VARIABLE THAT DETERMINES WHETHER OR NOT AVENPS
C                     WILL BE CALCULATED BY ACDCS OR READ FROM A
C                     DATA CARD AS PRE-DETERMINED INPUT
```

```
C          PARSUP          PARTIAL SUM IN NUMERICAL INTEGRATIONS
C          PRODHL(I,J)     PRODUCT NUCLIDE HALF-LIFE (S)
C          PRODNU(I,J)     5 DIGIT ID NUMBER OF PRODUCT NUCLIDE
C          R               RADIUS OF HOMOGENEOUS NON-ABSORBING SPHERE OR
C                          CYLINDER (M)
C          REALDUM         REAL DUMMY VARIABLE FOR ADVANCING DISK FILE
C                          RECORDS
C          SOU             DOSE RATE SOURCE STRENGTH DIVIDED BY THE
C                          UNIT DOSE RATE FLUX
C          STAFS(I)        SPECIFIC TIMES AFTER SHUTDOWN (H)
C          STOPHL(I)       HOLDING ARRAY FOR PRODUCT NUCLIDE ID NUMBERS
C          STOTAC(I,J)     HOLDING ARRAY FOR PRODUCT NUCLIDE ACTIVITIES
C          SUMACT(I)       SUM OF ACTIVITIES PRODUCED FROM A PARTICULAR
C                          TARGET NUCLIDE FOR UP TO 12 DIFFERENT TIMES
C          SUM1            EXPONENTIAL EFFECT OF TESTS AND PAUSES ON THE
C                          SHUTDOWN TIME ACTIVITY OF A SPECIFIC PRODUCT
C                          NUCLIDE
C          SUMDEL          RUNNING SUM OF AVERAGE CROSS SECTIONS
C          SUMINT          RESULT OF NUMERICAL INTEGRATIONS
C          SYSACT(I)       SYSTEM ACTIVITY FOR UP TO 12 DIFFERENT TIMES
C          SYSDOSE(I)      SYSTEM DOSERATE FOR UP TO 12 DIFFERENT TIMES
C          TARMAS          ATOMIC WEIGHT OF TARGET NUCLIDE (AMU)
C          TEMPS           TEMPORARY STORAGE FOR DO LOOP SUMS
C          TIMACT(I,J,K)   INDUCED ACTIVITY AS A FUNCTION OF TARGET
C                          NUCLIDE,REACTION, AND TIME
C          TMASS           TOTAL NUMBER OF KILOGRAMS OF THE TARGET
C          T1              LENGTH OF TEST (H)
C          T2              LENGTH OF PAUSE (H)
C          V               VOLTAGE (KV)
C          VOLU            VOLUME OF THE SOURCE
C          WIDTH           DELTA E USED IN NUMERICAL INTEGRATIONS
C          XSBIP1          LATEST REFINED GUESS FOR B
C          XSUBI           INDEPENDENT VARIABLE OF THE TRANSCENDENTAL
C                          EQUATION FOR B
C          ZINCR           INCREMENT IN ENERGY USED IN NUMERICAL
C                          INTEGRATIONS
C          ZNAME           VARIABLE FOR NUCLIDE NAMES
C          ZNUMER          NUMERATOR IN THE TRANSCENDENTAL EQUATION FOR B
C
C
C
C
      DIMENSION TIMACT(30,13,12),SYSACT(12),SUMACT(12),SYSDOSE(12),PRODHL
     +(30,13),PRODNU(30,13),DOSSUM(12),ZNAM1(30),STAFS(12),BFLUX(50),ION
     +D(30),GPXSEC(50),MASS(30),GPFLUX(50),GP(51),ZNAM2(30)
      DIMENSION CONST(50),FCONST(50)
      DIMENSION DOSNUC(13),DOSEGT(13),DOSPRO(13)
      COMMON A,V,F,OF,T1,T2,N,R,O,P,OPTION,IGEOM,ISAB
      REAL INSNFS,MASS
      CALL INPUT(NONUCL,NOEGPS,NOFAS,NG,NF)
      CALL ARAYIN(BFLUX,ZNAM1,IOND,MASS,STAFS,GP,NOEGPS,NONUCL,NOFAS,NG,
     +TMASS,ZNAM2)
      IF(OPTION.EQ.0.000000) GO TO 1
      AVEAFS=OPTION
      WRITE(6,20)
   20 FORMAT(1H1,48H*THE FOLLOWING DATA HAVE BEEN ENTERED INTO MEMORY.*,
     +49H **********************************************,//)
      GO TO 2
    1 CALL SOURCE(AVEAFS)
    2 CALL GAFLUX(AVEAFS,NOEGPS,GPFLUX,BFLUX)
      CALL WTFLUX(BFLUX,GP,CONST,FCONST,NOEGPS,NF,NG)
      CALL ACTVAT(TIMACT,SYSACT,SUMACT,GPFLUX,PRODNU,PRODHL,GPXSEC,IONC,
```

```
     +MASS,STAFS,GP,CONST,FCONST,BFLUX,NONUCL,NOEGPS,NOFAS,NG,NF)
      CALL  DOSRTE (TIMACT,PFDONU,NONUCL,NOPAS,DOSSUM,SYSDOS,IOND,STAFS,PR
     +ODHL,DOSNUC,TMASS,DOSDGT,DOSPRO)
      STOP
      END
```

1111111111.1111111111.1111111111.1111111111.1111111111.1111111111.1111111111.1111111111
9999999999.9999999999.9999999999.9999999999.9999999999.9999999999.9999999999.9999999999

```
      SUBROUTINE INPUT(NONUCL,NOEGPS,NOPAS,NG,NF)
C
C
CTHIS PROGRAM IS USED FOR ENTERING "VARIABLE" DATA INTO MEMORY
C
C
C     ARGUMENTS IN-NONE
C     ARGUMENTS OUT-NONUCL,NOEGPS,NOPAS,NG,NF
C
C
      COMMON A,V,F,DF,T1,T2,N,R,D,H,OPTION,IGEOM,ISAB
      READ(5,61) OPTION
   61 FORMAT(E14.7)
      IF(OPTION.NE.0.00000000E+00) GO TO 62
      READ(5,1) A,V,F,DF,T1,T2,N
    1 FORMAT(6(E10.3,2X),I3)
    3 READ(5,2) NOEGPS
    2 FORMAT(I2)
      READ(5,2) NOPAS
      READ(5,5)R,D,H,IGEOM,ISAB
    5 FORMAT(3(E10.3,2X),2(I1))
      READ(5,2) NONUCL
      READ(5,2) NF
      GO TO 19
   62 READ(5,63) T1,T2,N
   63 FORMAT(2(E10.3,2X),I3)
      GO TO 3
   19 WRITE(6,20)
   20 FORMAT(1H1 ,48HTHE FOLLOWING DATA HAVE BEEN ENTERED INTO MEMORY,/.
     +49H **********************************************,//)
      WRITE(6,21)
   21 FORMAT(1HO,85HAMPERES    KILO-VOLTS      BEAMFRACTION          OUTYFA
     +CTOR          T1          T2          N)
      IF(OPTION.EQ.0.00000001) WRITE(6,13) A,V,F,DF,T1,T2,N
   13 FORMAT(1HO,E8.3,4X,E8.3,8X,E8.3,11X,E8.3,6X,E8.3,3X,E8.3,3X,I3,///
     +)
      IF(OPTION.NE.0.00000001) WRITE(6,65) T1,T2,N
   65 FORMAT(1HO,55H********    ********    ********          *****
     +****,6X,2(E8.3,3X),I3,///)
      WRITE(6,22) NOEGPS
   22 FORMAT(1H ,39HNUMBER OF ENERGY GROUPS-NOEGPS          ,I2,/)
      WRITE(6,75) NONUCL
   75 FORMAT(1H ,39HNUMBER OF TARGET NUCLIDES-NONUCL        ,I2,/)
      WRITE(6,23) NOPAS
   23 FORMAT(1H ,39HNUMBER OF POINTS AFTER SHUTDOWN-NOPAS   ,I2,/)
      WRITE(6,89)ISAB,IGEOM
   89 FORMAT(1X,5HISAB=,I1,//,7H IGEOM=,I1,/)
      IF(ISAB.EQ.0)WRITE(6,83)
   83 FORMAT(1X,36HYOU ARE USING A NON-ABSORBING SOURCE,/)
      IF(ISAB.EQ.1)WRITE(6,84)
   84 FORMAT(1X,33HYOU ARE USING AN ABSORBING SOURCE,/)
      IF(IGEOM.EQ.1)WRITE(6,85)D
   85 FORMAT(1X,28HTHE SOURCE IS A POINT-SOURCE,/,42H THE OBSERVER IS ST
     +ANDING AT A DISTANCE D=,E10.3,23H METERS FROM THE SOURCE,/)
      IF(IGEOM.EQ.2)WRITE(6,86)R,D
   86 FORMAT(1X,23HTHIS SOURCE IS A SPHERE,/,17H ITS RADIUS IS R=,E10.3,
     +7H METERS,/,42H THE OBSERVER IS STANDING AT A DISTANCE D=,E10.3,39
     +H METERS FROM THE SURFACE OF THIS SPHERE./)
      IF(IGEOM.EQ.3)WRITE(6,87)R,H,D
   87 FORMAT(1X,25HTHIS SOURCE IS A CYLINDER,/,17H ITS RADIUS IS R=,E10.
     +3,7H METERS,/,17H ITS HEIGHT IS H=,E10.3,7H METERS,/,45H THE OBSER
     +VER FACES THE AXIS AT A DISTANCE D=,E10.3,7H METERS,/)
```

```
      IF(IGEOM.EQ.4)WRITE(6,99)R,H
   88 FORMAT(1X,33HTHIS SOURCE IS A SPHERICAL CAVITY,/,17H ITS RADIUS IS
     + R=,E10.3,7H METERS,/,16H ITS WIDTH IS H=,E10.3,7H METERS,/,44H TH
     +E OBSERVER IS AT THE CENTER OF THE CAVITY,/)
      NG=NOEGPS+1
      WRITE(6,72) NG
   72 FORMAT(1H ,39HNUMBER OF GROUPS BOUNDARIES-NG          ,I2,/)
      WRITE(6,76) NF
   76 FORMAT(1H ,39HNUMBER OF FAST NEUTRON GROUPS-NF        ,I2,/)
      IF(OPTION.NE.0.0000000) WRITE(6,66) OPTION
   66 FORMAT(1H ,46HAVERAGE NUMBER OF NEUTRONS PRODUCED PER SECOND,4X,E1
     +0.4,/)
      IF(OPTION.NE.0.000000E+00)GO TO 64
      IF(A.LE.0.0) GO TO 36
      IF(V.LT.36.0.OR.V.GT.300.0) GO TO 37
      IF(F.LE.0.0.OR.F.GT.1.0) GO TO 38
      IF(DF.LE.0.0.OR.DF.GT.1.0) GO TO 39
   64 IF(T1.LE.0.0) GO TO 40
      IF(T2.LT.0.0) GO TO 41
      DO 42 K=1,999
      IF(N.EQ.K) GO TO 430
   42 CONTINUE
      GO TO 44
  430 DO 45 K=1,50
      IF(NOEGPS.EQ.K) GO TO 460
   45 CONTINUE
      GO TO 9
  460 DO 47 K=1,12
      IF(NOPAS.EQ.K) GO TO 480
   47 CONTINUE
      GO TO 10
  480 IF(IGEOM.EQ.1)GO TO 80
      IF(IGEOM.EQ.2)GO TO 82
      IF(IGEOM.EQ.3)GO TO 83
      IF(IGEOM.EQ.4)GO TO 80
      GO TO 67
   80 IF(ISAB.EQ.0)GO TO 70
      IF(ISAB.EQ.1)GO TO 70
      GO TO 81
   70 IF(R.LT.0.0.OR.D.LT.0.0) GO TO 49
      IF(W.LT.0.0) GO TO 77
      DO 50 K=1,30
      IF(NONUCC.EQ.K) GO TO 510
   50 CONTINUE
      GO TO 11
    9 WRITE(6,12)
   12 FORMAT(1H ,41HPROGRAM "ACDOS" ABORTED-NUMBER OF ENERGY GROUPS MUS
     +T BE INTEGER AND LESS THAN OR EQUAL TO 50-RECHECK THIS DATA)
      STOP
   10 WRITE(6,14)
   14 FORMAT(1H ,41HPROGRAM "ACDOS" ABORTED-NUMBER OF POINTS AFTER SHUT
     +DOWN MUST BE INTEGER AND LESS THAN OR EQUAL TO 12-RECHECK THIS DAT
     +A)
      STOP
   11 WRITE(6,17)
   17 FORMAT(1H ,9HPROGRAM "ACIOS" ABORTED-NUMBER OF NUCLIDES IN SYSTEM
     +MUST BE INTEGER AND LESS THAN OR EQUAL TO 30)
      STOP
   36 WRITE(6,52)
   52 FORMAT(1H ,39HPROGRAM "ACIOS" ABORTED-CURRENT MUST BE GREATER THAN
     + 0 AMPERES-RECHECK THIS DATA)
      STOP
```

```
   37 WRITE(6,53)
   53 FORMAT(1H ,89HPROGRAM "ACCDS" ABORTED-VOLTAGE MUST BE BETWEEN 38 A
     +ND 300 KV INCLUSIVE-RECHECK THIS DATA)
      STOP
   38 WRITE(6,54)
   54 FORMAT(1H ,107HPROGRAM "ACDDS" ABORTED-BEAMFRACTION MUST BE GREATE
     +R THAN 0 AND LESS THAN OR EQUAL TO 1.0-RECHECK THIS DATA)
      STOP
   39 WRITE(6,55)
   55 FORMAT(1H ,107HPROGRAM "ACDDS" ABORTED-DUTYFACTOR MUST BE GREATER
     +THAN 0.0 AND LESS THAN OR EQUAL TO 1.0-RECHECK THIS DATA)
      STOP
   48 WRITE(6,56)
   56 FORMAT(1H ,78HPROGRAM "ACCDS" ABORTED-PULSE LENGTH MUST BE GREATER
     +THAN 0.0-RECHECK THIS DATA)
      STOP
   41 WRITE(6,57)
   57 FORMAT(1H ,98HPROGRAM "ACCDS" ABORTED-PAUSE LENGTH MUST BE GREATER
     +THAN OR EQUAL TO 0.0-RECHECK THIS DATA)
      STOP
   44 WRITE(6,58)
   58 FORMAT(1H ,104HPROGRAM "ACDDS" ABORTED-NUMBER OF PULSES MUST BE IN
     +TEGER AND LESS THAN OR EQUAL TO 999-RECHECK THIS DATA)
      STOP
   49 WRITE(6,60)
   60 FORMAT(1H ,104HPROGRAM "ACDDS" ABORTED-R MUST BE GREATER THAN OR
     +EQUAL TO 0.0 AND D GREATER THAN 0.0-RECHECK THIS DATA)
      STOP
   77 WRITE(6,78)
   78 FORMAT(1H ,80HPROGRAM "ACCDS" ABORTED-H MUST BE GREATER THAN OR EQ
     +UAL TO 0.0-RECHECK THIS DATA)
      STOP
   67 WRITE(6,68)
   68 FORMAT(1H ,66HPROGRAM "ACDDS" ABORTED-IGEOM MUST BE 1,2,3,OR 4-RECH
     +ECK THIS DATA)
      STOP
   81 WRITE(6,82)
   82 FORMAT(1H ,61HPROGRAM "ACCDS" ABORTED-ISAB MUST BE 0,OR 1-RECHECK
     +THIS DATA)
      STOP
  510 RETURN
      END
```

```
      SUBROUTINE ARRAYIN(BFLUX,ZNAM1,IDNO,MASS,STAFS,GP,NOEGPS,NONUCL,NOP
     *AS,NG,TMASS,ZNAM2)
C
C
CTHIS PROGRAM IS USED FOR ENTERING "ARRAY" DATA INTO MEMORY
C
C
C     ARGUMENTS IN-STAFS,NOEGPS,NONUCL,NOPAS,NG
C     ARGUMENTS OUT-BFLUX,ZNAME,IDNO,MASS,GP
C
C
      DIMENSION BFLUX(NOEGPS),ZNAM1(NONUCL),IDNO(NONUCL),MASS(NONUCL),ST
     *AFS(NOPAS),GP(NG),ZNAM2(NONUCL)
      REAL MASS,KWALL
      COMMON A,V,F,DF,T1,T2,A,B,C,H,OPTION,IGEOM,ISAE
      READ(5,4)(STAFS(I),I=1,NOPAS)
    4 FORMAT(6(E10.3,2X))
      DO 7 I=1,NONUCL
      READ(5,8) ZNAM1(I),ZNAM2(I),IDNO(I),MASS(I)
    8 FORMAT(2A10,2X,I5,1X,E10.3)
    7 CONTINUE
      READ(5,4)(GP(I),I=1,NG)
      DO 80 I=1,NONUCL-1
      IDMIN=IDNO(I)
      IMIN=I
      DO 90 J=I+1,NONUCL
      IF (IDMIN.LE.IDNO(J))GO TO 90
      IDMIN=IDNO(J)
      IMIN=J
   90 CONTINUE
      IF (I.EQ.IMIN) GO TO 80
      IDTEMP=IDNO(I)
      IDNO(I)=IDNO(IMIN)
      IDNO(IMIN)=IDTEMP
      TEMPM=MASS(I)
      MASS(I)=MASS(IMIN)
      MASS(IMIN)=TEMPM
      Z1TEMP=ZNAM1(I)
      ZNAM1(I)=ZNAM1(IMIN)
      ZNAM1(IMIN)=Z1TEMP
      Z2TEMP=ZNAM2(I)
      ZNAM2(I)=ZNAM2(IMIN)
      ZNAM2(IMIN)=Z2TEMP
   80  CONTINUE
      WRITE(6,84)
   84 FORMAT(/,1H ,33HSPECIFIC TIMES AFTER SHUTDOWN (H),/)
      DO 34 I=1,NOPAS
      WRITE(6,35) I,STAFS(I)
   35 FORMAT(1H ,4HTIME,1X,I2,1H=,E10.3)
   34 CONTINUE
      READ(5,10)IFLUX,IWALL,KWALL
   10 FORMAT(2(I2,1X),E10.3)
      WRITE(6,11)IFLUX
   11 FORMAT(/,28H OPTION ON THE FLUXES-IFLUX=,I2)
      IF(IFLUX.EQ.0)WRITE(6,12)
   12 FORMAT(39H THE FLUXES WILL BE READ FROM THE INPUT)
      IF(IFLUX.EQ.1)WRITE(6,13)
   13 FORMAT(36H THE FLUXES WILL BE READ FROM TAPE 8)
```

```
      IF((IFLUX.NE.1).AND.(IFLUX.NE.2))GO TO 40
      WRITE(6,14)IWALL
   14 FORMAT(/,49H OPTION ON THE PART OF THE ROOM WHERE ACTIVATION,/,19H
     + TAKES PLACE-IWALL=,I2)
      IF(IWALL.EQ.0)WRITE(6,15)
   15 FORMAT(17H ACTIVATION OF AN OBJECT PLACED INSIDE THE ROOM)
      IF(IWALL.EQ.1)WRITE(6,16)
   16 FORMAT(36H ACTIVATION OF THE WALLS OF THE ROOM)
      IF((IWALL.NE.0).AND.(IWALL.NE.1))GO TO 41
      GO TO(17,18)(IFLUX+1)
   17 READ(5,4)(BFLUX(I),I=1,NDEGPS)
      GO TO 19
   18 READ(8,4)(BFLUX(I),I=1,NDEGPS)
   19 GO TO(20,21)(IWALL+1)
   21 RK=R*KWALL*100.
      DK=D*KWALL*100.
      FF=3*RK*(1-((RK+DK)/SINH(DK))+RK/TANH(DK))/((RK+DK)**3-RK**3)
      DO 22 I=1,NDEGPS
      BFLUX(I)=FF*BFLUX(I)
   22 CONTINUE
      WRITE(6,23)KWALL
   23 FORMAT(///,52H AVERAGE UNIT NORMALIZED FLUXES IN THE WALLS (KWALL=
     +,E10.3,1H),/)
      GO TO 24
   20 WRITE(6,27)
   27 FORMAT(///,39H UNIT NORMALIZED FLUXES INSIDE THE ROOM,/)
   24 DO 32 I=1,NDEGPS
      II=NDEGPS+1-I
      WRITE(6,28)I,BFLUX(II)
   28 FORMAT(6H GROUP,1X,I2,1GX,E11.4)
   32 CONTINUE
      WRITE(6,73)
   73 FORMAT(///,1H ,22HGROUP BOUNDARIES (MEV),/)
      WRITE(6,74)(I,GP(NG+1-I),I=1,NG)
   74 FORMAT(1H ,8HBOUNDARY,1X,I3,5X,E11.4)
      WRITE(6,29)
   29 FORMAT(1H ,///,1H ,10X,4HNAME,10X,9HID-NUMBER,4X,8HMASS(KG),/)
      DO 30 I=1,NONUCL
      WRITE(6,31) ZNAM1(I),ZNAM2(I),IDNO(I),MASS(I)
   31 FORMAT(1X,2A10,5X,I5,5X,E8.3)
   30 CONTINUE
      TMASS=0.
      DO 50 I=1,NONUCL
      TMASS=TMASS+MASS(I)
   50 CONTINUE
      WRITE(6,25)
   25 FORMAT(///,55X,25H*ACDOS IS NOW READY TO RUN,/,55X,25H**************
     +**********)
      GO TO 26
   40 WRITE(6,42)
   42 FORMAT(///,63H PROGRAM *ACDOS* ABORTED-IFLUX MUST BE 0 OR 1-RECHECK
     + THIS DATA)
      STOP
   41 WRITE(6,43)
   43 FORMAT(///,63H PROGRAM *ACDOS* ABORTED-IWALL MUST BE 0 OR 1-RECHECK
     + THIS DATA)
      STOP
   26 RETURN
      END
```

```
      SUBROUTINE SOURCE(AVENPS)
C
C
CTHIS PROGRAM CALCULATES THE SOURCE NEUTRON PRODUCTION RATE
C
C
C     ARGUMENTS IN=NONE
C     ARGUMENTS OUT=AVENPS
C
C
      REAL INSNPS
      COMMON A,V,F,DF,T1,T2,N,P,C,H,OPTION,IGEOM,ISAE
      IF(V.GE.30.0.AND.V.LE.50.0) GO TO 3
      IF(V.GT.60.0.AND.V.LE.150.0) GO TO 4
      IF(V.GT.160.0.AND.V.LE.300.0) GO TO 5
    3 CF=(3.25917*V**2.83194)/38.5
      GO TO 7
    4 CF=(1.51725*V**2.45306)/38.5
      GO TO 7
    5 CF=(6.6-661*V**2.14132)/38.5
    7 INSNPS=(9.6%E+4)*(4)*(1.0E+6)*F*(DF*1.0E-4)
      AVENPS = INSNPS*DF
      WRITE(6,8)
    8 FORMAT(1H1,1H ,43HTHE FOLLOWING HAS BEEN CALCULATED BY ACODS2,,44H
     + **********,//)
      WRITE(6,1) INSNPS
    1 FORMAT(//,1H ,52HINSTANTANEOUS NUMBER OF NEUTRONS PRODUCED PER SEC
     +OND,4X,E11.4)
      WRITE(6,2) AVENPS
    2 FORMAT(/,1H ,46HAVERAGE NUMBER OF NEUTRONS PRODUCED PER SECOND,4X,
     +E11.4)
      RETURN
      END
```

```
      SUBROUTINE GPFLUX(AVENPS,NOEGPS,GPFLUX,BFLUX)
C
C
CTHIS PROGRAM CALCULATES UP TO 50 GROUP FLUXES
C
C
C     ARGUMENTS IN-AVENPS,NOEGPS,BFLUX
C     ARGUMENTS OUT-GPFLUX
C
C
      DIMENSION GPFLUX(NOEGPS),BFLUX(NOEGPS)
      DO 1 I = 1,NOEGPS
      GPFLUX(I) = BFLUX(I)*AVENPS
    1 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE WTFLUX(BFLUX,GP,CONST,FCONST,NOEGPS,NF,NG)
C
CTHIS PROGRAM DETERMINES THE CONSTANTS ASSOCIATED WITH THE ASSUMED
CWEIGHTING FUNCTIONS
C
C
C
C     ARGUMENTS IN-BFLUX,GP,NOEGPS,NF,NG
C     ARGUMENTS OUT-CONST,FCONST
C
C
      DIMENSION BFLUX(NOEGPS),GP(NG),CONST(NOEGPS),FCONST(NOEGPS)
      DO 106 JC=1,NG
      GP(JC)=GP(JC)*1.000E6
  106 CONTINUE
CCALCULATE THE THERMAL GROUP CONSTANT
      ICOUNT=1
      SUMINT=0.0
      WIDTH=(GP(2)-GP(1))/200.0
      ZINCR=WIDTH/2.0
      DPVAR=GP(1)+ZINCR
      DO 1 I=1,200
      PARSUM=SQRT(DPVAR)*EXP(-(DPVAR/0.025))*WIDTH
      SUMINT=SUMINT+PARSUM
      DPVAR=DPVAR+WIDTH
    1 CONTINUE
      CONST(ICOUNT)=BFLUX(ICOUNT)/SUMINT
      IF(NOEGPS.EQ.1) GO TO 1000
      IF(NOEGPS.EQ.2) GO TO 100
CCALCULATE THE 1/E GROUP CONSTANT(S)
      ICOUNT=ICOUNT+1
      IEPTH=0
    2 SUMINT=0.0
      WIDTH=(GP(ICOUNT+1)-GP(ICOUNT))/200.0
      ZINCR=WIDTH/2.0
      DPVAR=GP(ICOUNT)+ZINCR
      DO 3 I=1,200
      PARSUM=(1.0/DPVAR)*WIDTH
      SUMINT=SUMINT+PARSUM
      DPVAR=DPVAR+WIDTH
    3 CONTINUE
      CONST(ICOUNT)=BFLUX(ICOUNT)/SUMINT
      IEPTH=IEPTH+1
      NEPTH=NOEGPS-1-NF
      IF(IEPTH.EQ.NEPTH) GO TO 150
      ICOUNT=ICOUNT+1
      GO TO 2
  100 ICOUNT=ICOUNT+1
CTHE 1 GROUP FAST SPECTRUM WILL BE MATCHED TO THE MAXWELLIAN AT THE
CGROUP BOUNDARY
      FLUXBD=CONST(1)*SQRT(GP(2))*EXP(-(GP(2)/0.025))
      ZNUMER=GUESSI=BFLUX(NOEGPS)/FLUXBD
      ITER=1
    6 FXSLBI=ZNUMER/(EXP((GP(3)-GP(2))/GUESSI)-1)-GUESSI
      XSUBI=GUESSI
      FPRIME=ZNUMER*(GP(3)-GP(2))*EXP((GP(3)-GP(2))/GUESSI)/(GUESSI**2*(
     +EXP((GP(3)-GP(2))/GUESSI)-1)**2)-1
      XSUBI1=XSUBI-FXSLBI/FPRIME
```

```
      DIFF=ABS(XSBIP1-GUESSI)
      IF(DIFF.LT.0.1) GO TO 5
      ITER=ITER+1
      IF(ITER.GT.100) GO TO 75
      GUESSI=XSBIP1
      GO TO 6
   75 WRITE(6,76)
   76 FORMAT(1H ,114H****PROGRAM ABORTED****THE TRANSCENDENTAL EQUATION
     *USED TO MATCH THE THERMAL GROUP TO FAST GROUP IS NOT CONVERGING)
      WRITE(6,27)
      STOP
    5 B=XSBIP1
      A=BFLUX(NDEGPS)/(B*(1-EXP((GP(2)-GP(3))/B)))
      CONST(ICOUNT)=A
      FCONST(ICOUNT)=B
      GO TO 1000
  150 IF(NF.GT.2) GO TO 160
CTHE 1 GROUP FAST SPECTRUM WILL BE MATCHED TO THE LAST 1/E GROUP
      ITER=1
      NGP1=NDEGPS+1
      ZNUMER=GUESSI-(BFLUX(NDEGPS)*GP(NDEGPS)/CONST(ICOUNT))
   91 FXSLBI=ZNUMER/(EXP((GP(NGP1)-GP(NDEGPS))/GUESSI)-1)-GUESSI
      XSUBI=GUESSI
      FPRIME=ZNUMER*(GP(NGP1)-GP(NDEGPS))*EXP((GP(NGP1)-GP(NDEGPS))/GUES
     *SI)/(GUESSI**2*(EXP((GP(NGP1)-GP(NDEGPS))/GUESSI)-1)**2)-1
      XSBIP1=XSUBI-FXSLBI/FPRIME
      DIFF=ABS(XSBIP1-GUESSI)
      IF(DIFF.LT.0.1) GO TO 92
      ITER=ITER+1
      IF(ITER.GT.100) GO TO 25
      GUESSI=XSBIP1
      GO TO 91
   92 B=XSBIP1
      A=BFLUX(NDEGPS)/(B*(1-EXP((GP(NDEGPS)-GP(NGP1))/B)))
      CONST(NDEGPS)=A
      FCONST(NDEGPS)=B
      GO TO 1000
  160 ICP1=ICOUNT+1
CTHE FIRST OF 2 OR MORE FAST GROUPS WILL BE MATCHED TO THE LAST 1/E
CGROUP
      ICP2=ICOUNT+2
      ITER=1
      ZNUMER=GUESSI-(BFLUX(ICP1)*GP(ICP1)/CONST(ICOUNT))
   20 FXSLBI=ZNUMER/(EXP((GP(ICP2)-GP(ICP1))/GUESSI)-1)-GUESSI
      XSUBI=GUESSI
      FPRIME=ZNUMER*(GP(ICP2)-GP(ICP1))*EXP((GP(ICP2)-GP(ICP1))/GUESSI)/
     *(GUESSI**2*(EXP((GP(ICP2)-GP(ICP1))/GUESSI)-1)**2)-1
      XSBIP1=XSUBI-FXSLBI/FPRIME
      DIFF=ABS(XSBIP1-GUESSI)
      IF(DIFF.LT.0.1) GO TO 30
      ITER=ITER+1
      IF(ITER.GT.100) GO TO 25
      GUESSI=XSBIP1
      GO TO 20
   25 WRITE(6,26)
   26 FORMAT(1H ,116H****PROGRAM ABORTED****THE TRANSCENDENTAL EQUATIONS
     *WHICH MATCH 1/E TO FAST OR FAST TO FAST GROUPS ARE NOT CONVERGING)
      WRITE(6,27)
   27 FORMAT(1H ,75HMOST LIKELY PROBLEM IS UNREALISTIC OR UNUSUAL FLUX
     *AND GROUP BOUNDARY DATA)
      STOP
   30 B=XSBIP1
```

```
      A=BFLUX(ICP1)/(B*(1-EXP((GP(ICP1)-GP(ICP2))/B)))
      ICOUNT=ICOUNT+1
      ICP1=ICOUNT+1
      ICP2=ICOUNT+2
      CONST(ICOUNT)=A
      FCONST(ICOUNT)=B
      IF(ICOUNT.EQ.NOEGPS) GO TO 1000
      ZNUMER=BFLUX(ICP1)/CONST(ICOUNT)
      ITER=1
      GO TO 25
 1000 WRITE(6,11)
   11 FORMAT(//,1H ,63H      INTEGRALS OF THE FITTING FUNCTION OVER THE G
     *ROUP INTERVALS)
      WRITE(6,12)
   12 FORMAT(1H ,74HGROUP  LOWER BOUNDARY UPPER BOUNDARY REQUIRED INTEGR
     *AL CALCULATED INTEGRAL,/)
CCALCULATE THE THERMAL INTEGRAL
      ICOUNT=1
      SUMINT=0.0
      WIDTH=(GP(2)-GP(1))/200.0
      ZINCR=WIDTH/2.0
      DPVAR=GP(1)+ZINCR
      DO 21 I=1,200
      PARSUM=CONST(1)*SQRT(DPVAR)*EXP(-(DPVAR/0.025))*WIDTH
      SUMINT=SUMINT+PARSUM
      DPVAR=DPVAR+WIDTH
   21 CONTINUE
      IF(ICOUNT.EQ.NOEGPS) GO TO 109
      IF(ICOUNT.EQ.2) GO TO 46
      JJ=NG-ICOUNT
      WRITE(6,22) JJ,GP(ICOUNT),GP(ICOUNT+1),BFLUX(ICOUNT),SUMINT
   22 FORMAT(1H ,2X,I2,5X,E10.3,4X,E10.3,5X,E10.3,9X,E10.3)
      ICOUNT=ICOUNT+1
CCALCULATE THE 1/E INTEGRAL(S)
   45 SUMINT=0.0
      WIDTH=(GP(ICOUNT+1)-GP(ICOUNT))/200.0
      ZINCR=WIDTH/2.0
      DPVAR=GP(ICOUNT)+ZINCR
      DO 23 I=1,200
      PARSUM=(CONST(ICOUNT)/DPVAR)*WIDTH
      SUMINT=SUMINT+PARSUM
      DPVAR=DPVAR+WIDTH
   23 CONTINUE
      JJ=NG-ICOUNT
      WRITE(6,22) JJ,GP(ICOUNT),GP(ICOUNT+1),BFLUX(ICOUNT),SUMINT
      ICOUNT=ICOUNT+1
      IF(ICOUNT.LE.NEPTH+1) GO TO 45
      GO TO 16
   46 JJ=2
      WRITE(6,22) JJ,GP(ICOUNT),GP(ICOUNT+1),BFLUX(ICOUNT),SUMINT
      IF(NG.EQ.2) ICOUNT=ICOUNT+1
   16 SUMINT=0.0
CCALCULATE THE FAST INTEGRAL(S)
      WIDTH=(GP(ICOUNT+1)-GP(ICOUNT))/200.0
      ZINCR=WIDTH/2.0
      DPVAR=GP(ICOUNT)+ZINCR
      DO 24 I=1,200
      PARSUM=CONST(ICOUNT)*EXP((DPVAR-GP(ICOUNT+1))/FCONST(ICOUNT))*WIDT
     *H
      SUMINT=SUMINT+PARSUM
      DPVAR=DPVAR+WIDTH
   24 CONTINUE
```

```
      JJ=NG-ICOUNT
      WRITE(6,22) JJ,GP(ICOUNT),GP(ICOUNT+1),BFLUX(ICOUNT),SUMINT
      ICOUNT=ICOUNT+1
      IF(ICOUNT.LE.NCEGPS) GO TO 16
      GO TO 15
  109 JJ=1
      WRITE(6,22) JJ,GP(ICOUNT),GP(ICOUNT+1),BFLUX(ICOUNT),SUMINT
   15 DO 105 JC=1,NG
      GP(JC)=GP(JC)/1.0D5E6
  105 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ACTVAT(TIMACT,SYSACT,SUMACT,GPFLUX,PRODNU,PRODML,GPXSEC
     +,IDNO,MASS,STAFS,GP,CONST,FCONST,BFLUX,NONUCL,NDEGPS,NOPAS,NG,NF)
C
C
CTHIS PROGRAM CALCULATES ACTIVITIES DUE TO NEUTRON INDUCED REACTIONS
C
C
C     ARGUMENTS IN=GPFLUX,GPXSEC,IDNO,MASS,STAFS,GP,CONST,FCONST,BFLUX
C     ARGUMENTS IN=NONUCL,NDEGPS,NOPAS,NG,NF
C     ARGUMENTS OUT=TIMACT,SYSACT,PRODNU,PRODML
C
C
      DIMENSION IDNO(NONUCL),MASS(NONUCL),STAFS(NOPAS)
      DIMENSION TIMACT(NONUCL,13,NOPAS),SYSACT(NOPAS),SUMACT(NOPAS),GPFL
     +UX(NDEGPS),PRODNL(NONUCL,13),PRODML(NONUCL,13),GP(NG),GPXSEC(NDEGP
     +S),CONST(NDEGPS),FCONST(NDEGPS),BFLUX(NDEGPS)
      COMMON A,V,F,DF,T1,T2,N,P,E,M,OPTION,IGEOM,ISAE
      REAL MASS
      WRITE(6,102)
  102 FORMAT(///,1H ,57HTHE FOLLOWING OUTPUT DATA ARE CALCULATED ACTIVIT
     +IES IN BQ)
      I=1
      J=0
CINITIALIZE FLAGS AND ARRAYS
      DO 40 M=1,NONUCL
      DO 40 MM=1,13
      PRODML(M,MM)=0.000000E+00
      PRODNU(M,MM)=0.000000E+00
   40 CONTINUE
      DO 41 M=1,NONUCL
      DO 41 MM=1,13
      DO 41 MMM=1,NOPAS
      TIMACT(M,MM,MMM)=.0000E+00
   41 CONTINUE
      DO 22 JN=1,NOPAS
      SYSACT(JN)=SUMACT(JN)=0.0
   22 CONTINUE
      KFLAG=LFLAG=0
CPRINT HEADINGS
      WRITE(6,37)(STAFS(K),K=1,NOPAS)
   37 FORMAT(/,1H ,4X,7HTIME(H),4X,13(E8.3,1X),2X,2(E9.3,2X))
      WRITE(6,1)
    1 FORMAT(1H ,125HTARGET PRODUCT  ACT(T1)  ACT(T2)  ACT(T3)  ACT(T4)
     + ACT(T5)  ACT(T6)  ACT(T7)  ACT(T8)  ACT(T9)  ACT(T10)  ACT(T11)
     +ACT(T12))
    2 READ(7,25) ITAPE,TARMAS
   25 FORMAT(I6,7X,E11.4)
      IF(ITAPE.EQ.IDNO(I)) GO TO 7
      IF(ITAPE.GT.IDNO(I)) GO TO 44
      CALL POSITN
      GO TO 2
CTHE ABOVE STATEMENTS SEARCH THE TAPE FOR A MATCHING TARGET ID NUMBER
   44 WRITE(6,45) IDNO(I)
   45 FORMAT(///,32H ATTENTION-TARGET NUCLIDE NUMBER,I6,29H DOES NOT EXI
     +ST IN DATA LIBRARY-THEREFORE-NO CONTRIBUTION FROM THIS NUCLIDE IN
     +DOSE CALS,///)
      IF(ITAPE.EQ.IDNO(I+1)) GO TO 46
      I=I+1
```

```
      CALL POSITON
CPRINT HEADINGS
      WRITE(6,37)(STAFS(K),K=1,NOPAS)
      WRITE(6,1)
      GO TO 24
   46 I=I+1
CPRINT HEADINGS
      WRITE(6,37)(STAFS(K),K=1,NOPAS)
      WRITE(6,1)
    7 J=J+1
      READ(7,8) PRODNU(I,J),PRODML(I,J)
      READ(7,99) NP
      IF(ITAPE.EQ.IDNC(NONUCL)) LFLAG=1
   99 FORMAT(I3)
      IF(PRODML(I,J).GT.0.1000E+50) GO TO 50
    8 FORMAT (20X,E12.4,12X,E12.4)
      CALL AVERAGE(GPXSEC,CONST,FCONST,GFLUX,GP,NOEGPS,NG,NF,NP)
      IF(GPXSEC(1).GT.0.500E+49) GO TO 103
      SUM1A=SUM2A=0.0
      DO 11 JL=1,N
      TEMPS=EXP(-((0.693*((N-JL)*((T1*3600.0)+(T2*3600.0))))/PRODML(I,J)
     +))
      SUM1A=SUM1A+TEMPS
   11 CONTINUE
      DO 12 L=1,NOFGPS
      TEMPS=SUM1A*(1.0E-24)*GPXSEC(L)*GPFLUX(L)
      SUM2A=SUM2A+TEMPS
   12 CONTINUE
      ACT=(MASS(I)*1000.0/TARMAS)*6.023E+23*SUM2A*(1-EXP(-0.693*3600.0*T
     +1/PRODML(I,J)))
      DO 13 K=1,NOPAS
      TIMACT(I,J,K)=ACT*EXP(-(STAFS(K)*0.693*3600.0/PRODML(I,J)))
      SUMACT(K)=SUMACT(K)+TIMACT(I,J,K)
   13 CONTINUE
  103 WRITE(6,20) IDNC(I),IFIX(PRODNU(I,J)),(TIMACT(I,J,K),K=1,NOPAS)
   20 FORMAT(1X,I4,I5,2X,I5,2X,10(E8.3,1X),2X,2(E8.3,2X))
      READ(7,25) ITAPE,TARMAS
      IF(EOF(7).NE.0) KFLAG=1
      IF(KFLAG.EQ.1) GO TO 27
      IF(LFLAG.EQ.1.AND.ITAPE.NE.IDNC(NONUCL)) GO TO 27
      IF(ITAPE.EQ.IDNC(NONUCL)) LFLAG=1
      IF(ITAPE.NE.IDNC(I)) GO TO 27
      GO TO 7
CPRINT HEADINGS
   27 WRITE(6,37)(STAFS(K),K=1,NOPAS)
      WRITE(6,14)
   14 FORMAT(1H ,12FH    TARGET      ACT(T1)  ACT(T2)  ACT(T3)  ACT(T4)
     + ACT(T5)  ACT(T6)  ACT(T7)  ACT(T8)  ACT(T9)  ACT(T10)  ACT(T11)
     +ACT(T12))
      WRITE(6,15) IDNC(I),(SUMACT(K),K=1,NOPAS)
   15 FORMAT(1X,5X,I5,5X,10(E8.3,1X),2X,2(E8.3,2X),///)
      DO 10 K=1,NOPAS
      SYSACT(K)=SYSACT(K)+SUMACT(K)
   10 CONTINUE
      IF(ITAPE.EQ.IDNC(I+1)) GO TO 32
      IF(LFLAG.EQ.1) GO TO 16
   32 DO 23 JN=1,NOPAS
      SUMACT(JN)=0.0
   23 CONTINUE
      IF(ITAPE.EQ.IDNC(I+1)) GO TO 31
      IF(ITAPE.GT.IDNC(I+1)) GO TO 47
      I=I+1
```

```
      CALL POSITON
CPRINT HEADINGS
      WRITE(6,37)(STAFS(K),K=1,NOPAS)
      WRITE(6,1)
      J=0
      GO TO 24
   47 WRITE(6,45) IDNO(I+1)
      CALL POSITON
      I=I+2
      IF(ITAPE.GT.IDNO(I)) WRITE(6,45) IDNO(I)
      IF(ITAPE.GT.IDNO(I)) I=I+1
CPRINT HEADINGS
      WRITE(6,37)(STAFS(K),K=1,NOPAS)
      WRITE(6,1)
      J=0
      GO TO 24
CPRINT HEADINGS
   31 WRITE(6,37)(STAFS(K),K=1,NOPAS)
      WRITE(6,1)
      I=I+1
      J=0
      GO TO 7
CPRINT HEADINGS
   16 WRITE(6,544)
  544 FORMAT(//)
      WRITE(6,37)(STAFS(K),K=1,NOPAS)
      WRITE(6,21)
   21 FORMAT(1H ,12SH     SYSTEM       ACT(T1)  ACT(T2)  ACT(T3)  ACT(T4)
     + ACT(T5)  ACT(T6)  ACT(T7)  ACT(T8)  ACT(T9)  ACT(T10)  ACT(T11)
     +ACT(T12))
      WRITE(6,51)(SYSACT(K),K=1,NOPAS)
   51 FORMAT(1X,15Y,10(E9.3,1X),2X,2(E8.3,2X))
      IF(KFLAG.EQ.0) GO TO 42
      RETURN
   42 CALL POSITON
   43 READ(7,25) ITAPE,TAPMAS
      IF(EOF(7).NE.0) RETURN
      CALL POSITON
      GO TO 43
   53 CALL POSIT2(NP)
      GO TO 103
      END
```

```
      SUBROUTINE AVRAGE(GPXSEC,CONST,FCONST,BFLUX,GP,NOEGPS,NG,NF,NP)
C
C
CTHIS PROGRAM CALCULATES FLUX WEIGHTED GROUP CROSS SECTIONS BY AVERAGING
CMICROSCOPIC CROSS SECTION DATA
C
C
C     ARGUMENTS IN-CONST,FCONST,BFLUX,GP,NOEGPS,NG,NF,NP
C     ARGUMENTS    GPXSEC
C
C
      DIMENSION GPXSEC(NOEGPS),CONST(NOEGPS),FCONST(NOEGPS),BFLUX(NOEGPS
     +),GP(NG)
      DIMENSION CS(150),EN(150),CS1(201),E1(201)
CINITIALIZE ARRAY GPXSEC
      DO 41 J=1,NOEGPS
      GPXSEC(J)=0.0
   41 CONTINUE
CLOAD ENERGY AND CROSS SECTION DATA FROM THE ACTINIDE LIBRARY
      READ(7,3)(EN(I),CS(I),I=1,NP)
    3 FORMAT(6(E11.4))
CDETERMINE IF THE ENERGY OF THE FIRST ENERGY-CROSS SECTION PAIR READ
CFROM THE ACTINIDE LIBRARY IS BELOW THE GREATEST GROUP BOUNDARY
      IF(EN(1)-GP(NG)) 105,102,102
  105 CALL SMOOTH(GP,NG,EN,CS,NP,E1,CS1,NE1)
      I=1
      J=1
      SUMINT=0.0
CDETERMINE IF THE ENERGY AT WHICH THE CROSS SECTION WAS MEASURED IS
CBELOW THE NEXT GROUP BOUNDARY
   50 IF(E1(I).LT.GP(J+1)) GO TO 51
      GPXSEC(J)=0.0
      J=J+1
      GO TO 50
   52 IF(E1(I).LT.GP(J+1)) GO TO 51
CCALCULATE THE GROUP CROSS SECTION
      GPXSEC(J)=SUMINT/BFLUX(J)
      IF(J.EQ.NOEGPS) GO TO 106
      J=J+1
      SUMINT=0.0
      GO TO 52
   51 IF(J.EQ.1) GO TO 1000
      IF(NOEGPS.GE.3.AND.J.GT.1.AND.J.LE.(NOEGPS-NF)) GO TO 2000
      GO TO 3000
 1000 SUMDEL=0.0
CAVERAGE MICROSCOPIC CROSS SECTION DATA OVER THERMAL ENERGIES
      WIDTH=(E1(I+1)-E1(I))/200.0
      ZINCR=WIDTH/2.0
      DPVAR=E1(I)+ZINCR
      DO 1001 KK=1,200
      FARSUM=(CONST*(J)*SQRT(DPVAR*1.0E6)*EXP(-(DPVAR*1.0E6/0.025))*((CS1
     +(I+1)-CS1(I))*(DPVAR-E1(I))/(E1(I+1)-E1(I))+CS1(I)))*WIDTH*1.0E6
      SUMDEL=SUMDEL+FARSUM
      DPVAR=DPVAR+WIDTH
 1001 CONTINUE
      SUMINT=SUMINT+SUMDEL
      I=I+1
      GO TO 52
```

```
 2000 SUMDEL=0.0
CAVERAGE MICROSCOPIC CROSS SECTION DATA OVER INTERMEDIATE ENERGIES
      WIDTH=(E1(I+1)-E1(I))/200.0
      ZINCR=WIDTH/2.0
      DPVAR=E1(I)+ZINCR
      DO 2001 KK=1,200
      PARSUM=(CONST(J)/(DPVAR*1.0E6))*WIDTH*1.0E6*((CS1(I+1)-CS1(I))*(DP
     +VAR-E1(I))/(E1(I+1)-E1(I))+CS1(I))
      SUMDEL=SUMDEL+PARSUM
      DPVAR=DPVAR+WIDTH
 2001 CONTINUE
      SUMINT=SUMINT+SUMDEL
      I=I+1
      GO TO 52
 3000 SUMDEL=0.0
CAVERAGE MICROSCOPIC CROSS SECTION DATA OVER FAST ENERGIES
      WIDTH=(E1(I+1)-E1(I))/200.0
      ZINCR=WIDTH/2.0
      DPVAR=E1(I)+ZINCR
      DO 3001 KK=1,200
      PARSUM=CONST(J)*EXP((DPVAR-GP(J+1))*1.0E6/FCONST(J))*WIDTH*1.0E6*(
     +(CS1(I+1)-CS1(I))*(DPVAR-E1(I))/(E1(I+1)-E1(I))+CS1(I))
      SUMDEL=SUMDEL+PARSUM
      DPVAR=DPVAR+WIDTH
 3001 CONTINUE
      SUMINT=SUMINT+SUMDEL
      I=I+1
      GO TO 52
  102 GRPSEC(I)=1.0E+50
  106 READ(7,5) IDUMB
    5 FORMAT(I1X,I1)
      RETURN
      END
```

```
      SUBROUTINE SMOOTH(X1,NX1,X2,Y2,NX2,X3,Y3,NX3)
C
C
CTHIS PROGRAM CALCULATES CROSS SECTIONS AT GROUP BOUNDARIES BY LINEAR
CINTERPOLATION
C
C
C     ARGUMENTS IN-GP,NG,EN,CS,NP
C     ARGUMENTS OUT-E1,CS1,NE1
C
C
      DIMENSION X1(1),Y2(1),Y2(1),X3(1),Y3(1)
      K=1
   12 IF(X2(K)-X1(1)) 20,11,13
   20 K=K+1
      GO TO 12
   11 X3(1)=X2(K)
      Y3(1)=Y2(K)
      K=K+1
      L=2
      I1=2
      GO TO 14
   13 I1=2
      IF(X2(K).LT.X1(I1)) GO TO 11
   24 I1=I1+1
      IF(X2(K).LT.X1(I1)) GO TO 25
      GO TO 24
   25 X3(1)=X2(K)
      Y3(1)=Y2(K)
      K=K+1
      L=2
   14 DO 1 I=I1,NX1
    5 IF(X2(K)-X1(I)) 2,3,4
    2 X3(L)=X2(K)
      Y3(L)=Y2(K)
      L=L+1
      K=K+1
      IF(K-NX2 ) 5,5,10
    3 X3(L)=X2(K)
      Y3(L)=Y2(K)
      L=L+1
      K=K+1
      IF(K-NX2 ) 1,1,10
    4 X3(L)=X1(I)
      Y3(L)=Y3(L-1)+((Y2(K)-Y3(L-1))/(X2(K)-X3(L-1)))*(X3(L)-X3(L-1))
      L=L+1
    1 CONTINUE
   10 NX3=L-1
      RETURN
      END
```

```
      SUBROUTINE ADVAN(NOMODE)
C
C
CTHIS PROGRAM IS USED FOR POSITIONING THE FILE MARKER IN THE LEVDEC
CLIBRARY
C
C
C     ARGUMENTS IN-NOMODE
C     ARGUMENTS OUT-NONE
C
C
      DO 305 JB=1,NOMODE
      READ(7,202) IDUME
  202 FORMAT(36X,I2)
  305 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE POSITON
C
C
CTHIS PROGRAM IS USED FOR POSITIONING THE FILE MARKER IN THE ACTLE MFE
CLIBRARY
C
C
C     ARGUMENTS IN-NONE
C     ARGUMENTS OUT-NONE
C
C
      READ(7,30) NP
   30 FORMAT(/,I3)
      NP1=INT(FLOAT(NP)/3.000+0.800)
      DO 52 ICOUNT=1,NP1
      READ(7,53) REALDUM
   53 FORMAT(E11.4)
   52 CONTINUE
      READ(7,5) IDUMB
    5 FORMAT(71X,I1)
      RETURN
      END
```

```
      SUBROUTINE POSIT2(NP)
C
C
CTHIS PROGRAM IS USED FOR POSITIONING THE FILE MARKER IN THE ACTLEMFE
CLIBRARY
C
C
C     ARGUMENTS IN-NP
C     ARGUMENTS OUT-NONE
C
C
      NP1=INT(FLOAT(NP)/3.000+0.0001
      DO 52 ICOUNT=1,NP1
      READ(7,53) REALDUM
   53 FORMAT(E11.4)
   52 CONTINUE
      READ(7,5) IDUMB
    5 FORMAT(71X,I1)
      RETURN
      END
```

```
      SUBROUTINE DOSRTE(TIMACT,PRODNU,NONUCL,NOPAS,DOSSUM,SYSDOS,IDNO,ST
     +AFS,PRODHL,DOSNUC,TMASS,DOSDGT,DOSPRO)
C
C
CTHIS PROGRAM CALCULATES DOSE RATES AS A FUNCTION OF COMPONENT COMPOSIT-
CION,GEOMETRY,AND TIME AFTER SHUTDOWN
C
C
C
C
      DIMENSION TIMACT(NONUCL,13,NOPAS),PRODNU(NONUCL,13),DOSSUM(NOPAS),
     +SYSDOS(NOPAS),IDNO(NONUCL),STAFS(NOPAS),DOSDGT(NOPAS),DOSPRO(NOPAS
     +)
      DIMENSION PRODHL(NONUCL,13),DOSNUC(NOPAS),DOSDAU(390),DHA(390)
      DIMENSION NT(390),NP(390),AC(390),HA(390),ND(390),DOSPRO(390)
      DIMENSION IDEKH(30),IDAUE(30),DLEVL(30),PRJB(30)
      COMMON A,V,F,DF,T1,T2,N,R,C,H,OPTION,IGEOM,ISAB
      REAL MULT
      WRITE(6,100)
  100 FORMAT(/////,1H ,61HTHE FOLLOWING OUTPUT DATA ARE CALCULATED DOSE
     +RATES IN MREM/HR.//)
      DO 1 M=1,NOPAS
      DOSPRO(M)=0.0
      DOSDGT(M)=0.0
      SYSDOS(M)=0.0
      DOSNUC(M)=0.0
      DOSSUM(M)=0.0
    1 CONTINUE
      DO 101 I=1,390
      NT(I)=0
      NP(I)=0
      ND(I)=0
      AC(I)=0.0
      DOSPRO(I)=0.0
      HA(I)=0.0
      DHA(I)=0.0
      DOSDAU(I)=0.0
  101 CONTINUE
      DO 2 I=1,NONUCL
      DO 2 J=1,13
      K=(I-1)*13+J
      NP(K)=IFIX(PRODNU(I,J))
      HA(K)=PRODHL(I,J)
      AC(K)=TIMACT(I,J,1)
      NT(K)=IDNO(I)
    2 CONTINUE
      NO=NONUCL*13-1
      DO 3 J=1,NO
      NTEMP1=NP(J+1)
      NTEMP2=NT(J+1)
      ZTEMP3=AC(J+1)
      ZTEMP4=HA(J+1)
      DO 4 K=1,J
      I=J+1-K
      IF(NTEMP1.GE.NP(I)) GO TO 5
      NP(I+1)=NP(I)
      NT(I+1)=NT(I)
      AC(I+1)=AC(I)
```

```
        HA(I+1)=HA(I)
      4 CONTINUE
        I=0
      5 NP(I+1)=NTEMP1
        NT(I+1)=NTEMP2
        AC(I+1)=ZTEMP3
        HA(I+1)=ZTEMP4
      3 CONTINUE
        L=1
      7 IF(NP(L).NE.0) GO TO 205
        L=L+1
        GO TO 7
    205 IBASE=L
CBEGIN INTERROGATION OF THE LEVDEC LIBRARY
    200 READ(7,16) ITAPE,HALFLF,NDMODE
     16 FORMAT(I6,20X,E11.4,I3)
        IF(EOF(7).NE.0) GO TO 200
    280 IF(ITAPE.EQ.NP(L)) GO TO 17
        IF(ITAPE.GT.NP(L)) GO TO 28
        CALL ADVAN(NDMODE)
        GO TO 200
     28 IF(AC(L).EQ.0.00)GO TO 38
        WRITE(6,29) NP(L)
     29 FORMAT(/,33H ATTENTION-PRODUCT NUCLIDE NUMBER,I6,90H DOES NOT EXIS
       +T IN DECAY LIBRARY-THEREFORE NO CONTRIBUTION FROM THIS NUCLIDE IN
       +DOSE CALCS)
        WRITE(6,37) NT(L)
     37 FORMAT(1H ,20HTHE TARGET ATOM WAS ,I5,///)
     38 L=L+1
        IF(NP(L).EQ.0) GO TO 813
        GO TO 280
CCHECK TO SEE IF NP(L) EQUALS NP(L+1)
     17 IF(NP(L).EQ.NP(L+1)) GO TO 800
CCOMPARE HALFLIVES
    313 IF(HA(L)/HALFLF.LT.0.8.OR.HA(L)/HALFLF.GT.1.2) GO TO 13
        IF(HALFLF.EQ.1.0E+50.OR.AC(L).EQ.0.0) GO TO 19
        IMODE=0
    302 IMODE=IMODE+1
CBEGIN INTERROGATION OF THE LEVDEC LIBRARY
        READ(7,300) IDEKMO,IDAUGM,DLEVEL,MULT
    300 FORMAT(38X,I2,I7,E11.4,E12.4)
        IF(IDEKMO.EQ.9) AD(L)=IDAUGM
        IF(IDEKMO.EQ.7.OR.IDEKMO.EQ.9) GO TO 301
        IF(IDEKMO.EQ.8) GO TO 310
    303 IF(IMODE.EQ.NDMODE) GO TO 304
        GO TO 302
    301 IF(DLEVEL.EQ.0.0) GO TO 303
        CALL CURVE(DLEVEL,FLUXE)
        CALL CALC(DLEVEL,AC(L),DOSPRO(L),MULT,FLUXE,TMASS)
        GO TO 303
    310 IF(DLEVEL.EQ.0.0) GO TO 311
        CALL CURVE(DLEVEL,FLUXE)
        CALL CALC(DLEVEL,AC(L),DOSPRO(L),MULT,FLUXE,TMASS)
CIN ANY CASE ADD IN THE 0.511 MEV ANNILIHATION GAMMAS
    311 DO 312 IBETA=1,2
        CALL CURVE(0.511,FLUXE)
        CALL CALC(0.511,AC(L),DOSPRO(L),MULT,FLUXE,TMASS)
    312 CONTINUE
        GO TO 303
     13 CALL ADVAN(NDMODE)
CREAD THE NEXT LEVDEC NUCLIDE
     30 READ(7,16) ITAPE,HALFLF,NDMODE
```

```
      IF(EOF(7).NE.0) GO TO 304
      IF(ITAPE.EQ.NP(L)) GO TO 313
      IF(ITAPE.EQ.NP(L+1)) GO TO 21
      IF(NP(L+1).EQ.0) GO TO 813
      L=L+1
      GO TO 286
   21 L=L+1
      GO TO 17
  800 DO 801 IL=1,NDMODE
      READ(7,360) IDEKM(IL),IDAUG(IL),DLEVL(IL),PROB(IL)
  801 CONTINUE
      IBEGIN=L
  802 L=L+1
      IF(NP(L).EQ.NP(L+1)) GO TO 802
      IEND=L
  810 DO 805 IP=IBEGIN,IEND
      IF(MA(IP)/HALFLF.GT.0.0.AND.MA(IP)/HALFLF.LT.1.2.AND.HALFLF.NE.1.0
     *E+50.AND.AC(IP).NE.0.0)GO TO 804
      GO TO 805
  804 DO 820 IL=1,NDMODE
      IF(IDEKM(IL).EQ.9) NO(IP)=IDAUG(IL)
      IF(IDEKM(IL).EQ.7.OR.IDEKM(IL).EQ.9) GO TO 501
      IF(IDEKM(IL).EQ.8) GO TO 510
      GO TO 820
  501 IF(DLEVL(IL).EQ.0.0) GO TO 820
      CALL CURVE(DLEVL(IL),FLUXE)
      CALL CALC(DLEVL(IL),AC(IP),DOSPRD(IP),PROB(IL),FLUXE,TMASS)
      GO TO 820
  510 IF(DLEVL(IL).EQ.0.0) GO TO 511
      CALL CURVE(DLEVL(IL),FLUXE)
      CALL CALC(DLEVL(IL),AC(IP),DOSPRD(IP),PROB(IL),FLUXE,TMASS)
  511 DO 821 IBETA=1,2
      CALL CURVE(0.511,FLUXE)
      CALL CALC(0.511,AC(IP),DOSPRD(IP),PROB(IL),FLUXE,TMASS)
  821 CONTINUE
  820 CONTINUE
  805 CONTINUE
  806 READ(7,16) ITAPE,HALFLF,NDMODE
      IF(EOF(7).NE.0) GO TO 806
      IF(ITAPE.EQ.NP(IBEGIN)) GO TO 808
      GO TO 807
  808 DO 809 IL=1,NDMODE
      READ(7,300) IDEKM(IL),IDAUG(IL),DLEVL(IL),PROB(IL)
  809 CONTINUE
      GO TO 810
  807 IF(ITAPE.EQ.NP(IEND+1)) GO TO 811
      L=IEND+1
      IF(ITAPE.GT.NP(IEND+1)) GO TO 28
      GO TO 290
  811 L=IEND+1
      GO TO 17
  812 WRITE(6,29) NP(L)
      WRITE(6,37) NT(L)
      L=L+1
      IF(ITAPE.GT.NP(L)) GO TO 812
      GO TO 200
  813 REWIND 7
CMOVE THE FILE MARKER THROUGH THE ACTLNFE LIBRARY AND POSITION AT THE
CBEGINNING OF LEVDEC
   49 READ(7,47) ITAPE
   47 FORMAT(I6)
      IF(EOF(7).NE.0) GO TO 700
```

```
      CALL POSITDN
      GO TO 49
  700 ISTOP=L
      L=IBASE
CBEGIN INTERROGATION OF THE LEVDEC LIBRARY FOR POSSIBLE RADIOACTIVE
CDAUGHTERS-READ UNTIL THE ID NUMBER IS MATCHED
  701 IF(ND(L).NE.0) GO TO 702
      L=L+1
      IF(L.EQ.ISTOP+1) GO TO 913
      GO TO 701
  702 READ(7,16) ITAPE,HALFLF,NDMODE
      IF(EOF(7).NE.0) GO TO 702
      IF(ITAPE.EQ.ND(L)) GO TO 703
      IF(ITAPE.GT.ND(L)) GO TO 926
      CALL ADVAN(NDMODE)
      GO TO 702
  926 L=L+1
      IF(L.EQ.ISTOP+1) GO TO 913
      IF(ITAPE.EQ.ND(L)) GO TO 703
      CALL ADVAN(NDMODE)
      GO TO 701
CCHECK THE HALF LIFE OF THE DAUGHTER
  703 DHA(L)=HALFLF
      IF(HALFLF.GT.1.0E+08)GO TO 704
      GO TO 705
  704 CALL ADVAN(NDMODE)
  904 L=L+1
      IF(L.EQ.ISTOP+1) GO TO 913
      GO TO 701
  705 IMODE=0
  902 IMODE=IMODE+1
CBEGIN INTERROGATION OF THE LEVDEC LIBRARY FOR DAUGHTER DECAY INFO
      READ(7,7(7) IDEKMD,DLEVEL,MULT
  707 FORMAT(38X,I2,7X,E11.4,E12.4)
      SUMA1=0.0
      SUMA2=0.0
      DO 60 I=1,N
      SUMA1=SUMA1+EXP(-(N-I)*(T1+T2)*(0.693*3600./HA(L)))
      SUMA2=SUMA2+EXP(-(N-I)*(T1+T2)*(0.693*3600./DHA(L)))
   60  CONTINUE
      ACD=AC(L)*SUMA2*(1.-EXP(-0.693/DHA(L)*EXP(-0.693*3600.*T1/HA(L))-0.693/
     +HA(L)*EXP(-0.693*3600.*T1/DHA(L)))/(0.693/DHA(L)-0.693/HA(L)))/SUM
     +A1/(1.-EXP(-0.693*3600.*T1/HA(L)))
      IF(IDEKMD.EQ.7.OR.IDEKMD.EQ.9) GO TO 901
      IF(IDEKMD.EQ.8) GO TO 910
  903 IF(IMODE.EQ.NDMODE) GO TO 904
      GO TO 902
  901 IF(DLEVEL.EQ.0.0) GO TO 903
      CALL CURVE(DLEVEL,FLUXE)
      CALL CALC(DLEVEL,ACD,DCSCAU(L),MULT,FLUXE,TMASS)
      GO TO 903
  910 IF(DLEVEL.EQ.0.0) GO TO 911
      CALL CURVE(DLEVEL,FLUXE)
      CALL CALC(DLEVEL,ACD,DCSCAU(L),MULT,FLUXE,TMASS)
CIN ANY CASE ACD IN THE 0.511 MEV ANNIHILATION GAMMAS
  911 DO 912 IBETA=1,2
      CALL CURVE(0.511,FLUXE)
      CALL CALC(0.5110,ACD,DCSCAU(L),MULT,FLUXE,TMASS)
  912 CONTINUE
      GO TO 903
  913 REWIND 7
      NO=NONUCL*13
```

```
      DO 815 I=1,NONUCL
      WRITE(6,9)(STAFS(K),K=1,NOPAS)
    9 FORMAT(/,1H ,4X,7HTIME(H),4X,10(E8.3,1X),2X,2(E8.3,2X))
      WRITE(6,400)
400   FORMAT(1H ,125HTARGET PRODUCT  DSR(T1)  DSR(T2)  DSR(T3)  DSR(T4)
     + DSR(T5)  DSR(T6)  DSR(T7)  DSR(T8)  DSR(T9)  DSR(T10)  DSR(T11)
     +DSR(T12))
      DO 818 L=IBASE,NO
      IF(NT(L).EQ.IDNO(I)) GO TO 817
      GO TO 818
817   DO 819 K=1,NOPAS
      DOSPRO(K)=DOSPRD(L)*EXP(-(STAFS(K)*0.693*3600.0/HA(L)))
      IF(DHA(L).EQ.0.0)DOSDGT(K)=0.0
      IF(DHA(L).NE.0.0)DOSDGT(K)=DOSDAU(L)*EXP(-(STAFS(K)*0.693*3600.0/D
     +HA(L)))
      DOSNUC(K)=DOSPRO(K)+DOSDGT(K)
      DOSSUM(K)=DOSSUM(K)+DOSNUC(K)
      SYSDOS(K)=SYSDOS(K)+DOSNUC(K)
819   CONTINUE
      WRITE(6,20) IDNO(I),NP(L),(DOSPRO(K),K=1,NOPAS)
 20   FORMAT(1X,1X,I5,2X,I5,2X,10(E8.3,1X),2X,2(E8.3,2X))
818   CONTINUE
      WRITE(6,11)
 11   FORMAT(1H ,126HPRODUCT DAUGHTER DSR(T1)  DSR(T2)  DSR(T3)  DSR(T4)  DS
     +R(T5)  DSR(T6)  DSR(T7)  DSR(T8)  DSR(T9)  DSR(T10)  DSR(T11)  DSR
     +(T12))
      DO 618 L=IBASE,NO
      IF(NT(L).NE.IDNO(I))GO TO 618
      IF(ND(L).NE.0.0)GO TO 619
      IF(L.NE.NO)GO TO 618
      GO TO 618
619   WRITE(6,20)NP(L),ND(L),(DOSDGT(K),K=1,NOPAS)
618   CONTINUE
      WRITE(6,8)(STAFS(K),K=1,NOPAS)
      WRITE(6,10)
 10   FORMAT(1H ,125H    TARGET       DSR(T1)  DSR(T2)  DSR(T3)  DSR(T4)
     + DSR(T5)  DSR(T6)  DSR(T7)  DSR(T8)  DSR(T9)  DSR(T10)  DSR(T11)
     +DSR(T12))
      WRITE(6,23) IDNO(I),(DOSSUM(K),K=1,NOPAS)
 23   FORMAT(1X,5X,I5,5X,10(E8.3,1X),2X,2(E8.3,2X),///)
      DO 822 K=1,NOPAS
      DOSSUM(K)=0.0
822   CONTINUE
815   CONTINUE
      WRITE(6,414)
414   FORMAT(//)
      WRITE(6,8)(STAFS(K),K=1,NOPAS)
      WRITE(6,26)
 26   FORMAT(1H ,125H    SYSTEM       DSR(T1)  DSR(T2)  DSR(T3)  DSR(T4)
     + DSR(T5)  DSR(T6)  DSR(T7)  DSR(T8)  DSR(T9)  DSR(T10)  DSR(T11)
     +DSR(T12))
      WRITE(6,51)(SYSDOS(K),K=1,NOPAS)
 51   FORMAT(1X,15X,10(E8.3,1X),2X,2(E8.3,2X))
      RETURN
      END
```

```
      SUBROUTINE CALC(E,ACT,DSFRD,MULT,FLUXE,TMASS)
C
C
CTHIS PROGRAM CALCULATES DOSERATE FOR 4 DIFFERENT GEOMETRIES
C
C
C
C
      REAL MULT
      REAL MU
      COMMON A,V,F,OF,T1,T2,N,F,D,H,OPTION,IGEOM,ISAE
      GO TO(11,12)(ISAB+1)
 11   GO TO(31,32,33,34)IGEOM
   31 DOSRAT=(ACT*MULT*2.5/(4.0*3.1416*FLUXE*(D*100.0)**2))
      DSPRD=DSFRD+DOSRAT
      RETURN
CTHE ABOVE DOSERATE CALCULATION IS FOR A POINT SOURCE
 32   VOLU=4*3.141E*((R*100.)**3)/3
      SOU=(ACT*MULT*2.5)/(VOLU*FLUXE*4.)
      DOSRAT=SOU*(2*R*(R+D)*10000.-D*(2*R+D)*10000.*(ALOG((2*R+D)/D)))/(
     +(R+D)*100.)
      DSPRD=DSFRD+DOSRAT
      RETURN
CTHE ABOVE DOSERATE CALCULATION IS FOR A HOMOGENEOUS NON-ABSORBING
CSPHERE
   33 VOLU=3.1416*((R*100.)**2)*H*100.
      SOU=(ACT*MULT*2.5)/(VOLU*FLUXE*4.)
      DOSRAT=SOU*((H+D)*100.*(ALOG(1+(R**2)/((H+D)**2))+2*R*ATAN((H+D)/R
     +)/(H+D))-D*100.*(ALOG(1+(R**2)/(D**2))+2*R*ATAN(D/R)/D))
      DSPRD=DSFRD+DOSRAT
      RETURN
CTHE ABOVE CALCULATION IS FOR A HOMOGENEOUS NON-ABSORBING CYLINDER WHERE
CTHE OBSERVER FACES THE AXIS
   34 VOLU=4.*3.1416*((((P+H)*100.)**3)-(R*100.)**3)/3.
      SOU=(ACT*MULT*2.5)/(VOLU*FLUXE)
      DOSRAT=SOU*H*100.
      DSPRD=DSFRD+DOSRAT
      RETURN
C   ABOVE CALCULATION IS FOR A HOMOGENEOUS SPHERICAL CAVITY
C   WITHOUT ABSORTION WHERE THE OBSERVER IS AT THE CENTER
 12   GO TO(41,42,42,42)IGEOM
 41   WRITE(6,50)
 50   FORMAT(10X,36HNO SELF-ABSORTION FOR A POINT SOURCE)
      GO TO 31
C   THE ABOVE STATEMENTS RETURN TO NON-ABSORBING POINT SOURCE
 42   AMU=0.0488*(E**(-0.4633))
C   CALCULATION OF THE ATTENUATION FACTOR
      IF(E.LE.3.)BFA=44.1-(10.2*E)
      IF((E.GT.(3.0)).AND.(E.LE.(8.0)))BFA=-0.9*E+16.2
      IF(E.GT.(8.0))BFA=AMAX1(4.6,(-2.5*E+29.))
C   CALCULATION OF THE BUILD-UP FACTOR COEFFICIENT A
      IF(E.LE.2.)BALPH1=0.063*E-0.182
      IF((E.GT.(2.0)).AND.(E.LE.(8.0)))BALPH1=-0.02*E-0.015
      IF(E.GT.(8.0))BALPH1=-0.0085*E-0.107
C   CALCULATE THE BUILD-UP FACTOR COEFFICIENT ALPHA1
      IF(E.LE.(1.0))BALPH2=-0.032*E+0.048
      IF((E.GT.(1.0)).AND.(E.LE.(2.0)))BALPH2=-0.001*E+0.017
      IF((E.GT.(2.0)).AND.(E.LE.(4.0)))BALPH2=0.012*E-0.009
```

```
      IF((E.GT.(4.0)).AND.(E.LE.(8.0)))BALPH2=0.0125*E+0.034
      IF(E.GT.(8.0))BALPH2=0.012*E-0.052
C     CALCULATE THE BUILD-UP FACTOR COEFFICIENT ALPHA2
      GO TO(41,51,52,53)IGEOM
   51 VOLU=4*3.1416*((R*100.)**3)/3
      MU=1000.*AMU*TMASS/VOLU
      SOU=(ACT*MULT*2.5)/(VOLU*FLUXE)
      CALL GEOFSP(R,D,MU,BALPH1,GFS)
      DOSRAT=SOU*3*100.*GFS*BFA/3.1416
      CALL GEOFSP(R,D,MU,BALPH2,GFS)
      DOSRAT=DOSRAT+SOU*R*100.*(1.-BFA)*GFS/3.1416
      DSPRD=DSPRD+DOSRAT
      RETURN
C     CALCULATE THE DOSE RATE AT A POINT OUT OF AN ABSORBING SPHERE
   52 VOLU=3.1416*((R*100.)**2)*H*100.
      MU=1000.*AMU*TMASS/VOLU
      SOU=(ACT*MULT*2.5)/(VOLU*FLUXE)
      TETA=ATAN(R/(D+H/3.))
      IF((H*100.).GT.(3./MU))GO TO 60
      CALL GEOFCY(BALPH1,MU,TETA,H,GFC)
      DOSRAT=SOU*(1.-COS(TETA)+GFC)*BFA/(2.*MU*(1.+BALPH1))
      CALL GEOFCY(BALPH2,MU,TETA,H,GFC)
      DOSRAT=SOU*(1.-COS(TETA)+GFC)*(1.-BFA)/(2.*MU*(1.+BALPH2))+DOSRAT
      DSPRD=DSPRD+DOSRAT
      RETURN
   60 DOSRAT=SOU*(1.-COS(TETA))*(BFA/((1.+BALPH1)*MU)+(1.-BFA)/((1.+BALP
     +H2)*MU))/2.
      DSPRD=DSPRD+DOSRAT
      RETURN
C     CALCULATE THE DOSE RATE FOR A HOMOGENEOUS ABSORBING CYLINDER
C     WHERE THE OBSERVER FACES THE AXIS
   53 VOLU=4.*3.1416*((((R+H)*100.)**3)-(R*100.)**3)/3.
      MU=1000.*AMU*TMASS/VOLU
      SOU=(ACT*MULT*2.5)/(VOLU*FLUXE)
      DOSRAT=(SOU*BFA*(1.-EXP(-MU*(1.+BALPH1)*H*100.))/MU/(1.+BALPH1))+
     +(SOU*(1.-BFA)*(1.-EXP(-MU*(1.+BALPH2)*H*100.))/(MU*(1.+BALPH2)))
      DSPRD=DSPRD+DOSPAT
      RETURN
C     CALCULATE THE DOSE RATE AT THE CENTER OF A SPHERICAL
C     ABSORBING CAVITY
      END
```

```
      SUBROUTINE GEOFSP(X,Y,Z,T,GFS)
C
C
C     GIVEN THE RADIUS IN X, THE DISTANCE FROM THE SURFACE IN Y, THE
C     ATTENUATION FACTOR IN Z AND THE BUILD-UP FACTOR COEFFICIENTS IN T
C     CALCULATES  THE GEOMETRIC FUNCTION FOR ABSORBING SPHERE USING AN
C     ANALYTICAL APPROXIMATION OF THE G FUNCTION
C
C
      GFS=0.
      PSP=(X+Y)/X
      GFS=EXP(-((0.342*X*Z*(1.+T)+2.07322)*ALOG(PSP)+AMIN1((60.*X*Z*(1.+
     +T)-0.144),(46.37*X*Z*(1.+T)-0.035),(28.76*X*Z*(1.+T)+0.3168),(14.5
     +5*X*Z*(1.+T)+0.8861),(8.17*X*Z*(1.+T)+1.3966),(4.72*X*Z*(1.+T)+1.7
     +42))))
      RETURN
      END
```

```
      SUBROUTINE GEOFCY(X,Y,T,Z,GFC)
C
C
C     GIVEN THE BUILD-UP FACTOR COEFFICIENTS IN X, THE ATTENUATION FACTOR
C     IN Y, THE HEIGHT IN Z, THE ANGLE IN T, CALCULATES THE GEOMETRIC
C     FUNCTION FOR ABSORBING CYLINDER USING AN APPROXIMATION OF THE E2
C     FUNCTION
C
C
      REAL VAR,VARI
      VAR=0.
      VARI=0.
      GFC=0.
      VAR=(1+X)*Y*Z*100.
      VARI=VAR/COS(T)
      CALL E2(VARI,RES)
      GFC=COS(T)*RES
      CALL E2(VAR,RES)
      GFC=GFC-RES
      RETURN
      END
```

```
      SUBROUTINE E2(X,RES)
C
C
CESTIMATE E2(X) THE SECOND SPECIES EXPONENTIAL INTEGRAL FUNCTION
C
C
      RES=0.
      IF(X.GE.0.)GO TO 33
      TOL=0.0001
      TOTAL=0.0
      A=X
      B=5.*X
      DO 10 I=1,10
      CALL ROMB(A,B,TOL,RESULT)
      TOTAL=TOTAL+RESULT
      A=B
      B=B*5.
   10 CONTINUE
      RES=X*TOTAL
      RETURN
   33 RES=EXP(-X)*(1/(2.+X)+2./((2.+X)**3))
      RETURN
      END
```

```
      SUBROUTINE ROMB(A,B,TOL,RESULT)
C
C
CINTEGRATE USING THE ROMBERG METHOD
C
C
      DIMENSION TRAP(11,11)
      H=(B-A)/10.
      SUM=(EXP(-A))/(A**2)+(EXP(-B))/(B**2)
      X=A
      DO 10 I=2,10
      X=X+H
      SUM=SUM+((EXP(-X))/(X**2))*2.
   10 CONTINUE
      TRAP(1,1)=H/2.*SUM
      DO 20 I=1,10
      H=H/2
      X=A+H
      K=10*2**I
      DO 30 J=2,K,2
      SUM=SUM+((EXP(-X))/(X**2))*2
      X=X+H+H
   30 CONTINUE
      TRAP(1,I+1)=H/2.*SUM
      DO 40 L=1,I
      TRAP(L+1,I+1)=TRAP(L,I+1)+1./(4.**L-1.)*(TRAP(L,I+1)-TRAP(L,I))
   40 CONTINUE
      IF(ABS(TRAP(I+1,I+1)-TRAP(I,I+1))-TOL)50,50,20
   20 CONTINUE
   50 RESULT=TRAP(I,I)
      RETURN
      END
```

```
      SUBROUTINE CURVE(E,FLUXE)
C
C
CGIVEN THE ENERGY OF THE GAMMA RAY,THIS PROGRAM CALCULATES THE PARTICLE
CFLUX(QUANTA/CM**2*SEC) THAT CORRESPONDS TO A DOSE RATE OF 2.5 MR/HR --
CFLUXE
C
C
C     ARGUMENTS IN-DLEVEL
C     ARGUMENTS OUT-FLUXE
C
C
      IF(E.GE.0.010.AND.E.LE.0.020) GO TO 1
      IF(E.GT.0.020.AND.E.LE.0.040) GO TO 2
      IF(E.GT.0.040.AND.E.LE.0.050) GO TO 3
      IF(E.GT.0.050.AND.E.LE.0.060) GO TO 4
      IF(E.GT.0.060.AND.E.LE.0.080) GO TO 5
      IF(E.GT.0.080.AND.E.LE.0.150) GO TO 6
      IF(E.GT.0.150.AND.E.LE.0.400) GO TO 7
      IF(E.GT.0.400.AND.E.LE.0.600) GO TO 8
      IF(E.GT.0.6000.AND.E.LE.1.000) GO TO 9
      IF(E.GT.1.000.AND.E.LE.1.500) GO TO 10
      IF(E.GT.1.500.AND.E.LE.3.000) GO TO 11
      IF(E.GT.3.000.AND.E.LE.6.000) GO TO 12
      IF(E.GT.6.000.AND.E.LE.10.000) GO TO 13
      FLUXE=1.0E+99
      RETURN
    1 FLUXE=21495330.64*E**2.1759447
      RETURN
    2 FLUXE=1146C233.22*E**2.0136022
      RETURN
    3 FLUXE=1036918.975*E**1.2698653
      RETURN
    4 FLUXE=96497.38032*E**0.4772399
      RETURN
    5 FLUXE=11225.12221*E**(-0.2674410)
      RETURN
    6 FLUXE=55482.7832E*EXP(E*(-10.9132069))
      RETURN
    7 FLUXE=1330.569205*E**(-1.1036085)
      RETURN
    8 FLUXE=1462.198966*E**(-1.0004513)
      RETURN
    9 FLUXE=1546.957795*E**(-0.8891058)
      RETURN
   10 FLUXE=1549.091320*E**(-0.7797676)
      RETURN
   11 FLUXE=1508.205757*E**(-0.7186754)
      RETURN
   12 FLUXE=1488.362190*E**(-0.7051622)
      RETURN
   13 FLUXE=1656.852874*E**(-0.7649757)
      RETURN
      END
```

REFERENCES

(1) G.S. Keney, "Dose Rates from Neutron Activation of Neutral-Beam injectors" Lawrence Berkeley Laboratory Report LBL-12244.

(2) M.S. Singh, "D + D Reaction Neutron Yields from the Implantation of incident D+ in Metals", Lawrence Livermore National Laboratory Report UCRL-77067, July 1975.

(3) L. Ruby, Lawrence Berkeley Laboratory, private communication dated September 1980.

(4) J. McCaslin, Lawrence Berkeley Laboratory, "Calculated Energy Distribution of Neutrons Inside the TFTR test-cell shield" Application to Activation Analysis, Memo to L. Ruby dated March 1980.

(5) M.A. Gardner and R.J. Howerton, "ACTL Evaluation Neutron Activation Library", Lawrence Livermore National Laboratory Report UCRL-50400, Vol. 18, October 1978.

(6) R.J. Howerton, "Flux Weighted Group Cross-Sections based on the ACTMLFE Data File", Lawrence Livermore National Laboratory Report UCID-18749, July 1980.

(7) R.J. Howerton, "ENSL: the LLNL Evaluated Nuclear Structure Library", Lawrence Livermore National Laboratory Report UCRL-50400, Vol. 24, in press.

(8) R.G. Jaegger, "Engineering Compendium on Radiation Shielding," Vol. 1, Springer-Verlag, 1968.

(9) T. Rockwell III, "Reactor Shielding Design Manual", Van Nostrand, 1956.

(10) J.R. Lamarsh, "Introduction to Nuclear Engineering", Addison Wesley, 1977.

(11) R.G. Asmiller et al., "Dose Rates from Induced Activity in the TFTR Test Cell", Nucl. Technol. 48, 187 (1980).

ACKNOWLEDGEMENT

This work was supported by the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division of the U.S. Department of Energy under Contract No. W-7405-ENG-48.