NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

ORNL-TM-4322

Contract No. W-7405-eng-26

THE EXREM III COMPUTER CODE FOR ESTIMATING EXTERNAL RADIATION DOSES
TO POPULATIONS FROM ENVIRONMENTAL RELEASES

D. K. Trubey

Radiation Shielding Information Center
Neutron Physics Division

S. V. Kaye

Environmental Sciences Division

DECEMBER 1973

This document is
PUBLICLY RELEASABLE

B. Steele
Authorizing Official

Date: 3/22/06

OAK RIDGE NATIONAL LABORATORY

Oak Ridge, Tennessee 37830

operated by

UNION CARBIDE CORPORATION

for the

U.S. ATOMIC ENERGY COMMISSION

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CONTENTS

	Page
Abstract	1
1. Introduction	2
2. Estimating External Dose Equivalents	2
2.1 Dose Equivalent Models	2
2.2 Dose-Rate Factors	4
2.2.1 Beta and Gamma Rays	4
2.2.2 Positrons and Electrons	6
2.3 Calculation of the Concentration	6
2.4 Calculation of the Accumulated Concentration	11
3. The Computer Code	13
3.1 The Computer Solution	13
3.2 Special Calculations and Assumptions	13
3.3 Description of Subroutines	16
3.3.1 Overview	16
3.3.2 Variable Dimensioning	17
3.4 Definition of Program Variables	19
3.5 Description of Input	27
3.5.1 Input Categories	27
3.5.2 Description of Each Group	28
3.5.3 Input Summary	38
4. Acknowledgments	40
References	42
Appendix A	45
Appendix B	79

THE EXREM III COMPUTER CODE FOR ESTIMATING EXTERNAL RADIATION DOSES TO POPULATIONS FROM ENVIRONMENTAL RELEASES

D. K. Trubey and S. V. Kaye

ABSTRACT

EXREM III is a computer code to estimate the dose equivalent rate and the total dose equivalent from beta, positron, electron, and gamma radiation resulting from submersion in contaminated water, submersion in contaminated air, and exposure to a contaminated surface. There can be more than one environmental release, and exposure can begin at any time after the first release. EXREM III considers contributions from environmental releases and from nuclide decay chains. For a particular problem the user may choose to calculate either the dose rates, or the total doses, or both for any of the three modes of exposure. A separate solution array is printed for each mode of exposure.

EXREM III is a revised version of EXREM II which was available earlier.¹ The principal revisions include treatment of positron and electron radiations, selection of nuclear data from a data base, variable dimensioning of large data arrays, and free field input.

The code is available from the Radiation Shielding Information Center.

1. INTRODUCTION

The earlier revision of this computer code, EXREM II (see refs. 1 and 2), estimates the dose equivalent rate and the total dose equivalent from beta and gamma radiation resulting from submersion in contaminated water, submersion in contaminated air, and exposure to a contaminated surface. However, EXREM II can give underestimates for certain radionuclides since it does not consider contributions from positrons and conversion or Auger electrons. Thus, the computer code EXREM III, which considers these contributions, was developed.

The input format for EXREM III is essentially similar to that of EXREM II. However, the nuclear data available are handled as a data base and the remaining data as free form. There are also more options available in the new code, EXREM III.

This report, which is self-contained, is designed to acquaint the user with the capabilities of EXREM III and to serve as a reference manual for setting up the input data.

2. ESTIMATING EXTERNAL DOSE EQUIVALENTS

2.1 Dose Equivalent Models

For each radionuclide, the code determines the dose equivalent rate and the total dose equivalent from beta, positron, electron, X, and gamma radiation resulting from submersion in contaminated water, submersion in contaminated air, and exposure to a contaminated surface. There can be more than one environmental release, and exposure can

begin at any time after the first release. A quantity of a radionuclide may be present both from an environmental release and from the decay of another radionuclide.

The dose equivalent rate at time t , including the contribution from radionuclide chains, is denoted by

$$DR_{ipql}(t) = C_{ipl}(t) D_{iqp} \quad (1)$$

where

i = radionuclide index,

q = radiation index (β for beta radiation, p for positrons, e for electrons, γ for gamma radiation),

p = exposure index (w for water, a for air, s for surface),

l = location index,

$C_{ipl}(t)$ = concentration ($\mu\text{Ci/cc}$ for $p = w$ and $p = a$, $\mu\text{Ci/cm}^2$ for $p = s$) of the i th radionuclide for the p th mode of exposure at the l th location at time t ,

D_{iqp} = dose-rate factor [$(\frac{\text{mrem}\cdot\text{cc}}{\mu\text{Ci}\cdot\text{hr}})$] for $p = w$ and $p = a$; [$(\frac{\text{mrem}\cdot\text{cm}^2}{\mu\text{Ci}\cdot\text{hr}})$] for $p = s$, and

t = time (hr).

The total dose equivalent from t_1 to t_2 is denoted by

$$TD_{ipql}(t_1, t_2) = D_{iqp} \int_{t_1}^{t_2} C_{ipl}(t) dt \quad (2)$$

where t_1 and t_2 are in hours.

2.2 Dose-Rate Factors

2.2.1 Beta and Gamma Rays

The dose-rate factors (see ref. 3) are denoted by

$$D_{i\beta w} = \frac{25.6}{24.0} \sum_{n=1}^{N_{\beta i}} (f_{\beta in} \bar{E}_{\beta in}), \quad (3)$$

$$D_{i\gamma w} = \frac{51.2}{24.0} \sum_{n=1}^{N_{\gamma i}} (f_{\gamma in} E_{\gamma in}), \quad (4)$$

$$D_{i\gamma a} = \frac{29.2}{(24.0)(1.2 \times 10^{-3})} \sum_{n=1}^{N_{\gamma i}} (f_{\gamma in} E_{\beta in}), \quad (6)$$

$$D_{i\beta s} = 1.07 \sum_{n=1}^{N_{\beta i}} \{v\alpha(F[C, v, a(x)] + \exp[1 - v\alpha(x)]) f_{\beta in} \bar{E}_{\beta in}\}, \text{ and} \quad (7)$$

$$D_{i\gamma s} = 827 \text{ Bs} \sum_{n=1}^{N_{\gamma i}} [\sigma_{in} E_1(\sigma_{in} x) f_{\gamma in} E_{\gamma in}], \quad (8)$$

where

n = particle or photon index,

N_{qi} = number of beta particles ($q = \beta$) or photons

($q = \gamma$) emitted by the i th radionuclide,

f_{qin} = abundance (dimensionless) of the n th beta particle
or photon emitted by the i th radionuclide,

$\bar{E}_{\beta in}$ = average energy (MeV) of the n th beta particle
emitted by the i th radionuclide,

$E_{\gamma in}$ = energy (MeV) of the n th photon emitted by
the i th radionuclide,

x = the distance (cm) from the exposed individual to the contaminated surface,

$$C = \begin{cases} 3.0, & E_{\beta in} < 0.17, \\ 2.0, & 0.17 \leq E_{\beta in} < 0.5, \\ 1.5, & 0.5 \leq E_{\beta in} < 1.5, \\ 1.0, & 1.5 \leq E_{\beta in}, \end{cases}$$

$E_{\beta in}$ = maximum energy (MeV) of the nth beta particle emitted by the ith radionuclide,

$$\alpha = \begin{cases} 0.190, & E_{\beta in} < 0.17, \\ 0.260, & 0.17 \leq E_{\beta in} < 0.5, \\ 0.297, & 0.5 \leq E_{\beta in} < 1.5, \\ 0.333, & 1.5 \leq E_{\beta in} \end{cases}$$

$$v = \begin{cases} \frac{(18.6)}{(E_{\beta in} - 0.036)^{1.37}} & \text{if the radionuclide is not Sr-90,} \\ \frac{(0.83)(18.6)}{(E_{\beta in} - 0.036)^{1.37}} & \text{if the radionuclide is Sr-90,} \end{cases}$$

$$F[C, v, a(x)] = \begin{cases} C \{ 1 + \ln[\frac{C}{va(x)}] - \exp[1 - (\frac{va(x)}{C})] \} & \text{if } va(x) < C, \\ 0 & \text{if } va(x) \geq C, \end{cases}$$

$a(x)$ = distance from the contaminated surface multiplied by the density of air (g/cm^2),

$\bar{E}_{\beta in} = 0$ if $E_{\beta in} \leq 0.036$ MeV,

$$= 1/3 E_{\beta in} (1 - 0.02\sqrt{Z})(1 + 0.25\sqrt{E_{\beta in}}) \text{ if } E_{\beta in} > 0.036 \text{ MeV}$$

Z = atomic number

Bs = backscatter correction (dimensionless) for a body immersed in air,

σ_{in} = linear energy absorption coefficient (cm^{-1}) [$\sigma = \sigma(E_{\gamma in})$],

and

$E_1(\sigma \cdot x)$ = Exponential integral (E-function) of the first order.

2.2.2 Positrons and Electrons

The dose rate factors for positrons and electrons are added to those for the beta rays. The average electron energy is taken to be the input energy; the average positron energy is calculated as follows:

$$\bar{E}_{pin} = 1/3 E_{pin} (1 + 0.25\sqrt{E_{pin}}).$$

2.3 Calculation of the Concentration

In general, nuclide decay chains may be characterized by steps, each represented by a particular nuclide. A particular nuclide will decay by various modes (e.g., β decay), branching with certain probabilities (fractions or branching ratios) to other nuclides which may or may not be stable. Consider one possible sequence of decays from a starting nuclide to a stable one with a certain fraction, f , decaying to the next nuclide. This will be called a nuclide pathway. A decay chain may be resolved into one or more such pathways, each of which is represented as follows where each nuclide is numbered from 1 to s :

$$1 \xrightarrow{f_1} 2 \xrightarrow{f_2} 3 \xrightarrow{f_3} \dots \xrightarrow{f_{n-2}} n-1 \xrightarrow{f_{n-1}} n \xrightarrow{f_n} s.$$

The following system of differential equations describes the decay process in the nuclide pathway (see refs. 4 and 5):

$$\begin{cases}
 \dot{N}_1(t) = -\lambda_1 N_1(t) \\
 \dot{N}_2(t) = -\lambda_2 N_2(t) + \lambda_1 f_1 N_1(t) \\
 \dot{N}_3(t) = -\lambda_3 N_3(t) + \lambda_2 f_2 N_2(t) \\
 \vdots \\
 \dot{N}_n(t) = -\lambda_n N_n(t) + \lambda_{n-1} f_{n-1} N_{n-1}(t) \\
 N_i(t_0) = N_i^0, \quad i = 1, 2, \dots, n,
 \end{cases} \quad (9)$$

where

$N_i(t)$ = number of nuclei of the i th radionuclide present at time t (hr).

λ_i = decay constant ($\frac{1}{\text{hr}}$) of the i th radionuclide,

f_i = fraction of nuclei of the i th radionuclide which decays to the $i+1$ st nuclide in the pathway,

t_0 = initial time (hr), and

$$\dot{N}_i(t) = \frac{dN_i(t)}{dt}.$$

Now the activity is related to the number of disintegrations per hour by

$$A_i(t) = \frac{\lambda_i}{k} N_i(t) \quad (10)$$

where

$$k = 1.332 \times 10^8 \frac{\text{dis}}{\text{hr} \cdot \mu\text{Ci}}$$

$A_i(t)$ = activity (μCi) of the i th radionuclide at time t .

For submersion in air ($p = a$) or water ($p = w$), let $C_{ip\ell}(t) = A_i(t)$ per unit volume ($\frac{\text{dis}}{\text{hr} \cdot \mu\text{Ci} \cdot \text{cm}^3}$). (11)

and for exposure to surface contamination ($p = s$), let

$$C_{ip\ell}(t) = A_i(t) \text{ per unit surface area } \left(\frac{\text{dis}}{\text{hr} \cdot \mu\text{Ci} \cdot \text{cm}^2} \right). \quad (12)$$

Further, let

$$\left\{ \begin{array}{l} q_i = \lambda_i, \\ S_i = \lambda_{i+1} f_i, \\ C_{ip\ell}(t_0) = A_i(t_0) g_{pi\ell} = C_{ip\ell}^0 \end{array} \right. \quad (13)$$

where

$g_{pi\ell}$ = location correction factor for the i th radionuclide, the p th mode of exposure, and the ℓ th location.

Substituting Eqs. (11), (12), and (13) into Eqs. (9), one obtains

$$(14) \quad \begin{cases} \dot{C}_{1p\ell}(t) = -q_1 C_{1p\ell}(t) \\ \dot{C}_{2p\ell}(t) = -q_2 C_{2p\ell}(t) + S_1 C_{1p\ell}(t) \\ \dot{C}_{3p\ell}(t) = -q_3 C_{3p\ell}(t) + S_2 C_{2p\ell}(t) \\ \vdots \\ \dot{C}_{np\ell}(t) = -q_n C_{np\ell}(t) + S_{n-1} C_{(n-1)p\ell}(t) \\ C_{ip\ell}(t_0) = A_i(t_0) g_{pi\ell} = C_{ip\ell}^0, \quad i = 1, 2, \dots, n. \end{cases} \quad (14)$$

The general solution to this system of equations is

$$C_{ipm}(t) = \begin{cases} C_{ipm}^0 e^{-q_1 T}, & i = 1, \\ C_{ipm}^0 e^{-q_i T} + T \left\{ \sum_{k=1}^{i-1} C_{kpm}^0 \left[\sum_{j=k}^{i-1} Y_{ij}(T) S_j \prod_{\substack{\ell=k \\ \ell \neq j}}^{i-1} \left(\frac{S_\ell}{q_\ell - q_j} \right) \right] \right\}, & i > 1, \end{cases} \quad (15)$$

where

$$T = t - t_0,$$

$$\prod_{\substack{\ell=k \\ \ell \neq j}}^{i-1} \left(\frac{S_\ell}{q_\ell - q_j} \right) = 1 \text{ if } k = i-1.$$

and

$$Y_{ij}(T) = \begin{cases} \left\{ \frac{1 - \exp[-(q_i - q_j)T]}{(q_i - q_j)T} \right\} e^{-q_j T}, & \text{if } q_i > q_j, \\ \left\{ \frac{1 - \exp[-(q_j - q_i)T]}{(q_j - q_i)T} \right\} e^{-q_i T}, & \text{if } q_i \leq q_j. \end{cases} \quad (16)$$

Thus for one environmental release, let t_0 equal the time of the release and Y_i equal the yield vented by the release so that $C_{ipl}^0 = Y_i g_{pil}$. Then $C_{ipl}(t)$ is given by Eq. (15). However, when $p = a$,

$$C_{ial}(t) = 0 \text{ if } t > t_c \quad (17)$$

where t_c = time (hr) required for the radioactive cloud from the environmental release to pass the location.

The above procedure can be extended to estimate $C_{ipl}(t)$ when there exists more than one environmental release.

Next, consider a nuclide chain with branching and locate each pathway in the chain. The concentration for each radionuclide in each of the pathways of the chain can be solved by Eq. (15). For certain radionuclides, the contributions in some pathways must be added to the contributions from previous pathways. As an example, examine the following nuclide chain:

Radionuclides 3 and 5 decay into a stable nuclide. Each pathway in the nuclide chain is depicted below:

1 → 2 → 3 → 4 → 5

1 → 2 → 3 →

1 → 2 → 504 → 505 →

relationships are $1 \rightarrow 503 \rightarrow 504 \rightarrow 505 \rightarrow$ and $1 \rightarrow 503 \rightarrow 504 \rightarrow 505 \rightarrow$.

For a particular pathway, 500 is added to the index of a radionuclide,

as 503, 504, and 505, to indicate that the contribution for the nuclide in this pathway is added to the contribution from previous pathways.

Note that the partial activity of nuclide 3 can be calculated from either pathways 1 and 2; thus 500 is not added. The rest of the activity for nuclides 3, 4, and 5 is determined from pathway 4. Pathway 5 does not add further activity to nuclide 3; thus 500 is not added.

2.4 Calculation of the Accumulated Concentration

To obtain an algorithm for approximating the integral in Eq. (2), consider the simpler case involving only one environmental release. Let

$$I_{ip\ell}(t_1, t_2) = \int_{t_1}^{t_2} C_{ip\ell}(t) dt. \quad (18)$$

When $p = a$, the upper limit of integration is actually the minimum of t_2 and t_c . By integrating the first equation in Eqs. (14), one obtains

$$I_{ip\ell}(t_1, t_2) = \frac{1}{q_1} [C_{ip\ell}(t_1) - C_{ip\ell}(t_2)]. \quad (19)$$

By integrating the second equation in Eqs. (14) and combining the results with Eq. (19), one obtains

$$I_{2p\ell}(t_1, t_2) = \frac{1}{q_2} [C_{2p\ell}(t_1) - C_{2p\ell}(t_2) + S_1 I_{1p\ell}(t_1, t_2)], \quad (20)$$

or in general

$$I_{ip\ell}(t_1, t_2) = \frac{1}{q_i} [C_{ip\ell}(t_1) - C_{ip\ell}(t_2) + S_{i-1} I_{(i-1)p\ell}(t_1, t_2)]. \quad (21)$$

Thus Eqs. (19) and (21) can be used to evaluate the integral in Eq. (2).

If there is more than one environmental release, then let τ_i denote the time of the i th release. Define k and m so that $\tau_k \leq t_1 < \tau_{k+1}$ and $\tau_m < t_2 \leq \tau_{m+1}$. (If k is the number of the final release, then $k+1$ will not exist, and if M is the number of the final release, then $m+1$ will not exist.)

Then

$$I_{ip\ell}(t_1, t_2) = I_{ip\ell}(t_1, \tau_{k+1}) + \sum_{n=k+1}^{m-1} I_{ip\ell}(\tau_n, \tau_{n+1}) + I_{ip\ell}(\tau_m, t_2). \quad (22)$$

Let

$$C_{ip\ell n}^0 = Y_{in} g_{pi\ell n}. \quad (23)$$

For $i = 1$, combine Eq. (22) with Eq. (19) to obtain

$$I_{1p\ell}(t_1, t_2) = \frac{1}{q_1} C_{1p\ell}(t_1) + \sum_{n=k+1}^m C_{ip\ell n}^0 - C_{1p\ell}(t_2). \quad (24)$$

For $i > 1$, combine Eq. (22) with Eq. (21) to obtain

$$I_{ip\ell}(t_1, t_2) = \frac{1}{q_i} C_{ip\ell}(t_1) + \sum_{n=k+1}^m C_{ip\ell n}^0 - C_{ip\ell}(t_2) + S_{i-1} I_{(i-1)p\ell}(t_1, t_2). \quad (25)$$

3. THE COMPUTER CODE

This section describes the computer code, EXREM III, written in FORTRAN IV for the IBM 360 75/91. The code can calculate the dose rates at a specified time and the total doses accumulated during a specified time interval resulting from submersion in contaminated water, submersion in contaminated air, and exposure to a contaminated surface. For each of the modes of exposure, the code performs the calculations for contamination from beta, positron, electron, and gamma or x-ray radiation. This section considers the computer solutions for the equations derived in Section 2.0, the special calculations and assumptions used by the code, a brief description of each subroutine, the definition of the program variables, and the input format.

3.1 The Computer Solution

The computer code EXREM III is programmed to solve Eqs. (1) and (2) by using Eqs. (3) through (8), Eq. (15), and Eqs. (24) and (25).

3.2 Special Calculations and Assumptions

A term of the form

$$f(x) = \frac{1-e^{-x}}{x}, \quad x > 0,$$

appears in Eq. (16). If $0 < x \ll 1$, then a loss of significance can occur when the expression is evaluated on a digital computer. However, the expression can be expanded in a power series to obtain

$$f(x) = 1 - \frac{x}{2!} + \frac{x^2}{3!} - \frac{x^3}{4!} + \dots$$

By choosing a sufficient number of terms, $f(x)$ can be evaluated accurately. The code uses this procedure to evaluate expressions containing terms of the form $f(x)$ when $0 < x < 0.01$.

The maximum energy of the n th beta particle emitted by the i th radionuclide, $E_{\beta in}$, and the atomic number of the i th radionuclide, Z_i , are part of the data base input for EXREM III. The code uses these data to approximate the average beta energy, $\bar{E}_{\beta in}$, and positron energy, $\bar{E}_{pin}$, with the equations (see ref. 6):

$$\bar{E}_{\beta in} = 1/3 E_{\beta in} (1 - 0.02 \sqrt{Z_i}) (1 + 0.25 \sqrt{E_{\beta in}}) \quad (26a)$$

$$\bar{E}_{pin} = 1/3 E_{pin} (1 + 0.25 \sqrt{E_{pin}}) \quad (26b)$$

A table containing values for the linear energy absorption coefficient, σ , as a function of energy is stored in the subroutine CALCUL. The table consists of two arrays: the energies, which are the independent variables, are contained in the array, E; the array, SIGMA, contains the linear energy absorption coefficients and is in one-to-one correspondence with the energy array. There are 22 entries in each array, and the largest and smallest entries in the energy array are 5.0 MeV and 0.01 MeV, respectively. From this table the code uses the subroutine LAGRAN (ref. 7) to generate a second table, TABLE,

(currently, containing 1001 entries) by means of Lagrangian log-log interpolation. Then for each $E_{\gamma in}$, the code chooses the appropriate value for σ from the generated table by the following method:

$$\sigma = \text{TABLE}(K)$$

where

$$K = \ln(E_{\gamma in}/0.01) + 1.49.$$

DELX is the spacing of the generated table, TABLE. If $E_{\gamma in} < 0.01$ MeV, the code chooses the value of σ for $E_{\gamma in} = 0.01$ MeV. If $E_{\gamma in} > 5.0$ MeV, EXREM III chooses the value of σ for $E_{\gamma in} = 5.0$ MeV.

The backscatter correction, Bs, (see ref. 3) is equal to 1.14 (dimensionless). The density of air is stored as 1.2×10^{-3} g/cm³ (20°C and 76 cm Hg pressure, see ref. 8).

3.3 Description of Subroutines

3.3.1 Overview

The MAIN PROGRAM controls the other subroutines.

AINPUT reads the input parameters.

PRINT prints the basic input parameters.

CALCUL calculates sum of the beta, positron, and electron dose factors and the gamma-ray dose-rate factors defined in Section 2.2 and performs other basic calculations.

LAGRAN and G3R3G3 are the Lagrangian interpolation subroutines used by CALCUL to approximate σ in Eq. (8). (See ref. 7.)

ENOFX is the subroutine used by CALCUL to approximate the E-function in Eq. (8). (See ref. 9.)

TOTCON estimates the total concentration from t_1 to t_2 [i.e., the integral in Eq. (2)].

CONRAT estimates the concentration at time t [i.e., $C_{ipl}(t)$ in Eq. (1)].

CHAIN estimates $C_{ipl}(t)$ defined by Eq. (15). CHAIN is used by both TOTCON and CONRAT.

OUTPUT performs the final calculations indicated by Eqs. (1) and (2) and prints the headings for each case.

OUTARA prints the answer array for each case.

ORDER arranges the doses from radionuclides in descending order before they are printed by OUTARA.

FMTGEN generates the format for the output of each line in the answer array.

CORE determines the size of the storage area in memory for use by the large variably dimensioned arrays.

BLOCK DATA initializes parameters and limits, some of which are used as variable dimensions.

SPECTRA locates and retrieves from scratch disk storage the energies and intensities of the selected nuclides.

The FREEFORM¹⁰ subroutines allow the reading of unformatted (free form) input.

3.3.2 Variable Dimensioning

The large data arrays are stored in blank COMMON. The maximum space is governed by the subroutine CORE. The following is an example of CORE which reserves 2000 words (8K bytes) of storage.

```
SUBROUTINE CORE(MAXC)
```

```
COMMON C(2000)
```

```
MAXC = 2000
```

```
RETURN
```

```
END
```

The value of MAXC is returned to the main routine for comparison with NEED, the computed requirement based on input and BLOCK DATA. If NEED > MAXC, the problem is terminated.

The BLOCK DATA routine sets limits. The routine provided with the reference version of EXREM III is as follows:

```
BLOCK DATA
COMMON/MAX/MAXDET,MAXDR,MAXHTS,MAXNUC,MAXTD
COMMON/OUT1/T1(50),T2(50),TIME(50),TITLE(20),IDET,LIST,MAXB,
1MAXG,NDOSER,NTDOSE,MAXP,MAXE
COMMON/XCHAIN/MAXINC,MAXNUM,NCHAIN,MAXCHN
COMMON/OUT2/ILOC,MAXLIN,IYEAR
COMMON/PARM/HEIGHT(3),IAIR,ISUR,IWATER,NDET,NHTS,NLOC,NRNUC,MAXLOC
REAL*8 RADNUC
DATA MAXDET/25/,MAXDR/50/,MAXHTS/3/,
1MAXNUC/250/,MAXTD/50/,MAXB/15/,MAXG/30/,MAXP/3/,MAXE/30/,
2MAXINC/10/,MAXLIN/55/,MAXLOC/2/,MAXNUM/500/
END
```

Space is reserved in C as follows:

```
RADNUC(2*NRNUC),ANAME1(2*NRNUC),ANAME2(2*NRNUC),ANAME3(2*NRNUC),
NBETA(NRNUC),NGAMMA(NRNUC),NELECT(NRNUC),BPROB(NRNUC*MAXB),
EO(NRNUC*MAXB),GENERY(NRNUC*MAXG),GPROB(NRNUC*MAXG),
PPROB(NRNUC*MAXP),EPOS(NRNUC*MAXP),EPROB(NRNUC*MAXE),
EELECT(NRNUC*MAXE),Y(NRNUC*NTAU),IATOM(NRNUC),
F(NCHAIN,MAXINC),NUMNUC(NCHAIN),IDATA(2*NRNUC),
GA(NRNUC*NLOC*NTAU),GS(NRNUC*NLOC*NTAU),GW(NRNUC*NLOC*NTAU),
RDECAY(NRNUC),GDDOSE(2*NRNUC*NHTS),SUBDOSE(2*2*NRNUC),
DOSE(2*NRNUC),CA(NRNUC*NLOC),CS(NRNUC*NLOC),CW(NRNUC*NLOC),
```

IFLAG(NRNUC*NLOC), IFILE(NRNUC), BENERY(NRNUC*MAXB),
 PENERY(NRNUC*MAXP), VALUE1(NRNUC), VALUE2(NRNUC), VALUE3(NRNUC),
 ID1(NRNUC), ID2(NRNUC), ID2(NRNUC), LABEL1(NRNUC), LABEL2(NRNUC),
 LABEL3(NRNUC).

With the BLOCK DATA as given, NEED can be calculated from:

$$NEED = NRNUC(180 + 3 \cdot NTAU(NLOC + 1) + 4 \cdot NLOC + 2 \cdot NHTS) + 21 \cdot NCHAIN$$

In general:

$$NEED = NRNUC (3 \cdot MAXB + 2 \cdot MAXG + 3 \cdot MAXP + 2 \cdot MAXE + 3 \cdot NTAU(NLOC + 1) \\ + 4 \cdot NLOC + 2 \cdot NHTS) + NCHAIN(2 \cdot MAXINC + 1)$$

In the subroutine CORE, C must be dimensioned $\geq$ NEED.

Several examples:

171 nuclides, 137 pathways, NEED $\approx$ 40000

6 nuclides, 5 pathways, NEED $\approx$ 1500

3.4 Definition of Program Variables

The FORTRAN variables used in EXREM III are defined in this section. These variables, listed in alphabetical order, are divided into three groups: the input variables, the more important internal variables, and the output variables. The subscript I denotes the Ith radionuclide, the subscript J denotes electron, (J=1 for beta, positron, or conversion/Auger electron) or photon (J=2 for gamma ray or x-ray) radiation, the subscript K denotes the Kth release, the subscript L denotes the Lth location, the subscript N denotes the Nth beta particle or photon, the

subscript NP denotes the NP_{th} pathway, and the subscript IP denotes the IP_{th} radionuclide in a pathway. Variables marked A are obtained from the data base; variables marked B are problem input. Variables marked by * determine dimensioning (see Section 3.3.2 Variable Dimensioning).

Input Variables

- B ALCF: Location correction factor (cm^{-3}), g_{ailk} , defined in Section 2.3. (To be used if the location correction factor is constant.)
- A BPROB(I,N): Abundance (dimensionless), $f_{\beta in}$, defined in Section 2.2.
- B CLOUDT(K): Time (hr), t_c , required for the cloud from the k th detonation to pass the area of concern (defined in Section 2.3.).
- A EELECT(I,N): Energy (MeV) of conversion/Auger electron, see Section 2.2.2.
- A EO(I,N): Maximum energy (MeV), $E_{\beta in}$, defined in Section 2.2.
- A EPOS(I,N): Energy (MeV) of positrons, see Section 2.2.2.
- A EPROB(I,N): Abundance (dimensionless), $f_{e in}$, see Section 2.2.2.
- A F(NP,IP): The fraction of the IP_{th} radionuclide which decays to the IP+1_{st} nuclide in the NP_{th} pathway.
- B GA(I,L,K): Location correction factor (cm^{-3}), g_{ailk} , defined in Section 2.3.
- A GENERY(I,N): Energy (MeV), $E_{\gamma in}$, defined in Section 2.2.

- A **GPROB(I,N):** Abundance (dimensionless), f_{yin} , defined in Section 2.2.
- B **GS(I,L,K):** Location correction factor (cm^{-2}), g_{silK} , defined in Section 2.3.
- B **GW(I,L,K):** Location correction factor (cm^{-3}), g_{wilK} , defined in Section 2.3.
- B **HEIGHT(IH):** The IHth distance (cm), x , of an individual from a contaminated surface (see Section 2.2).
- B **IAIR:** Flag for submersion in air. If $\text{IAIR} \neq 0$, the dose rates and total doses for submersion in air are calculated. If $\text{IAIR} = 0$, the calculations are omitted.
- A **IATOM(I):** Atomic number, Z_i , defined in Section 3.2.
- A **ICHAIN(NP,IP):** The index, $\text{NONUC}(I)$, for the IPth radionuclide in the NPth pathway.
- B **IDET:** Release reference number. All time parameters entered as input should be measured relative to the time of this release ($t=0$ at release IDET).
- B **ISUR:** Flag for exposure to a surface. If $\text{ISUR} \neq 0$, the dose rates and total doses for exposure to a contaminated surface are calculated. If $\text{ISUR} = 0$, the calculations are omitted.

- B IWATER: Flag for submersion in water. If IWATER $\neq$ 0, the dose rates and total doses for submersion in water are calculated. If IWATER=0, the calculations are omitted.
- B LIST: Output flag. LIST=0 deletes the listing of the input data. LIST=1 lists the input data and solves the problem. LIST=2 lists the input data and stops without solving the problem.
- A NBETA(I): Number of beta particles, $N_{\beta i}$, defined in Section 2.2 [NBETA(I) $\leq$ MAXB].
- B* NCHAIN: Maximum number of nuclide pathways. The actual number ($\leq$ NCHAIN) depends on data base.
- B* NDET(NTAU): Number of releases (NDET $\leq$ MAXDET).
- B NDOSER: Number of times, t, for the dose rate calculation (NDOSER $\leq$ MAXDR).
- A NELECT(I): Number of electrons, N_{ei} , see Section 2.2.2 [NELECT(I) $\leq$ MAXE].
- A NGAMMA(I): Number of gamma or x-ray photons, $N_{\gamma i}$, defined in Section 2.2 [NGAMMA(I) $\leq$ MAXG].
- B* NHTS: Number of distances from a contaminated surface for which the dose is to be calculated (NHTS $\leq$ MAXHTS).
- B* NLOC: Number of locations (NLOC $\leq$ MAXLOC).

A	NONUC(I):	An index used to identify the <u>I</u> th radionuclide
[NONUC(I) ≤ MAXNUM].
A	NPOS(I):	Number of positrons, N_{pi} , see Section 2.2.2.
B*	NRNUC:	Number of radionuclides (NRNUC ≤ MAXNUC).
B	NTAU(NDET):	Number of releases (NTAU ≤ MAXDET).
B	NTDOSE:	Number of time intervals, $[t_1, t_2]$, for the
total dose calculation (NTDOSE ≤ MAXTD).
A	NUMNUC(NC):	Number of radionuclides in the <u>N</u> Cth pathway
[NUMNUC(NC) ≤ MAXINC)].
A	PPROB(I):	Abundance (dimensionless), f_{pin} , see Section 2.2.2.
B	RADNUC(I):	The name of the <u>I</u> th radionuclide (REAL*8).
A	RDECAY(I):	The radiological decay constant, (hr^{-1}) , λ_i ,
defined in Section 2.3.
B	SLCF:	Location correction factor (cm^{-2}), g_{silk} , defined
in Section 2.3. (To be used if the location
correction factor is constant.)
B	TAU(K):	Time of the <u>k</u> th environmental release (hr),
t_k , defined in Section 2.4.
B	TIME(II):	Time for dose-rate calculation (hr), t , for
the <u>II</u> th case.
B	TIMEUNIT:	Alphanumeric switch to set time unit of dose
rate. If TIMEUNIT = Y or YEAR, the dose is in
units of millirem/yr. If TIMEUNIT is anything
else, the unit is millirem/hr.
B	TITLE:	An array containing the title of the problem.

- B T1(II): Lower limit of integration (hr), t_1 , for the calculation of the total dose for the IIth case.
- B T2(II): Upper limit of integration (hr), t_2 , for the calculation of the total dose for the IIth case.
- B WLCF: Location correction factor (cm^{-3}), g_{wilk} , defined in Section 2.3. (To be used if the location correction factor is constant.)
- B Y(I,K): Yield released (μCi), Y_{ik} , defined in Section 2.3.

Internal Variables

- A(IH): HEIGHT(IH) * $1.2\text{E-}3$, (g/cm^2).
- BENERY(I,N): Average energy (MeV), $\bar{E}_{\beta\text{in}}$, defined in Section 2.2
- BS: Backscatter correction, B_s , defined in Section 2.2.
- C: Location of variably dimensioned data (blank COMMON).
- CA(I,L): Either $C_{\text{ial}}(t)$ defined in Sect. 2.3 or $I_{\text{ial}}(t_1, t_2)$ defined in Section 2.4.
- CON(J,IT): An array containing the coefficients

$$\frac{25.6}{24.0}, \frac{51.2}{24.0}, \frac{29.2}{(24.0)(1.2\text{E-}3)}, \frac{29.2}{(24.0)(1.2\text{E-}3)}$$
 (IT=1 for submersion in water; IT=2 for submersion in air.)

- CS(I,L): Either $C_{isl}(t)$ defined in Section 2.3 or $I_{isl}(t_1, t_2)$ defined in Section 2.4.
- CW(I,L): Either $C_{iwl}(t)$ defined in Section 2.3 or $I_{iwl}(t_1, t_2)$ defined in Section 2.4.
- E1(1): Contains the value of $E_1(\sigma \cdot x)$.
- GDDOSE(I,J,IH): Dose rate factor, D_{ijs} , at the IHth height (defined in Section 2.2).
- * MAXB: Maximum number of beta particles (MAXB=15).
- MAXC: Size (in words) of C (subroutine CORE).
- MAXCHN: Maximum number of nuclide pathways equals NCHAIN.
- MAXDET: Maximum number of releases (MAXDET=25).
- * MAXE: Maximum number of conversion/Auger electrons (MAXE=30).
- MAXDR: Maximum number of dose rate calculations for a problem (MAXDR=50).
- * MAXG: Maximum number of photons (MAXG=30).
- MAXHTS: Maximum number of heights above a contaminated surface (MAXHTS=3).
- * MAXINC: Maximum number of radionuclides in a pathway (MAXINC=10).
- MAXLOC: Maximum number of locations (MAXLOC=2).
- MAXLIN: Maximum number of lines on a page of output (MAXLIN=55).
- MAXNUC: Maximum number of radionuclides (MAXNUC=200).
- MAXNUM: Maximum radionuclide index (MAXNUM=500).

- * MAXP: Maximum number of positrons (MAXP=3).
- MAXTD: Maximum number of total dose calculations for a problem (MAXTD=50).
- NEED: Maximum number of 4-byte locations (words) needed by variably dimensioned variables. Calculated in main routine based on input and BLOCK DATA routine.
- PENERY(I,N): Average energy (MeV), E_{pin} , see Section 2.2.2 and in Eq. (26b) in Section 3.2.
- SUBDOS(I,J,M): Dose rate factor, D_{ijm} , ($m = w$ or $m = s$) defined in Section 2.2.

Output Variables

- DOSE(I,J): $DR_{ipj\ell}(t)$ (millirem/hr or millirem/yr) defined in Eq. (1) or $TD_{ipj\ell}(t_1, t_2)$ defined in Eq. (2). The electron dose rate includes beta rays, positrons, and conversion and Auger electrons.
- L: The Lth location.
- TOTAL: An array containing the sum of the dose rates or total doses for all radionuclides.

The output variables IDET, NONUC(I), RADNUC(I), HEIGHT(IH), TIME(II), TITLE, T1(II), and T2(II) were defined above.

3.5 DESCRIPTION OF INPUT

A description of the card input for EXREM III is presented in this section. The entire deck for a problem is divided into eight groups which are listed below. Except for the TITLE card and Group 2, columns 73 through 80 are reserved for identification to aid the user in the preparation and handling of the data. Examples are given to suggest identification for each card.

3.5.1 Input Categories

A. Data Base (formatted)

1. Group 1

- a. Data base unit number
- b. NUCLID cards

2. Group 2

- a. B cards
- b. P cards
- c. E cards
- d. G cards

3. Group 3

- a. PAT card

- b. FRA card

} for each pathway

B. Problem Input (all free field except title card)

4. Group 4 (formatted)

- a. TITLE card

5. Group 5 (free field)

- a. LIMIT card
- b. HEIGHT card
- c. DETON card

6. Group 6

RADNUC cards

7. Group 7

PROD cards

8. Group 8

- a. WLOC cards
- b. ALOC cards
- c. SLOC cards

9. Group 9

CLOUD card

10. Group 10

- a. DOSRAT card
- b. TOTDOS card

3.5.2 Description of Each Group

Each card is described by listing the variables in the order in which they are to be entered, by giving the FORTRAN format used to read the card, including identification to be used. The input variables were defined in Section 3.4.

A. Data Base (Formatted)

1. Group 1

a. Data Base Unit Number

Variable Read: IM

Format (I3)

This is the unit number for reading the data base. It may be the normal input unit or may be another unit.

b. NUCLID_i cards for $i = 1, 2, \dots, \text{NRNUC}$.

Variables Read: NONUC(I), IATOM(I), RADNUC(I),

RDECAY(I), NBETA(I), NGAMMA(I), NPOS(I), NELECT(I),

for $I = i$.

Format: (2I3, A8, 1X, E10.0, 4I5).

Identification: Reference number (source of data) in column 73. See Sppendix B.

Identification: Enter the word NUCLID in columns 75-80.

The radionuclide names (RADNUC) should be left-adjusted in columns 7-13. In order for the radionuclide SR-90 to be treated as described in Section 2.2, the index, NONUC(I), must equal 42.

2. Group 2

a. B_i cards for $i=1, 2, \dots$

Variables Read: (EO(I,IP), BPROB(I,IP)) for $IP=1, 2, \dots$, NBETA(I) and for $I=i$, NONUC(I).

Format: (12E6.0, 5X, I3).

Identification: Enter B in column 73 and the value

of NONUC(I) in columns 78-80. The values of NONUC(I) are required by EXREM III to find the data.

There can be six sets of energies and abundances per card. For each radionuclide i , the code continues to read B cards until all these sets have been read.

The data are terminated by a blank card (may have zeros). If $NBETA(I)=0$ for a particular I , then the

B card corresponding to that radionuclide is omitted.

The data for the radionuclides should appear in the same sequence as the radionuclides appeared in Group 1.

b. P_i cards for $i=1, 2, \dots$,

Variables Read: $[EPOS(I,IP), PPROB(I,IP)]$ for $IP=1, 2, \dots$, $NPOS(I)$ and for $I=i$, $NONUC(I)$.

Format: (12E6.0, 5X, I3).

Identification: Enter P in column 73 and the value of $NONUC(I)$ in columns 78-80.

There can be six sets of energies and abundances per card. For each radionuclide i , the code continues to read P cards until all these sets have been read.

The data are terminated by a blank card (may have zeros). If $NPOS(I)=0$ for a particular nuclide, then

the P card corresponding to that radionuclide is

omitted. The data for the radionuclides should appear in the same sequence as the radionuclides appeared in

Group 1.

c. E_i cards for $i=1, 2, \dots$

Variables Read: $[EELECT(I,IP), EPROB(I,IP)]$ for $IP=1, 2, \dots$, $NELECT(I)$ and for $I=i$, $NONUC(I)$.

Format: (12E6.0, 5X, I3).

Identification: Enter E in column 73 and the value of NONUC(I) in columns 78-80.

There can be six sets of energies and abundances per card. For each radionuclide i , the code continues to read E cards until all these sets have been read.

The data are terminated by a blank card (may have zeros). If NELECT(I)=0 for a particular nuclide, then the P card corresponding to that radionuclide is omitted. The data for the radionuclides should appear in the same sequence as the radionuclides appeared in Group 1.

d. G_i cards for $i=1, 2, \dots$

Variables Read: (GENERY(I,IP), GPROB(I,IP)) for IP=1, 2, ..., NGAMMA(I) and for I=i, NONUC(I).

Format: (12E6.0, 5X, I3).

Identification: Enter G in column 73 and the value of NONUC(I) in columns 78-80.

There can be six sets of energies and abundances per card. For each radionuclide i , the code continues to read G cards until all these sets have been read.

The data are terminated by a blank card (may have zeros). If NGAMMA(I)=0 for a particular nuclide, then the G card corresponding to that radionuclide is omitted. The data for the radionuclides should appear

in the same sequence as the radionuclides appeared in Group 1.

3. Group 3

This group consists of a PAT card and a FRA card for each nuclide pathway. The group is repeated for each pathway in a nuclide chain and then for each nuclide chain.

a. PAT card for the NP^{th} nuclide pathway.

Variables Read: NUMNUC(NP), ICHAIN(NP,IP) for IP=1, 2, . . . , NUMNUC(NP).

Format: (14I5).

Identification: Enter the number of the pathway in column 71, the total number of pathways for the chain in column 72, the mass chain index in columns 74-76, and the word PAT in columns 78-80.

NOTE: To indicate additional contributions to a nuclide which appeared in a previous pathway, add 500 to the nuclide index. (See Section 2.3.)

b. FRA card for the NP^{th} nuclide pathway.

Variables Read: F(NP,IP) for IP=1, 2, . . . , NUMNUC(NP).

Format: (5X,13F5.0).

Identification: Enter the number of the pathway in column 71, the total number of pathways for the chain

in column 72, the mass chain index in columns 74-76,
and the word FRA in columns 78-80.

The data are terminated by a blank card (may be zeros).

B. Problem Input

4. Group 4 (Formatted)

TITLE card.

Variables Read: TITLE(J) for J=1, 2, . . . , 20.

Format: (20A4)

This card contains the title for the problem which can be from 1 to 80 alphanumeric characters and which should be centered on the card.

5. Group 5 (Unformatted, free field)*

a. LIMIT card.

Variables Read: NRNUC, NCHAIN, NTAU, NLOC, NHTS, IDET, IWATER, IAIR, ISUR, LIST, NDOSER, NTDOSE, TIMEUNIT

Form: 12 integers, alphanumeric character(s)

NOTE: If CLOUDT(K) = CLOUD for each release, then enter NTAU as a negative number so that $|NTAU|$ = number of releases. Then Group 9 will be omitted. See Par. 6 of Section 3.5.2.

NOTE: If the location correction factor is constant for each mode of exposure, then enter NLOC as a negative number

* The unformatted, free field data variables must be separated by at least one blank. As many data "islands" may appear on a card as desired. For convenience, however, the data description will be described here as "cards".

so that $|NLOC|$ = number of locations and for Group 8, use the cards described in Par. 4b of Section 3.5.2.

Otherwise, let $NLOC$ = number of locations and for Group 8, use the cards described in Par. 4a of Section 3.5.2.

NOTE: TIMEUNIT should be YEAR or Y to make the dose rate units mrem/yr. If TIMEUNIT is HR (or something else), the dose rate is in units of mrem/hr.

b. HEIGHT card.

Variables Read: HEIGHT(IH) for IH = 1, 2, . . . , NHTS.

Form: real

NOTE: If ISUR=0, then the HEIGHT card is omitted.

c. RELEASE TIME card.

Variables Read: TAU(K) for K = 1, 2, . . . , NTAU.

Form: real

The code continues to read cards until all NTAU release times have been read.

6. Group 6

RADNUC_i cards for i=1, 2, . . . , NRNUC.

Variables Read: RADNUC(I) for I=1, 2, . . . , NRNUC.

Form: Alphanumeric

Example: ZR95M

This input specifies the particular nuclides to be treated in the problem. It is necessary that data for these nuclides be present in the data base.

7. Group 7

PROD_i cards for $i=1, 2, \dots, \text{NRNUC}$.

Variables Read: $Y(I,K)$ for $K=1, 2, \dots, \text{NTAU}$ and for $I=i$.

Form: real.

For each radionuclide i , the code continues to read PROD cards until all NTAU release quantities have been read. The data for the radionuclides must appear in the same sequence as the radionuclides appeared in Group 6.

If all releases are the same for nuclide I and subsequent nuclides, this can be specified by giving $Y(I+1,1) < 0$ as the final data value. For example, Let $\text{NTAU}=2$, $\text{NRNUC}=100$ and all $Y(I,1)=1$, and $Y(I,2)=2$. The data can be entered as: 1. 2. -1.

8. Group 8

This group consists of sets of WLOC, ALOC, and SLOC cards containing the location correction factors for submersion in water, submersion in air, and exposure to a surface, respectively. The entire group is repeated for each location ℓ , where $\ell = 1, 2, \dots, \text{NLOC}$.

a. When $\text{NLOC} > 0$, Group 8 has the following form:

(1) WLOC _{$i\ell$} cards for $i=1, 2, \dots, \text{NRNUC}$.

Variables Read: $\text{GW}(I,L,K)$ for $K=1, 2, \dots, \text{NTAU}$ and for $I=i$ and $L=\ell$.

Form: real.

For each radionuclide i , the code continues to read WLOC cards until all NDET factors have been read.

The data for the radionuclides must appear in the same sequence as the radionuclides appeared in Group 6.

NOTE: If IWATER=0, the WLOC cards are omitted.

(2) ALOC _{i l} cards for $i=1, 2, \dots, \text{NRNUC}$.

Variables Read: GA(I,L,K) for $K=1, 2, \dots, \text{NTAU}$ and for $I=i$ and $L=l$.

Form: real.

For each radionuclide i , the code continues to read ALOC cards until all NTAU factors have been read.

The data for the radionuclides must appear in the same sequence as the radionuclides appeared in Group 6.

NOTE: If IAIR=0, the ALOC cards are omitted.

(3) SLOC _{i l} cards for $i=1, 2, \dots, \text{NRNUC}$.

Variables Read: GS(I,L,K) for $K=1, 2, \dots, \text{NTAU}$ for $I=i$ and $L=l$.

Form: real.

For each radionuclide i , the code continues to read SLOC cards until all NDET factors have been read.

The data for the radionuclides must appear in the same sequence as the radionuclides appeared in Group 6.

NOTE: If ISUR=0, the SLOC cards are omitted.

b. When $NLOC < 0$, Group 8 has the following form:

(1) WLOC card.

Variable Read: WLCF for $L=2$.

Format: real.

NOTE: If $IWATER=0$, the WLOC card is omitted.

(2) ALOC card.

Variable Read: ALCF for $L=2$.

Format: real.

NOTE: If $IAIR=0$, the ALOC card is omitted.

(3) SLOC card.

Variables Read: SLCF for $L=2$.

Format: real.

NOTE: If $ISUR=0$, the SLOC card is omitted.

9. Group 9

CLOUD card.

Variables Read: CLOUDT(K) for $K=1, 2, \dots, NTAU$

Format: real.

The code continues to read CLOUD cards until all $NTAU$ of the CLOUDT times have been read.

NOTE: If $NTAU < 0$, then Group 9 is omitted, and the code assumes that $CLOUDT=CLOUD$ for each release (currently, $CLOUD=1.0$ hours).

NOTE: If $IAIR=0$ then Group 9 is omitted.

10. Group 10

a. DOSRAT card.

Variables Read: TIME(J) for J=1, 2, . . . , NDOSER.

Format: real.

The code continues to read DOSRAT cards until all NDOSER of the entries have been read.

NOTE: If NDOSER=0, then these cards are omitted.

b. TOTDOS card.

Variables Read: T1(J), T2(J) for J=1, 2, . . . , NTDOSE.

Format: real.

The code continues to read pairs of values until all NTDOSE of the integration limits, T1 and T2, have been read.

NOTE: If NTDOSE=0, then these cards are omitted.

3.5.3 Input Summary

<u>Data Base Input Summary</u>	<u>Format</u>
1.(a) Data Base Unit, IM	(I3)
(b) NUCLID (Repeat for all nuclides)	
NONUC(I), IATOM(I), RADNUC(I), RDECAY(I),	(2I3, A8, 1X, E10.0, 4I5)
NBETA(I), NGAMMA(I), NPOS(I), NELECT(I)	
Blank card	
2.(a) Betas (Repeat for all nuclides)	
(EO(I, IP), BPROB(I, IP), IP=1, NBETA(I)),	
NONUC(I)	(12E6.0, 5X, I3)

Data Base Input SummaryFormat

Blank Card

- (b) Positrons (Repeat for all nuclides)
 ((EPOS(I,IP),PPROB(I,IP),IP=1,NPOS(I)),
 NONUC(I) (12E6.0,5X,I3)

Blank card

- (c) Electrons (Repeat for all nuclides)
 ((EELECT(I,IP),EPROB(I,IP),IP=1,
 NELECT(I)),NONUC(I) (12E6.0,5X,I3)

Blank card

- (d) Gamma or X-Rays (Repeat for all nuclides)
 ((GENERY(I,IP),GPROB(I,IP),IP=1,NGAMMA(I)),
 NONUC(I) (12E6.0,5X,I3)

3. PAT,FRA

Repeat for all pathways { NUMNUC(NP),ICHAIN(NP,IP),
 IP=1,NUMNUC(NP) (14I5)
 F(NP,IP),IP=1,NUMNUC(NP) (5X,13F5.0)

Blank card

Problem Input Summary (Free Format)

4. Title (80 col)

5. LIMITS

- (a) NRNUC,NCHAIN,NTAU,NLOC,NHTS,IDET,IWATER,IAIR,ISUR,

LIST,NDOSER,NTODOSE,TIMEUNIT

- (b) (HEIGHT(IH),IH=1,NHTS)

- (c) (TAU(K),K=1,NTAU)

6. Nuclides

(RADNUC(I), I=1, NRNUC)

7. Release Quantities (PROD)

((Y(I,K), K=1, NTAU), I=1, NRNUC)

8. Location Correction Factors

(a) If NLOC > 0

Read all factors L=1, NLOC

Repeat for each location $\left\{ \begin{array}{l} ((GW(I,L,K), K=1, NTAU), I=1, NRNUC) \quad (WLOC) \\ ((GA(I,L,K), K=1, NTAU), I=1, NRNUC) \quad (ALOC) \\ ((GS(I,L,K), K=1, NTAU), I=1, NRNUC) \quad (SLOC) \end{array} \right.$

(b) If NLOC < 0 Factors constant for all times and nuclides.

Read all factors L=1, NLOC

WLCF, ALCF, SLCF (repeat for each location)

9. CLOUD Times

(CLOUDT(K), K=1, NTAU)

10.(a) DOSRAT Times

(TIME(J), J=1, NDOSE)

(b) TOTDOS Times

(TI(J), T2(J), J=1, NTDOS)

4. ACKNOWLEDGEMENTS

The authors wish to acknowledge that the original code and much of this report was taken from the work of W. D. Turner, presently with Computer Sciences Division, Union Carbide Corporation, Nuclear Division, Oak Ridge, Tennessee.

The assistance of C. F. Holoway, of the ORNL Information Center for Internal Exposure, in providing unpublished data, and F. C. Von derlage in computing otherwise unavailable emission spectra is also gratefully acknowledged.

5. REFERENCES

1. W. Doyle Turner, The EXREM II Computer Code for Estimating External Doses to Populations from Construction of a Sea-Level Canal with Nuclear Exposure, CTC-8, Union Carbide Corp., Computing Technology Center (1969).
2. W. D. Turner, S. V. Kaye, and P. S. Rohwer, EXREM and INREM Computer Codes for Estimating Radiation Doses to Populations from Construction of a Sea-Level Canal with Nuclear Explosives, K-1752, Computing Technology Center and Oak Ridge National Laboratory, Oak Ridge, Tennessee (September 1968).
3. K. E. Cowser, S. V. Kaye, P. S. Rohwer, W. S. Snyder, and E. G. Struxness, Dose-Estimation Studies Related to Proposed Construction of an Atlantic-Pacific Interoceanic Canal with Nuclear Explosives: Phase I, ORNL-4101, Oak Ridge National Laboratory, Oak Ridge, Tennessee (March 1967).
4. D. R. Vondy, Development of a General Method of Explicit Solution to the Nuclide Chain Equations for Digital Machine Calculations, ORNL-TM-361, Oak Ridge National Laboratory, Oak Ridge, Tennessee (October 1962).
5. Irving Kaplan, Nuclear Physics, Addison-Wesley Publishing Company, Inc., Reading, Massachusetts, 1955.
6. International Commission on Radiological Protection, Report of Committee II on Permissible Dose for Internal Radiation, ICRP Publ. 2, Pergamon Press, London (1959); Health Phys. 3 (June 1960).

7. S. K. Penny, and M. B. Emmett, An IBM-7090 Subroutine Package for Lagrangian Interpolation, ORNL-3428, Oak Ridge National Laboratory, Oak Ridge, Tennessee (May 2, 1963).
8. Radiological Health Handbook, U.S. Dept. Health, Education, and Welfare, 1960.
9. S. K. Penny, D. K. Trubey, and M. B. Emmett, OGRE, A Monte Carlo System for Gamma-Ray Transport Studies, Including an Example (OGRE-P1) for Transmission Through Laminated Slabs, ORNL-3805, Oak Ridge National Laboratory, Oak Ridge, Tennessee (April 1966).
10. R. C. Durfee, FORTRAN Free-Form Input, ORNL-CF-70-1-45, Oak Ridge National Laboratory Internal Memorandum (1970).

APPENDIX A

SAMPLE PROBLEMS FOR EXREM III

In this section, two examples are presented to illustrate the input format that is required to solve a problem using the code EXREM III.

First Sample Problem for EXREM III

Determine the dose-equivalent rates and the total dose equivalents from both beta and gamma radiation resulting from exposure from submersion in water, submersion in air and exposure 100 cm above a surface contaminated with the radionuclides ZR-95, NB-95M, and NB-95. The radionuclides are the results of a single release. Calculate the dose rate one hour after the release and the total dose accumulated during the first hour after the release.

The following chain describes the decay process of the three radionuclides:

The format of the input cards containing the data necessary to describe the problem is given in Table 1, and the computer output for the problem is given in Table 2.

Table 1

005

65	40ZR95	C.4409E-03	4	4	0	4	2 NUCLID
66	41NB95M	0.8000E-02	0	1	0	3	2 NUCLID
67	41NE95	0.8228E-03	1	2	0	2	2 NUCLID

000

.3640	.543	.3970	.435	.8860	.0181	.1210	.004	B	65
-------	------	-------	------	-------	-------	-------	------	---	----

.1597	1.000							B	67
-------	-------	--	--	--	--	--	--	---	----

000

END2

000

END3

.00215	.014	.01405	.003	.07525	.001	.73789	.001	E	1	65
--------	------	--------	------	--------	------	--------	------	---	---	----

.2164	.580	.2327	.116	.2349	.031			E		66
-------	------	-------	------	-------	------	--	--	---	--	----

.00227	.002	.74584	.002					E		67
--------	------	--------	------	--	--	--	--	---	--	----

000

END4

.00217	.001	.01690	.009	.75687	.543	.72424	.435	G		65
--------	------	--------	------	--------	------	--------	------	---	--	----

.2354	.242							G		66
-------	------	--	--	--	--	--	--	---	--	----

.01779	.001	.76584	.998					G		67
--------	------	--------	------	--	--	--	--	---	--	----

000

END5

3	65	66	067					12	95PAT
---	----	----	-----	--	--	--	--	----	-------

.018	1.	1.						12	95PRA
------	----	----	--	--	--	--	--	----	-------

2	65	567						22	95PAT
---	----	-----	--	--	--	--	--	----	-------

.982	1.							22	95PRA
------	----	--	--	--	--	--	--	----	-------

000

END6

TEST OF SAMPLE PROBLEM FOR EXREM III

3 3 1 -2 1 1 1 1 1 1 1 N

100. 0.

ZR95 NB95M NB95

1. 1. 1. 1. 2. 1.

3. 1. 4. 10. 1. 0. 1.

)*

Table 2

SAMPLE PROBLEM I FOR EXREM III

LIMITS: 3 3 1 -2 1 1 1 1 1 1 N

SUBROUTINE AINPT3 REQUIRES A NUMBERED COMMON OF AT LEAST 1389

HEIGHT 100.0

TIMES 0.0

NUCLIDE 65 40ZR95

NUCLIDE 66 41NB95M

NUCLIDE 67 41NB95

NO. OF PATHWAYS 2, MAXIMUM IS 3

DIMENSION OF VARIABLE STORAGE IS 5000 NEED IS 738.

Y 1.0

Y 1.0

Y 1.0

WLOC, ALOC, SLOC

LOCATION 1

NUCLIDE WLOC (BY RELEASE)

ZR95 0.1000E 01

NB95M 0.1000E 01

NB95 0.1000E 01

NUCLIDE ALOC (BY RELEASE)

ZR95 0.2000E 01

NB95M 0.2000E 01

NB95 0.2000E 01

NUCLIDE SLOC (BY RELEASE)

ZR95 0.1000E 01

NB95M 0.1000E 01

NB95 0.1000E 01

LOCATION 2

NUCLIDE WLOC (BY RELEASE)

ZR95 0.3000E 01

NB95M 0.3000E 01

NB95 0.3000E 01

NUCLIDE	ALOC	(BY RELEASE)	
ZR95	0.1000E	01	
NB95M	0.1000E	01	
NB95	0.1000E	01	
NUCLIDE	SLOC	(BY RELEASE)	
ZR95	0.4000E	01	
NB95M	0.4000E	01	
NB95	0.4000E	01	
CLOUD	10.0		
DOSE RATE TIMES		1.0	
TOTAL DOSE TIMES		0.0	1.0

LISTING OF BASIC INPUT PARAMETERS FOR EXREM III

SAMPLE PROBLEM I FOR EXREM III

TOTAL NO. OF RADIONUCLIDES	=	3
TOTAL NO. OF PATHWAYS	=	2
TOTAL NO. OF RELEASES	=	1
TOTAL NO. OF LOCATIONS	=	2

ESTIMATE DOSES FOR SUBMERSION IN WATER.

ESTIMATE DOSES FOR SUBMERSION IN AIR.

ESTIMATE DOSES FOR EXPOSURE TO A SURFACE.

HEIGHT ABOVE GROUND SURFACE.

NO.	HEIGHT
	(CM)
1	100.000

TIME OF EACH RELEASE.

NO.	RELEASE TIME (HRS)	CLOUD TIME (HRS)
1	0.0	10.0

RADIONUCLIDE IDENTIFICATION.

INDEX	ATOMIC NUMBER	NAME	DECAY CONSTANT (1/HRS)	NO. BETA-PARTICLES	POSITRON PARTICLES	NUMBER PHOTONS	CONVERSION/AUGER ELECTRONS
65	40	ZR95	4.40900E-04	4	0	4	4
66	41	NB95M	8.00000E-03	0	0	1	3
67	41	NB95	8.22800E-04	1	0	2	2

YIELD.

INDEX	RADIONUCLIDE	NUMBER OF RELEASE	QUANTITY (MICROCURIES)
65	ZR95	1	1.00000E 00
66	NB95M	1	1.00000E 00
67	NB95	1	1.00000E 00

LOCATION CORRECTION FACTOR.

FOR ALL RADIONUCLIDES AND FOR ALL RELEASES.

LOCATION NUMBER	SUBMERSION IN WATER (1/CC)	SUBMERSION IN AIR (1/CC)	EXPOSURE TO SURFACE (1/SQ CM)
1	1.0000E 00	2.0000E 00	1.0000E 00
2	3.0000E 00	1.0000E 00	4.0000E 00

ENERGY AND INTENSITY FOR EACH BETA PARTICLE.

INDEX	RADIONUCLIDE	NO.	MAXIMUM ENERGY (MEV)	INTENSITY (FRACTION)
65	ZR95	1	0.3640	0.543
		2	0.3970	0.435
		3	0.8860	0.018
		4	1.1210	0.004
67	NB95	1	0.1597	1.000

ENERGY AND INTENSITY FOR EACH POSITRON.

INDEX	RADIONUCLIDE	NO.	MAXIMUM ENERGY (MEV)	INTENSITY (FRACTION)
-------	--------------	-----	-------------------------	-------------------------

ENERGY AND INTENSITY FOR EACH ELECTRON.

INDEX	RADIONUCLIDE	NO.	ENERGY (MEV)	INTENSITY (FRACTION)
65	ZR95	1	0.0021	0.014
		2	0.0140	0.003
		3	0.0752	0.001
		4	0.7379	0.001
66	NB95M	1	0.2164	0.580
		2	0.2327	0.116
		3	0.2349	0.031
67	NB95	1	0.0023	0.002
		2	0.7458	0.002

ENERGY AND INTENSITY FOR EACH PHOTON.

INDEX RADIONUCLIDE NO.

ENERGY
(MEV)

INTENSITY
(FRACTION)

65 ZR95

1

0.0022

0.001

2

0.0169

0.009

3

0.7569

0.543

4

0.7242

0.435

66 NB95M

1

0.2354

0.242

67 NB95

1

0.0178

0.001

2

0.7658

0.998

RADIONUCLIDE PATHWAYS.

PATHWAY

POSITION

INDEX

FRACTION

1

1

65

0.0180

2

66

1.0000

3

67

1.0000

2

1

65

0.9820

2

567

1.0000

SAMPLE PROBLEM I FOR EXREM III

LISTING OF RADIONUCLIDES FOR SUBMERSION DOSE RATES IN CONTAMINATED WATER

LOCATION NUMBER = 1

TIME AFTER RELEASE 1 = 1.00000E 00 HOURS.

ELECTRON DOSE RATE				PHOTON DOSE RATE			TOTAL DOSE RATE		
NO.	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR
1	66	NB95M	0.169E 03	67	NB95	0.163E 04	65	ZR95	0.169E 04
2	65	ZR95	0.141E 03	65	ZR95	0.155E 04	67	NB95	0.169E 04
3	67	NB95	0.561E 02	66	NB95M	0.121E 03	66	NB95M	0.290E 03
TOTAL			0.367E 03				0.367E 04		

LOCATION NUMBER = 2

TIME AFTER RELEASE 1 = 1.00000E 00 HOURS.

ELECTRON DOSE RATE				PHOTON DOSE RATE			TOTAL DOSE RATE		
NO.	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR
1	66	NB95M	0.507E 03	67	NB95	0.490E 04	65	ZR95	0.507E 04
2	65	ZR95	0.424E 03	65	ZR95	0.465E 04	67	NB95	0.506E 04
3	67	NB95	0.168E 03	66	NB95M	0.362E 03	66	NB95M	0.869E 03
TOTAL			0.110E 04				0.110E 05		

SAMPLE PROBLEM I FOR EXREM III

LISTING OF RADIONUCLIDES FOR SUBMERSION DOSE RATES IN CONTAMINATED AIR

LOCATION NUMBER = 1
TIME AFTER RELEASE 1 = 1.00000E 00 HOURS.

ELECTRON DOSE RATE				PHOTON DOSE RATE			TOTAL DOSE RATE		
NO.	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR
1	66	NB95M	0.321E 06	67	NB95	0.155E 07	65	ZR95	0.174E 07
2	65	ZR95	0.269E 06	65	ZR95	0.147E 07	67	NB95	0.166E 07
3	67	NB95	0.107E 06	66	NB95M	0.115E 06	66	NB95M	0.436E 06
TOTAL			0.697E 06						0.383E 07

LOCATION NUMBER = 2
TIME AFTER RELEASE 1 = 1.00000E 00 HOURS.

ELECTRON DOSE RATE				PHOTON DOSE RATE			TOTAL DOSE RATE		
NO.	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR
1	66	NB95M	0.161E 06	67	NB95	0.776E 06	65	ZR95	0.870E 06
2	65	ZR95	0.134E 06	65	ZR95	0.736E 06	67	NB95	0.829E 06
3	67	NB95	0.533E 05	66	NB95M	0.573E 05	66	NB95M	0.218E 06
TOTAL			0.349E 06				0.157E 07	0.192E 07	

SAMPLE PROBLEM I FOR EXREM III

LISTING OF RADIONUCLIDES FOR DOSE RATES ABOVE A CONTAMINATED GROUND SURFACE

LOCATION NUMBER = 1
 HEIGHT = 100.000 CM.
 TIME AFTER RELEASE 1 = 1.00000E 00 HOURS.

ELECTRON DOSE RATE				PHOTON DOSE RATE			TOTAL DOSE RATE		
NO.	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR
1	65	ZR95	0.114E 02	67	NB95	0.135E 03	65	ZR95	0.140E 03
2	67	NB95	0.108E 01	65	ZR95	0.129E 03	67	NB95	0.136E 03
3	66	NB95M	0.620E-05	66	NB95M	0.962E 01	66	NB95M	0.962E 01
TOTAL			0.124E 02	0.274E 03			0.286E 03		

LOCATION NUMBER = 2
 HEIGHT = 100.000 CM.
 TIME AFTER RELEASE 1 = 1.00000E 00 HOURS.

ELECTRON DOSE RATE				PHOTON DOSE RATE			TOTAL DOSE RATE		
NO.	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR
1	65	ZR95	0.455E 02	67	NB95	0.542E 03	65	ZR95	0.561E 03
2	67	NB95	0.432E 01	65	ZR95	0.516E 03	67	NB95	0.546E 03
3	66	NB95M	0.248E-04	66	NB95M	0.385E 02	66	NB95M	0.385E 02
TOTAL			0.498E 02	0.110E 04			0.115E 04		

SAMPLE PROBLEM I FOR EXREM III

LISTING OF RADIONUCLIDES FOR ACCUMULATED SUBMERSION DOSES IN CONTAMINATED WATER

LOCATION NUMBER = 100
 INTEGRATION PERIOD -- 0.0 TO 1.00000E 00 HOURS.

NO.	ELECTRON DOSE			PHOTON DOSE			TOTAL DOSE		
	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS
1	66	NB95M	0.170E 03	67	NB95	0.163E 04	65	ZR95	0.169E 04
2	65	ZR95	0.142E 03	65	ZR95	0.155E 04	67	NB95	0.169E 04
3	67	NB95	0.561E 02	66	NB95M	0.121E 03	66	NB95M	0.291E 03
TOTAL			0.367E 03			0.330E 04			0.367E 04

LOCATION NUMBER = 200
 INTEGRATION PERIOD -- 0.0 TO 1.00000E 00 HOURS.

NO.	ELECTRON DOSE			PHOTON DOSE			TOTAL DOSE		
	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS
1	66	NB95M	0.509E 03	67	NB95	0.489E 04	65	ZR95	0.507E 04
2	65	ZR95	0.425E 03	65	ZR95	0.465E 04	67	NB95	0.506E 04
3	67	NB95	0.168E 03	66	NB95M	0.363E 03	66	NB95M	0.872E 03
TOTAL			0.110E 04			0.990E 04			0.110E 05

SAMPLE PROBLEM I FOR EXREN III

LISTING OF RADIONUCLIDES FOR ACCUMULATED SUBMERSION DOSES IN CONTAMINATED AIR

LOCATION NUMBER = 1

INTEGRATION PERIOD -- 0.0 TO 1.00000E 00 HOURS.

NO.	ELECTRON DOSE			PHOTON DOSE			TOTAL DOSE		
	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS
1	66	NB95M	0.323E 06	67	NB95	0.155E 07	65	ZR95	0.174E 07
2	65	ZR95	0.269E 06	65	ZR95	0.147E 07	67	NB95	0.166E 07
3	67	NB95	0.107E 06	66	NB95M	0.115E 06	66	NB95M	0.438E 06
TOTAL			0.698E 06			0.314E 07			0.384E 07

LOCATION NUMBER = 2

INTEGRATION PERIOD -- 0.0 TO 1.00000E 00 HOURS.

NO.	ELECTRON DOSE			PHOTON DOSE			TOTAL DOSE		
	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS
1	66	NB95M	0.161E 06	67	NB95	0.775E 06	65	ZR95	0.871E 06
2	65	ZR95	0.135E 06	65	ZR95	0.736E 06	67	NB95	0.829E 06
3	67	NB95	0.533E 05	66	NB95M	0.575E 05	66	NB95M	0.219E 06
TOTAL			0.349E 06			0.157E 07			0.192E 07

SAMPLE PROBLEM I FOR EXREM III

LISTING OF RADIONUCLIDES FOR ACCUMULATED DOSES ABOVE A CONTAMINATED GROUND SURFACE

LOCATION NUMBER = 1

HEIGHT = 100.000 CM.

INTEGRATION PERIOD -- 0.0 TO 1.00000E 00 HOURS.

ELECTRON DOSE				PHOTON DOSE			TOTAL DOSE		
NO.	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS
1	65	ZR95	0.114E 02	67	NB95	0.135E 03	65	ZR95	0.140E 03
2	67	NB95	0.108E 01	65	ZR95	0.129E 03	67	NB95	0.136E 03
3	66	NB95M	0.622E-05	66	NB95M	0.966E 01	66	NB95M	0.966E 01
TOTAL			0.124E 02	0.274E 03			0.286E 03		

LOCATION NUMBER = 2

HEIGHT = 100.000 CM.

INTEGRATION PERIOD -- 0.0 TO 1.00000E 00 HOURS.

ELECTRON DOSE				PHOTON DOSE			TOTAL DOSE		
NO.	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS
1	65	ZR95	0.455E 02	67	NB95	0.541E 03	65	ZR95	0.562E 03
2	67	NB95	0.432E 01	65	ZR95	0.516E 03	67	NB95	0.546E 03
3	66	NB95M	0.249E-04	66	NB95M	0.386E 02	66	NB95M	0.386E 02
TOTAL			0.498E 02	0.110E 04			0.115E 04		

Second Sample Problem for EXREM III

Determine the total dose equivalent from both beta and gamma radiation resulting from submersion in water and exposure 100 cm above a surface contaminated with the radionuclides SR-91, Y-91M, Y-91, CD-117M, CD-117, IN-117, SN-117M, and W-187. The radionuclides are the results of two environmental releases. One release occurs 1440 hours after the other. Calculate the total dose accumulated during the first 1500 hours following the first release.

The following chains describe the decay process of the radionuclides:

The format of the input cards containing the data necessary to describe the problem is given in Table 3, and the computer tabulation of the output is given in Table 4.

59

Table 3												
005												
46	38SR91	7.296-2	5	5								2 NUCLID
47	39Y91M	8.285-1	0	6			8					5 NUCLID
48	39Y91	4.903-4	2	1								5 NUCLID
133	48CD117M	2.040-1	0	6								0 NUCLID
134	48CD117	2.890-1	8	11								0 NUCLID
135	49IN117M	3.650-1	3	5								0 NUCLID
136	49IN117	9.240-1	1	3								0 NUCLID
137	50SN117M	2.060-3	0	3								0 NUCLID
291	74W187	2.900-2	8	11			23					5 NUCLID
000												END1
	.61	.07	1.09	.33	1.37	.29	2.03	.04	2.67	.27		B 46
	.3400	.00211	.5450	.998								B 48
	.5	.03	.63	.38	.83	.09	1.47	.06	1.77	.16	1.86	.09B1 134
	1.93	.07	2.230	.12								B2 134
	.95	.04	1.62	.23	1.77	.53						B 135
	.74	1.										B 136
	.43	.005	.44	.0090	.54	.05	.62	.70	.68	.0130	.69	.07B1 291
	.80	.003	1.31	.15								B2 291
000												END2
000												END3
	.534	.04483	.5488	.006151	.5507	.00205	.0127	.00908	.0146	.00308	.0164	.00035E1 47
	.0016	.05243	.0003	.11740								E2 47
	.0003	.10682	.0604	.01102	.0696	.00534	.0349	.00688	.0950	.00140	.1442	.00047E1 291
	.0420	.00284	.1021	.00035	.1114	.00012	.0625	.15273	.1226	.03182	.1319	.01061E2 291
	.1345	.00148	.1946	.00043	.2039	.00014	.1674	.00068	.2275	.00011	.1749	.00033E3 291
	.4081	.00373	.4682	.00089	.4774	.00030	.4408	.00024	.4800	.00028		E4 291
000												END4
	.6450	.14	.748	.29	.93	.03	1.025	.30	1.413	.07		G 46
	.5510	.94696	.01500	.01842	.0149	.00921	.0167	.00413	.0170	.00057	.0019	.00259G 47
	1.210	.002										G 48
	.281	.570	.43	.120	.840	.140	1.270	.700	1.550	.150	.024	.320G 133
	.089	.070	.273	.310	.314	.160	.345	.180	.434	.130	.832	.040G1 134
	.880	.030	.950	.040	1.052	.050	1.304	.190	1.577	.170		G2 134
	.310	.087	.822	.020	.622	.020	.161	.221	.025	.142		G 135
	.565	1.00	.161	.885	.026	.115						G 136
	.161	.885	.159	.310	.026	.805						G 137
	.0720	.10682	.1066	.00275	.1137	.00109	.1342	.08984	.2062	.00064	.2391	.00097G1 291
	.2466	.00110	.2522	.00200	.4798	.23309	.5125	.01858	.5517	.04966		G2 291

000

3	46	47	48
	.59	1.	1.
2	46	548	
	.41	1.	
1	291		
	1.		
4	133	134	135 136
	.49	1.	.47 1.
3	133	635	636
	.44	.47	1.
2	133	636	
	.07	1.	
4	133	134	135 137
	.49	1.	.001 1.
3	133	135	637
	.44	.001	1.
3	133	134	135
	.49	1.	.53
2	133	135	
	.44	.53	

END5

PAT
FRA
PAT
FRA
PAT
FRA
PAT
FRA
PAT
FRA
PAT
FRA
PAT
FRA
PAT
FRA
PAT
FRA
PAT
FRA

000

SECOND SAMPLE PROBLEM FOR EXREM III

9 12 2 -1 1 1 1 0 1 1 2 1 N

100. 0. 1440.

SR91 Y91M Y91 CD117M CD117 IN117M IN117 SN117M W187

6.4E05 5.8E5 6.2E5 6.0E5 0. 0. 7.2E5 4.2E5 4.1E5 3.8E5

6.1E5 4.0E5 2.3E5 0.0 1.0E5 0. 3.0E5 3.0E5 1.0E-6 1.0E-5

0. 1500. 0. 1500.

/*

END6

IHC002I STOP 00000

Table 4

SECOND SAMPLE PROBLEM FOR EXREM III
 LIMITS 9 12 2 -1 1 1 1 0 1 1 2 1 N
 DIMENSION OF VARIABLE STORAGE IS 3000 NEED IS 2246.
 HEIGHT 100.0
 TIMES 0.0 1440.0
 NUCLIDE SR91
 NUCLIDE Y91M
 NUCLIDE Y91
 NUCLIDE CD117M
 NUCLIDE CD117
 NUCLIDE IN117M
 NUCLIDE IN117
 NUCLIDE SN117M
 NUCLIDE W187
 Y 640000.0 580000.0
 Y 620000.0 600000.0
 Y 0.0 0.0
 Y 720000.0 420000.0
 Y 410000.0 380000.0
 Y 610000.0 400000.0
 Y 230000.0 0.0
 Y 100000.0 0.0
 Y 300000.0 300000.0
 WLOC, ALOC, SLOC
 LOCATION 1
 NUCLIDE WLOC (BY RELEASE)
 SR91 0.1000E-05 0.1000E-05
 Y91M 0.1000E-05 0.1000E-05
 Y91 0.1000E-05 0.1000E-05
 CD117M 0.1000E-05 0.1000E-05
 CD117 0.1000E-05 0.1000E-05
 IN117M 0.1000E-05 0.1000E-05
 IN117 0.1000E-05 0.1000E-05
 SN117M 0.1000E-05 0.1000E-05
 W187 0.1000E-05 0.1000E-05

NUCLIDE ALOC (BY RELEASE)

SR91	0.0	0.0
Y91M	0.0	0.0
Y91	0.0	0.0
CD117M	0.0	0.0
CD117	0.0	0.0
IN117M	0.0	0.0
IN117	0.0	0.0
SN117M	0.0	0.0
W187	0.0	0.0

NUCLIDE SLOC (BY RELEASE)

SR91	0.1000E-04	0.1000E-04
Y91M	0.1000E-04	0.1000E-04
Y91	0.1000E-04	0.1000E-04
CD117M	0.1000E-04	0.1000E-04
CD117	0.1000E-04	0.1000E-04
IN117M	0.1000E-04	0.1000E-04
IN117	0.1000E-04	0.1000E-04
SN117M	0.1000E-04	0.1000E-04
W187	0.1000E-04	0.1000E-04

CLOUD 0.0 0.0

NO. OF PATHWAYS 10, MAXIMUM IS 12

DOSE RATE TIMES 0.0 1500.0

TOTAL DOSE TIMES 0.0 1500.0

LISTING OF BASIC INPUT PARAMETERS FOR EXREM III

SECOND SAMPLE PROBLEM FOR EXREM III

TOTAL NO. OF RADIONUCLIDES = 9

TOTAL NO. OF PATHWAYS = 10

TOTAL NO. OF RELEASES = 2

TOTAL NO. OF LOCATIONS = 1

ESTIMATE DOSES FOR SUBMERSION IN WATER.

ESTIMATE DOSES FOR EXPOSURE TO A SURFACE.

HEIGHT ABOVE GROUND SURFACE.

NO.	HEIGHT (CM)
1	100.000

TIME OF EACH RELEASE.

NO.	RELEASE TIME (HRS)	CLOUD TIME (HRS)
1	0.0	0.0
2	1440.0	0.0

RADIONUCLIDE IDENTIFICATION.

INDEX	ATOMIC NUMBER	NAME	DECAY CONSTANT (1/HRS)	NO. BETA- PARTICLES	POSITRON PARTICLES	NUMBER PHOTONS	CONVERSION/AUGER ELECTRONS
46	38	SR91	7.29600E-02	5	0	5	0
47	39	Y91M	8.28500E-01	0	0	6	8
48	39	Y91	4.90300E-04	2	0	1	0
133	48	CD117M	2.04000E-01	0	0	6	0
134	48	CD117	2.89000E-01	8	0	11	0
135	49	IN117M	3.65000E-01	3	0	5	0
136	49	IN117	9.24000E-01	1	0	3	0
137	50	SN117M	2.06000E-03	0	0	3	0
291	74	W187	2.90000E-02	8	0	11	23

YIELD.

INDEX	RADIONUCLIDE	NUMBER OF RELEASE	QUANTITY (MICROCURIES)
46	SR91	1	6.40000E 05
		2	5.80000E 05
47	Y91M	1	6.20000E 05
		2	6.00000E 05
48	Y91	1	0.0
		2	0.0
133	CD117M	1	7.20000E 05
		2	4.20000E 05
134	CD117	1	4.10000E 05
		2	3.80000E 05
135	IN117M	1	6.10000E 05
		2	4.00000E 05

YIELD.

INDEX	RADIONUCLIDE	NUMBER OF RELEASE	QUANTITY (MICROCURIES)
136	IN117	1	2.30000E 05
		2	0.0
137	SN117M	1	1.00000E 05
		2	0.0
291	W187	1	3.00000E 05
		2	3.00000E 05

LOCATION CORRECTION FACTOR.

FOR ALL RADIONUCLIDES AND FOR ALL RELEASES.

LOCATION NUMBER	SUBMERSION IN WATER (1/CC)	SUBMERSION IN AIR (1/CC)	EXPOSURE TO SURFACE (1/SQ CM)
1	1.0000E-06	0.0	1.0000E-05

ENERGY AND INTENSITY FOR EACH BETA PARTICLE.

INDEX	RADIONUCLIDE	NO.	MAXIMUM ENERGY (MEV)	INTENSITY (FRACTION)
46	SR91	1	6.1000E-01	0.07000
		2	1.0900E 00	0.33000
		3	1.3700E 00	0.29000
		4	2.0300E 00	0.04000
		5	2.6700E 00	0.27000
48	Y91	1	3.4000E-01	0.00210
		2	1.5450E 00	0.99800
134	CD117	1	5.0000E-01	0.03000
		2	6.3000E-01	0.38000
		3	8.3000E-01	0.09000
		4	1.4700E 00	0.06000
		5	1.7700E 00	0.16000
		6	1.8600E 00	0.09000
		7	1.9300E 00	0.07000
		8	2.2300E 00	0.12000
135	IN117M	1	9.5000E-01	0.04000
		2	1.6200E 00	0.23000
		3	1.7700E 00	0.53000
136	IN117	1	7.4000E-01	1.00000
291	W187	1	4.3000E-01	0.00500
		2	4.4000E-01	0.00900
		3	5.4000E-01	0.05000
		4	6.2000E-01	0.70000
		5	6.8000E-01	0.01300
		6	6.9000E-01	0.07000
		7	8.0000E-01	0.00300
		8	1.3100E 00	0.15000

ENERGY AND INTENSITY FOR EACH POSITRON.

INDEX	RADIONUCLIDE	NO.	MAXIMUM ENERGY (MEV)	INTENSITY (FRACTION)
-------	--------------	-----	-------------------------	-------------------------

ENERGY AND INTENSITY FOR EACH ELECTRON.

INDEX	RADIONUCLIDE	NO.	ENERGY (MEV)	INTENSITY (FRACTION)
-------	--------------	-----	-----------------	-------------------------

47	Y91M	1	5.3400E-01	0.04483
		2	5.4880E-01	0.00615
		3	1.5507E 00	0.00205
		4	1.2700E-02	0.00908
		5	1.4600E-02	0.00308
		6	1.6400E-02	0.00035
		7	1.6000E-03	0.05243
		8	3.0000E-04	0.11740

291	W187	1	3.0000E-04	0.10682
		2	6.0400E-02	0.01102
		3	6.9600E-02	0.00534
		4	3.4900E-02	0.00688
		5	9.5000E-02	0.00140
		6	1.4420E-01	0.00047
		7	4.2000E-02	0.00284
		8	1.0210E-01	0.00035
		9	1.1140E-01	0.00012
		10	6.2500E-02	0.15273
		11	1.2260E-01	0.03182
		12	1.3190E-01	0.01061
		13	1.3450E-01	0.00148
		14	1.9460E-01	0.00043
		15	2.0390E-01	0.00014
		16	1.6740E-01	0.00068
		17	2.2750E-01	0.00011
		18	1.7490E-01	0.00033
		19	4.0810E-01	0.00373
		20	4.6820E-01	0.00089
		21	4.7740E-01	0.00030
		22	4.4080E-01	0.00024
		23	4.8000E-01	0.00028

ENERGY AND INTENSITY FOR EACH PHOTON.

INDEX	RADIONUCLIDE	NO.	ENERGY (MEV)	INTENSITY (FRACTION)
-------	--------------	-----	-----------------	-------------------------

46	SR91	1	6.4500E-01	0.14000
		2	7.4800E-01	0.29000
		3	9.3000E-01	0.03000
		4	1.0250E 00	0.30000
		5	1.4130E 00	0.07000

47	Y91M	1	5.5100E-01	0.94696
		2	1.5000E-02	0.01842
		3	1.4900E-02	0.00921
		4	1.6700E-02	0.00413
		5	1.7000E-02	0.00057
		6	1.9000E-03	0.00259
48	Y91	1	1.2100E 00	0.00200
133	CD117M	1	2.8100E-01	0.57000
		2	4.3000E-01	0.12000
		3	8.4000E-01	0.14000
		4	1.2700E 00	0.70000
		5	1.5500E 00	0.15000
		6	2.4000E-02	0.32000
134	CD117	1	8.9000E-02	0.07000
		2	2.7300E-01	0.31000
		3	3.1400E-01	0.16000
		4	3.4500E-01	0.18000
		5	4.3400E-01	0.13000
		6	8.3200E-01	0.04000
		7	8.8000E-01	0.03000
		8	9.5000E-01	0.04000
		9	1.0520E 00	0.05000
		10	1.3040E 00	0.19000
		11	1.5770E 00	0.17000
135	IN117M	1	3.1000E-01	0.08700
		2	8.2200E-01	0.02000
		3	6.2200E-01	0.02000
		4	1.6100E-01	0.22100
		5	2.5000E-02	0.14200
136	IN117	1	5.6500E-01	1.00000
		2	1.6100E-01	0.88500
		3	2.6000E-02	0.11500
137	SN117M	1	1.6100E-01	0.88500
		2	1.5900E-01	0.31000
		3	2.6000E-02	0.80500

ENERGY AND INTENSITY FOR EACH PHOTON.

INDEX	RADIONUCLIDE NO.	ENERGY (MEV)	INTENSITY (FRACTION)
291	W187		
	1	7.2000E-02	0.10682
	2	1.0660E-01	0.00275
	3	1.1370E-01	0.00109
	4	1.3420E-01	0.08984
	5	2.0620E-01	0.00064
	6	2.3910E-01	0.00097
	7	2.4660E-01	0.00110
	8	2.5220E-01	0.00200
	9	4.7980E-01	0.23309
	10	5.1250E-01	0.01858
	11	5.5170E-01	0.04966

RADIONUCLIDE PATHWAYS.

PATHWAY	POSITION	INDEX	FRACTION
1	1	46	0.5900
	2	47	1.0000
	3	48	1.0000
2	1	46	0.4100
	2	548	1.0000
3	1	291	1.0000
4	1	133	0.4900
	2	134	1.0000
	3	135	0.4700
	4	136	1.0000
5	1	133	0.4400
	2	635	0.4700
	3	636	1.0000
6	1	133	0.0700
	2	636	1.0000
7	1	133	0.4900
	2	134	1.0000
	3	135	0.0010
	4	137	1.0000
8	1	133	0.4400
	2	135	0.0010
	3	637	1.0000
9	1	133	0.4900
	2	134	1.0000
	3	135	0.5300
10	1	133	0.4400
	2	135	0.5300

Table 4

	SECOND SAMPLE PROBLEM FOR EXREM III												
LIMITS	9	12	2	-1	1	1	1	0	1	1	2	1	N
SUBROUTINE AINPT3 REQUIRES A NUMBERED COMMON OF AT LEAST 1578													
HEIGHT	100.0												
TIMES	0.0	1440.0											
NUCLIDE	46	38SR91											
NUCLIDE	47	39Y91M											
NUCLIDE	48	39Y91											
NUCLIDE	133	48CD117M											
NUCLIDE	134	48CD117											
NUCLIDE	135	49IN117M											
NUCLIDE	136	49IN117											
NUCLIDE	137	50SN117M											
NUCLIDE	291	74W187											
NO. OF PATHWAYS	10,	MAXIMUM IS	12										
DIMENSION OF VARIABLE STORAGE IS	5000	NEED IS	2246.										
Y	640000.0	580000.0											
Y	620000.0	600000.0											
Y	0.0	0.0											
Y	720000.0	420000.0											
Y	410000.0	380000.0											
Y	610000.0	400000.0											
Y	230000.0	0.0											
Y	100000.0	0.0											
Y	300000.0	300000.0											
WLOC, ALOC, SLOC													
LOCATION	1												
NUCLIDE	WLOC	(BY RELEASE)											
SR91	0.1000E-05	0.1000E-05											
Y91M	0.1000E-05	0.1000E-05											
Y91	0.1000E-05	0.1000E-05											
CD117M	0.1000E-05	0.1000E-05											
CD117	0.1000E-05	0.1000E-05											
IN117M	0.1000E-05	0.1000E-05											

IN117	0.1000E-05	0.1000E-05
SN117M	0.1000E-05	0.1000E-05
W187	0.1000E-05	0.1000E-05
NUCLIDE	SLOC (BY RELEASE)	
SR91	0.1000E-04	0.1000E-04
Y91M	0.1000E-04	0.1000E-04
Y91	0.1000E-04	0.1000E-04
CD117M	0.1000E-04	0.1000E-04
CD117	0.1000E-04	0.1000E-04
IN117M	0.1000E-04	0.1000E-04
IN117	0.1000E-04	0.1000E-04
SN117M	0.1000E-04	0.1000E-04
W187	0.1000E-04	0.1000E-04
CLOUD	0.0	0.0
DOSE RATE TIMES	0.0	1500.0
TOTAL DOSE TIMES	0.0	1500.0

LISTING OF BASIC INPUT PARAMETERS FOR EXREM III

6

SECOND SAMPLE PROBLEM FOR EXREM III

TOTAL NO. OF RADIONUCLIDES	=	9
TOTAL NO. OF PATHWAYS	=	10
TOTAL NO. OF RELEASES	=	2
TOTAL NO. OF LOCATIONS	=	1

ESTIMATE DOSES FOR SUBMERSION IN WATER.

ESTIMATE DOSES FOR EXPOSURE TO A SURFACE.

HEIGHT ABOVE GROUND SURFACE.

NO.	HEIGHT (CM)
1	100.000

TIME OF EACH RELEASE.

NO.	RELEASE TIME (HRS)	CLOUD TIME (HRS)
1	0.0	0.0
2	1440.0	0.0

RADIONUCLIDE IDENTIFICATION.

INDEX	ATOMIC NUMBER	NAME	DECAY CONSTANT (1/HRS)	NO. BETA- PARTICLES	POSITRON PARTICLES	NUMBER PHOTONS	CONVERSION/AUGER ELECTRONS
46	38	SR91	7.29600E-02	5	0	5	0
47	39	Y91M	8.28500E-01	0	0	6	8
48	39	Y91	4.90300E-04	2	0	1	0
133	48	CD117M	2.04000E-01	0	0	6	0
134	48	CD117	2.89000E-01	8	0	11	0
135	49	IN117M	3.65000E-01	3	0	5	0
136	49	IN117	9.24000E-01	1	0	3	0
137	50	SN117M	2.06000E-03	0	0	3	0
291	74	W187	2.90000E-02	8	0	11	23

YIELD.

INDEX	RADIONUCLIDE	NUMBER OF RELEASE	QUANTITY (MICROCURIES)
46	SR91	1	6.40000E 05
		2	5.80000E 05
47	Y91M	1	6.20000E 05
		2	6.00000E 05
48	Y91	1	0.0
		2	0.0
133	CD117M	1	7.20000E 05
		2	4.20000E 05
134	CD117	1	4.10000E 05
		2	3.80000E 05
135	IN117M	1	6.10000E 05
		2	4.00000E 05

YIELD. INDEX	RADIONUCLIDE	NUMBER OF RELEASE	QUANTITY (MICROCURIES)
136	IN117	1	2.30000E 05
		2	0.0
137	SN117M	1	1.00000E 05
		2	0.0
291	W187	1	3.00000E 05
		2	3.00000E 05

LOCATION CORRECTION FACTOR.

FOR ALL RADIONUCLIDES AND FOR ALL RELEASES.

LOCATION NUMBER	SUBMERSION IN WATER (1/CC)	SUBMERSION IN AIR (1/CC)	EXPOSURE TO SURFACE (1/SQ CM)
1	1.0000E-06	1.0000E 00	1.0000E-05

ENERGY AND INTENSITY FOR EACH BETA PARTICLE.

INDEX	RADIONUCLIDE	NO.	MAXIMUM ENERGY (MEV)	INTENSITY (FRACTION)
46	SR91	1	0.6100	0.070
		2	1.0900	0.330
		3	1.3700	0.290
		4	2.0300	0.040
		5	2.6700	0.270
48	Y91	1	0.3400	0.002
		2	1.5450	0.998
134	CD117	1	0.5000	0.030
		2	0.6300	0.380
		3	0.8300	0.090
		4	1.4700	0.060
		5	1.7700	0.160
		6	1.8600	0.090
		7	1.9300	0.070
		8	2.2300	0.120
135	IN117M	1	0.9500	0.040
		2	1.6200	0.230
		3	1.7700	0.530
136	IN117	1	0.7400	1.000
291	W187	1	0.4300	0.005
		2	0.4400	0.009
		3	0.5400	0.050
		4	0.6200	0.700
		5	0.6800	0.013
		6	0.6900	0.070
		7	0.8000	0.003
		8	1.3100	0.150

ENERGY AND INTENSITY FOR EACH POSITRON.

INDEX	RADIONUCLIDE	NO.	MAXIMUM ENERGY (MEV)	INTENSITY (FRACTION)
-------	--------------	-----	-------------------------	-------------------------

ENERGY AND INTENSITY FOR EACH ELECTRON.

INDEX	RADIONUCLIDE	NO.	ENERGY (MEV)	INTENSITY (FRACTION)
-------	--------------	-----	-----------------	-------------------------

47	Y91M	1	0.5340	0.045
		2	0.5488	0.006
		3	1.5507	0.002
		4	0.0127	0.009
		5	0.0146	0.003
		6	0.0164	0.000
		7	0.0016	0.052
		8	0.0003	0.117

291	W187	1	0.0003	0.107
		2	0.0604	0.011
		3	0.0696	0.005
		4	0.0349	0.007
		5	0.0950	0.001
		6	0.1442	0.000
		7	0.0420	0.003
		8	0.1021	0.000
		9	0.1114	0.000
		10	0.0625	0.153
		11	0.1226	0.032
		12	0.1319	0.011
		13	0.1345	0.001
		14	0.1946	0.000
		15	0.2039	0.000
		16	0.1674	0.001
		17	0.2275	0.000
		18	0.1749	0.000
		19	0.4081	0.004
		20	0.4682	0.001
		21	0.4774	0.000
		22	0.4408	0.000
		23	0.4800	0.000

ENERGY AND INTENSITY FOR EACH PHOTON.

INDEX	RADIONUCLIDE	NO.	ENERGY (MEV)	INTENSITY (FRACTION)
-------	--------------	-----	-----------------	-------------------------

46	SR91	1	0.6450	0.140
		2	0.7480	0.290
		3	0.9300	0.030
		4	1.0250	0.300
		5	1.4130	0.070
47	Y91M	1	0.5510	0.947
		2	0.0150	0.018
		3	0.0149	0.009
		4	0.0167	0.004
		5	0.0170	0.001
		6	0.0019	0.003
48	Y91	1	1.2100	0.002
133	CD117M	1	0.2810	0.570
		2	0.4300	0.120
		3	0.8400	0.140
		4	1.2700	0.700
		5	1.5500	0.150
		6	0.0240	0.320
134	CD117	1	0.0890	0.070
		2	0.2730	0.310
		3	0.3140	0.160
		4	0.3450	0.180
		5	0.4340	0.130
		6	0.8320	0.040
		7	0.8800	0.030
		8	0.9500	0.040
		9	1.0520	0.050
		10	1.3040	0.190
		11	1.5770	0.170
135	IN117M	1	0.3100	0.087
		2	0.8220	0.020
		3	0.6220	0.020
		4	0.1610	0.221
		5	0.0250	0.142
136	IN117	1	0.5650	1.000
		2	0.1610	0.885
		3	0.0260	0.115
137	SN117M	1	0.1610	0.885
		2	0.1590	0.310
		3	0.0260	0.805

ENERGY AND INTENSITY FOR EACH PHOTON.

INDEX	RADIONUCLIDE NO.	ENERGY (MEV)	INTENSITY (FRACTION)
291	W187	1	0.0720
		2	0.1066
		3	0.1137
		4	0.1342
		5	0.2062
		6	0.2391
		7	0.2466
		8	0.2522
		9	0.4798
		10	0.5125
		11	0.5517
			0.107
			0.003
			0.001
			0.090
			0.001
			0.001
			0.001
			0.002
			0.233
			0.019
			0.050

RADIONUCLIDE PATHWAYS.

PATHWAY	POSITION	INDEX	FRACTION
1	1	46	0.5900
	2	47	1.0000
	3	48	1.0000
2	1	46	0.4100
	2	548	1.0000
3	1	291	1.0000
4	1	133	0.4900
	2	134	1.0000
	3	135	0.4700
	4	136	1.0000
5	1	133	0.4400
	2	635	0.4700
	3	636	1.0000
6	1	133	0.0700
	2	636	1.0000
7	1	133	0.4900
	2	134	1.0000
	3	135	0.0010
	4	137	1.0000
8	1	133	0.4400
	2	135	0.0010
	3	637	1.0000
9	1	133	0.4900
	2	134	1.0000
	3	135	0.5300
10	1	133	0.4400
	2	135	0.5300

SECOND SAMPLE PROBLEM FOR EXEM III

LISTING OF RADIONUCLIDES FOR SUBMERSION DCSE RATES IN CONTAMINATED WATER

LOCATION NUMBER = 1

TIME AFTER RELEASE 1 = 0.0

HOURS.

ELECTRON DOSE RATE				PHOTON DOSE RATE			TOTAL DOSE RATE		
NO.	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR
1	46	SR91	0.428E 03	133	CD117M	0.224E 04	133	CD117M	0.224E 04
2	135	IN117M	0.334E 03	46	SR91	0.101E 04	46	SR91	0.144E 04
3	134	CD117	0.209E 03	134	CD117	0.810E 03	134	CD117	0.102E 04
4	291	W187	0.842E 02	47	Y91M	0.691E 03	47	Y91M	0.711E 03
5	136	IN117	0.632E 02	136	IN117	0.349E 03	135	IN117M	0.457E 03
6	47	Y91M	0.204E 02	135	IN117M	0.124E 03	136	IN117	0.412E 03
7	48	Y91	0.0	291	W187	0.109E 03	291	W187	0.193E 03
8	133	CD117M	0.0	137	SN117M	0.454E 02	137	SN117M	0.454E 02
9	137	SN117M	0.0	48	Y91	0.0	48	Y91	0.0
TOTAL			0.114E 04				0.538E 04		

LISTING OF RADIONUCLIDES FOR DOSE RATES ABOVE A CONTAMINATED GROUND SURFACE

LOCATION NUMBER = 1

HEIGHT = 100.000 CM.

TIME AFTER RELEASE 1 = 0.0

HOURS.

ELECTRON DOSE RATE				PHOTON DOSE RATE			TOTAL DOSE RATE		
NO.	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR
1	46	SR91	0.962E 04	133	CD117M	0.179E 04	46	SR91	0.104E 05
2	135	IN117M	0.911E 04	46	SR91	0.820E 03	135	IN117M	0.923E 04
3	134	CD117	0.455E 04	134	CD117	0.635E 03	134	CD117	0.519E 04
4	291	W187	0.659E 03	47	Y91M	0.589E 03	133	CD117M	0.179E 04
5	136	IN117	0.417E 03	136	IN117	0.292E 03	291	W187	0.749E 03
6	47	Y91M	0.788E 02	135	IN117M	0.114E 03	136	IN117	0.709E 03
7	48	Y91	0.0	291	W187	0.904E 02	47	Y91M	0.668E 03
8	133	CD117M	0.0	137	SN117M	0.477E 02	137	SN117M	0.477E 02
9	137	SN117M	0.0	48	Y91	0.0	48	Y91	0.0
TOTAL			0.244E 05				0.438E 04		

SECOND SAMPLE PROBLEM FOR EXREM III

LISTING OF RADIONUCLIDES FOR SUBMERSION DOSE RATES IN CONTAMINATED WATER

LOCATION NUMBER = 1

TIME AFTER RELEASE 1 = 1.50000E 03 HOURS.

ELECTRON DOSE RATE				PHOTON DOSE RATE			TOTAL DOSE RATE		
NO.	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR
1	291	W187	0.148E 02	291	W187	0.191E 02	291	W187	0.339E 02
2	46	SR91	0.487E 01	46	SR91	0.115E 02	46	SR91	0.164E 02
3	48	Y91	0.400E 01	47	Y91M	0.525E 01	47	Y91M	0.540E 01
4	47	Y91M	0.155E 00	137	SN117M	0.207E 01	48	Y91	0.403E 01
5	135	IN117M	0.528E-02	48	Y91	0.328E-01	137	SN117M	0.207E 01
6	134	CD117	0.172E-02	136	IN117	0.909E-02	136	IN117	0.107E-01
7	136	IN117	0.165E-02	134	CD117	0.666E-02	134	CD117	0.838E-02
8	133	CD117M	0.0	133	CD117M	0.632E-02	135	IN117M	0.723E-02
9	137	SN117M	0.0	135	IN117M	0.195E-02	133	CD117M	0.632E-02
TOTAL			0.238E 02				0.380E 02		
							0.618E 02		

LISTING OF RADIONUCLIDES FOR DOSE RATES ABOVE A CONTAMINATED GROUND SURFACE

LOCATION NUMBER = 1

HEIGHT = 100.000 CM.

TIME AFTER RELEASE 1 = 1.50000E 03 HOURS.

ELECTRON DOSE RATE				PHOTON DOSE RATE			TOTAL DOSE RATE		
NO.	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR	NUCLIDE LABEL	NUCLIDE NAME	DOSE RATE MILLIREMS/HR
1	291	W187	0.116E 03	291	W187	0.159E 02	291	W187	0.131E 03
2	46	SR91	0.109E 03	46	SR91	0.933E 01	46	SR91	0.119E 03
3	48	Y91	0.108E 03	47	Y91M	0.448E 01	48	Y91	0.108E 03
4	47	Y91M	0.598E 00	137	SN117M	0.218E 01	47	Y91M	0.508E 01
5	135	IN117M	0.144E 00	48	Y91	0.256E-01	137	SN117M	0.218E 01
6	134	CD117	0.374E-01	136	IN117	0.762E-02	135	IN117M	0.146E 00
7	136	IN117	0.109E-01	134	CD117	0.522E-02	134	CD117	0.427E-01
8	133	CD117M	0.0	133	CD117M	0.505E-02	136	IN117	0.185E-01
9	137	SN117M	0.0	135	IN117M	0.181E-02	133	CD117M	0.505E-02
TOTAL			0.334E 03				0.319E 02		
							0.366E 03		

SECOND SAMPLE PROBLEM FOR EXREM III

LISTING OF RADIONUCLIDES FOR ACCUMULATED SUBMERSION DOSES IN CONTAMINATED WATER

LOCATION NUMBER = 1
INTEGRATION PERIOD -- 0.0

TO 1.50000E 03 HOURS.

ELECTRON DOSE				PHOTON DOSE			TOTAL DOSE		
NO.	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS
1	46	SR91	0.111E 05	46	SR91	0.263E 05	46	SR91	0.374E 05
2	135	IN117M	0.645E 04	137	SN117M	0.210E 05	137	SN117M	0.210E 05
3	291	W187	0.530E 04	133	CD117M	0.174E 05	133	CD117M	0.174E 05
4	48	Y91	0.322E 04	47	Y91M	0.126E 05	134	CD117	0.136E 05
5	134	CD117	0.279E 04	134	CD117	0.108E 05	47	Y91M	0.129E 05
6	136	IN117	0.170E 04	136	IN117	0.937E 04	291	W187	0.121E 05
7	47	Y91M	0.370E 03	291	W187	0.685E 04	136	IN117	0.111E 05
8	133	CD117M	0.0	135	IN117M	0.239E 04	135	IN117M	0.884E 04
9	137	SN117M	0.0	48	Y91	0.265E 02	48	Y91	0.325E 04
TOTAL			0.309E 05				0.107E 06		
							0.138E 06		

LISTING OF RADIONUCLIDES FOR ACCUMULATED DOSES ABOVE A CONTAMINATED GROUND SURFACE

LOCATION NUMBER = 1
HEIGHT = 100.000 CM.
INTEGRATION PERIOD -- 0.0

TO 1.50000E 03 HOURS.

ELECTRON DOSE				PHOTON DOSE			TOTAL DOSE		
NO.	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS	NUCLIDE LABEL	NUCLIDE NAME	DOSE MILLIREMS
1	46	SR91	0.250E 06	137	SN117M	0.221E 05	46	SR91	0.271E 06
2	135	IN117M	0.176E 06	46	SR91	0.213E 05	135	IN117M	0.178E 06
3	48	Y91	0.870E 05	133	CD117M	0.139E 05	48	Y91	0.870E 05
4	134	CD117	0.607E 05	47	Y91M	0.107E 05	134	CD117	0.692E 05
5	291	W187	0.414E 05	134	CD117	0.847E 04	291	W187	0.471E 05
6	136	IN117	0.112E 05	136	IN117	0.785E 04	137	SN117M	0.221E 05
7	47	Y91M	0.143E 04	291	W187	0.569E 04	136	IN117	0.191E 05
8	133	CD117M	0.0	135	IN117M	0.221E 04	133	CD117M	0.139E 05
9	137	SN117M	0.0	48	Y91	0.206E 02	47	Y91M	0.122E 05
TOTAL			0.628E 06				0.923E 05		
							0.720E 06		

 

APPENDIX B

DATA BASE (SEPT 1973)

The nuclear data base made available with the code in September 1973 includes 189 nuclides comprising 141 pathways. The data were assembled in 1973 from five sources and are numbered accordingly on the NUCLID cards. The five sources are:

1. M. J. Martin, Radioactive Atoms, Supplement 1. ORNL-4293. Oak Ridge National Laboratory. (to be published)
2. M. J. Martin and P. H. Blichert-Toft, "Radioactive Atoms, Auger-Electron, α -, β -, γ -, and X-Ray Data," Nuclear Data Tables, Section A, 8(1-2), 1-198 (1970).
3. L. T. Dillman, "Radionuclide Decay Schemes and Nuclear Parameters for Use in Radiation-Dose Estimation," Medical Internal Radiation Dose Committee Pamphlet No. 4., J. Nuclear Medicine, Supplement No. 2., Vol. 10 (March 1969).
4. L. T. Dillman, "Radioactive Decay Schemes and Nuclear Parameters for Use in Radiation-Dose Estimation, Part 2," MIRD Committee Pamphlet No. 6, J. Nuclear Medicine, Supplement No. 4, Vol. 11 (March 1970).
5. Unpublished data of the Information Center for Internal Exposure, Oak Ridge National Laboratory. Some of the data were especially prepared at our request by F. C. Von der Lage.

If data for a given nuclide were available in more than one of the sources, the source with the lower number was selected. In cases where there were more than 15 beta rays, 30 photons, or 30 conversion/Auger electrons, data were generally combined. That is, for two or more spectral lines, a representative energy was chosen and the abundance was combined to result in the same total energy as if the separate lines were used.

The data library in its most current form is available from the Radiation Shielding Information Center under the name DECAYREM.

Internal Distribution

1-3.	L. S. Abbott	173.	R. E. Reichle
4-53.	S. I. Auerbach	174.	P. S. Rohwer
54.	J. A. Auxier	175.	E. G. Struxness
55.	C. J. Barton	176.	J. R. Trabalka
56.	F. T. Binford	177-186.	D. K. Trubey
57.	B. G. Blaylock	187.	W. D. Turner
58.	R. S. Booth	188.	R. I. Van Hook
59.	F. H. Clark	189.	H. A. Vanderploeg
60.	C. C. Coutant	190.	J. P. Witherspoon
61.	K. E. Cowser	191.	A. Zucker
62.	R. C. Dahlman	192.	H. Feshbach (consultant)
63.	J. O. Duguid	193.	P. E. Fox (consultant)
64.	C. E. Easterly	194.	C. R. Mehl (consultant)
65.	G. S. Henderson	195.	H. T. Motz (consultant)
66.	F. B. K. Kam	196-205.	RSIC
67-166.	S. V. Kaye	206-215.	Mathematics Division Library
167.	L. R. McKay	216-217.	Central Research Library
168.	F. C. Maienschein	218.	ORNL - Y-12 Technical Library
169.	R. E. Moore		Document Reference Section
170.	D. J. Nelson	219-228.	Laboratory Records Department
171.	C. J. Oen	229.	Laboratory Records, ORNL R.C.
172.	R. V. O'Neill	230.	ORNL Patent Office

External Distribution

- 231-232. Nathaniel F. Barr, Division of Biomedical and Environmental Research, U. S. Atomic Energy Commission, Washington, D. C. 20545
233. Raymond D. Cooper, Division of Biomedical and Environmental Research, U. S. Atomic Energy Commission, Washington, D. C. 20545
234. Douglas Grahn, Division of Biomedical and Environmental Research, U. S. Atomic Energy Commission, Washington, D. C. 20545
235. Rudolf J. Engleman, Division of Biomedical and Environmental Research, U. S. Atomic Energy Commission, Washington, D. C. 20545
236. Jacob Kastner, Radiological Assessment Branch, Directorate of Licensing, U. S. Atomic Energy Commission, Washington, D. C. 20545
237. Michael A. Parsont, Radiological Assessment Branch, Directorate of Licensing, U. S. Atomic Energy Commission, Washington, D. C. 20545
238. D. S. Barth, National Environmental Research Center, EPA, P. O. Box 15027, Las Vegas, Nevada 89114

239. K. Z. Morgan, School of Nuclear Engineering, Georgia Institute of Technology, Atlanta, Georgia 20332
- 240-241. Carl Gamertsfelder, Directorate of Licensing, U. S. Atomic Energy Commission, Washington, D. C. 20545
242. Reginald L. Gotchy, Directorate of Licensing, U. S. Atomic Energy Commission, Washington, D. C. 20545
243. John E. Hardaway, Surveillance and Analysis Division, Technical Support Branch, Suite 900, 1860 Lincoln Street, Denver, Colorado 80203
244. Jon A. Broadway, Eastern Environmental Research Facility, P. O. Box 61, Montgomery, Alabama 36101
- 245-246. C. C. Palmiter, Office of Radiation Programs, Environmental Protection Agency, 401 M Street SW, Washington, D. C. 20460
247. Jerry Cohen, Lawrence Livermore Laboratory, P. O. Box 808, Livermore, California 94551
248. Daniel W. Wilson, Lawrence Livermore Laboratory, P. O. Box 808, Livermore, California 94551
249. Todd V. Crawford, Savannah River Laboratory, E. I. du Pont de Nemours & Company, Aiken, South Carolina 29801
250. Peter J. Mellinger, Environmental Safeguards Division, NUS Corporation, 4 Research Place, Rockville, Maryland 20850
251. Stephen Jinks, Institute of Environmental Medicine, New York University Medical Center, Long Meadow Road, Tuxedo, New York 10987
252. Jack G. Christian, Office of Radiation Programs, U. S. Environmental Protection Agency, 401 M Street SW, Washington, D. C. 20460
253. Andre Bouville, United Nations, Scientific Committee on the Effects of Atomic Radiation, New York, New York 10016
254. Warren Donnelly, Library of Congress Legislative Reference Service, Washington, D. C. 20504
255. F. A. Gifford, Jr., Air Resources Atmospheric Turbulence and Diffusion Laboratory, NOAA, Oak Ridge, Tennessee 37830
256. Murray Calkins, National Environmental Research Center, Environmental Protection Agency, Cincinnati, Ohio 45268
257. DeVaughn R. Nelson, Directorate of Licensing, Environmental Project Branch No. 3, Mail Station 008, Washington, D. C. 20545
258. W. H. Ray, Office of Regulation, U. S. Atomic Energy Commission, Bethesda, Maryland 20545
259. Don F. Harmon, Office of Regulation, U. S. Atomic Energy Commission, Bethesda, Maryland 20545
260. J. K. Soldat, Pacific Northwest Laboratories, Battelle Memorial Institute, Richland, Washington 99352
261. David McCurdy, Ecology Section, Los Alamos Scientific Laboratory, P. O. Box 1663, Los Alamos, New Mexico 87544
- 262-263. Technical Information Center, AEC, Oak Ridge, Tennessee
264. Research and Technical Support Division, ORO, Oak Ridge, Tennessee 37830
265. Patent Office, AEC, Oak Ridge, Tennessee 37830