ACDOS3: A Further Improved Neutron Dose-Rate Code

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Abstract

ACDOS3 is a computer code designed primarily to calculate the activities and dose rates produced by neutron activation in a variety of simple geometries. Neutron fluxes, in up to 50 groups and with energies up to 20 MeV, must be supplied as part of the input data. The neutron-source strength must also be supplied, or alternately, the code will compute it from neutral-beam operating parameters in the case where the source is a fusion-reactor injector. ACDOS3 differs from the previous version ACDOS2 in that additional geometries have been added, the neutron cross-section library has been updated, an estimate of the energy deposited by neutron reactions has been provided, and a significant increase in efficiency in reading the data libraries has been incorporated.

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I. INTRODUCTION

A. Description of ACDOS3

In order to improve the calculation of the expected dose rates produced by prolonged periods of testing on a neutral beam injector, and to add an estimate of the energy absorption in the target, a computer code, ACDOS3, has been written, based on the existing code ACDOS2⁽¹⁾. ACDOS3 utilizes an up-to-date cross-section library and a radioisotope decay data library. It is written in an ANSI FORTRAN IV, in order to make it readily adaptable elsewhere.

ACDOS3 calculates the dose rate as a function of geometry, composition and time after shutdown. Compared to ACDOS2, ACDOS3 can handle two more specific geometries, namely a hollow sphere and a hollow cylinder. (The latter represents a pipe open at both ends.)

In contrast to ACDOS2, it also allows the specification of the dose rate at a distance exactly zero from the surface of a spherical target or from the end of a cylindrical target.

The estimate for the energy absorption in the target during a single testing period has been added, and this energy can be calculated in the case of a sphere or a cylinder, hollow or solid.

ACDOS3 also eliminates a major inefficiency of ACDOS2. In the latter, the neutron cross-section library and the radioisotope decay library were combined into one file. In order to read the decay library for a second time (to search for radioactive daughters), it was necessary to re-read the cross-section library although no data

was wanted from the latter. In ACDOS3, the two libraries constitute two separate files and no unwanted re-reading is allowed to occur.

ACDOS3 also incorporates an updated cross-section library compared to that originally contained in ACDOS2.

Finally, a test problem has been run with ACDOS3 to compare predictions with a sample problem taken from another activation code, and the differences are evaluated.

B. Summary on the activation model

This thesis is mainly concerned with the changes and additions which characterize ACDOS3, and the reader will have to refer to the ACDOS2 report⁽¹⁾ for a more thorough description of the unchanged parts of the code briefly described below.

1. Neutron production model: The code is designed to calculate the activation and the dose rate following a series of N tests of duration T_1 (typically a few hours), with a length of time T_2 between two series. The neutron source is assumed to be monoenergetic.

2. Fluxes: The group fluxes produced by the slowing down of the fast neutrons in the shielding walls surrounding the injector, are input from a previous calculation. The program uses those to calculate weighting fluxes $\phi(E)$ whose form depends on the type of group.

3. Flux weighted cross-section: The groups are divided into three types - thermal groups represented by a Maxwell-Boltzmann distribution, intermediate-energy groups assumed to be proportional

to $1/E$, and source groups with exponential-energy dependence. The group cross-sections are calculated from the data available in the ACTLMFE library⁽²⁾, as follows:

$$\sigma_{av} = \frac{\int_{\Delta E} \sigma(E) \cdot \phi(E) \cdot dE}{\int_{\Delta E} \phi(E) \cdot dE}, \quad E \text{ in the group } E1, E2.$$

4. Activation of target nuclide T: The code considers the product nuclide P and its daughter D. The daughter's daughter is assumed to be stable. The decay equations are:

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

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

The program takes into account the periods containing pulses and the periods between. Then it sums over all the energy groups giving the final value for the activity of:

- the product nuclide P:

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

- and the daughter nuclide D:

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

where k (1 to n) is the number of a particular energy group,

N is the total number of test periods,

t is the time after shutdown.

II. ENERGY ABSORPTION IN THE TARGET

A. Introduction

The objective is to calculate the energy absorbed in the target during a period of test T_1 in order to determine how well the target will withstand the resultant temperature rise (whose value will depend on the heat capacity, not directly accessible from the data library).

A conservative assumption has been made in this calculation, by assuming adiabatic conditions during the test period.

B. Nuclear reactions in the target

The energy which will heat the target arises from the reactions between the neutrons incident of the beam and the target nuclides.

These reactions have the following form:

where y is any sort of material particle, (neutron or charged particles; sometimes it stands for several),

γ represents a gamma-ray,

Q is the energy released (when > 0), or absorbed (when < 0)

($Q < 0$ means that there is a threshold for the incident neutron energy).

T represents a target nuclide,

P represents a product nuclide.

C. Released energy

The target is assumed to be at rest, therefore the total available energy is the sum of Q and the kinetic energy of the incident neutron E_n , and is shared between the different particles emitted. When Q has a negative value the threshold energy for the incident neutron is given by:

$$E_{th} = -Q \cdot \left(\frac{t_{mass} + 1}{t_{mass}} \right) ;$$

where t_{mass} is the target mass (in AMU).

ACDOS3 reads from the ACTL2 library the ID number of the reaction (i.e. the nature of the emitted particle), and the energy Q at the same time that it reads the product nuclide name and half-life. So the energy absorption calculation is included in the subroutine which calculates the activities; however the user can skip the calculation if desired, by setting the flag IHEAT equal to 0.

For the heating calculation, only the more probable reactions are considered by ACDOS3, assuming that the heating by the other reactions, principally (n,n') and $(n,2n)$, will be insignificant; Those considered are: (n,H) , (n,D) , (n,T) , $(n,T,2\alpha)$, $(n,^3He)$, (n,α) and (n,γ) . In the case of a particle emitted, the latter is assumed to stop in the target (the mfp being much smaller than the usual target dimensions). The energy E_n+Q initially shared between p and γ will therefore stay in the target. In the case of a gamma-ray emission, the program neglects the neutron kinetic energy compared to Q , since this sort of reaction occurs only at low incident kinetic energies, and Q is in the 1-10 MeV range.

In contrast to the activation calculation, ACDOS3 considers each reaction no matter what the half-life of the product is, since there is a release of energy with any product formation. Since for the charged particle reactions, the kinetic energy of the neutron has to be considered, the program computes the average neutron energy in each group as:

$$E_{av}(I) = 1/2 \times (E(I) + E(I+1))$$

Then it looks for a possible threshold by comparing $E_{av}(I)$ and E_{th} . The groups below and up to the one containing E_{th} are skipped in the calculation. However it can happen that E_{th} is in the I^{th} group of energy, but above $E_{av}(I)$. Therefore, since $(E_{av} - E_{th})$ is negative, the group I is skipped and the reaction at energies between E_{th} and $E(I+1)$ neglected in the energy absorption calculation.

The energy computed for the (n,y) reaction over all the retained energy groups is, in joules:

$$HEAT = \sum_{i=1}^{noegps} (E_{av}(i) + Q) \times (\sigma_T(i) \times \phi(i) \times T) \times T_1$$

where

- E_{av} and Q are in joules,
- σ_T is in cm^2 ,
- ϕ is in neutrons/ cm^2 s,
- T the number of target nuclides,
- T_1 is the test period in seconds,
- noegps is the number of energy groups.

Case of a (n, γ) reaction

In the case of a gamma-ray emission, the mfp is not negligible compared to the target dimensions. Therefore the γ -ray will only deposit a fraction of its energy as it suffers collisions in the target. The three main types of collisions to be considered are:

- the photoelectric effect for $Q < .5$ Mev,
- the compton effect for $.5 \text{ Mev} < Q < 5 \text{ Mev}$,
- The pair formation for $Q > 5 \text{ Mev}$.

(Actually the energy limits vary from one material to another). In these collisions, the γ -ray energy is partially or totally degraded.

An Energy Transfer Coefficient has been defined⁽³⁾ which is a sum of the absorption coefficient for each, multiplied by a correction factor f , $0 \leq f \leq 1$. This coefficient is:

$$\nu_{en} = f_{ph} \times \mu_{ph} + f_{cpt} \times \mu_{cpt} + f_{pair} \times \mu_{pair} ;$$

ν_{en} is tabulated with f_{ph} taken equal to unity, since the entire energy is taken by an electron which stays in the target (the electron path is very tortuous, especially for high Z values and energy below 10 Mev). An analytical approximation of ν_{en} has been calculated as a function of the γ -ray energy Q , and adjusted to be applicable to the more used materials. As is proved later, a value greater than the actual value for each material is desired, for a conservative result for the energy absorption in the target. The table I compares the function values with those tabulated.⁽³⁾⁽⁴⁾

One can see that C, H_2O and metals like Fe, Al, Cu are fitted.

But lead and hydrogen behave very differently and therefore have not been matched.

The analytic function used for ν_{en} is:

$$\nu_{en}(Q) = 2.3376 \exp(-23.1712 Q) + (0.042 \exp(-0.1972 Q) + 0.0024 Q - 0.006,$$

where Q is in Mev,

ν_{en} is in cm^2/g .

The escape probability depends on the target geometry as well as on the material and on the γ -ray energy.

The escape probability for a sphere is⁽⁵⁾:

$$P_0 = 3/8 \cdot \frac{1}{x^3} \cdot (2x^2 - 1 + (1 + 2x) \cdot \exp(-2x)) ,$$

where

$$x = \nu_{en} \cdot \frac{\text{tmass} \cdot R}{\text{volu}} ,$$

R is the sphere radius in cm,

tmass is the target mass in g,

volu is the sphere volume in cm^3 .

The escape probability for an infinite cylinder⁽⁵⁾ is a function of the modified Bessel functions K_1 and I_1 . Therefore it has to be expanded for calculational purposes. For "small" x values and "large" x values the expansions already exist. For intermediate values of x the escape probability is tabulated and an analytical approximation has been found. See for more on this escape probability, Appendix 2. Note that in the expression of " x ", R is the cylinder radius.

What actually interests the user is the "collision probability" $P_c = 1 - P_0$, which is needed to calculate the part of the γ -ray energy that stays in the target. One can see that P_c increases with x . So, to be conservative, a greater estimation of x is desirable. This means the energy transfer coefficient approximation must be greater than the tabulated one, for a given target geometry.

ACDOS3 uses P_c for a spherical geometry, and both the sphere and infinite cylinder functions in the case of a finite cylinder, since no exact expression is available for this geometry. In the latter case, the program assumes a sphere of the same volume as the cylinder as the first approximation. The approximation by an infinite cylinder of the same radius seems more appropriate when the value R/H is smaller than .05: in such a case the error in the energy-absorption result should be very small. Both approximations are considered simultaneously however, and printed out with the approximated sphere radius and the ratio R/H , so that the user can decide which one is the more appropriate to the considered cylinder.

Table I : Mass Energy Transfer Coefficient (cm^2 / g)

Gamma ray Energy (Mev)	.15	.20	.30	.50	1.0	1.5	2.0	.5.0	10.0
Analytical Function	.1075	.0576	.0365	.0333	.0309	.0288	.0271	.0217	.0238
Tabulated									
Fe	.0803	.0486	.0338	.0295	.0264	.0239	.0224	.0211	.0238
Cu	.1050	.0588	.0365	.0297	.0257	.0231	.0216	.0198	.0212
Al	.0281	.0273	.0281	.0288	.0279	.0247	.0229	.0184	.0172
H ₂ O	.0276	.0297	.031'	.0332	.0310	.0283	.0260	.0190	.0154
C	.0244	.0264	.02	.0299	.0279	.0255	.0234	.0170	.0136
H	.0481	.0525	.070	.0593	.0555	.0508	.0464	.0316	.0222
Pb	1.08	.779	.441	.0904	.0391	.0290	.0224	.0317	.0428

III. DOSE RATE CALCULATION

A. Introduction

The purpose is to calculate the dose rate as a function of geometry and time after shutdown.

The available geometries are:

- A point source,
- A sphere (hollow or solid),
- A cylinder (hollow - like a pipe - or solid),
- A spherical cavity (for the test-cell walls).

An option for no-absorption or self-absorption of the radioisotope decay γ -rays in the target is available.

B. Source Term

Using the previously calculated activities as part of the input information, ACDOS3 reads the LEVDEC radioisotope decay library (sublet of ENSL⁽⁶⁾), for the energy and multiplicity of every γ -ray produced by a specific activated nuclide and its daughter if any. Only the γ , β^+ or β^- decay modes are considered.

The expression of the source strength divided by the flux per unit dose rate is⁽¹⁾:

$$S_0 = (\text{ACT} * \text{MULT}) * \left(\frac{2.5}{\text{FLUXE}}\right), \text{ in cm}^2 \cdot \text{mrem/h, where:}$$

- The activity ACT is in Bq,
- the multiplicity MULT is no. of γ ray/desintegration,
- FLUXE is the effective particle flux corresponding to a dose rate of 2.5 mrem/h in soft tissue.

Point source strength

The dose rate measured at a distance D from a point source emitting isotropically is:

$$\text{DOSRAT} = \frac{S_0}{4 \cdot \pi \cdot D^2} \quad \text{in mrem/h} ,$$

where S_0 has been defined previously.

Volumetric source

The volumetric source is, for an homogeneous source: $(\text{MULT} \cdot \text{ACT}) / \text{VOLU}$, where VOLU is the volume of the source. Then, dividing by the flux per unit dose rate one obtains, in $\text{cm}^{-1} \cdot \text{mrem/h}$:

$$\text{SOU} = (\text{MULT} \cdot \text{ACT} \cdot 2.5) / (\text{FLUXE} \cdot \text{VOLU}) .$$

One has to sum SOU over the geometry when the distance to the observer from each unit volume in the source varies, to find the dose rate in mrem/h.

C. Geometry-No Self-Absorption

Notation: in each case, in centimeters:

R is the outer radius of the hollow sphere, cylinder or cavity;

TH is the thickness of the hollow sphere, cylinder or cavity;

H is the height of the cylinder;

D is the distance from the observer to the surface; the observer stands on the axis of the cylinder.

Note that the definitions have been modified for the spherical cavity in going from ACDOS2 to ACDOS3, in order to be more consistent for all the cases considered in ACDOS3. This change

requires that the expressions defined in ACDOS2⁽¹⁾ be rewritten before the additional geometries can be considered. Using the definitions above for lengths:

Solid Sphere:

The dose rate produced by a solid sphere is⁷:

$$\text{DOSRAT} = \frac{\text{SOU}}{4 \cdot a} \cdot (2 \cdot R \cdot a - (a^2 - R^2) \cdot \ln \left(\frac{a + R}{a - R} \right)),$$

where $a = R + D$, distance from the center to the observer.

When $D=0$, the expression reduces to:

$$\text{DOSRAT} = (\text{SOU}/2) \cdot R.$$

The factor which contains R and a has been written as a separate function DSP in the program. (See Appendix 1).

Solid Cylinder:

The dose rate produced by a solid cylinder on its axis is⁷:

$$\begin{aligned} \text{DOSRAT} = & \frac{\text{SOU}}{4} \cdot ((D+H) \cdot (\ln(1 + \frac{R^2}{(D+H)^2}) + \frac{2 \cdot R}{D+H} \cdot \text{Arctan}(\frac{D+H}{R})) \\ & - D \cdot (\ln(1 + \frac{R^2}{H^2}) + 2 \cdot \frac{R}{H} \cdot \text{Arctan}(\frac{H}{R})) \end{aligned}$$

when $D=0$, the expression reduces to:

$$\text{DOSRAT} = \frac{\text{SOU}}{4} \cdot H \cdot (\ln(1 + \frac{R^2}{H^2}) + 2 \cdot \frac{R}{H} \cdot \text{Arctan}(\frac{H}{R})).$$

The factor function of R , H and D has been written as a separate function in the program, DOS. (See Appendix 1).

Spherical Cavity

At the center of a spherical cavity, the dose rate is:

$$\text{DOSRAT} = \text{SOU} * \text{TH.}$$

Outside a Hollow Source

When no self-absorption is considered, one can use a method of superposition in order to determine the dose rate from a hollow source. The quantity SOU can still be calculated by dividing S_0 by the volume of the actual source. Then one calculates the dose rate induced by a solid source having the same outer radius and a volumetric strength SOU , and by a solid source having its radius equal to the inner radius of the actual source, and a volumetric strength $(-\text{SOU})$. Hence, summing the two latter dose rates one obtains the desired dose rate produced by the source, since the dose rates produced by the sources within the small radius cancel out. For a hollow sphere, using the notation defined above:

$$\text{DOSRAT} = \frac{\text{SOU}}{4} * (\text{DSP } (R, R+D) - \text{DSP } (R-\text{TH}, R+D));$$

the volume is:

$$\text{VOLUME} = 4/3 * \pi * (R^3 - (R-\text{TH})^3).$$

For a hollow cylinder (pipe), similarly:

$$\text{DOSRAT} = \frac{\text{SOU}}{4} * (\text{DOSE } (R,D,H) - \text{DOSE } (R-\text{TH},D,H));$$

the volume is:

$$VOLU = \pi * H * (R^2 - (R - TH)^2).$$

D. Absorption Case

The case of a solid sphere, a solid cylinder and the inside of a spherical cavity have been considered in ACDOS2. Since the same analytic method cannot be applied for a hollow geometry, ACDOS3 uses an approximation which makes it possible to use the ACDOS2 expressions.

The approximation consists of taking an equivalent solid geometry (which has the same volume) and to move the observer to a distance such that he sees the same dose rate in the non absorbing situation.

For a solid sphere: The equivalent parameters are calculated by making the following assumptions:

- The volume is the same so that the source strength SOU and the absorption coefficient⁽¹⁾ stay unchanged. This gives the equivalent radius of the solid sphere:

$$R'^3 = R^3 - (R-TH)^3.$$

- The dose rate induced at a distance D' by this solid sphere without self-absorption is equal to that induced by the actual hollow sphere at the distance D with no absorption. This gives the following equation where the unknown is D':

$$DSP (D', R'+D') = DSP (R, R+D) - DSP (R-TH, R+D),$$

where DSP is the function defined above.

This equation is solved by a Newton iteration method.

At this point ACDOS3 is ready to use the formula for a solid sphere in the absorbing situation.¹

For a hollow cylinder: The equivalent parameters are calculated by making the following assumptions:

- The height H stays unchanged,
- The volume stays the same to preserve the absorption coefficient and the source strength SOU. This leads to an equivalent radius for the equivalent cylinder:

$$R'^2 = R^2 - (R-TH)^2.$$

- The dose rate induced at a distance D' on the axis of this solid cylinder without absorption, is equal to that induced by the actual cylinder at the distance D with no absorption.
- This gives the following equation where the unknown is D':

$$\text{DOSE}(R', D', H) = \text{DOSE}(R, D, H) - \text{DOSE}(R-TH, D, H) ,$$

- where DOSE is the function defined above. This equation is solved by the bisection method.

At this point ACDOS3 is ready to use the formula for an absorbing solid cylinder given in the ACDOS2 report.¹

For the inside of a spherical cavity: No changes were needed, so the user will find the formula for the self-absorption situation in the ACDOS2 report, but he must replace the notation for the thickness "H" by "TH."

IV. COMPARISON PROBLEM

A. Description of the Problem

The purpose of this chapter is to adapt the data available from the sample program in the description of the MAGIK code⁸, and to compare the activity and dose rate values obtained with ACDOS3, with the MAGIK results.

The geometry consists initially of an aluminum cylinder of radius 15 cm, surrounded by a cylindrical shell of iron with an outer radius of 1 meter and a thickness of 10 cm. The height of each cylinder is 2 meters.

The timing of the pulses, with an intensity of $1.0\text{E}+12$ neutrons/sec is 0.5 second duration at intervals of 5 minutes, for 100 pulses a day, on 10 consecutive days.

The calculations are made for 1,2,4,8,16 hours after shutdown and 1,3,7 days after shutdown.

Al has one isotope (density number $6.023\text{ E}-2$), Fe has four naturally occurring isotopes (density number for Fe: $8.411\text{ E}-2$).

The activities and induced dose rates have been calculated by MAGIK, averaged over 100 cm of the side-surface of the cylinders.

B. Adaptation for ACDOS3

ACDOS3 calculates the activities and induced dose rates, with self-absorption at a distance $D=0$ from the end of the cylinder, on the axis.

- ACDOS3 uses the test period duration, that is:

$$T1 = (N-1) \times \text{Interval length, or}$$

$$T1 = 99 \times 5 \left(\frac{1}{60} \right) = 8.25 \text{ hours.}$$

(The 0.5 second of one pulse being included in the pause duration).

- Hence the pause length between two series of tests is:

$$T2 = 24 - 8.25 = 15.75 \text{ hours.}$$

- The instantaneous number of neutrons per second given in MAGIK has to be multiplied by the duty factor DF:

$$DF = \frac{\text{length of a pulse}}{\text{length of a pause}}, \text{ or:}$$

$$DF = \frac{.5}{5 * 60} = 1.6666667 \text{ E-03}.$$

Therefore the average number of neutrons per second used in ACDOS3 is:

$$\text{AVENPS} = 1.0 \text{ E+12} * DF = 1.6666667 \text{ E+09 neutrons/s.}$$

- In this problem there are 35 energy groups, in ranges up to 15 Mev, of which one will be considered as a fast group (for it is required for the input data file of ACDOS3).

- The flux in each group is the same, normalized to AVENPS = 1, and its value is a function of the source volume in MAGIK.

Therefore the fluxes for the aluminum and iron cylinders are different and it is necessary to run ACDOS3 twice: one time with Al and its associated flux and the second time with Fe and its associated flux.

The fluxes are written directly on the file DONNEE (see Appendix 1) by setting the flag IFLUX equal to 0 in the data. The total results are the sum of the two separate runs.

- The times after shutdown will be given in hours.

Finally the parameters common to the two data files are:

OPTION	average no. of neutrons/s	1.66667E+09	,
T ₁	length of test (hours)	8.25	,
T ₂	length of pause (hours)	15.75	,
N	number of tests	10	,
NOEGPS	number of energy groups	35	,
NOPAS	number of points after shutdown	8	,
IGEOM	geometry designator	3	,
ISAB	strategy on self-absorption	1	,
IHEAT	option of energy absorption	0 or 1	,
	calculation in the target		
NONUCL	number of nuclides (at least 2)	2(Al); 4(Fe)	,
NF	number of fast groups	1	
IFLUX	option on fluxes	0	
IWALL	option on wall	0	

The specific data for aluminum are:

Solid absorbing cylinder: $R = 15 \text{ cm}$,

$TH = 15 \text{ cm}$,

$H = 200 \text{ cm}$,

$D = 0$.

The volume is therefore: $VOLU = \pi * H * R^2 = 1.414 \text{ E}+0.5 \text{ cm}^3$;

The density number is $6.023 \text{ E}+22 \text{ atoms/cm}^3$;

The atomic mass is 26.983 g/mole .

So the target mass is:

$$\begin{aligned} TMASS &= 26.983 * (6.023\text{E}+22/6.023\text{E}+23) * 1.414\text{E}+05, \\ &= 381.5 \text{ kg}. \end{aligned}$$

Since ACDOS3 requires at least two nuclides in the input file, it has been necessary to add the isotope ^{30}Al to the current one ^{27}Al . The mass $1\text{E}-10 \text{ kg}$ has been attributed to ^{30}Al so that its contribution be negligible.

In the MAGIK code the target was divided into four regions of the same volume, and the flux in each region taken equal to: $1./\text{volume}$ of the region. Therefore for ACDOS3, the uniform flux, normalized to unity average source strength is

$$\phi = 1./(VOLU/4) = 4./VOLU$$

$$\phi = 4./1.414\text{E}+05 = 2.829\text{E}-05 \text{ neutrons/cm}^2\text{s}.$$

The specific data for iron are:

Hollow absorbing cylinder: $R = 100 \text{ cm},$
 $TH = 10 \text{ cm},$
 $H = 200 \text{ cm},$
 $D = 0.$

The volume is: $VOLU = \pi * H * (R^2 - (R-TH)^2),$
 $= 3.1416 * 200 * (100^2 - 90^2) = 1.194E+06 \text{ cm}^3$

(Therefore the equivalent solid cylinder has its radius $P' = 43.59 \text{ cm}$, the ratio $R'/H=0.218$). The flux uniform in each energy group is: $= 1./(VOLU/4) = 4./1.194E + 06 = 3.350E-06 \text{ n./cm}^2.\text{s}$.

Below is a table given the respective contribution of each isotope considered:

Table 2.

	Density Number	Atomic Mass (g)	Atomic	Weight	Mass in the Target
Fe	8.411 (-2)	55.85	-	-	9,320.0 kg
Fe 54	4.895 (-3)	53.94	5.82	5.62	523.5 kg
Fe 56	7.71 (-2)	55.935	91.66	91.81	8,547.5 kg
Fe 57	1.842 (-3)	56.935	2.18	2.23	217.5 kg
Fe 58	2.776 (-4)	57.933	0.33	0.34	31.5 kg

C. Discussion of the results

In MAGIK the dose rate is averaged over the first 100 cm of length on the side-surface of the cylinder, when the ACDOS3 code gives the dose rate value at the end of the cylinders, at the axial point.

A correction factor has been estimated in order to compare the dose rates at the axial point on the end surface. This has been done by calculating the ratio of the dose rate value on a point at 50 cm on the side-surface to the dose rate at the end, with no radiation attenuation. The latter predicts that the MAGIK results of 20.7 mrem/h would be reduced to a value of 18.1 mrem/h at the axial point of the end surface, 1.0 hour after shutdown.

In ACDOS3 one would be tempted to use the truncated-cone approximation for the cylinder. (The one having its apex angle given by $\tan \theta = R/(H/3)$). But, such an approximation is poor when $D < H$ and very poor when $D = 0$, as in the case in question: With this approximation the program will take into account only a small fraction of the actual volume-source.

The latter approximation considers only the part of the cone of which the length is $H' = 3/\mu$. For example, for the case of aluminum, the radiation energies from the product decay are $E_1 = 1.37$ MeV and $E_2 = 2.75$ MeV. With the given mass and volume, the attenuation coefficients are $\mu_1 = 0.1125 \text{ cm}^{-1}$ and $\mu_2 = 0.0815 \text{ cm}^{-1}$. Therefore, the truncated-cones considered by ACDOS3 have their heights respectively $H_1 = 26.7$ cm and $H_2 = 36.8$ cm. The angle is given by $\tan \theta = 0.225$. Then the volume of

the cone considered by the ACDOS3 code is 5% the volume of a cylinder of the same height for the first radiation, and 10% for the second radiation. This produces an unrealistically small estimate of the dose rate, i.e., 1.27 mrem/h for the two γ -rays together.

When $D = 0$, a much better estimate of the MAGIK result can be obtained from a spherical approximation to the aluminum cylinder. Assuming the same volume in each case, the ACDOS3 spherical approximation predicts a dose rate at the surface of 21.6 mrem/h (See Appendix 3), and this compares well with the reduced result from MAGIK.

V. CONCLUSIONS

The ACDOS3 code has several advantages over the previous version, ACDOS2:

1. It provides an estimate of the energy absorbed in the target, at the option of the user.
2. The parts of ACDOS3 which calculate the dose rate due to activation of the target, can handle two more geometries. This improvement has made it possible to run a problem similar to the sample problem shown in the description of the MAGIK code.
3. The efficiency has been greatly improved by separating the two data libraries on individual files.
4. Besides the latter improvement, the ACDOS2 listing has been reviewed and some changes have been made for better efficiency, which makes ACDOS3 the version to be preferred when a given problem could be run with either version.
5. In the comparison problem, ACDOS3 predicted similar results, considering the fact that a spherical approximation of the cylinders was necessary in using the ACDOS3 code.

APPENDIX 1

DESCRIPTION OF NEW SUBROUTINES

1. File Description

General Structure

ACDOS3 is available on the National Magnetic Fusion Energy Computer Facility. Users should read the following files under User Number 14453 and Directory .ACDOS3: LEVDEC, ACTL2, FLUXIN, DONNEE, SOURCE3.

The data to run the sample test in the ACDOS2 manual¹ are on the files FLUXIN and DONNEE (i.e., data for a Cu target).

LEVDEC

This library is a condensed decay mode library based on the more detailed ENSL⁽⁶⁾ library. It is a shortened version of the latter. It has 12962 lines.

The description of the format is to be found in the ACDOS2 report¹.

ACTL2

The file contains the latest version (January 1982) of the ACTLMFE energy cross-section library (20654 lines). It differs slightly from the version used in ACDOS2 for the format of the number of pairs NP and in the identification of the product ZA. Therefore the user can use the description given on the ACDOS2 manual¹, replacing: in line 3: 1 to 3.....13 by: 1 to 11E11.4 and reading E12.4 instead of I6 for the "ZA of Product."

2. New Subroutines Description

The reader is referred to the ACDOS2 manual¹ for those subroutines which already exist in the code.

Some additions and changes have been made in:

INPUT

In ACDOS3, after reading and writing on the output file the geometric data for the target, this subroutine calculates the volume and the geometrically-dependent part of the dose rate for the target and, when it is needed, the characteristics of the equivalent solid geometry; then the INPUT subroutine prints out these characteristics.

INPUT calls the following subroutines:

*DPOINT: Calculates the geometrically dependent part of the dose rate for a point source.

*DECAV: Calculates the volume and the geometrically dependent part of the dose rate for a spherical cavity.

*NEWTON: Calculates the volume and the geometrically dependent part of the dose rate for a spherical source. It also determines, in the case of a hollow sphere, the equivalent solid sphere characteristics, using a Newton iteration method for finding the zero of a function.

*CYLIN: Calculates the volume and the geometrically dependent part of the dose rate for a cylindrical source. CYLIN also determines in the case of a hollow cylindrical shell the equivalent solid

cylinder characteristics, using the bisection method for finding the zero of a function.

The addition concerning the energy absorption in the target has been made inside the ACTVAT subroutine of the ACDOS2 code¹. The new description of this subroutine is:

- ACTVAT: 1. Calculates the activities according to the equation given in the part I. The results are printed out. More on this part can be found in the ACDOS2 report¹.
2. Given the ID number of the neutron-target reaction and the reaction energy Q, ACTVAT calculates the energy absorbed in a spherical or cylindrical source, when the user set the option IHEAT equal to 1. The energy absorbed in each nuclide and the total energy absorption in the target are printed out. In the case of a cylinder, both the calculations for a spherical and an infinite cylindrical source are made and printed out.

For this option, ACTVAT calls when the reaction produces a γ -ray, the following functions:

*PCS: Calculates the collision probability for a sphere.

*PCC: Calculates the collision probability for an infinite cylinder.

Furthermore, for the cylinder case, ACTVAT prints out the radius of the sphere of the same volume used in the energy absorption calculation, and the ratio (radius/height) of the cylinder, to help

the user to estimate that approximation which is the best for the absorbed energy estimate.

CALC: This subroutine calculates the dose rate for the different allowed geometries, in both of the following options. "No self-absorption" or "self-absorption."

In the previous version of the code, CALC would calculate the geometrically dependent part of the dose rate and the volume of the given target each time it would be called, that is for each decay reaction found by DOSRTE.

In the new version, ACDOSS3, these values, constant for a given target, are defined in a common and computed in the INPUT subroutine only once (see "INPUT" above).

4. Functions Descriptions

DSP: The arguments of this function are "X" and "Y", which will be defined below. The value of this function is:

$$DSP = Y * (2 * X - (1 - X^2) * \ln(\frac{1 + X}{1 - X})) .$$

The subroutines NEWTON calls the function DSP for two purposes:

1. To calculate the geometric part of the dose rate produced by a solid sphere of radius R with a distance "Y" from its center to the observer. In this case the argument "X" is the ratio: R/Y.
2. In the Newton iteration method, when searching the distance D' for the solid sphere equivalent to the given hollow

sphere. Calling "K" the latter dose rate value, calculated previously by using (1) twice, the problem is to find the zero of the function $(1)-K$, or equivalently of the function $g(X)$:

$$g(X) = \frac{R'}{K} * (2 * X - (1-X^2) * \ln(\frac{1+X}{1-X})) - X \quad (1)$$

that is: $g(X) = \text{DSP}(X, Y) - X$,

where $X = R'/(R' + D')$,

$$Y = R'/K.$$

DSP1: is the derivative of the function defined above:

$$\text{DSP1}(X, Y) = 2 * Y * X * \ln(\frac{1+X}{1-X}).$$

It is used in the Newton iteration method.

DOS (R, X, H): The arguments are respectively: The radius, the distance on the axis to the observer, the height, for a given solid cylinder.

The value of the function is:

$$\text{DOS} = (X + H) * \text{FDOS}(R/(X + H)). \quad (2)$$

FDOS (Z): the argument is defined in (2) above.

The value of this function is:

$$\text{FDOS} = \ln(1 + Z^2) + 2 * Z * \text{Arctan}(\frac{1}{Z}).$$

The two functions described above are used to calculate the geometric part of the dose rate for a cylinder, on its axis.

They are used also in the bisection method for finding the zero of the function:

$$g(X) = (X+H) \left(\ln(1+R'^2/(X+H)^2) + 2 R'/(X+H) \operatorname{Arctan} \left(\frac{X+H}{R'} \right) \right) - K,$$

where: K is the dose rate geometric part of the given hollow cylinder, calculated previously,

X is the resultant distance between the equivalent solid cylinder and the observer.

The function "g" decreases when X increases; Since it is positive for X=0, the given distance where the observer stands, this shows that in order to get $g(D')=0$, one must increase the distance between the cylinder and the observer in replacing the hollow cylinder by a solid cylinder.

The collision probability functions are:

PCS: For a sphere of radius R and attenuation coefficient $\mu^{(5)}$:

- if $\mu R < 0.1$,

$$PCS = 3/4 \cdot \mu R;$$

- if $0.1 \leq \mu R \leq 6.0$,

$$- PCS = 1 - 3/8 \cdot \frac{1}{(\mu R)^3} \cdot (2 \cdot (\mu R)^2 - 1 + (1 + 2 \cdot \mu R) \cdot \exp(-2 \cdot \mu R));$$

- if $\mu R > 6.0$,

$$- PCS = 1 - 3/4 \cdot \frac{1}{\mu R} \cdot \left(1 - \frac{1}{2 \cdot (\mu R)^2} \right).$$

PCC: For an infinite cylinder of radius R and attenuation coefficient $\mu^{(5)}$:

- if $\mu R < 0.1$,

$$PCC = 4/3 \cdot \mu R - (\mu R)^2/2 \cdot (\log(2/(\mu R)) + 0.672784...),$$

- if $\mu R < 6.0$,

$$PCC = 1 - \frac{1}{2 \cdot (\mu R)} \cdot (1 - 3/16/(\mu R)^2).$$

In the situation where the value of μR is between the two boundaries above, the collision probability is only tabulated.⁽⁵⁾ An analytic approximation to the function has been made for all μR , to allow its use in the program calculation. The coefficients of a series of cubic functions which match the table have been found, by running the program SPLINE, giving 7 points in the table. Then these coefficients have been written as the data for the function SEVAL in the ACDOS3 code. The function PCC calls the function SEVAL in order to calculate the escape probability when $0.1 \leq \mu R \leq 6$.

3. ACDOS3 Chart .

APPENDIX 2

Input file description

INPUT DATA DESCRIPTION FOR ACDOS3

card #	Variable description	columns	format
1	<u>OPTION</u> - if 0.000 ACDOS3 will calculate the average number of neutrons - any other value will be used as the neutron average number	1 to 14	E14.7
2	<u>A</u> : current in amperes (only if Option=0.000) <u>V</u> : voltage in kilovolts (only if Option=0.000) <u>F</u> : fraction of the beam which is monoatomic (if Option=0.000) <u>DF</u> : duty factor (only if Option=0.000) <u>T1</u> : time length of test (hours) <u>T2</u> : length of pause (hours) <u>N</u> : number of tests	1 to 10 13 to 22 25 to 34 37 to 46 49 to 58 if opt=0 1 to 10 if opt≠0 61 to 70 if opt=0 13 to 22 if opt≠0 72 to 75 if opt=0 25 to 27 if opt≠0	E10.3 E10.3 E10.3 E10.3 E10.3 E10.3 I 3
3	<u>NOEGPS</u> : number of energy groups (up to 50)	1 to 2	I2
4	<u>NOPAS</u> : number of points after shutdown (up to 12)	1 to 2	I2

5	<u>R</u> : outer radius of sphere cylinder or cavity (in m)	1 to 10	E10.3
	<u>TH</u> : thickness of cavity or hollow cylinder or sphere (m) - TH = R if solid geometry	13 to 22	E10.3
	<u>H</u> : height of cylinder (in m) - H = 0 if not a cylinder	25 to 34	E10.3
	<u>D</u> : distance from point source or surface of sphere or cylinder to the observer (in m) - d = 0 for a cavity	37 to 46	E10.3
	<u>IGEOM</u> : 1 for point source 2 for outside a sphere 3 for a cylinder on axis 4 for center of a cavity	49	I1
	<u>ISAB</u> : 0 for non absorbing source 1 for self absorbing source	50	I1
6	<u>IHEAT</u> : 0 for not calculating heating 1 for calculating heating in the target	51	I1
	<u>NONUCL</u> : number of target nuclides (up to 30)	1 to 2	I2
7	<u>NF</u> : number of fast neutrons groups	1 to 2	I2
8,9 if needed	<u>STAFS(I)</u> (I from 1 to NOEPAS) times after shutdown in hours (6 per card)	1 to 72	NOEPAS* E10.3,2x

# above One per nuclide	<u>ZNAME1(I)</u> First part of the name of the I th nuclide	1 to 10	A10
at least 2 cards	<u>ZNAME2(I)</u> Second part of the name of the I th nuclide	11 to 20	A10
	<u>IDNO(I)</u> ID number (1000.2+A) of the I th nuclide	22 to 26	I5
	<u>MASS(I)</u> number of kilograms of the I th nuclide	28 to 37	E10.3
as many as needed	<u>GP(I)</u> (I from 1 to NOEGPS+1) Group boundaries in Mev in ascending order	1 to 72	6* (E10.3,2x)
One above	<u>IFLUX</u> Option on the fluxes 0: fluxes read from input data check 1: fluxes read from tape 8	1 to 2	I2
	<u>IWALL</u> Option on the place of activation 0: activation of an object inside the test cell 1: activation of the wall	4 to 5	I2
	<u>KWALL</u> (only if IWALL=1) inverse of the relaxation length of the wall material in cm-1	6 to 15	E10.3
as many as needed	<u>BFLUX(I)</u> (only if IFLUX=0) (I from 1 to NOEGPS) unity normalized group fluxes: cm-2/s	1 to 72	6* E10.3,2x

APPENDIX 3

Output from the comparison problem .

DATA FOR THE ALUMINUM CYLINDER

```

+1.6666667E+09
+0.825E+01 +1.575E+01 10
35
8
.150E+00 .150E+00 .200E+01 .800E+00 311
2
1
1.000E+00 2.000E+00 4.000E+00 8.000E+00 1.600E+01 2.400E+01
7.200E+01 1.600E+02
ALUMINUM-27 13027 3.773E+02
ALUMINUM-30 13030 1.000E-10
1.000E-10 4.140E-07 1.125E-06 2.382E-06 5.044E-06 1.060E-05
2.260E-05 1.013E-04 4.540E-04 1.595E-03 3.355E-03 7.102E-03
1.503E-02 3.183E-02 8.652E-02 1.500E-01 2.347E-01 3.337E-01
4.979E-01 7.427E-01 9.072E-01 1.100E+00 1.353E+00 1.653E+00
2.019E+00 2.466E+00 3.012E+00 3.679E+00 4.493E+00 5.480E+00
6.703E+00 8.187E+00 1.000E+01 1.221E+01 1.350E+01 1.492E+01
0 0
2.829E-05 2.829E-05 2.829E-05 2.829E-05 2.829E-05 2.829E-05
2.829E-05 2.829E-05 2.829E-05 2.829E-05 2.829E-05 2.829E-05
2.829E-05 2.829E-05 2.829E-05 2.829E-05 2.829E-05 2.829E-05
2.829E-05 2.829E-05 2.829E-05 2.829E-05 2.829E-05 2.829E-05
2.829E-05 2.829E-05 2.829E-05 2.829E-05 2.829E-05 2.829E-05
2.829E-05 2.829E-05 2.829E-05 2.829E-05 2.829E-05 2.829E-05

```

Next pages : output for the equivalent solid sphere ;
 energy absorption output in the case of the cy-
 linder for comparison.

THE FOLLOWING DATA HAVE BEEN ENTERED INTO MEMORY

AMPERES	KILO-VOLTS	BEAMFRACTION	DUTYFACTOR	T1	T2	N
*****	*****	*****	*****	8.25E+00	1.58E+01	10

NUMBER OF ENERGY GROUPS-NOEGPS 35

NUMBER OF TARGET NUCLIDES-HONUCL 2

NUMBER OF POINTS AFTER SHUTDOWN-NOPAS 8

ISAB=1

ISECH=2

IHEAT=1

YOU ARE USING AN ABSORBING SOURCE

YOU ARE CALCULATING THE ENERGY ABSORPTION IN THE TARGET

THE SOURCE IS A HOLLOW SPHERE

ITS OUTER RADIUS IS R= 3.231E-01 METERS

ITS THICKNESS IS TH= 3.231E-01 METERS

THE OBSERVER IS AT A DISTANCE D= 0. METERS FROM THE SURFACE OF THIS SPHERE

NUMBER OF GROUPS BOUNDARIES-NG 36

NUMBER OF FAST NEUTRON GROUPS-NF 1

AVERAGE NUMBER OF NEUTRONS PRODUCED PER SECOND 1.6667E+09

SPECIFIC TIMES AFTER SHUTDOWN (H)

TIME 1	1.000E+00
TIME 2	2.000E+00
TIME 3	4.000E+00
TIME 4	8.000E+00
TIME 5	1.600E+01
TIME 6	2.400E+01
TIME 7	7.200E+01
TIME 8	1.600E+02

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

OPTION ON THE PART OF THE ROOM WHERE ACTIVATION,

TAKES PLACE-IWALL= 0
ACTIVATION OF AN OBJECT PLACED INSIDE THE ROOM

UNIT NORMALIZED FLUXES INSIDE THE ROOM		GROUP BOUNDARIES (MEV)	
GROUP 1	2.8290E-05	BOUNDARY 1	1.4920E+01
GROUP 2	2.8290E-05	BOUNDARY 2	1.3500E+01
GROUP 3	2.8290E-05	BOUNDARY 3	1.2210E+01
GROUP 4	2.8290E-05	BOUNDARY 4	1.0300E+01
GROUP 5	2.8290E-05	BOUNDARY 5	9.1870E+00
GROUP 6	2.8290E-05	BOUNDARY 6	6.7030E+00
GROUP 7	2.8290E-05	BOUNDARY 7	5.4880E+00
GROUP 8	2.8290E-05	BOUNDARY 8	4.4930E+00
GROUP 9	2.8290E-05	BOUNDARY 9	3.6790E+00
GROUP 10	2.8290E-05	BOUNDARY 10	3.0120E+00
GROUP 11	2.8290E-05	BOUNDARY 11	2.4680E+00
GROUP 12	2.8290E-05	BOUNDARY 12	2.0190E+00
GROUP 13	2.8290E-05	BOUNDARY 13	1.6530E+00
GROUP 14	2.8290E-05	BOUNDARY 14	1.3530E+00
GROUP 15	2.8290E-05	BOUNDARY 15	1.1000E+00
GROUP 16	2.8290E-05	BOUNDARY 16	9.3720E-01
GROUP 17	2.8290E-05	BOUNDARY 17	7.4270E-01
GROUP 18	2.8290E-05	BOUNDARY 18	4.9790E-01
GROUP 19	2.8290E-05	BOUNDARY 19	3.3370E-01
GROUP 20	2.8290E-05	BOUNDARY 20	2.3470E-01
GROUP 21	2.8290E-05	BOUNDARY 21	1.5030E-01
GROUP 22	2.8290E-05	BOUNDARY 22	8.6520E-02
GROUP 23	2.8290E-05	BOUNDARY 23	3.1830E-02
GROUP 24	2.8290E-05	BOUNDARY 24	1.5830E-02
GROUP 25	2.8290E-05	BOUNDARY 25	7.1020E-03
GROUP 26	2.8290E-05	BOUNDARY 26	3.3550E-03
GROUP 27	2.8290E-05	BOUNDARY 27	1.5850E-03
GROUP 28	2.8290E-05	BOUNDARY 28	4.5400E-04
GROUP 29	2.8290E-05	BOUNDARY 29	1.0130E-04
GROUP 30	2.8290E-05	BOUNDARY 30	2.2600E-05
GROUP 31	2.8290E-05	BOUNDARY 31	1.0600E-05
GROUP 32	2.8290E-05	BOUNDARY 32	5.0440E-06
GROUP 33	2.8290E-05	BOUNDARY 33	2.3820E-06
GROUP 34	2.8290E-05	BOUNDARY 34	1.1250E-06
GROUP 35	2.8290E-05	BOUNDARY 35	4.1400E-07
		BOUNDARY 35	1.6600E-10

NAME	ID-NUMBER	MASS(KG)
ALUMINUM-27	13027	3.77E+02
ALUMINUM-30	13030	1.00E-10

ACDOS IS NOW READY TO RUN

THE FOLLOWING DATA HAVE BEEN ENTERED INTO MEMORY

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

35	1.000E-04	4.140E-01	2.029E-05	2.029E-05
34	4.140E-01	1.125E+00	2.029E-05	2.029E-05
33	1.125E+00	2.302E+00	2.029E-05	2.029E-05
32	2.302E+00	5.044E+00	2.029E-05	2.029E-05
31	5.044E+00	1.068E+01	2.029E-05	2.029E-05
30	1.068E+01	2.260E+01	2.029E-05	2.029E-05
29	2.260E+01	1.013E+02	2.029E-05	2.029E-05
28	1.013E+02	4.540E+02	2.029E-05	2.029E-05
27	4.540E+02	1.585E+03	2.029E-05	2.029E-05
26	1.585E+03	3.355E+03	2.029E-05	2.029E-05
25	3.355E+03	7.102E+03	2.029E-05	2.029E-05
24	7.102E+03	1.503E+04	2.029E-05	2.029E-05
23	1.503E+04	3.183E+04	2.029E-05	2.029E-05
22	3.183E+04	8.652E+04	2.029E-05	2.029E-05
21	8.652E+04	1.500E+05	2.029E-05	2.029E-05
20	1.500E+05	2.347E+05	2.029E-05	2.029E-05
19	2.347E+05	3.337E+05	2.029E-05	2.029E-05
18	3.337E+05	4.979E+05	2.029E-05	2.029E-05
17	4.979E+05	7.427E+05	2.029E-05	2.029E-05
16	7.427E+05	9.072E+05	2.029E-05	2.029E-05
15	9.072E+05	1.100E+06	2.029E-05	2.029E-05
14	1.100E+06	1.353E+06	2.029E-05	2.029E-05
13	1.353E+06	1.653E+06	2.029E-05	2.029E-05
12	1.653E+06	2.019E+06	2.029E-05	2.029E-05
11	2.019E+06	2.466E+06	2.029E-05	2.029E-05
10	2.466E+06	3.012E+06	2.029E-05	2.029E-05
9	3.012E+06	3.679E+06	2.029E-05	2.029E-05
8	3.679E+06	4.493E+06	2.029E-05	2.029E-05
7	4.493E+06	5.490E+06	2.029E-05	2.029E-05
6	5.490E+06	6.703E+06	2.029E-05	2.029E-05
5	6.703E+06	8.107E+06	2.029E-05	2.029E-05
4	8.107E+06	1.000E+07	2.029E-05	2.029E-05
3	1.000E+07	1.221E+07	2.029E-05	2.029E-05
2	1.221E+07	1.350E+07	2.029E-05	2.029E-05
1	1.350E+07	1.492E+07	2.029E-05	2.029E-05

THE FOLLOWING OUTPUT DATA ARE CALCULATED ACTIVITIES IN BQ

TIME(H)		1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET PRODUCT	ACT(T1)	ACT(T2)	ACT(T3)	ACT(T4)	ACT(T5)	ACT(T6)	ACT(T7)	ACT(T8)	
T(T12)									
13027	13026	1.65E-01	1.65E-01	1.65E-01	1.65E-01	1.65E-01	1.65E-01	1.65E-01	1.65E-01
13027	12027	2.60E+06	3.27E+04	5.16E+00	1.29E-07	7.99E-23	4.97E-38	2.86E-129	0.
13027	12026	0.	0.	0.	0.	0.	0.	0.	0.
13027	12025	0.	0.	0.	0.	0.	0.	0.	0.
13027	11024	8.20E+07	7.83E+07	7.14E+07	5.93E+07	4.10E+07	2.83E+07	3.08E+06	3.65E+04
13027	13028	2.87E+00	4.37E-08	1.01E-23	5.45E-55	1.58E-117	4.57E-190	0.	0.

TIME(H)		1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET	ACT(T1)	ACT(T2)	ACT(T3)	ACT(T4)	ACT(T5)	ACT(T6)	ACT(T7)	ACT(T8)	
T(T12)									
13027		8.46E+07	7.83E+07	7.14E+07	5.93E+07	4.10E+07	2.83E+07	3.08E+06	3.65E+04

ATTENTION-TARGET NUCLIDE NUMBER 13030 DOES NOT EXIST IN DATA LIBRARY.

THEREFORE-NO CONTRIBUTION FROM THIS NUCLIDE IN DOSE CALS.

TIME(H)		1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
SYSTEM	ACT(T1)	ACT(T2)	ACT(T3)	ACT(T4)	ACT(T5)	ACT(T6)	ACT(T7)	ACT(T8)	
T(T12)									
		3.46E+07	7.83E+07	7.14E+07	5.93E+07	4.10E+07	2.83E+07	3.08E+06	3.65E+04

THE FOLLOWING OUTPUT DATA ARE CALCULATED ENERGY ABSORPTION IN THE TARGET, FROM PRODUCT REACTION

SPHERE

TARGET ABSORBED ENERGY IN JOULES IN TIME T1
13027 2.00E+01
13030 0.

SYSTEM ABSORBED ENERGY IN JOULES IN TIME T1
2.00E+01

INFINITE CYLINDER

HEIGHT TO RADIUS RATIO= 7.50E-02
EQUIVALENT SPHERE RADIUS= 3.231E+01 CM

TARGET ABSORBED ENERGY IN JOULES IN TIME T1
13027 2.18E+01
13030 0.

SYSTEM ABSORBED ENERGY IN JOULES IN TIME T1
2.18E+01

THE FOLLOWING OUTPUT DATA ARE CALCULATED DOSERATES IN MREM/H.

TIME(H)		1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET PRODUCT		DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
R(T12)									
13027	11024	2.16E+01	2.06E+01	1.88E+01	1.56E+01	1.08E+01	7.45E+00	8.11E-01	9.62E-03
13027	12025	0.	0.	0.	0.	0.	0.	0.	0.
13027	12026	0.	0.	0.	0.	0.	0.	0.	0.
13027	13027	3.77E-03	4.74E-05	7.43E-09	1.87E-16	1.16E-31	7.20E-47	4.14-138	0.
13027	13028	0.	0.	0.	0.	0.	0.	0.	0.
13027	13028	7.10E-15	1.88E-22	2.51E-38	1.35E-69	3.90-132	1.13-194	0.	0.
PRODUCT DAUGHTER		DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
R(T13)									
11024	12024	0.	0.	0.	0.	0.	0.	0.	0.
13027	13027	0.	0.	0.	0.	0.	0.	0.	0.
13028	14028	0.	0.	0.	0.	0.	0.	0.	0.

TIME(H)		1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET		DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
R(T12)									
13027		2.16E+01	2.06E+01	1.88E+01	1.56E+01	1.08E+01	7.45E+00	8.11E-01	9.62E-03
TIME(H)		1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET PRODUCT		DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)

R(T12)
 PRODUCT DAUGHTER DSR(T1) DSR(T2) DSR(T3) DSR(T4) DSR(T5) DSR(T6) DSR(T7) DSR(T8)
 R(T12)

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.60E+02
TARGET	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
R(T12)								
13030	0.	0.	0.	0.	0.	0.	0.	0.

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.60E+02
SYSTEM	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
R(T12)								
	2.10E+01	2.06E+01	1.88E+01	1.56E+01	1.08E+01	7.43E+00	0.11E+01	9.62E-03

DATA FOR THE HOLLOW IRON CYLINDER .

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+1.6666667E+09
+0.025E+01 +1.575E+01 10
35
8
.100E+01 .100E+00 .200E+01 .000E+00 311
4
1
1.000E+00 2.000E+00 4.000E+00 8.000E+00 1.600E+01 2.400E+01
7.200E+01 1.600E+02
IRON-54 26054 5.233E+02
IRON-56 26056 8.548E+03
IRON-57 26057 2.077E+02
IRON-58 26058 3.166E+01
1.000E-10 4.140E-07 1.125E-06 2.302E-06 5.044E-06 1.068E-05
2.260E-05 1.013E-04 4.540E-04 1.505E-03 3.355E-03 7.102E-03
1.503E-02 3.103E-02 9.652E-02 1.500E-01 2.347E-01 3.337E-01
4.979E-01 7.427E-01 9.072E-01 1.100E+00 1.353E+00 1.653E+00
2.019E+00 2.466E+00 3.012E+00 3.679E+00 4.493E+00 5.400E+00
6.703E+00 8.187E+00 1.000E+01 1.221E+01 1.350E+01 1.492E+01
0 0
3.350E-06 3.350E-06 3.350E-06 3.350E-06 3.350E-06 3.350E-06
3.350E-06 3.350E-06 3.350E-06 3.350E-06 3.350E-06 3.350E-06
3.350E-06 3.350E-06 3.350E-06 3.350E-06 3.350E-06 3.350E-06
3.350E-06 3.350E-06 3.350E-06 3.350E-06 3.350E-06 3.350E-06
3.350E-06 3.350E-06 3.350E-06 3.350E-06 3.350E-06 3.350E-06
3.350E-06 3.350E-06 3.350E-06 3.350E-06 3.350E-06 3.350E-06

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Next pages : output for the cylinder when the tronccated-cone
assumption is used .

THE FOLLOWING DATA HAVE BEEN ENTERED INTO MEMORY

AMPERES	KILO-VOLTS	BEAMFRACTION	DUTYFACTOR	T1	T2	N
*****	*****	*****	*****	8.25E+00	1.58E+01	10

NUMBER OF ENERGY GROUPS-NOEGPS 35

NUMBER OF TARGET NUCLIDES-NUUCL 4

NUMBER OF POINTS AFTER SHUTDOWN-NOPAS 8

ISAB=1

IGEOM=3

IHEAT=1

YOU ARE USING AN ABSORBING SOURCE

YOU ARE CALCULATING THE ENERGY ABSORPTION IN THE TARGET

THIS SOURCE IS A HOLLOW CYLINDER

ITS OUTER RADIUS IS R= 1.000E+00 METERS

ITS THICKNESS IS TH= 1.000E-01 METERS

ITS HEIGHT IS H= 2.000E+00 METERS

THE OBSERVER FACES THE AXIS AT DISTANCE D= 0. METERS

THE SOLID CYLINDER EQUIVALENT TO THIS HOLLOW CYLINDER HAS

ITS RADIUS R= 4.359E-01 METERS

ITS HEIGHT H= 2.000E+00 METERS

A DISTANCE D= 5.879E-01 METERS FROM THE SURFACE TO THE OBSERVER ON ITS AXIS

NAME	ID-NUMBER	MASS(KG)
IRON-54	26054	5.23E+02
IRON-56	26056	8.55E+03
IRON-57	26057	2.08E+02
IRON-58	26058	3.17E+01

ACDOS IS NOW READY TO RUN

THE FOLLOWING DATA HAVE BEEN ENTERED INTO MEMORY

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

35	1.000E+04	4.140E+01	3.350E-06	3.350E-06
34	4.140E+01	1.125E+00	3.350E-06	3.350E-06
33	1.125E+00	2.382E+00	3.350E-06	3.350E-06
32	2.382E+00	5.044E+00	3.350E-06	3.350E-06
31	5.044E+00	1.060E+01	3.350E-06	3.350E-06
30	1.060E+01	2.260E+01	3.350E-06	3.350E-06
29	2.260E+01	1.013E+02	3.350E-06	3.350E-06
28	1.013E+02	4.540E+02	3.350E-06	3.350E-06
27	4.540E+02	1.585E+03	3.350E-06	3.350E-06
26	1.585E+03	3.355E+03	3.350E-06	3.350E-06
25	3.355E+03	7.102E+03	3.350E-06	3.350E-06
24	7.102E+03	1.503E+04	3.350E-06	3.350E-06
23	1.503E+04	3.183E+04	3.350E-06	3.350E-06
22	3.183E+04	8.652E+04	3.350E-06	3.350E-06
21	8.652E+04	1.500E+05	3.350E-06	3.350E-06
20	1.500E+05	2.347E+05	3.350E-06	3.350E-06
19	2.347E+05	3.337E+05	3.350E-06	3.350E-06
18	3.337E+05	4.979E+05	3.350E-06	3.350E-06
17	4.979E+05	7.427E+05	3.350E-06	3.350E-06
16	7.427E+05	9.072E+05	3.350E-06	3.350E-06
15	9.072E+05	1.100E+06	3.350E-06	3.350E-06
14	1.100E+06	1.353E+06	3.350E-06	3.350E-06
13	1.353E+06	1.653E+06	3.350E-06	3.350E-06
12	1.653E+06	2.019E+06	3.350E-06	3.350E-06
11	2.019E+06	2.466E+06	3.350E-06	3.350E-06
10	2.466E+06	3.012E+06	3.350E-06	3.350E-06
9	3.012E+06	3.679E+06	3.350E-06	3.350E-06
8	3.679E+06	4.493E+06	3.350E-06	3.350E-06
7	4.493E+06	5.438E+06	3.350E-06	3.350E-06
6	5.438E+06	6.703E+06	3.350E-06	3.350E-06
5	6.703E+06	8.107E+06	3.350E-06	3.350E-06
4	8.107E+06	1.000E+07	3.350E-06	3.350E-06
3	1.000E+07	1.221E+07	3.350E-06	3.350E-06
2	1.221E+07	1.350E+07	3.350E-06	3.350E-06
1	1.350E+07	1.492E+07	3.350E-06	3.350E-06

THE FOLLOWING OUTPUT DATA ARE CALCULATED ACTIVITIES IN 80

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET PRODUCT	ACT(T1)	ACT(T2)	ACT(T3)	ACT(T4)	ACT(T5)	ACT(T6)	ACT(T7)	ACT(T8)
26054 26053	2.96E+03	2.26E+01	1.32E-03	4.49E-12	5.21E-29	6.03E-46	1.46E-147	0.
26054 26053	1.50E-02	1.50E-02	1.50E-02	1.50E-02	1.50E-02	1.50E-02	1.50E-02	1.50E-02
26054 24050	0.	0.	0.	0.	0.	0.	0.	0.
26054 25054	9.17E+05	9.17E+05	9.16E+05	9.16E+05	9.15E+05	9.15E+05	9.11E+05	9.03E+05
26054 25053	1.60E+00	1.60E+00	1.60E+00	1.60E+00	1.60E+00	1.60E+00	1.60E+00	1.60E+00
26054 25052	5.13E+02	5.11E+02	5.05E+02	4.95E+02	4.75E+02	4.56E+02	3.56E+02	2.17E+02
26054 25052	1.09E+02	1.52E+01	2.95E-01	1.11E-04	1.59E-11	2.26E-18	1.88E-59	1.30E-141
26054 24051	7.54E+05	7.53E+05	7.51E+05	7.48E+05	7.42E+05	7.36E+05	7.08E+05	6.33E+05
26054 26055	3.16E+05	3.16E+05	3.16E+05	3.16E+05	3.16E+05	3.16E+05	3.16E+05	3.15E+05

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET	ACT(T1)	ACT(T2)	ACT(T3)	ACT(T4)	ACT(T5)	ACT(T6)	ACT(T7)	ACT(T8)
26054	1.99E+06	1.99E+06	1.98E+06	1.98E+06	1.97E+06	1.97E+06	1.93E+06	1.85E+06

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET PRODUCT	ACT(T1)	ACT(T2)	ACT(T3)	ACT(T4)	ACT(T5)	ACT(T6)	ACT(T7)	ACT(T8)
26056 26055	8.23E+05	8.00E+05	6.00E+05	8.00E+05	7.99E+05	7.99E+05	7.98E+05	7.96E+05
26056 25055	0.	0.	0.	0.	0.	0.	0.	0.
26056 24052	0.	0.	0.	0.	0.	0.	0.	0.
26056 25056	1.49E+08	1.13E+08	6.68E+07	2.25E+07	2.63E+06	3.08E+05	7.81E-01	5.04E-12
26056 25055	0.	0.	0.	0.	0.	0.	0.	0.
26056 25054	1.24E+02	1.24E+02	1.24E+02	1.24E+02	1.24E+02	1.24E+02	1.23E+02	1.22E+02
26056 24053	0.	0.	0.	0.	0.	0.	0.	0.
26056 26057	0.	0.	0.	0.	0.	0.	0.	0.

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET	ACT(T1)	ACT(T2)	ACT(T3)	ACT(T4)	ACT(T5)	ACT(T6)	ACT(T7)	ACT(T8)
26056	1.49E+08	1.14E+08	6.68E+07	2.33E+07	3.43E+06	1.11E+06	7.99E+05	7.96E+05

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET PRODUCT	ACT(T1)	ACT(T2)	ACT(T3)	ACT(T4)	ACT(T5)	ACT(T6)	ACT(T7)	ACT(T8)
26057 26056	0.	0.	0.	0.	0.	0.	0.	0.
26057 26055	0.	0.	0.	0.	0.	0.	0.	0.
26057 25056	1.44E+04	1.10E+04	6.43E+03	2.20E+03	2.57E+02	3.00E+01	7.61E-05	4.91E-16
26057 24053	0.	0.	0.	0.	0.	0.	0.	0.
26057 25057	1.37E-05	6.04E-17	1.17E-39	4.34E-85	6.02E-176	8.36E-267	0.	0.
26057 25056	3.49E+04	2.67E+04	1.56E+04	5.32E+03	6.20E+02	7.23E+01	1.81E-04	1.13E-15
26057 25055	0.	0.	0.	0.	0.	0.	0.	0.
26057 24054	0.	0.	0.	0.	0.	0.	0.	0.
26057 26058	0.	0.	0.	0.	0.	0.	0.	0.

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET	ACT(T1)	ACT(T2)	ACT(T3)	ACT(T4)	ACT(T5)	ACT(T6)	ACT(T7)	ACT(T8)
26057	4.93E+04	3.77E+04	2.20E+04	7.52E+03	8.77E+02	1.02E+02	2.57E-04	1.62E-15

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET PRODUCT	ACT(T1)	ACT(T2)	ACT(T3)	ACT(T4)	ACT(T5)	ACT(T6)	ACT(T7)	ACT(T8)
26050 26057	0.	0.	0.	0.	0.	0.	0.	0.
26050 26056	0.	0.	0.	0.	0.	0.	0.	0.
26050 25057	0.	0.	0.	0.	0.	0.	0.	0.
26050 24054	0.	0.	0.	0.	0.	0.	0.	0.
26050 25050	2.23E-12	4.77E-29	2.19E-62	4.63-129	2.06-262	0.	0.	0.
26050 25056	1.30E+01	9.97E+00	5.02E+00	1.99E+00	2.32E-01	2.70E-02	6.76E-08	4.23E-19
26050 24055	6.17E-01	5.22E-06	3.74E-16	1.92E-36	5.05E-77	1.33-117	0.	0.
26050 26059	2.23E+05	2.22E+05	2.22E+05	2.22E+05	2.20E+05	2.19E+05	2.13E+05	2.00E+05

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET	ACT(T1)	ACT(T2)	ACT(T3)	ACT(T4)	ACT(T5)	ACT(T6)	ACT(T7)	ACT(T8)
26058	2.23E+05	2.22E+05	2.22E+05	2.22E+05	2.20E+05	2.19E+05	2.13E+05	2.00E+05

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
SYSTEM	ACT(T1)	ACT(T2)	ACT(T3)	ACT(T4)	ACT(T5)	ACT(T6)	ACT(T7)	ACT(T8)
	1.51E+09	1.16E+08	6.90E+07	2.56E+07	5.63E+06	3.29E+06	2.94E+06	2.85E+06

THE FOLLOWING OUTPUT DATA ARE CALCULATED ENERGY ABSORPTION IN THE TARGET, FROM PRODUCT REACTION

SPHERE

TARGET ABSORBED ENERGY IN JOULES IN TIME T1

26054	1.08E+01
26056	9.75E+01
26057	2.84E+00
26058	1.39E-01

SYSTEM ABSORBED ENERGY IN JOULES IN TIME T1

1.11E+02

INFINITE CYLINDER

HEIGHT TO RADIUS RATIO= 2.179E-01
EQUIVALENT SPHERE RADIUS= 6.578E+01 CM

TARGET ABSORBED ENERGY IN JOULES IN TIME T1

26054	1.08E+01
26056	9.75E+01
26057	2.83E+00
26058	1.39E-01

SYSTEM ABSORBED ENERGY IN JOULES IN TIME T1

1.11E+02

THE FOLLOWING OUTPUT DATA ARE CALCULATED DOSERATES IN REM/H.

ATTENTION-PRODUCT NUCLIDE NUMBER 26056 DOES NOT EXIST IN DECAY
LIBRARY-THEREFORE NO CONTRIBUTION FROM THIS NUCLIDE IN DOSE CALCS
THE TARGET ATOM WAS 26057

TIME (H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET PRODUCT	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
26054 24050	0.	0.	0.	0.	0.	0.	0.	0.
26054 24051	0.	0.	0.	0.	0.	0.	0.	0.
26054 25052	3.24E-07	3.22E-07	3.19E-07	3.13E-07	3.00E-07	2.88E-07	2.25E-07	1.37E-07
26054 25052	2.87E-08	2.88E-09	5.60E-11	2.11E-14	3.81E-21	4.28E-29	3.56E-69	2.47E-151
26054 25053	0.	0.	0.	0.	0.	0.	0.	0.
26054 25053	0.	0.	0.	0.	0.	0.	0.	0.
26054 25054	0.	0.	0.	0.	0.	0.	0.	0.
26054 26053	0.	0.	0.	0.	0.	0.	0.	0.
26054 26055	0.	0.	0.	0.	0.	0.	0.	0.
PRODUCT DAUGHTER	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)

TIME (H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
26054	3.45E-07	3.25E-07	3.19E-07	3.13E-07	3.00E-07	2.88E-07	2.25E-07	1.37E-07

TIME (H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET PRODUCT	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
26056 24052	0.	0.	0.	0.	0.	0.	0.	0.
26056 24053	0.	0.	0.	0.	0.	0.	0.	0.
26056 25054	0.	0.	0.	0.	0.	0.	0.	0.
26056 25055	0.	0.	0.	0.	0.	0.	0.	0.
26056 25055	0.	0.	0.	0.	0.	0.	0.	0.
26056 25056	7.72E-02	5.90E-02	3.45E-02	1.18E-02	1.38E-03	1.61E-04	4.09E-10	2.64E-21
26056 26053	0.	0.	0.	0.	0.	0.	0.	0.
26056 26057	0.	0.	0.	0.	0.	0.	0.	0.
PRODUCT DAUGHTER	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
25056 26056	0.	0.	0.	0.	0.	0.	0.	0.

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
26056	7.72E-02	5.90E-02	3.45E-02	1.10E-02	1.30E-03	1.61E-04	4.09E-10	2.64E-21

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET PRODUCT	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
26057 24053	0.	0.	0.	0.	0.	0.	0.	0.
26057 24054	0.	0.	0.	0.	0.	0.	0.	0.
26057 25055	0.	0.	0.	0.	0.	0.	0.	0.
26057 25056	7.52E-06	5.75E-06	3.36E-06	1.15E-06	1.34E-07	1.57E-08	3.98E-14	2.57E-25
26057 25057	8.75E-27	3.85E-38	7.42E-61	2.76E-106	3.84E-197	5.32E-288	0.	0.
26057 26055	0.	0.	0.	0.	0.	0.	0.	0.
26057 26056	0.	0.	0.	0.	0.	0.	0.	0.
26057 26057	0.	0.	0.	0.	0.	0.	0.	0.
26057 26058	0.	0.	0.	0.	0.	0.	0.	0.
PRODUCT DAUGHTER	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
25056 26056	0.	0.	0.	0.	0.	0.	0.	3.
25057 26057	0.	0.	0.	0.	0.	0.	0.	0.

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
26057	7.52E-06	5.75E-06	3.36E-06	1.15E-06	1.34E-07	1.57E-08	3.98E-14	2.57E-25

TIME(H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET PRODUCT	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
26058 24054	0.	0.	0.	0.	0.	0.	0.	0.
26058 24055	1.52E-18	1.20E-23	9.19E-34	4.71E-54	1.24E-94	3.27E-135	0.	0.
26058 25056	6.02E-09	5.21E-09	3.05E-09	1.04E-09	1.21E-10	1.41E-11	3.53E-17	2.21E-28
26058 25057	0.	0.	0.	0.	0.	0.	0.	0.
26058 25058	3.67E-38	7.86E-55	3.61E-88	7.62E-155	3.40E-288	0.	0.	0.

26050	26056	0.	0.	0.	0.	0.	0.	0.	0.
26050	26057	0.	0.	0.	0.	0.	0.	0.	0.
26050	26059	1.43E-04	1.43E-04	1.43E-04	1.43E-04	1.42E-04	1.41E-04	1.37E-04	1.29E-04
PRODUCT	DAUGHTER	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
24055	25055	0.	0.	0.	0.	0.	0.	0.	0.
25056	26056	0.	0.	0.	0.	0.	0.	0.	0.
25050	26050	0.	0.	0.	0.	0.	0.	0.	0.
26059	27059	0.	0.	0.	0.	0.	0.	0.	0.

TIME (H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
TARGET	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
26058	1.43E-04	1.43E-04	1.43E-04	1.43E-04	1.42E-04	1.41E-04	1.37E-04	1.29E-04

TIME (H)	1.00E+00	2.00E+00	4.00E+00	8.00E+00	1.60E+01	2.40E+01	7.20E+01	1.68E+02
SYSTEM	DSR(T1)	DSR(T2)	DSR(T3)	DSR(T4)	DSR(T5)	DSR(T6)	DSR(T7)	DSR(T8)
	7.73E-02	5.92E-02	3.45E-02	1.19E-02	1.52E-03	3.03E-04	1.37E-04	1.29E-04

APPENDIX 4

ACDOS3 listing

```

PROGRAM ACDS3(INPUT,OUTPUT,TAP5=INPUT,TAP6,TAP7,TAP9,
+TAP6=OUTPUT)
CALL LINK('UNIT5=DONNEE,UNIT6=(RESULTS.CREATE,HARDCOPY),UNIT7=
+ACTL2,UNIT9=LEVDEC,UNIT8=FLUXIN,READ5,PRINT6//')

```

ACDS3

A NEUTRON-INDUCED DOSE RATE CALCULATION CODE
 WRITTEN BY G S KENEY, J-C LAGACHE AND C S MARTIN
 AT THE UNIVERSITY OF CALIFORNIA BERKELEY

ACDS3 IS A STANDARD FORTRAN-4 CODE DEVELOPED FOR CALCULATING DOSE
 RATES FROM NEUTRON ACTIVATION OF NEUTRAL-BEAM INJECTORS. SUFFICIENT
 VERSATILITY HAS ALSO BEEN INCORPORATED INTO THE CODE TO MAKE IT
 APPLICABLE TO A WIDE VARIETY OF GENERAL ACTIVATION PROBLEMS DUE TO
 NEUTRONS OF ENERGY LESS THAN 20 MEV. FOR FURTHER INFORMATION
 CONCERNING THIS PROGRAM, SEE LBL REPORT NO. 12711 BY J-C LAGACHE,
 AND LBL REPORT NO. 14547 BY C. S. MARTIN.

VARIABLES AND ARRAYS ARE DEFINED AS BELOW

A	CURRENT IN AMPERES
ACT	ACTIVITY DUE TO ACTIVATION OF A PARTICULAR TARGET NUCLEIDE BY A SPECIFIC NEUTRON REACTION
AMU	MASS ATTENUATION COEFFICIENT
AVENPS	AVERAGE NUMBER OF NEUTRONS PRODUCED PER SECOND
BFA	COEFFICIENT A OF THE TAYLOR EXPANSION OF THE BUILD-UP FACTOR
BALPH1	COEFFICIENT ALPHA 1 OF THE TAYLOR EXPANSION OF THE BUILD-UP FACTOR
BALPH2	COEFFICIENT ALPHA 2 OF THE TAYLOR EXPANSION OF THE BUILD-UP FACTOR
BFUX(I)	UNIT NORMALIZED FLUX
CF	NEUTRON YIELD CORRECTION FACTOR FOR VOLTAGES DIFFERENT FROM 150 KV
CONST(I)	CONSTANTS FOR WEIGHTING FUNCTIONS
CS(I)	CROSS SECTION VALUE
CS1(I)	CROSS SECTION VALUE
D	DISTANCE FROM POINT SOURCE OR SURFACE OF SPHERE OR CYLINDER
DF	DUTY-FACTOR

C	DIFF	DIFFERENCE BETWEEN THE LATEST REFINED GUESS AND THE PREVIOUS GUESS
C	DOSE	GEOMETRIC FACTOR IN THE DOSERATE CALCULATION (VOLUMETRIC SOURCE- CM ; POINT SOURCE- CM-2)
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	DOSPRD(I)	DOSE DUE TO A PRODUCT AT SHUTDOWN
C	DOSPRO(I)	DOSE DUE TO A GIVEN PRODUCT ALONE
C	DOSSUM(I)	DOSE RATE DUE TO A PARTICULAR TARGET NUCLIDE FOR UP TO 12 DIFFERENT TIMES
C	DPVAR	VALUE OF DEPENDENT VARIABLE IN NUMERICAL INTEGRATION'S
C	DR	TOTAL ENERGY ABSORPTION IN THE TARGET
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	FLUXBD	WEIGHTING FLUX AT A GROUP BOUNDARY
C	FPRINE	EVALUATED VALUE OF THE DERIVATIVE OF THE TRANSCENDENTAL EQUATION FOR B
C	FXSUBI	EVALUATED VALUE OF THE TRANSCENDENTAL EQUATION FOR B
C	GFC	GEOMETRIC CORRECTION IN THE CASE OF AN ABSORBING CYLINDER
C	GFS	GEOMETRIC CORRECTION IN THE CASE OF AN ABSORBING SPHERE
C	GME(I)	MEAN ENERGY IN GROUP I-UP TO 50
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 EQUATIONS
C	H	HEIGHT OF CYLINDER (M)
C	HEATSP(I)	ENERGY ABSORPTION IN NUCLIDE I-UP TO 30
C	HEATCY(I)	ENERGY ABSORPTION IN NUCLIDE I-UP TO 30
C	ICOUNT	NEUTRON GROUP COUNTER
C	ICP1	ICOUNT+1
C	ICP2	ICOUNT+2
C	ID	2 DIGIT REACTION ID-NUMBER IN ACTL2
C	IDNO(I)	5 DIGIT ID NUMBER OF TARGET NUCLIDE
C	IDUMB	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	IHEAT	OPTION TO CALCULATE OR SKIP THE ENERGY ABSORPTION IN THE TARGET
C	INSNPS	INSTANTANEOUS NUMBER OF NEUTRONS PRODUCED PER 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 MATERIAL

C	MASS(1)	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(1)	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(1)	HOLDING ARRAY FOR PRODUCT NUCLIDE NUMBERS THAT 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 WILL BE CALCULATED BY ACDS OR READ FROM A DATA CARD AS PRE-DETERMINED INPUT
C	PARSUM	PARTIAL SUM IN NUMERICAL INTEGRATIONS
C	PCS	COLLISION PROBABILITY FOR A SPHERE
C	PCC	COLLISION PROBABILITY FOR A INFINITE CYLINDER
C	PRODHL(1,J)	PRODUCT NUCLIDE HALF-LIFE (S)
C	PRODNU(1,J)	5 DIGIT ID NUMBER OF PRODUCT NUCLIDE
C	Q	REACTION ENERGY IN ACTL2 LIBRARY (MEV)
C	R	OUTER RADIUS OF CAVITY OR HOLLOW SPHERE OR HOLLOW CYLINDER (M)
C	REALDUM	REAL DUMMY VARIABLE FOR ADVANCING DISK FILE RECORDS
C	SOU	DOSE RATE SOURCE STRENGTH DIVIDED BY THE UNIT DOSE RATE FLUX
C	STAFS(1)	SPECIFIC TIMES AFTER SHUTDOWN (H)
C	STOPHL(1)	HOLDING ARRAY FOR PRODUCT NUCLIDE ID NUMBERS
C	STOTAC(1,J)	HOLDING ARRAY FOR PRODUCT NUCLIDE ACTIVITIES
C	SUMACT(1)	SUM OF ACTIVITIES PRODUCED FROM A PARTICULAR TARGET NUCLIDE FOR UP TO 12 DIFFERENT TIMES
C	SUM1	EXPONENTIAL EFFECT OF TESTS AND PHASES ON THE SHUTDOWN TIME ACTIVITY OF A SPECIFIC PRODUCT NUCLIDE
C	SUMDEL	RUNNING SUM OF AVERAGE CROSS SECTIONS
C	SUMINT	RESULT OF NUMERICAL INTEGRATIONS
C	SYSACT(1)	SYSTEM ACTIVITY FOR UP TO 12 DIFFERENT TIMES
C	SYSDOSE(1)	SYSTEM DOSE RATE FOR UP TO 12 DIFFERENT TIMES
C	TARMA5	ATOMIC WEIGHT OF TARGET NUCLIDE (AMU)
C	TEMPS	TEMPORARY STORAGE FOR DO LOOP SUMS
C	TH	THICKNESS OF CAVITY OR HOLLOW SPHERE OR HOLLOW CYLINDER (M)
C	TIMACT(1,J,K)	INDUCED ACTIVITY AS A FUNCTION OF TARGET 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	XSUB1	INDEPENDENT VARIABLE OF THE TRANSCENDENTAL EQUATION FOR B
C	ZINCR	INCREMENT IN ENERGY USED IN NUMERICAL INTEGRATIONS
C	ZNAME	VARIABLE FOR NUCLIDE NAMES
C	ZNUMBER	NUMERATOR IN THE TRANSCENDENTAL EQUATION FOR B

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C

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      DIMENSION TIMACT(30,13,12),SYSACT(12),SUMACT(12),SYSDOS(12),PRODHL
      +(30,13),PRODNU(30,13),DOSSUM(12),ZNAM1(30),STAFS(12),BFLUX(50),IDN
      +O(30),GPXSEC(50),MASS(30),GPFLUX(50),GP(51),ZNAM2(30)
      DIMENSION CONST(50),FCONST(50),GME(50),HEATSP(30),HEATCY(30)
      DIMENSION DOSNUC(13),DOSDGT(13),DOSPRO(13)
      COMMON A,V,F,DF,T1,T2,N,R,TH,D,H,OPTION,IGEOM,ISAO,IHEAT,VOLU,DOSE
      REAL INSNPS,MASS
      CALL INPUT(NONUCL,NOEGPS,NOPAS,NG,NF)
      CALL ARRAYIN(BFLUX,ZNAM1,IDNO,MASS,STAFS,GP,NOEGPS,NONUCL,NOPAS,NG,
      +TMASS,ZNAM2)
      IF(OPTION.EQ.0.0000000) GO TO 1
      AVENPS=OPTION
      WRITE(6,20)
20  FORMAT(1H1,40HTHE FOLLOWING DATA HAVE BEEN ENTERED INTO MEMORY.,/)
      +49H ////////////////////////////////////////////////////////////////////
      GO TO 2
1  CALL SOURCE(AVENPS)
2  CALL GRFLUX(AVENPS,NOEGPS,GPFLUX,DFLUX)
   CALL WFLUX(BFLUX,GP,CONST,FCONST,NOEGPS,NF,NG)
   CALL ACTVAT(TIMACT,SYSACT,SUMACT,GPFLUX,PRODNU,PRODHL,GPXSEC,IDNO,
      +MASS,STAFS,GP,CONST,FCONST,BFLUX,NONUCL,NOEGPS,NOPAS,NG,NF,TMASS,G
      +ME,HEATSP,HEATCY)
   CALL DOSRTE(TIMACT,PRODNU,NONUCL,NOPAS,DOSSUM,SYSDOS,IDNO,STAFS,PR
      +ODHL,DOSNUC,TMASS,DOSDGT,DOSPRO)
   CALL EXIT
   STOP
   END
   SUBROUTINE INPUT(NONUCL,NOEGPS,NOPAS,NG,NF)

```

C

C
C
C
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C

THIS PROGRAM IS USED FOR ENTERING 'VARIABLE' DATA INTO MEMORY

ARGUMENTS IN-NONE

ARGUMENTS OUT-NONUCL,NOEGPS,NOPAS,NG,NF

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      COMMON A,V,F,DF,T1,T2,N,R,TH,D,H,OPTION,IGEOM,ISAO,IHEAT,VOLU,DOSE
      READ(5,61) OPTION
61  FORMAT(E14,7)
      IF(OPTION.NE.0.0000000E+00) GO TO 62
      READ(5,1) A,V,F,DF,T1,T2,N
1   FORMAT(6(E10.3,2X),13)
3   READ(3,2) NOEGPS
2   FORMAT(12)
      READ(5,2) NOPAS
      READ(5,5) R,TH,H,D,IGEOM,ISAO,IHEAT
5   FORMAT(4(E10.3,2X),3(11))
      READ(5,2) NONUCL
      READ(5,2) NF
      GO TO 19
62  READ(5,63) T1,T2,N
63  FORMAT(2(E10.3,2X),13)
      GO TO 3
19  WRITE(6,20)
20  FORMAT(1H1,40HTHE FOLLOWING DATA HAVE BEEN ENTERED INTO MEMORY.,/)

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+49H *****)
WRITE(6,21)
21 FORMAT(1H0,85HAMPERES      KILO-VOLTS      BEAMFRACTION      DUTYFA
+CTOR      T1      T2      H)
IF(OPTION.EQ.0.0000000) WRITE(6,13) A,V,F,DF,T1,T2,N
13 FORMAT(1H0,E8.2,4X,E8.2,8X,E8.2,11X,E8.2,6X,E8.2,3X,E8.2,3X,13,///
+)
IF(OPTION.NE.0.0000000) WRITE(6,65) T1,T2,N
65 FORMAT(1H0,55H*****      *****      *****      *)
+***,6X,2(E8.2,3X),13,///)
WRITE(6,22) NOEGPS
22 FORMAT(1H ,39HNUMBER OF ENERGY GROUPS-NOEGPS      ,12,/)
WRITE(6,75) NONUCL
75 FORMAT(1H ,39HNUMBER OF TARGET NUCLIDES-NONUCL      ,12,/)
WRITE(6,23) NOPAS
23 FORMAT(1H ,39HNUMBER OF POINTS AFTER SHUTDOWN-NOPAS      ,12,/)
WRITE(6,89) ISAB,IGEOM,IHEAT
89 FORMAT(1X,5HISAB=,11,///,7H IGEOM=,11,///,7H IHEAT=,11,/)
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 ADSORBING SOURCE,/)
IF(IHEAT.EQ.0) WRITE(6,103)
103 FORMAT(1X,59HYOU ARE NOT CALCULATING THE ENERGY ABSORPTION IN THE +
+TARGET,/)
IF(IHEAT.EQ.1) WRITE(6,104)
104 FORMAT(1X,55HYOU ARE CALCULATING THE ENERGY ABSORPTION IN THE TARG+
+ET,/)
IF(IGEOM.EQ.1)GO TO 80
IF(IGEOM.EQ.2)GO TO 80
IF(IGEOM.EQ.3)GO TO 80
IF(IGEOM.EQ.4)GO TO 80
GO TO 67
80 IF(ISAB.EQ.0)GO TO 71
IF(ISAB.EQ.1)GO TO 71
GO TO 81
71 IF(IHEAT.EQ.0) GO TO 107
IF(IHEAT.EQ.1) GO TO 107
GO TO 101

C
C DETERMINATION OF GEOMETRIC PARAMETERS BEGINS
C
107 IF(IGEOM.EQ.1) GOTO 105
GOTO 106
105 WRITE(6,85) D
85 FORMAT(1X,29HTHE SOURCE IS A POINT-SOURCE,/,42H THE OBSERVER IS ST
+ANDING AT A DISTANCE D=,E10.3,23H METERS FROM THE SOURCE,/)
IF(D.LE.0.0) GOTO 49
CALL DPOINT(D,DOSE)
GOTO 95

C
105 IF(IGEOM.EQ.2) GOTO 92
GOTO 91
92 WRITE(6,86) R,TH,D
86 FORMAT(1X,29HTHE SOURCE IS A HOLLOW SPHERE,/,
+23H ITS OUTER RADIUS IS R=,E10.3,7H METERS,/,
+21H ITS THICKNESS IS TH=,E10.3,7H METERS,/,
+33H THE OBSERVER IS AT A DISTANCE D=,E10.3,
+39H METERS FROM THE SURFACE OF THIS SPHERE,/)
IF((R.LE.0.0).OR.(D.LT.0.0)) GOTO 49

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      IF (TH.LE.0.0) GOTO 93
      CALL NEWTON(R,TH,D,VOLU,DOSE)
      IF (TH.EQ.R) GOTO 95
      WRITE(6,90) R,D
90  FORMAT(1X,53H THE SOLID SPHERE EQUIVALENT TO THIS HOLLOW SPHERE HAS
      +,/,14H ITS RADIUS R=,E10.3,7H METERS,/,14H A DISTANCE D=,E10.3,
      +40H METERS FROM ITS SURFACE TO THE OBSERVER,/)
      GOTO 95
C
91  IF (IGEOM.EQ.3) GOTO 90
      GOTO 99
98  WRITE(6,87) R,TH,H,D
87  FORMAT(1X,32H THIS SOURCE IS A HOLLOW CYLINDER,/,23H ITS OUTER RADI
      +US IS R=,E10.3,7H METERS,/,21H ITS THICKNESS IS TH=,E10.3,
      +7H METERS,/,17H ITS HEIGHT IS H=,E10.3,7H METERS,/,
      +43H THE OBSERVER FACES THE AXIS AT DISTANCE D=,E10.3,7H METERS,/)
      IF ((R.LE.0.0).OR.(D.LT.0.0)) GOTO 49
      IF (H.LE.0.0) GOTO 77
      IF (TH.LE.0.0) GOTO 93
      CALL CYLIN(R,TH,H,D,VOLU,DOSE)
      IF (TH.EQ.R) GOTO 95
      WRITE(6,96) R,H,D
96  FORMAT(1X,57H THE SOLID CYLINDER EQUIVALENT TO THIS HOLLOW CYLINDER
      + HAS,/,14H ITS RADIUS R=,E10.3,7H METERS,/,14H ITS HEIGHT H=,
      +E10.3,7H METERS,/,14H A DISTANCE D=,E10.3,
      +52H METERS FROM THE SURFACE TO THE OBSERVER ON ITS AXIS,/)
      GOTO 95
C
99  IF (IGEOM.EQ.4) WRITE(6,80) R,TH
88  FORMAT(1X,33H THIS SOURCE IS A SPHERICAL CAVITY,/,23H ITS OUTER RAD
      +IUS IS R=,E10.3,7H METERS,/,21H ITS THICKNESS IS TH=,E10.3,7H METE
      +RS,/,44H THE OBSERVER IS AT THE CENTER OF THE CAVITY,/)
      IF (R.LE.0.0) GOTO 49
      IF (TH.LE.0.0) GOTO 93
      CALL DCAV(R,TH,VOLU,DOSE)
C
95  NG=NOEGPS+1
      WRITE(6,72) NG
72  FORMAT(1H,39H NUMBER OF GROUPS BOUNDARIES-NG,12,/)
      WRITE(6,76) NF
76  FORMAT(1H,39H NUMBER OF FAST NEUTRON GROUPS-NF,12,/)
      IF (OPTION.NE.0.0000000) WRITE(6,66) OPTION
66  FORMAT(1H,46H AVERAGE NUMBER OF NEUTRONS PRODUCED PER SECOND,4X,E1
      +0.4,/)
      IF (OPTION.NE.0.000000E+00) GOTO 64
      IF (A.LE.0.0) GOTO 36
      IF (V.LT.30.0.OR.V.GT.300.0) GOTO 37
      IF (F.LE.0.0.OR.F.GT.1.0) GOTO 38
      IF (DF.LE.0.0.OR.DF.GT.1.0) GOTO 39
64  IF (T1.LE.0.0) GOTO 40
      IF (T2.LT.0.0) GOTO 41
      DO 47 K=1,999
      IF (N.EQ.K) GOTO 430
42  CONTINUE
      GO TO 44
430  DO 45 K=1,50
      IF (NOEGPS.EQ.K) GOTO 460
45  CONTINUE
      GO TO 9
460  DO 47 K=1,12

```

```

      IF(NOPAS.EQ.K) GO TO 70
47  CONTINUE
      GO TO 10
70  DO 50 K=1,30
      IF(NONUCL.EQ.K) GO TO 510
50  CONTINUE
      GO TO 11
      9  WRITE(6,12)
12  FORMAT(1H ,110HPROGRAM 'ACDOS' ABORTED-NUMBER OF ENERGY GROUPS MUST
      +T BE INTEGER AND LESS THAN OR EQUAL TO 50-RECHECK THIS DATA)
      STOP
10  WRITE(6,14)
14  FORMAT(1H ,110HPROGRAM 'ACDOS' ABORTED-NUMBER OF POINTS AFTER SHUT
      +DOWN MUST 25 INTEGER AND LESS THAN OR EQUAL TO 12-RECHECK THIS DAT
      +A)
      STOP
11  WRITE(6,17)
17  FORMAT(1H ,96HPROGRAM 'ACDOS' ABORTED-NUMBER OF NUCLIDES IN SYSTEM
      +MUST BE INTEGER AND LESS THAN OR EQUAL TO 30)
      STOP
36  WRITE(6,52)
52  FORMAT(1H ,80HPROGRAM 'ACDOS' ABORTED-CURRENT MUST BE GREATER THAN
      + 0 AMPERES-RECHECK THIS DATA)
      STOP
37  WRITE(6,53)
53  FORMAT(1H ,89HPROGRAM 'ACDOS' ABORTED-VOLTAGE MUST BE BETWEEN 30 A
      +ND 300 KV INCLUSIVE-RECHECK THIS DATA)
      STOP
38  WRITE(6,54)
54  FORMAT(1H ,107HPROGRAM 'ACDOS' ABORTED-BEAMFRACTION MUST BE GREATER
      +R THAN 0 AND LESS THAN OR EQUAL TO 1.0-RECHECK THIS DATA)
      STOP
39  WRITE(6,55)
55  FORMAT(1H ,107HPROGRAM 'ACDOS' ABORTED-DUTYFACTOR MUST BE GREATER +
      +THAN 0.0 AND LESS THAN OR EQUAL TO 1.0-RECHECK THIS DATA)
      STOP
40  WRITE(6,56)
56  FORMAT(1H ,78HPROGRAM 'ACDOS' ABORTED-PULSE LENGTH MUST BE GREATER
      +THAN 0.0-RECHECK THIS DATA)
      STOP
93  WRITE(6,94)
94  FORMAT(1H ,105HPROGRAM 'ACDOS' ABORTED-THICKNESS OF HOLLOW SPHERE +
      +OR CYLINDER MUST BE GREATER THAN 0.0-RECHECK THIS DATA)
      STOP
41  WRITE(6,57)
57  FORMAT(1H ,90HPROGRAM 'ACDOS' ABORTED-PAUSE LENGTH MUST BE GREATER
      +THAN 0.0-RECHECK THIS DATA)
      STOP
44  WRITE(6,58)
58  FORMAT(1H ,104HPROGRAM 'ACDOS' 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 'ACDOS' ABORTED-R MUST BE GREATER THAN 0.0 +
      +EQUAL TO 0.0 AND 0 GREATER THAN 0.0-RECHECK THIS DATA)
      STOP
77  WRITE(6,78)
78  FORMAT(1H ,80HPROGRAM 'ACDOS' ABORTED-H MUST BE GREATER THAN 0.0 +
      +UAL TO 0.0-RECHECK THIS DATA)
      STOP

```

```

67 WRITE(6,63)
68 FORMAT(1H,66HPROGRAM 'ACDOS' ABORTED-IGEOM MUST BE 1,2,3,OR 4-RECH
+ECK THIS DATA)
STOP
81 WRITE(6,82)
82 FORMAT(1H,60HPROGRAM 'ACDOS' ABORTED-ISAB MUST BE 0,OR 1-RECHECK
+THIS DATA)
STOP
101 WRITE(6,102)
102 FORMAT(1H,62HPROGRAM 'ACDOS' ABORTED-IHEAT MUST BE 0,OR 1-RECHECK+
+ THIS DATA)
STOP
510 RETURN
END
SUBROUTINE ARRAYIN(BFLUX,ZNAM1,IDNO,MASS,STAFS,GP,NOEGPS,NOUCL,NOP
+AS,NG,TMASS,ZNAM2)
C
C THIS PROGRAM IS USED FOR ENTERING 'ARRAY' DATA INTO MEMORY
C
C ARGUMENTS IN-STAFS,NOEGPS,NOUCL,NOPAS,NG
C ARGUMENTS OUT-BFLUX,ZNAME,IDNO,MASS,GP,TMASS
C
C DIMENSION BFLUX(NJEGPS),ZNAM1(NOUCL),IDNO(NOUCL),MASS(NOUCL),ST
+AFS(NOPAS),GP(NG),ZNAM2(NOUCL)
REAL MASS,KWALL
COMMON A,V,F,DF,T1,T2,N,R,TH,D,H,OPTION,IGEOM,ISAB,IHEAT,VOLU,DOSE
READ(5,4)(STAFS(I),I=1,NOPAS)
4 FORMAT(6(E10.3,2X))
DO 7 I=1,NOUCL
READ(5,8) ZNAM1(I),ZNAM2(I),IDNO(I),MASS(I)
8 FORMAT(2A10,1X,15,1X,E10.3)
7 CONTINUE
READ(5,4)(GP(I),I=1,NG)
NNN=NOUCL-1
DO 80 I=1,NNN
IDMIN=IDNO(I)
IMIN=1
III=I+1
DO 90 J=III,NOUCL
IF (IDMIN.LE.IDNO(J))GO TO 90
IDMIN=IDNO(J)
IMIN=J
90 CONTINUE
IF (1.EQ.IMIN) GO TO 80
IDTEMP=IDNO(I)
IDNO(I)=IDNO(IMIN)
IDNO(IMIN)=IDTEMP
TEMPH=MASS(I)
MASS(I)=MASS(IMIN)
MASS(IMIN)=TEMPH
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,12,10X,E10.3)
34 CONTINUE
READ(5,10) IFLUX,IWALL,KWALL
10 FORMAT(2(12,1X),E10.3)
WRITE(6,11) IFLUX
11 FORMAT(/,20H OPTION ON THE FLUXES-IFLUX=,12)
IF(IFLUX.EQ.0)WRITE(6,12)
12 FORMAT(39H THE FLUXES WILL BE READ FROM THE INPUT)
IF(IFLUX.NE.0)WRITE(6,13)
13 FORMAT(36H THE FLUXES WILL BE READ FROM TAPE 0)
IF((IFLUX.NE.1).AND.(IFLUX.NE.0))GO TO 40
WRITE(6,14) IWALL
14 FORMAT(/,49H OPTION ON THE PART OF THE ROOM WHERE ACTIVATION,/,19H
+ TAKES PLACE-IWALL=,12)
IF(IWALL.EQ.0)WRITE(6,15)
15 FORMAT(47H 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
INDEX1=IFLUX+1
GO TO(17,18),INDEX1
17 READ(5,4)(BFLUX(I),I=1,NOEGPS)
GO TO 19
18 READ(8,4)(BFLUX(I),I=1,NOEGPS)
19 INDEX2=IWALL+1
GO TO(20,21),INDEX2
21 RK=R*KWALL*100.
DK=TH*KL**1*100.
FF=3*RK*(1-((RK+DK)/SINH(DK))+RK/TANH(DK))/((RK+DK)**3-RK**3)
DO 22 I=1,NOEGPS
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,NOEGPS
II=NOEGP: I-I
WRITE(6,28)I,BFLUX(II)
28 FORMAT(6H GROUP,1X,12,10X,E11.4)
32 CONTINUE
WRITE(6,73)
73 FORMAT(///,1H ,22HGROUP BOUNDARIES (MEV),/)
WRITE(6,74)(I,GP(NI+1-I),I=1,NIG)
74 FORMAT(1H ,8HBOUNDARY,1X,13,5X,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,15,5X,E8.2)
30 CONTINUE
THASS=0.
DO 50 I=1,NONUCL
THASS=THASS+MASS(I)

```

```

50  CONTINUE
    WRITE(6,25)
25  FORMAT(////,55X,25HACDOS 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
C THIS 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,R,TH,D,H,OPTION,IGEOM,ISAB,IHEAT,VOLU,DOSE
    IF(V.GE.30.0.AND.V.LE.80.0) GO TO 3
    IF(V.GT.80.0.AND.V.LE.100.0) GO TO 4
    IF(V.GT.100.0.AND.V.LE.300.0) GO TO 5
3  CF=(3.25917*V**2.63194)/30.5
    GO TO 7
4  CF=(1.51725*V**2.40306)/30.5
    GO TO 7
5  CF=(8.84661*V**2.14132)/30.5
7  INSNPS=(0.64E+4)*(A)*(1.0E+6)*F*(CF*1.0E-4)
    AVENPS = INSNPS*DF
    WRITE(6,8)
8  FORMAT(////,1X,43H THE FOLLOWING HAS BEEN CALCULATED BY ACDO3,/,45
+H *****
    WRITE(6,1) INSNPS
1  FORMAT(//,1H ,52H INSTANTANEOUS NUMBER OF NEUTRONS PRODUCED PER SEC
+OND,4X,E11.4)
    WRITE(6,2) AVENPS
2  FORMAT(//,1H ,46H AVERAGE NUMBER OF NEUTRONS PRODUCED PER SECOND,4X,
+E11.4)
    RETURN
    END
    SUBROUTINE GRFLUX(AVENPS,NOEGPS,GPFLUX,BFLUX)

C
C
C THIS 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

```



```

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 ,74HMOST LIKELY PROBLEM IS UNREALISTIC OR UNUSUAL FLUX +
+AND GROUP BOUNDARY DATA)
STOP
30 B=XSB1P1
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 20
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)*SORT(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,12.5X,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.NEPHT+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.NOEGPS) 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)/1.000E+06
105 CONTINUE
RETURN
END
SUBROUTINE ACTVAT(TIMACT,SYSACT,SUMACT,GPFLUX,PRODNU,PRODHL,GPXSEC
+,IDNO,MASS,STAFS,GP,CONST,FCONST,BFLUX,NOUCL,NOEGPS,NOPAS,NG,NF,T
+MASS,GME,HEATSP,HEATCY)

```

```

C
C
C THIS PROGRAM CALCULATES ACTIVITIES DUE TO NEUTRON INDUCED REACTIONS
C ALSO CONSIDERS THE ENERGY ABSORPTION IN THE TARGET IN TIME T1
C IN THE CASE OF A SPHERE OR A CYLINDER

```

```

C
C
C ARGUMENTS IN=GPFLUX,GPXSEC,IDNO,MASS,STAFS,GP,CONST,FCONST,BFLUX
C ARGUMENTS IN=NOUCL,NOEGPS,NOPAS,NG,NF,TMASS
C ARGUMENTS OUT=TIMACT,SYSACT,PRODNU,PRODHL,HEATSP,HEATCY
C
C

```

```

C
C
C DIMENSION IDNO(NONUCL),MASS(NONUCL),STAFS(NOPAS),GME(NOEGPS)
C DIMENSION TIMACT(NONUCL,13,NOPAS),SYSACT(NOPAS),SUMACT(NOPAS),GPFL
+UX(NOEGPS),PRODNU(NONUCL,13),PRODHL(NONUCL,13),GP(NG),GPXSEC(NOEGP
+S),CONST(NOEGPS),FCONST(NOEGPS),BFLUX(NOEGPS),HEATSP(NONUCL),HEATC
+Y(NONUCL)
C COMMON A,V,F,DF,T1,T2,N,R,TH,D,H,OPTION,IGEOH,ISAB,IHEAT,VOLU,DOSE
REAL MASS,MU
WRITE(6,102)
102 FORMAT(///,1H ,57H THE FOLLOWING OUTPUT DATA ARE CALCULATED ACTIVIT
+IES IN BQ)
C INITIALIZE FLAGS AND ARRAYS
DO 40 M=1,NONUCL
DO 40 MM=1,13
PRODHL(M,MM)=0.0000000E+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)=.000E+00
41 CONTINUE
DO 22 JN=1,NOPAS
SYSACT(JN)=0.0
SUMACT(JN)=0.0

```



```

22 CONTINUE
  IF (IHEAT.EQ.0) GOTO 3
  DQSP=0.0
  DQCY=0.0
  DO 2 JN=1, NONUCL
    HEATSP(JN)=0.0
    HEATCY(JN)=0.0
  2 CONTINUE
  DO 3 JN=1, NOEGPS
    GME(JN)=(GP(JN)+GP(JN+1))/2.
  3 CONTINUE
  I=1
  J=0
  KFLAG=0
  LFLAG=0
CPRINT HEADINGS
  WRITE(6,37) (STAFS(K), K=1, NOPAS)
  37 FORMAT(/, 1H, 4X, 7P TIME(H), 4X, 10(EB.2, 1X), 2X, 2(EB.2, 2X))
  WRITE(6,1)
  1 FORMAT(1H, 12SHTARGET 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))
  24 READ(7,25) ITAPE,TARMA5
  25 FORMAT(16,7X,E11.4)
  IF (ITAPE.EQ.IDNO(1)) GO TO 7
  IF (ITAPE.GT.IDNO(1)) GO TO 44
  CALL POSITON
  GO TO 24
CTHE ABOVE STATEMENTS SEARCH THE TAPE FOR A MATCHING TARGET ID NUMBER
  44 WRITE(6,45) IDNO(1)
  45 FORMAT(/, 32H ATTENTION-TARGET NUCLIDE NUMBER, 16,89H DOES NOT EXIST
+ IN DATA LIBRARY-THEREFORE-NO CONTRIBUTION FROM THIS NUCLIDE IN DO
+SE CALS.///)
  IF (I.GE.NONUCL) GO TO 16
  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
  JFLAG=0
  READ(7,9) ID,0,PRODNU(I,J),PRODH(I,J)
  9 FORMAT(12,7X,E11.4,E12.4,12X,E12.4)
  READ(7,99) PN
  99 FORMAT(E11.4)
  NP=IF1X(PN)
  IF (ITAPE.EQ.IDNO(NONUCL)) LFLAG=1
  IF ((IGEOM.EQ.1).OR.(IGEOM.EQ.4)) GOTO 6
  IF (IHEAT.EQ.0) GOTO 6
C THIS SKIPS THE ENERGY CALCULATION WHEN IT IS NOT WANTED
  IF ((ID.LE.39).OR.(ID.GE.47)) GOTO 6
C NO CONTRIBUTION OF THIS REACTION TO ENERGY ABSORPTION IN THE TARGET
  GO TO 4
  6 IF (PRODH(I,J).GT.0.1000E+50) GOTO 50

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```

      JFLAG=1
      4 CALL AVRAGE(GPXSEC,CONST,FCONST,BFLUX,GP,NOEGPS,NG,NF,NP)
      IF(GPXSEC(1).GT.0.500E+49) GO TO 103
      IF(JFLAG.EQ.1) GOTO 30
C BEGINNING OF ENERGY ABSORPTION CALCULATION
      SHEAT=0.0
      IF(ID.EQ.46) GOTO 110
      AMAT=AMOD(FLOAT(IDNO(I)),1000.)
      AMAT=(AMAT+1.)/AMAT
      DO 111 JN=1,NOEGPS
      ENGY=GME(JN)*AMAT*Q
      IF(ENGY.LE.0.0) GOTO 111
C MEANS THE THRESHOLD FOR THE REACTION IS IN THE JN GROUP
C THEREFORE NO CONTRIBUTION FROM THIS GROUP TO ENERGY ABSORPTION
      ENGY=GME(JN)+Q
      SHEAT=SHEAT+ENGY*GPXSEC(JN)*GPFLUX(JN)
      111 CONTINUE
      SHEAT=SHEAT*(1.E-24)*(MASS(I)*1000./TARMAS)*6.023E+23
      HEATSP(I)=HEATSP(I)+SHEAT*T1*3600.
      IF(IGEOM.EQ.3) HEATCY(I)=HEATCY(I)+SHEAT*T1*3600.
      GOTO 29
C ABOVE IS THE ENERGY ABSORPTION FOR A (N.PARTICLE) REACTION
      110 AMU=2.3376*EXP(-23.1712*Q)+0.042*EXP(-0.1972*Q)+0.0024*Q-0.006
      MU=1000.*AMU*TMASS/VOLU
      RATE=0.0
      DO 112 JN=1,NOEGPS
      RATE=RATE+GPXSEC(JN)*GPFLUX(JN)
      112 CONTINUE
      RATE=RATE*1.E-24*(MASS(I)*1000./TARMAS)*6.023E+23
C THIS IS THE RATE OF (N.GAMMA) REACTIONS IN THE NUCLIDE I
      IF(IGEOM.EQ.2) GOTO 113
      IF(IGEOM.EQ.3) GOTO 115
      113 AT=MU*100.
      HEATSP(I)=HEATSP(I)+Q*PCS(AT)*RATE*T1*3600.
      GOTO 29
C
      115 RS=(3./4.*3.1416)*VOLU**0.3333
      AT=MU*RS
      HEATSP(I)=HEATSP(I)+Q*PCS(AT)*RATE*T1*3600.
      AT=MU*100.
      HEATCY(I)=HEATCY(I)+Q*PCC(AT)*RATE*T1*3600.
C
C ABOVE IS THE ENERGY ABSORPTION FOR A (N.GAMMA) REACTION
C END OF ENERGY ABSORPTION CALCULATION
C
      29 IF(PRODHL(I,J).GT.0.1000E+50) GOTO 103
      30 SUM1A=0.0
      SUM2A=0.0
      DO 11 JL=1,N
      TEMPS=EXP(-(0.693*(N-JL))*((T1*3600.0)+(T2*3600.0))/PRODHL(I,J))
      SUM1A=SUM1A+TEMPS
      11 CONTINUE
      DO 12 L=1,NOEGPS
      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/PRODHL(I,J)))
      DO 13 K=1,NOPAS
      T1*ACT(I,J,K)=ACT*EXP(-(STAFS(K)*0.693*3600.0/PRODHL(I,J)))

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      SUMACT(K)=SUMACT(K)+TIMACT(I,J,K)
13  CONTINUE
103 WRITE(6,20) IDNO(I), IFIX(FRODNU(I,J)), (TIMACT(I,J,K),K=1,NOPAS)
20  FORMAT(1X,1X,15,2X,15,2X,10(E8.2,1X),2X,2(E8.2,2X))
      READ(7,25) ITAPE,TARMA5
      IF(EOF,7)3030,3031
3030 KFLAG=1
3031 IF(KFLAG.EQ.1)GO TO 27
      IF(LFLAG.EQ.1.AND.ITAPE.NE.IDNO(NONUCL)) GO TO 27
      IF(ITAPE.GE.IDNO(NONUCL)) LFLAG=1
      IF(ITAPE.NE.IDNO(1)) GO TO 27
      GO TO 7
CPRINT HEADINGS
27  WRITE(6,37)(STAFS(K),K=1,NOPAS)
      WRITE(6,14)
14  FORMAT(1H,125H 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) IDNO(I),(SUMACT(K),K=1,NOPAS)
15  FORMAT(1X,5X,15,5X,10(E8.2,1X),2X,2(E8.2,2X),///)
      DO 10 K=1,NOPAS
      SYSACT(K)=SYSACT(K)+SUMACT(K)
10  CONTINUE
      IF(ITAPE.EQ.IDNO(I+1)) GO TO 32
      IF(LFLAG.EQ.1) GO TO 160
32  DO 23 JN=1,NOPAS
      SUMACT(JN)=0.0
23  CONTINUE
      IF(ITAPE.EQ.IDNO(I+1)) GO TO 31
      IF(ITAPE.GT.IDNO(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
160 IF(I.GE.NONUCL) GOTO 16
      JN1=I+1
      DO 165 JN=JN1,NONUCL
      WRITE(6,45) IDNO(JN)
165 CONTINUE
16  WRITE(6,544)

```

```

544 FORMAT(//)
      WRITE(6,37) (STAFS(K),K=1,NOPAS)
      WRITE(6,21)
51  FORMAT(1H ,125H      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,15X,10(E8.2,1X),2X,2(E8.2,2X),////)
      IF(IHEAT.EQ.0) GOTO 57
      IF((IGEOM.EQ.1).OR.(IGEOM.EQ.4)) GOTO 58
      WRITE(6,52)
52  FORMAT(//,1X,94HTHE FOLLOWING OUTPUT DATA ARE CALCULATED ENERGY AB+
+SORPTION IN THE TARGET,FROM PRODUCT REACTION)
      WRITE(6,61)
51  FORMAT(//,1X,64HSPHERE,/,1X,6(1H-),/)
      WRITE(6,53)
53  FORMAT(//,1X,43HTARGET ABSORBED ENERGY IN JOULES IN TIME T1)
C BELOW:CONVERSION IN JOULES-TOTAL ENERGY ABS. CALCULATION
      DO 54 JN=1,NO NUCL
      HEATSP(JN)=HEATSP(JN)*1.602E-13
      DQSP=DQSP+HEATSP(JN)
      WRITE(6,55) IDNO(JN),HEATSP(JN)
55  FORMAT(1X,1X,15,2X,E8.2)
54  CONTINUE
      WRITE(6,56) DQSP
56  FORMAT(//,1X,43HSYSTEM ABSORBED ENERGY IN JOULES IN TIME T1,
+/,8X,E8.2,////)
      IF(IGEOM.EQ.2) GOTO 57
      WRITE(6,62)
52  FORMAT(//,1X,17HINFINITE CYLINDER,/,1X,17(1H-),/)
      ROH=R/H
      WRITE(6,63) ROH,RS
53  FORMAT(1X,23HHEIGHT TO RADIUS RATIO=,E10.3,
+/,2SHEQUIVALENT SPHERE RADIUS=,E10.3,3H CM,/)
      WRITE(6,53)
      DO 60 JN=1,NO NUCL
      HEATCY(JN)=HEATCY(JN)*1.602E-13
      DQCY=DQCY+HEATCY(JN)
      WRITE(6,55) IDNO(JN),HEATCY(JN)
60  CONTINUE
      WRITE(6,56) DQCY
57  REWIND 7
      RETURN
58  WRITE(6,59)
59  FORMAT(//,1X,102HTHE PROGRAM DOES NOT CALCULATE THE ENERGY ABSORPT+
+ION IN THE TARGET FOR THIS GEOMETRY-IHEAT SHOULD BE 0,/)
      GOTO 57
50  CALL POSIT2(NP)
      GOTO 103
      END
      SUBROUTINE AVRAGE(GPXSEC,CONST,FCONST,BFLUX,GP,NOEGPS,NG,NF,NP)
C
C THIS PROGRAM CALCULATES FLUX WEIGHTED GROUP CROSS SECTIONS BY
C AVERAGING MICROSCOPIC CROSS SECTION DATA
C
C
C
C
C ARGUMENTS IN-CONST,FCONST,BFLUX,GP,NOEGPS,NG,NF,NP
C ARGUMENTS OUT-GPXSEC

```

```

      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 JK=1,NOEGPS
        GPXSEC(JK)=0.0
      41 CONTINUE
CLOAD ENERGY AND CROSS SECTION DATA FROM THE ACTLMFE 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 ACTLMFE 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
        PARSUM=(CONST(J)*SORT(DPVAR*1.0E6)*EXP(-(DPVAR*1.0E6/2.025))*((CS1
+ (I+1)-CS1(I))* (DPVAR-E1(I))/(E1(I+1)-E1(I))+CS1(I)))*WIDTH*1.0E6
      SUMDEL=SUMDEL+PARSUM
      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 GPXSEC(I)=1.0E+50
105 READ(7,5) IDUMB
      5 FORMAT(71X,11)
      RETURN
      END
      SUBROUTINE SMOOTH(X1,NX1,X2,Y2,NX2,X3,Y3,NX3)

```

```

C
C
C THIS PROGRAM CALCULATES CROSS SECTIONS AT GROUP BOUNDARIES BY LINEAR
C INTERPOLATION
C
C
C

```

```

      ARGUMENTS IN=GP,NG,EN,CS,NP
      ARGUMENTS OUT=E1,CS1,NE1

```

```

C
      DIMENSION X1(1),X2(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   N'X3=L-1
      RETURN
      END
      SUBROUTINE POSITON

```

```

C
C
C THIS PROGRAM IS USED FOR POSITIONING THE FILE MARKER IN THE ACTL2
CLIBRARY ; PN = NP

```

```

C
C
C   ARGUMENTS IN-NONE
C   ARGUMENTS OUT-NONE
C
C
      READ(7,30) PN
30   FORMAT(/,E11.4)
      NP1=INT(PN/3.000+0.000)
      DO 52 ICOUNT=1,NP1
      READ(7,53) REALDUM
53   FORMAT(E11.4)
52   CONTINUE
      READ(7,5) IDUMB
5    FORMAT(71X,11)
      RETURN
      END
      SUBROUTINE POSIT2(NP)

```

```

C
C
C THIS PROGRAM IS USED FOR POSITIONING THE FILE MARKER IN THE ACTL2
CLIBRARY

```

```

C
C
C   ARGUMENTS IN-NP
C   ARGUMENTS OUT-NONE
C
C
      NP1=INT(FLOAT(NP)/3.000+0.000)
      DO 52 ICOUNT=1,NP1
      READ(7,53) REALDUM
53   FORMAT(E11.4)
52   CONTINUE
      READ(7,5) IDUMB
5    FORMAT(71X,11)
      RETURN
      END
      SUBROUTINE DOSRTE(TIMACT,PRODNU,NOUCL,NOPAS,DOSSUM,SYSPOS,IDNO,ST
+AFS,PRODDL,DOSNUC,TMASS,DOSDGT,DOSPRO)

```

```

C
C
C THIS PROGRAM CALCULATES DOSE RATES AS A FUNCTION OF COMPONENT COMPOSIT-
TION,GEOMETRY,AND TIME AFTER SHUTDOWN

```

```

C
C

```

C

```

      DIMENSION TIMACT(NONUCL,13,NOPAS),PRODNU(NONUCL,13),DOSSUM(NOPAS),
      +SYSDOS(NOPAS),IDNO(NONUCL),STAFS(NOPAS),DOSDGT(NOPAS),DOSPRD(NOPAS
      +)
      DIMENSION PRODHL(NONUCL,13),DOSNUC(NOPAS),DOSDAU(390),DHA(390)
      DIMENSION NT(390),NP(390),AC(390),HA(390),ND(390),DOSPRD(390)
      DIMENSION IDEKM(30),IDAUG(30),DLEVL(30),PROB(30)
      COMMON A,V,F,DF,T1,T2,N,R,TH,D,H,OPTIOH,IGEOM,ISAB,IHEAT,VOLU,DOSE
      REAL MULT
      WRITE(6,100)
100  FORMAT(//////,1H ,61N THE FOLLOWING OUTPUT DATA ARE CALCULATED DOSE
      +RATES IN REM/H,/)
      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
      DOSPRD(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(9,16) ITAPE,HALFLF,NDMODE
16 FORMAT(16,20X,E11.4,13)
   IF(EOF,9) 200,280
200 IF(ITAPE.EQ.NP(L))GO TO 17
   IF(ITAPE.GT.NP(L)) GO TO 28
   CALL ADVAN(NDMODE)
   GO TO 200
20 IF(AC(L).EQ.0.00)GO TO 38
   WRITE(6,29) NP(L)
29 FORMAT(/,33H ATTENTION-PRODUCT NUCLEIDE NUMBER,16,90H DOES NOT EXIS
+T IN DECAY LIBRARY-THEREFORE NO CONTRIBUTION FROM THIS NUCLEIDE IN +
+DOSE CALCS)
   WRITE(6,37) NT(L)
37 FORMAT(1H ,20HTHE TARGET ATOM WAS ,15,///)
38 L=L+1
   IF(NP(L).EQ.0) GO TO 813
   GO TO 200
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 19
   IF(HALFLF.EQ.1.00E+50.OR.AC(L).EQ.0.0) GO TO 19
   IMODE=0
302 IMODE=IMODE+1
CBEGIN INTERROGATION OF THE LEVDEC LIBRARY
   READ(9,300) IDEKMD,IDAUGH,DLEVEL,MULT
300 FORMAT(30X,12,17,E11.4,E12.4)
   IF(IDEKMD.EQ.9) ND(L)=IDAUGH
   IF(IDEKMD.EQ.7.OR.IDEKMD.EQ.9) GO TO 301
   IF(IDEKMD.EQ.0) 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),DOSPRD(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),DOSPRD(L),MULT,FLUXE,TMASS)
CIN ANY CASE ADD IN TWO 0.511 MEV ANNIHILATION GAMMAS
311 DO 312 IBETA=1,2
   CALL CURVE(0.511,FLUXE)
   CALL CALC(0.511,AC(L),DOSPRD(L),MULT,FLUXE,TMASS)
312 CONTINUE
   GO TO 303
19 CALL ADVAN(NDMODE)
CREAD THE NEXT LEVDEC NUCLEIDE
304 READ(9,16) ITAPE,HALFLF,NDMODE
   IF(EOF,9)814,3034
3034 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 200
21 L=L+1
   GO TO 17

```

```

800 DO 801 IL=1,NDMODE
  READ(9,300) 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(HA(IP)/HALFLF.GT.0.8.AND.HA(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 JL=1,NDMODE
  IF(IDEKM(IL).EQ.9) ND(IP)=IDAL'(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(9,16) ITAPE,HALFLF,NDMODE
  IF(EOF,9)814,3035
3035 IF(ITAPE.EQ.NP(IBEGIN))GO TO 808
  GO TO 807
808 DO 809 IL=1,NDMODE
  READ(9,300) 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 20
  GO TO 200
811 L=IEND+1
  GO TO 17
814 WRITE(6,8014)
8014 FORMAT(////,IX,133HEOF-LEVDEC ENCOUNTERED-THE REMAINING PRODUCTS AR
  +E NOT IN THE LIBRARY-THEREFORE THEY WON'T BE CONSIDERATED IN THE D
  +OSERATE CALCULATION)
813 REWIND 9

C
C MOVE THE FILE MARKER TO THE BEGINNING
C OF LEVDEC TO INTERROGATE THE LIBRARY
C FOR POSSIBLE RADIOACTIVE DAUGHTERS
C READ UNTIL THE ID-NUMBER IS MATCHED
C
  ISTOP=L
  L=IBASE
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(9,16) ITAPE,HALFLF,NDMODE
IF(EOF,9)702,3037
3037 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
CHECK THE HALF LIFE OF THE DAUGHTER
703 DHA(L)=HALFLF
IF(HALFLF.GT.1.0E+48)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(9,707) IDEKMD,DLEVEL,MULT
707 FORMAT(30X,12,7X,E11.4,E12.4)
SUMA1=0.0
SUMA2=0.0
DO 80 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)))
80 CONTINUE
ACD=AC(L)*SUMA2*(1-(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
+1/(1.-EXP(-0.693*3600.*T1/HA(L)))
IF(IDEKMD.EQ.7.OR. IDEKMD.EQ.5) GO TO 901
IF(IDEKMD.EQ.0) 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,DOSDAU(L),MULT,FLUXE,TMASS)
GO TO 903
910 IF(DLEVEL.EQ.0.0) GO TO 911
CALL CURVE(DLEVEL,FLUXE)
CALL CALC(DLEVEL,ACD,DOSDAU(L),MULT,FLUXE,TMASS)
CIN ANY CASE ADD IN TWO 0.511 MEV ANNIHILATION GAMMAS
911 DO 912 IBETA=1,2
CALL CURVE(0.511,FLUXE)
CALL CALC(0.5110,ACD,DOSDAU(L),MULT,FLUXE,TMASS)
912 CONTINUE
GO TO 903
913 REWIND 9
NO=NONUCL*13
DO 815 I=1,NONUCL
WRITE(6,8) (STAFS(K),K=1,NOPAS)
8 FORMAT(/,14.4X,7HTIME(H),4X,10(EB.2,1X),2X,2(EB.2,2X))
WRITE(6,406)
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

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      IF (NT(L).EQ.IDNO(I)) GO TO C17
      GO TO 818
817 DO 819 K=1,NOPAS
      DOSPRO(K)=DOSPRD(L)*EXP(-(STAF5(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(-(STAF5(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,15,2X,15,2X,10(E8.2,1X),2X,2(E8.2,2X))
818 CONTINUE
      WRITE(6,11)
11  FORMAT(12GHPRODUCT 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) (STAF5(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,15,5X,10(E8.2,1X),2X,2(E8.2,2X),///)
      DO 822 K=1,NOPAS
      DOSSUM(K)=0.0
822 CONTINUE
815 CONTINUE
      WRITE(6,414)
414 FORMAT(//)
      WRITE(6,8) (STAF5(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(E8.2,1X),2X,2(E8.2,2X))
      RETURN
      END
      SUBROUTINE ADVAN(NDMODE)

```

```

C
C
C THIS PROGRAM IS USED FOR POSITIONING THE FILE MARKER IN THE LEVDEC
C LIBRARY
C

```

```

C ARGUMENTS IN-NDMODE
C ARGUMENTS OUT-NONE
C

```

```

C DO 385 JB=1,NDMODE
C READ(9,202) IDUMB

```

```

202 FORMAT(38X,12)
305 CONTINUE
      RETURN
      END
      SUBROUTINE CALC(E,ACT,DSPRD,MULT,FLUXE,TMASS)

C
C
C THIS PROGRAM CALCULATES DOSERATE FOR 4 DIFFERENT GEOMETRIES
C
C
      REAL MULT
      REAL MU
      COMMON A,V,F,DF,T1,T2,N,R,TH,D,H,OPTION,IGEOM,ISAB,IHEAT,VOLU,DOSE
      INDEX3=ISAB+1
      GO TO (11,12),INDEX3
11  GOTO(31,32,32,32),IGEOM
31  SOU=(ACT*MULT*2.5)/FLUXE
      DOSRAT=SOU*DOSE
      DSPRD=DSPRD+DOSRAT
      RETURN

C
C THE ABOVE CALCULATION IS FOR A POINT SOURCE
C
32  SOU=(ACT*MULT*2.5)/(VOLU*FLUXE)
      DOSRAT=SOU*DOSE
      DSPRD=DSPRD+DOSRAT
      RETURN

C
C THE ABOVE CALCULATION IS THE DOSERATE FOR NON-ABSORBING GEOMETRY
C 1. FOR A SPHERE, THE OBSERVER STANDING OUTSIDE
C 2. FOR A CYLINDER, THE OBSERVER STANDING ON THE AXIS
C 3. FOR A SPHERICAL CAVITY, THE OBSERVER STANDING AT THE CENTER
C
12  GO TO(41,42,42,42),IGEOM
41  WRITE(6,50)
50  FORMAT(10X,37HNO SELF-ABSORPTION FOR A POINT SOURCE)
      GO TO 31

C THE ABOVE STATEMENTS RETURN TO NON-ABSORBING POINT SOURCE
C
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(4.0,(-2.5*E+29.))
C CALCULATION OF THE BUILD-UP FACTOR COEFFICIENT A
      IF(E.LE.2.)BALPH1=0.063*E-0.102
      IF((E.GT.(2.0)).AND.(E.LE.(8.0)))BALPH1=-0.02*E-0.015
      IF(E.GT.(8.0))BALPH1=-0.0005*E-0.107
C CALCULATE THE BUILD-UP FACTOR COEFFICIENT ALPHA1
      IF(E.LE.(1.0))BALPH2=-0.032*E+0.040
      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=0.00125*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
C
51  MU=1000.*AMU*TMASS/VOLU
      SOU=(ACT*MULT*2.5)/(VOLU*FLUXE)
      CALL GEOFSF(R,D,IU,BALPH1,GFS)

```

```

DOSRAT=SOU*R*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
C CALCULATE THE DOSE RATE AT A POINT OUT OF AN ABSORBING SPHERE
C
52 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.+BALPH2)*MU))/2.
DSPRD=DSPRD+DOSRAT
RETURN

C
C CALCULATE THE DOSE RATE FOR A HOMOGENEOUS ABSORBING CYLINDER
C WHERE THE OBSERVER FACES THE AXIS
C
53 MU=1000.*AMU*TMASS/VOLU
SOU=(ACT*MULT*2.5)/(VOLU*FLUXE)
PART3=(1.-EXP(-MU*(1.+BALPH1)*TH*100.))/(MU*(1.+BALPH1))
PART4=(1.-EXP(-MU*(1.+BALPH2)*TH*100.))/(MU*(1.+BALPH2))
DOSRAT=(SOU*BFA*PART3)+(SOU*(1.-BFA)*PART4)
DSPRD=DSPRD+DOSRAT
RETURN

C
C CALCULATE THE DOSE RATE AT THE CENTER OF A SPHERICAL
C ABSORBING CAVITY
C
END
SUBROUTINE GEOFSP(X,Y,Z,T,GFS)

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)+AMH1((60.*X*Z*(1.+T)-0.144), (46.37*X*Z*(1.+T)-0.035), (28.78*X*Z*(1.+T)+0.3168), (14.5+5*X*Z*(1.+T)+0.0861), (0.17*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 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      ESTIMATE E2(X) THE SECOND SPECIES EXPONENTIAL INTEGRAL FUNCTION
C
      RES=0.
      IF(X.GE.10.)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      INTEGRATE USING THE ROMBERG METHOD
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

```



```

      RETURN
13 FLUXE=1656.852874*E**((-0.7649757)
      RETURN
      END
      SUBROUTINE DPOINT(D,DOSE)
C
C
C ARGUMENT-IN: D DISTANCE TO THE OBSERVER
C ARGUMENT-OUT: DOSE
C
C THIS IS FOR A POINT SOURCE
C
C
      DOSE=4.*(3.1416)*((D*100.)**2)
      DOSE=1./DOSE
      RETURN
      END
      SUBROUTINE NEWTON(R,TH,D,VOLU,DOSE)
C
C
C GIVEN THE DIMENSIONS OF THE (HOLLOW) SPHERE
C NEWTON CALCULATES: THE VOLUME,
C THE DOSE IN THE NON ABSORBING CASE
C
C
C ARGUMENTS IN : R,TH,D
C ARGUMENTS OUT: R,D,VOLU,DOSE
C
C
      AC=R+D
      XDUT=R/AC
      VOLU=R**3
      DOSE=DSP(XDUT,AC)
      IF(TH.EQ.R) GOTO 5
      VOLU=VOLU-(R-TH)**3
      XIN=(R-TH)/AC
      DOSE=DOSE-DSP(XIN,AC)
C
C BEGINNING OF NEWTON'S ITERATION METHOD
C
      R=VOLU**0.33333
      AC=R/DOSE
      X=0.99999
      NI=1
1  G=DSP(X,AC)-X
   G1=DSP1(X,AC)-1.
   XNEW=X-G/G1
   IF(ABS(XNEW/X-1.).LE.1.E-4) GOTO 2
   IF(NI.GE 75) GOTO 3
   NI=NI+1
   X=XNEW
   GOTO 1
2  D=R/XNEW-R
   VOLU=4./3.*(3.1416)*((1.E+06)*VOLU
   DOSE=100.*DOSE/4.
   RETURN
3  WRITE(6,4)
4  FORMAT(1H ,94HPROGRAM 'ACDOS' ABORTED-EQUIVALENT SPHERE PARAMETERS
   + NOT REACHED BY NEWTON'S METHOD-CHECK DATA)

```

```

        STOP
        END
        FUNCTION DSP(X,Y)

C
C
C X=(SPHERE RADIUS)/(DISTANCE FROM THE SURFACE TO THE OBSERVER)
C Y=DISTANCE FROM THE CENTER TO THE OBSERVER FOR DOSE CALCULATION
C   =(RADIUS)/(DOSE OF SPHERICAL GEOMETRY) IN NEWTON'S ITERATION
C
C
        DSP=2.*X
        U=1.+X
        V=1.-X
        IF(V.GT.1.E-10) DSP=DSP-U*V*ALOG(U/V)
        DSP=Y*DSP
        RETURN
        END
        FUNCTION DSP1(X,Y)

C
C
C THIS IS THE FIRST DERIVATIVE OF THE ABOVE FUNCTION
C
C
        U=1.+X
        V=1.-X
        IF(V.LT.1.E-50) GOTO 1
        DSP1=Y*2.*X*ALOG(U/V)
        RETURN
1 DSP1=Y*2.*50*ALOG(2.)
        RETURN
        END
        SUBROUTINE CYLIN(R,TH,H,D,VOLU,DOSE)

C
C
C GIVEN THE (HOLLOW) CYLINDER DIMENSIONS 'CYLIN' CALCULATES:
C 1. THE VOLUME AND DOSE OF THE CYLINDER IN NON ABSORBING CASE
C 2. THE EQUIVALENT SOLID CYLINDER CHARACTERISTICS USING THE
C    BISSECTION METHOD FOR FINDING THE ZERO OF  $G(X)=DOS(R,X,H)-DSR$ 
C
C
C    ARGUMENTS IN-R,TH,H,D    OF HOLLOW CYLINDER
C    ARGUMENTS OUT-R,H,D      OF THE EQUIVALENT SOLID CYLINDER
C                               VOLU,DOSE FOR A SOLID CYLINDER
C
C
        DSR=DOS(R,D,H)
        VOLU=H*(R**2)
        IF(TH.EQ.R) GOTO 6
        RIN=R-TH
        VOLU=VOLU-H*(RIN**2)
        DSR=DSR-DOS(RIN,D,H)
        R=SQRT((R+RIN)*(R-RIN))
        K=1
        D1=D
        IF(D.LE.1.E-10) D1=1.E-10
        DOS1=DOS(R,D1,H)
        G1=DOS1-DSR
        IF(ABS(G1/DSR).LE.1.E-4) GOTO 3
        IS1=ISIGN(1,INT(G1))
        IF(IS1.EQ.1) GOTO 20

```

```

C
C BELOW : D-EQUIVALENT SMALLER THAN D FOR HOLLOW CYLINDER
C
      D2=0.01*D
      DOS2=DOS(R,D2,H)
      G2=DOS2-DSR
      IS2=ISIGN(1,INT(G2))
      IF (IS2.NE.IS1) GOTO 1
      WRITE(6,12)
12  FORMAT(1X,/,62HD-EQUIVALENT FOR EQUIVALENT SOLID CYLINDER SMALLER
      + THAN 0.01*D,/)
      STOP

C
C BELOW : D-EQUIVALENT GREATER THAN D FOR HOLLOW CYLINDER
C
20  D2=100.*D
      IF (D.LT.1.E-10) D2=H
      DOS2=DOS(R,D2,H)
      G2=DOS2-DSR
      IS2=ISIGN(1,INT(G2))
      IF (IS2.EQ.IS1) GOTO 4

C
C BISECTION METHOD STARTS
C
1  K=K+1
      IF (K.GT.100) GOTO 5
      D3=(D2+D1)/2.
      DOS3=DOS(R,D3,H)
      G3=DOS3-DSR
      IS3=ISIGN(1,INT(G3))
      IF (IS3.EQ.IS1) GOTO 2
      D2=D3
      IF (ABS((D2-D1)/D1).GE.1.E-3) GOTO 1
      GOTO 3
2  D1=D3
      IF (ABS((D2-D1)/D1).GE.1.E-3) GOTO 1
      GOTO 3
4  WRITE(6,14)
14  FORMAT(1X,/,61HD-EQUIVALENT FOR EQUIVALENT SOLID CYLINDER GREATER
      + THAN 100*D,/)
      STOP
5  WRITE(6,17) K
17  FORMAT(1X,/,42HWARNING-NO SOLUTION FOR D-EQUIVALENT AFTER,13,
      +11H ITERATIONS,/)
      STOP
3  D=D1
6  VOLU=3.1416*VOLU*1.E+06
      DOSE=100.*DSR/4.
      RETURN
      END
      FUNCTION DOS(R,X,H)

C
C CALCULATES DOSERATE FOR A SOLID CYLINDER
C
      ZY=R/(H+X)
      DOS=(H+X)*FDOS(ZY)
      IF (X.LE.1.E-10) RETURN
      ZX=R/X

```

```

      DOS=DOS-X*FDOS(ZX)
      RETURN
      END
      FUNCTION FDOS(Z)

```

```

C
C
C
C
C USED TO CALCULATE THE DOSE RATE FROM A SOLID CYLINDER

```

```

      IF(Z.LE.0.1E-50) GOTO 1
      FDOS=ALOG(1.+Z*Z)+2.*Z*ATAN(1./Z)
      RETURN
      1 WRITE(6,10)
      10 FORMAT(1X,38HZ CANNOT BE 0. IN THE FUNCTION FDOS(Z),/)
      STOP
      END
      SUBROUTINE DCAV(R,TH,VOLU,DOSE)

```

```

C
C
C
C
C CALCULATES THE VOLUME OF A SPHERICAL CAVITY AND
C THE DOSE VALUE AT THE CENTER OF THE CAVITY

```

```

      VOLU=4./3.*(3.1416)*(R**3-(R-TH)**3)
      VOLU=1.E+06*VOLU
      DOSE=TH*100.
      RETURN
      END
      FUNCTION PCS(AT)

```

```

C
C
C
C
C COLLISION PROBABILITY FOR A SPHERE

```

```

      IF(AT.LE.0.1) GOTO 1
      IF(AT.GT.6.0) GOTO 2
      AT2=AT*AT
      AT3=AT2*AT
      PCS=1.-3./8.*(2.*AT2-1.+(1.+2.*AT)*EXP(-2.*AT))/AT3
      GOTO 3
      1 PCS=3./4.*AT
      GOTO 3
      2 PCS=1.-3./4./AT*(1.-0.5/(AT*AT))
      3 RETURN
      END
      FUNCTION PCC(AT)

```

```

C
C
C
C
C COLLISION PROBABILITY FOR A INFINITE CYLINDER

```

```

      IF(AT.LT.0.1) GOTO 1
      IF (AT.GT.6.0) GOTO 2
      PCC=SEVAL(AT)
      GOTO 3
      1 PCC=4./3.*AT-0.5*AT*AT*(ALOG10(2./AT)+0.672784)
      GOTO 3
      2 AT1=1./AT
      PCC=1.-AT1/2.*(1.-3./16.*AT1*AT1)
      3 RETURN

```

```

      END
      FUNCTION SEVAL(AT)
C
C C ANALYTICAL APPROXIMATION OF PCC FOR 0.1<AT<6.0
C C
      COMMON X(7),Y(7),B(7),C(7),D(7)
      N=7
      DATA I/1/
      IF(I.GE.N) I=1
      IF(AT.LT.X(I)) GOTO 20
      IF(AT.LE.X(I+1)) GOTO 40
20  I=1
      J=N+1
30  K=(I+J)/2
      IF(AT.LT.X(K)) J=K
      IF(AT.GE.X(K)) I=K
      IF(J.GT.I+1) GOTO 30
40  DX=AT-X(I)
      SEVAL=Y(I)+DX*(B(I)+DX*(C(I)+DX*D(I)))
      RETURN
      END
      BLOCK DATA
      COMMON X(7),Y(7),B(7),C(7),D(7)
      DATA (X(I),I=1,7)/0.1,0.4,0.8,1.5,2.5,4.0,6.0 /
      DATA (Y(I),I=1,7)/ 0.115,0.348,0.531,0.698,0.807,0.877,0.917 /
      DATA (B(I),I=1,7)/ 0.956711,0.613139,0.342236,0.162299,
      S0.072230,0.025901,0.029490 /
      DATA (C(I),I=1,7)/ -0.655203,-0.490036,-0.187223,-0.069829,
      S-0.020241,-0.010646,0.012440 /
      DATA (D(I),I=1,7)/ 0.103519,0.252344,0.055902,0.016529,
      S0.002132,0.003040,0.003040 /
      END

```

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