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INDOS — CONVERSATIONAL COMPUTER CODES TO IMPLEMENT ICRP-10-10A MODELS FOR ESTIMATION OF INTERNAL RADIATION DOSE TO MAN

G. G. Killough
P. S. Rohwer

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MARCH 1974

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G. G. Killough[a] and P. S. Rohwer

ABSTRACT

INDOS1, INDOS2, and INDOS3 (the INDOS codes) are conversational FORTRAN IV programs, implemented for use in time-sharing mode on the ORNL PDP-10 System. These codes use ICRP-10-10A models to estimate the radiation dose to an organ of the body of Reference Man resulting from the ingestion or inhalation of any one of various radionuclides. Two patterns of intake are simulated: intakes at discrete times and continuous intake at a constant rate. The INDOS codes provide tabular output of dose rate and dose vs time, graphical output of dose vs time, and punched-card output of organ burden and dose vs time. The models of internal dose calculation are discussed and instructions for the use of the INDOS codes are provided. The INDOS codes are available from the Radiation Shielding Information Center, Oak Ridge National Laboratory, P. O. Box X, Oak Ridge, Tennessee 37830.

1. INTRODUCTION

INDOS1, INDOS2, and INDOS3 (hereinafter referred to collectively as the INDOS codes) compute the radiation dose to an organ of the body of Reference Man resulting from a deposition in the organ of any

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one of a number of radionuclides. These codes, written in FORTRAN and implemented on the ORNL PDP-10 System, are conversational and depend on the time-sharing mode of operation.

While they differ in details, the INDOS codes are computationally similar. INDOS1 depends entirely on input by the user, whereas INDOS2 and INDOS3 access an on-line data-base file for parameter values. INDOS1 offers only tabular output of dose rate and dose as functions of time; in addition to the foregoing, INDOS2 also provides graphs of dose vs time; whereas INDOS3 gives only punched-card output of organ burden and dose as functions of time.

Section 2 of this report describes in some detail the mathematical models on which the INDOS codes are based; this section, together with references 4, 5, and 6, serves as an introduction to the models used for internal dose calculations. The user may prefer to read only subsection 2.1 and refer to the remainder of the section to whatever extent he deems necessary.

Section 3 serves as a brief user's manual for the codes; details of interaction at the terminal and examples of actual runs are given for all three codes. Subsection 3.4 discusses the numerical methods employed by the subroutines which perform the calculations.

2. THE MATHEMATICAL MODELS OF INTERNAL DOSE

2.1 Patterns of Intake

In general, we are concerned with the ingestion or inhalation of a definite quantity of a radionuclide into the body of Reference Man, resulting in the deposition of all or part of this material in

an organ of reference (sometimes thought of as the critical organ for the particular radionuclide). We wish to estimate the quantity of the radionuclide in the reference organ as it yields to radioactive decay and to the metabolic processes of the organ, and as it is possibly replenished by subsequent depositions; and we wish to calculate the dose to the organ which results from its exposure to this varying burden.

The two patterns of intake considered are:

a. Discrete intakes. At specified times $0 \leq t_1 < t_2 < \ldots < t_N$, amounts $a_1, a_2, \ldots, a_N$, respectively, of the radionuclide are taken into the body and result in corresponding depositions in the reference organ. The t_i are measured in days and the a_i are measured in microcuries. It is assumed that the organ experiences no contamination other than that resulting directly from these specified intakes.

b. Initial burden plus a continuous subsequent intake at a specified constant rate. Initially the burden of the radionuclide in the body is the quantity α μCi, where α is a nonnegative number; throughout the period of observation, the body experiences a continuous intake at the constant rate of c μCi/day ($c \geq 0$). We assume that no other contamination is experienced.

Of these modes of intake, the single intake is an important special case [(a) with N = 1 or (b) with c = 0]. Publication 10 (ref. 5) of the International Commission on Radiological Protection (ICRP) presents recent parameter values and other information for the single intake

model for one or more radioactive isotopes of each of 24 elements. From this information for the single intake case, it is possible to derive models for the more general patterns of intake described in (a) and (b). Such derivations have been treated recently in Publication 10A of the ICRP;[6] essentially the same equations, arrived at independently by the authors of this report before they had access to Publication 10A, are the basis of the INDOS codes. We shall consider these models in detail in subsections 2.2, 2.3, and 2.4.

The two modes of intake we consider are inhalation and ingestion. With each of these modes there is associated a fraction f of each unit (μCi) intake which will be deposited in the reference organ or whose uptake will expose the reference organ. Often these fractions are, respectively, f_a (inhalation) and f_w (ingestion) which are published for each radionuclide.[5] Thus, if the body experiences a single intake of α μCi of a radionuclide, it is assumed that the associated deposition in the reference organ is $f \cdot \alpha$ μCi, where f is the appropriate fraction; and an intake rate of c μCi/day into the body would result in a deposition rate of $f \cdot c$ μCi/day in the reference organ. In the INDOS codes, which access a stored data base (INDOS2 and INDOS3), the fraction f is a parameter which depends only on the particular radionuclide, the reference organ, and the mode of intake. The fractions stored in the data base file were derived from information published in references 4 and 5.

2.2 Retention and Dose Functions for the Single Intake Case

Publication 10 of the ICRP bases its presentation on the single intake model. If at time t = 0 a deposition of a μCi of a radionuclide is introduced into the reference organ, the retention of the material is governed by the differential equation

$$\left\{\begin{array}{l} q'(t) = -\lambda_r q(t) - E(t) \\ q(0) = a \end{array}\right\} \qquad (t \geq 0) \qquad (2.1)$$

where

$q(t)$ = the amount (μCi) of the radionuclide retained by the reference organ t days after uptake,

λ_r = the radioactive decay constant ($days^{-1}$) of the radionuclide, and

$E(t)$ = the rate (μCi/day) at which the reference organ is excreting its burden of the radionuclide at time t.

The cumulative burden $Q(t)$ (μCi-days) of the organ is defined as the time integral of $q(t)$:

$$Q(t) = \int_0^t q(u)\, du \ , \qquad (2.2)$$

where u is a time variable of integration with upper limit t. The dose to the reference organ is

$$51.2 \frac{\varepsilon}{m} Q(t) \quad \text{(rems)}, \qquad (2.3)$$

where

ε = the effective absorbed energy (MeV) per disintegration, and

m = the mass (g) of the reference organ.

The quantity 51.2 (ε/m) q(t) (rems/day) is the dose rate. The INDOS codes compute dose rate and dose as functions of time.

The two basic retention models can be derived from the differential equation (2.1) by making appropriate state-dependent assumptions about the excretion rate function E:

(1) Single-compartment exponential.

$$E(t) = \beta q(t), \tag{2.4}$$

where β is a positive constant.

(2) Power function.

$$E(t) = [n/(t + x)]\, q(t) \tag{2.5}$$

where $0 < n < 1$ and x lies in the range [0,10].

Substitution of Eq. (2.4) into Eq. (2.1) and integration of the resulting linear differential equation gives

$$q(t) = a\, e^{-(\lambda_r + \beta)t} \qquad (t \geq 0) \tag{2.6}$$

for the single-compartment exponential case, from which the dose rate and dose may be computed.

Similarly, from the differential equation and (2.5) one derives

$$q(t) = a \exp(-\lambda_r t) A (t + x)^{-n} \qquad (t \geq 0), \tag{2.7}$$

where the constant $A = x^n$ if $x \neq 0$; this is the retention function for the power function model.

When the reference organ is regarded as the sum of M compartments, each compartment has a retention function. The burden $q_\nu(t)$ of the ν-th compartment satisfies

$$\begin{aligned} q'_\nu(t) &= -\lambda_r\, q_\nu(t) - E_\nu(t) \\ q_\nu(0) &= aK_\nu \end{aligned} \qquad (t \geq 0), \tag{2.8}$$

where

$E_\nu(t)$ = the rate (μCi/day) at which the ν-th compartment is excreting its burden of the radionuclide at time t, and

K_ν = the fraction of the total uptake of a μCi which reaches the ν-th compartment; $\sum_{\nu=1}^{M} K_\nu = 1$.

The most common multiple-compartment model is based on the assumption that each compartment excretes its content exponentially:

$$E_\nu(t) = \beta_\nu q_\nu(t), \tag{2.9}$$

which, by analogy with Eq. (2.6), leads to

$$q_\nu(t) = aK_\nu e^{-(\lambda_r + \beta_\nu)t} \qquad (t \geq 0). \tag{2.10}$$

The retention function for the organ is the sum of the partial retentions, namely

$$q(t) = a \sum_{\nu=1}^{M} K_\nu e^{-(\lambda_r + \beta_\nu)t} \qquad (t \geq 0) \tag{2.11}$$

for the multiple-compartment exponential model.

For some radionuclides, it is convenient to add an (M+1)-th compartment which does not excrete its burden. For such a case, $\sum_{\nu=1}^{M} K_\nu < 1$, and

$$K_{M+1} = 1 - \sum_{\nu=1}^{M} K_\nu ,$$

while

$$\beta_{M+1} = 0.$$

Accordingly,

$$q_{M+1}(t) = a \left[1 - \sum_{\nu=1}^{M} K_\nu \right] e^{-\lambda_r t} \quad (t \geq 0).$$

If all other compartments are exponential, we have for the total retention equation

$$q(t) = ae^{-\lambda_r t} \left[1 - \sum_{\nu=1}^{M} K_\nu + \sum_{\nu=1}^{M} K_\nu \, e^{-\beta_\nu t} \right] \quad (t \geq 0). \qquad (2.12)$$

We may regard Eq. (2.11) as a special case of Eq. (2.12) for which $\sum_{\nu=1}^{M} K_\nu = 1$. With this understanding, we adopt Eq. (2.12) as our prototype for the multiple-compartment exponential model.

We may use a similar device to add a nonexcretory compartment to the power function model. Accordingly, we conceive of two compartments which initially receive fractions Ax^{-n} (<1) and $1 - Ax^{-n}$ of the total uptake of α μCi; we assume that the latter fraction is associated with the nonexcretory compartment. These assumptions imply that

$$q(t) = ae^{-\lambda_r t}\,[1 - Ax^{-n} + A(t + x)^{-n}] \qquad (t \geq 0). \tag{2.13}$$

We may regard the simple power function model given by Eq. (2.7) as a special case of Eq. (2.13) for which $Ax^{-n} = 1$. Equation (2.13) will serve as our general power function model for the single intake case.

We should remark that in many instances, published retention equations for power function models are of the form

$$q(t) = a\,e^{-\lambda_r t}\,t^{-n} \qquad (t > 0), \tag{2.14}$$

i.e., $x = 0$. Such functions, of course, cannot approximate the organ's initial uptake or its actual retention at times t near zero; but when they are integrated over a relatively long time interval for dose calculation, the poor representation near the origin may be of minor concern. In this situation the INDOS codes put $q(0) = \alpha$ and otherwise use Eq. (2.14); the integral $Q(t)$ of Eq. (2.14) exists, for $0 < n < 1$, as a finite improper integral at 0.

The final single-intake that we consider is a mixture of exponential and power functions. We present it as a two-compartment model in

which the compartments excrete their burdens according to Eqs. (2.6) and (2.7), respectively. We assume that the fraction of the initial uptake which goes to the exponential compartment is K, where $0 < n < 1$. These assumptions imply that

$$q(t) = a\, e^{-\lambda_r t} \left[K e^{-\beta t} + (1 - K)A(t + x)^{-n}\right] \qquad (t \geq 0). \tag{2.15}$$

We shall refer to this case as a <u>mixed model</u>.

For later reference, we restate here the single-intake retention functions q(t), together with their respective time integrals Q(t). These equations form the basis for models of other intake patterns.

<u>Multiple compartment exponential</u>

$$q(t) = a\, e^{-\lambda_r t} \left[1 - \sum_{\nu=1}^{M} K_\nu + \sum_{\nu=1}^{M} K_\nu\, e^{-\beta_\nu t}\right] \tag{2.16}$$

$$Q(t) = a \left\{ \frac{1}{\lambda_r} \left[1 - \sum_{\nu=1}^{M} K_\nu\right]\left(1 - e^{-\lambda_r t}\right) + \sum_{\nu=1}^{M} \frac{K_\nu}{\lambda_r + \beta_\nu} \left[1 - e^{-(\lambda_r + \beta_\nu)t}\right] \right\} \tag{2.17}$$

Power functions

$$q(t) = a\, e^{-\lambda_r t} [1 - Ax^{-n} + A(t + x)^{-n}] \tag{2.18}$$

$$Q(t) = a \left[\frac{1}{\lambda_r} (1 - Ax^{-n})(1 - e^{-\lambda_r t}) + A \int_0^t e^{-\lambda_r u} (u + x)^{-n}\, du \right] \tag{2.19}$$

Mixed model

$$q(t) = K\, q_e(t) + (1 - K)\, q_p(t) \tag{2.20}$$

$$Q(t) = K\, Q_e(t) + (1 - K)\, Q_p(t) \tag{2.21}$$

where

$$q_e(t) = a\, e^{-(\lambda_r + \beta)t} \tag{2.22}$$

$$Q_e(t) = \frac{a}{\lambda_r + \beta} \left[1 - e^{-(\lambda_r + \beta)t} \right] \tag{2.23}$$

and

$$q_p(t) = a\, e^{-\lambda_r t}\, A\, (t + x)^{-n} \tag{2.24}$$

$$Q_p(t) = a\, A \int_0^t e^{-\lambda_r u} (u + x)^{-n}\, du\ . \tag{2.25}$$

The integral which appears in Eqs. (2.19) and (2.25) cannot be evaluated in closed form. The INDOS codes evaluate it numerically; these numerical methods are discussed in section 3. Also, the factor $1 - Ax^{-n}$ is undefined when $x = 0$; the INDOS codes replace this factor by zero in this event.

References 4, 5, and 6 ordinarily print the fractional retention function for a given radionuclide and reference organ. The fractional retention function $r(t)$ is defined by the equation

$$q(t) = ar(t),$$

where $q(t)$ is the burden at time t resulting from a single intake at time zero. If $t \geq t_0$, $r(t - t_0)$ can be regarded as the reference organ's burden at time t resulting from the uptake of 1 μCi at time t_0. We shall continue to use the notation $q(t)$ for the burden at time t which results from more complex histories of deposition. The function $r(t)$ will be useful, however, in subsections 2.3 and 2.4.

2.3 Multiple Intakes at Discrete Times

We now assume that at times $0 \leq t_1 < t_2 \ldots < t_N$ (days), intakes of a radionuclide into the body result in depositions a_1, a_2, ..., a_N (μCi), respectively, in the reference organ [(a) of Section 2.1]. That part of the burden remaining at time t from the deposition at time t_i is

$$a_i r(t - t_i).$$

The total burden q(t) is the sum of these partial contributions:

$$q(t) = \sum_{i=1}^{N} a_i r(t - t_i). \tag{2.26}$$

The cumulative burden is given by

$$Q(t) = \sum_{i=1}^{N} a_i \int_0^{t-t_i} r(u)\, du \ , \tag{2.27}$$

where it should be noted that each term in the sum for which $t - t_i < 0$ is zero, because $r(u) = 0$ for $u < 0$.

Equations (2.16) to (2.25) of subsection 2.2 provide expressions for $r(t - t_i)$ and the integral of $r(u)$ which appears in Eq. (2.27). In each case, t in the right member of the equation is replaced by $t - t_i$, a by a_i, and the result is summed on i from 1 to N. These operations produce the following equations:

<u>Multiple-compartment exponential</u>

$$q(t) = \sum_{i=1}^{N} a_i\, e^{-\lambda_r(t-t_i)} \left[1 - \sum_{\nu=1}^{M} K_\nu + \sum_{\nu=1}^{M} K_\nu e^{-\beta_\nu(t-t_i)}\right] \tag{2.28}$$

$$Q(t) = \sum_{i=1}^{N} a_i \left\{\frac{1}{\lambda_r}\left[1 - \sum_{\nu=1}^{M} K_\nu\right]\left[1 - e^{-\lambda_r(t-t_i)}\right] + \sum_{\nu=1}^{M} \frac{K_\nu}{\lambda_r + \beta_\nu}\left[1 - e^{-(\lambda_r + \beta_\nu)(t-t_i)}\right]\right\} \tag{2.29}$$

Power function

$$q(t) = \sum_{i=1}^{N} a_i \, e^{-\lambda_r(t-t_i)} \left[1 - Ax^{-n} + A(t - t_i + x)^{-n}\right] \quad (2.30)$$

$$Q(t) = \sum_{i=1}^{N} a_i \left\{ \frac{1}{\lambda_r} (1 - Ax^{-n}) \left[1 - e^{-\lambda_r(t-t_i)}\right] + A \int_0^{t-t_i} e^{-\lambda_r u} (u + x)^{-n} \, du \right\} \quad (2.31)$$

Mixed model

Equations (2.20) and (2.21), where

$$q_e(t) = \sum_{i=1}^{N} a_i \, e^{-(\lambda_r + \beta)(t - t_i)} \quad (2.32)$$

$$Q_e(t) = \sum_{i=1}^{N} \frac{a_i}{\lambda_r + \beta} \left[1 - e^{-(\lambda_r + \beta)(t - t_i)}\right] \quad (2.33)$$

$$q_p(t) = \sum_{i=1}^{N} a_i \, e^{-\lambda_r(t - t_i)} \, A \, (t - t_i + x)^{-n} \quad (2.34)$$

$$Q_p(t) = \sum_{i=1}^{N} a_i \, A \int_0^{t-t_i} e^{-\lambda_r u} (u + x)^{-n} \, du \quad (2.35)$$

2.4 Continuous Intake at a Specified Rate

Our next assumption is that throughout the time interval [0,t] (days) the body experiences a continuing intake of a radionuclide which results in an accumulating deposition in the reference organ at

the rate of $I(\tau)$ (μCi/day) ($0 \leq \tau \leq t$). The rate function $I(\tau)$ might be fairly general, but in the INDOS codes its form has been restricted to a constant. In this discussion, however, we shall first consider a varying rate function before presenting formulas for the constant case.

At a fixed time τ in $[0,t]$ the material deposited in the reference organ between time τ and $\tau + d\tau$ is $I(\tau)\, d\tau$, and at subsequent time t, the burden remaining from this element is $I(\tau)\, r(t - \tau)\, d\tau$. The total burden at time t is the integral of all such elements for $0 \leq \tau \leq t$:

$$q(t) = \int_0^t I(\tau)\, r(t - \tau)\, d\tau = \int_0^t I(t - \tau)\, r(\tau)\, d\tau. \qquad (2.36)$$

If at time zero there is already a burden of a (μCi) in the organ, we must add to the integral in Eq. (2.36) the term $ar(t)$ to account for its contribution:

$$q(t) = ar(t) + \int_0^t I\,(t-\tau)\, r(\tau)\, d\tau \qquad (2.37)$$

Thus a general expression for $Q(t)$ is

$$Q(t) = a \int_0^t r(u)\, du + \int_0^t \int_0^u I(u - \tau)\, r(\tau)\, d\tau\, du\,. \qquad (2.38)$$

Further transformations of Eq. (2.38) are suggested in Appendix A of reference 6, but the formulas of interest in this report are conveniently obtained from Eq. (2.38).

We now look at the special case

$$I(\tau) = c(\mu Ci/day) \quad (0 \leq \tau \leq t), \tag{2.39}$$

where $c \geq 0$ is a constant. Formulas used in the INDOS codes may be derived by substituting expressions for the function r from Eqs. (2.16) through (2.25) into Eqs. (2.37) and (2.38) and taking Eq. (2.39) into account. The following equations are obtained after integration:

Multiple-compartment exponential

$$\begin{aligned} q(t) = {} & a\, e^{-\lambda_r t} \left\{ 1 - \sum_{\nu=1}^{M} K_\nu + \sum_{\nu=1}^{M} K_\nu\, e^{-\beta_\nu t} \right\} \\ & + c \left\{ \frac{1}{\lambda_r} \left(1 - \sum_{\nu=1}^{M} K_\nu \right) \left(1 - e^{-\lambda_r t} \right) \right. \\ & \left. + \sum_{\nu=1}^{M} \frac{K_\nu}{\lambda_r + \beta_\nu} \left[1 - e^{-(\lambda_r + \beta_\nu)t} \right] \right\} \end{aligned} \tag{2.40}$$

$$\begin{aligned} Q(t) = {} & a \left\{ \frac{1}{\lambda_r} \left(1 - \sum_{\nu=1}^{M} K_\nu \right) \left(1 - e^{-\lambda_r t} \right) \right. \\ & \left. + \sum_{\nu=1}^{M} \frac{K_\nu}{\lambda_r + \beta_\nu} \left[1 - e^{-(\lambda_r + \beta_\nu)t} \right] \right. \\ & + c \left\{ \left[\frac{1}{\lambda_r} \left(1 - \sum_{\nu=1}^{M} K_\nu \right) + \sum_{\nu=1}^{M} \frac{K_\nu}{\lambda_r + \beta_\nu} \right] t \right. \\ & - \frac{1}{\lambda_r^2} \left(1 - \sum_{\nu=1}^{M} K_\nu \right) \left(1 - e^{-\lambda_r t} \right) \end{aligned}$$

$$- \sum_{\nu=1}^{M} \frac{K_\nu}{(\lambda_r + \beta_\nu)^2} \left[1 - e^{-(\lambda_r + \beta_\nu)t}\right] \Bigg\} \qquad (2.41)$$

Power function

$$q(t) = a\, e^{-\lambda_r t} \left[1 - Ax^{-n} + A(t + x)^{-n}\right]$$

$$+ c \left[\frac{1}{\lambda_r} (1 - Ax^{-n}) (1 - e^{-\lambda_r t}) + A \int_0^t e^{-\lambda_r u} (u + x)^{-n}\, du\right] \qquad (2.42)$$

$$Q(t) = a \left[\frac{1}{\lambda_r} (1 - Ax^{-n}) (1 - e^{-\lambda_r t})\right.$$

$$\left. + A \int_0^t e^{-\lambda_r u} (u + x)^{-n}\, du\right]$$

$$+ c \left\{\frac{1}{\lambda_r} (1 - Ax^{-n}) \left[t - \frac{1}{\lambda_r} (1 - e^{-\lambda_r t})\right]\right.$$

$$+ A \left[t + x - \frac{1 - n}{\lambda_r}\right] \int_0^t e^{-\lambda_r u} (u + x)^{-n}\, du$$

$$\left. - \frac{A}{\lambda_r} \left[x^{-n+1} - e^{-\lambda_r t} (t + x)^{-n+1}\right]\right\} \qquad (2.43)$$

$$q_e(t) = a\, e^{-(\lambda_r + \beta)t} + \frac{c}{\lambda_r + \beta} \left[1 - e^{-(\lambda_r + \beta)t}\right] \qquad (2.44)$$

$$Q_e(t) = \frac{a}{\lambda_r + \beta} \left[1 - e^{-(\lambda_r + \beta)t}\right]$$

$$+ c \left\{\frac{t}{\lambda_r + \beta} - \frac{1}{(\lambda_r + \beta)^2} \left[1 - e^{-(\lambda_r + \beta)t}\right]\right\} \qquad (2.45)$$

Expressions for $q_p(t)$ and $Q_p(t)$ are identical to the right members, respectively, of Eqs. (2.42) and (2.43) with the factor $1 - Ax^{-n} = 0$.

3. THE INDOS CODES

3.1 INDOS1

INDOS1 computes radiation dose rate (rems/day) and dose (rems) to the reference organ as functions of time (days); this dose is assumed to result from the deposition of a specified quantity of a radionuclide in the organ. Inasmuch as INDOS1 does not access a database file, the user must specify all parameters related to the radionuclide and organ, together with the appropriate mathematical model (exponential, power function, or mixture of the two) and information concerning pattern of intake (at discrete times, or continuous at a constant rate) and initial values. Such information will be requested by INDOS1 during a dialogue phase with the user.

It should be pointed out that INDOS1 deals with the quantity of radioactive material deposited in the organ of reference or with an uptake which exposes the reference organ. If the user's inputs are in terms of the amount of material inhaled or ingested into the body, he must correct these by multiplying by the appropriate uptake fractions; otherwise, excessive dose estimates will occur for radionuclides with uptake fractions less than 1.0.

INDOS1 uses the term <u>critical organ</u> in some of its messages, but the user is in no way restricted to consideration of that organ which is regarded as critical for a specified radionuclide. If the necessary

information is available, INDOS1 can be used to estimate the dose to any organ resulting from a deposition of the radionuclide in that organ or an uptake which exposes that organ.

Output by INDOS1 consists of a tabulation, at equal time increments, of time (days), dose rate (rems/day), and dose (rems). The dose is restricted to that which accumulates during the period covered by the current run, i.e., from the time of the earliest intake; there is no provision for adding a prior accumulation.

The dialogue phase of INDOS1 permits the user to supply, in answer to a succession of questions, the following information:

I. Name of the radionuclide

Name of the critical organ

Radioactive half-life T_r (days)

Effective absorbed energy per disintegration ε (MeV) and mass m of critical organ (g)

Choice of models:

1-exponential model

Number M of exponential compartments

For each compartment, a fractional coefficient K_n and a biological half-life (days)

2-power function model

Power function parameters n, x, A

3-mixed model

Fractional coefficient K of exponential part of model

Number M of exponential compartments (normally 1 for the mixed model)

For each exponential compartment a fractional coefficient K_ν and a biological half-life (days); with a single exponential compartment in the mixed model, $K_\nu = 1$

Power function parameters n, x, A; normally, A = 1 for the mixed model

II. Pattern of intake

1-discrete

Number N of discrete intakes

Times t_i (days) and corresponding intakes a_i (μCi)

2-continuous at a constant rate

Initial burden of critical organ α (μCi)

Rate of deposition in critical organ c (μCi/day)

III. Specifications for tabulation: minimum time, time increment, maximum time (days)

Option of a typed summary of the information given during the dialogue phase.

After the run is complete, the user may choose one of the following options:

1-more tabulation. Return to stage III of dialogue phase

2-change intakes. Return to stage II of dialogue phase

3-change nuclides. Return to stage I (beginning) of dialogue phase

4-exit. End the run.

The following example shows the remote terminal record of a run of INDOS1. The information used concerning the radionuclide ^{35}S was taken from reference 5 (pp. 38-39).

Numeric inputs by the user are free form. Thus, he may specify real quantities with or without a decimal point, and multiple entries on a line may be spaced however he wishes, provided that they are

separated by commas or one or more spaces. Other details concerning free-form input may be found in reference 2. The dashes typed by the program may be ignored at the user's discretion. Since most of the computations are carried out with the binary equivalent of approximately eight decimal digits, inputs with higher precision would be meaningless. The INDOS codes round output to five-digit precision.

The user's attention is directed to the following points concerning tabulation. If a positive tabular increment is specified, tabulation proceeds from minimum to maximum time in intervals of the increment. If the increment does not divide the time range into an integral number of parts, as many lines as possible within the time range will be typed, and the last line will correspond to the maximum time. The user is not protected against the accidental specification of an excessively long table.

A time increment of zero is permitted. There are two possibilities: (1) minimum time < maximum time, in which case the table consists of two lines; (2) minimum time = maximum time, and in this instance the table is one line. If the user specifies a minimum time which is larger than the maximum time, an error message will result, and he will be asked to reenter the tabulation data.

3.2 INDOS2

INDOS2 computes radiation dose rate (rems/day) and dose (rems) to the reference organ as functions of time (days); this dose results from the deposition of any one of a given list of radionuclides in the organ, and the organ usually is the one which is regarded as critical for the radionuclide selected. Parameter values associated

```
CRITICAL ORGAN RADIATION DOSE CALCULATION
-----------------------------------------
ENTER NAME OR FORMULA OF NUCLIDE (20 CHAR. OR LESS)
S-35

TYPE NAME OF CRITICAL ORGAN (20 CHAR. OR LESS)
WHOLE BODY

ENTER RADIOACTIVE HALF-LIFE (DAYS)
87.

ENTER EPSILON (MEV) AND MASS (G) OF CRITICAL
ORGAN
0.056 70000.

TYPE
1-FOR EXPONENTIAL MODEL
2-FOR POWER FUNCTION MODEL
3-FOR MIXED MODEL
1

HOW MANY EXPONENTIAL TERMS? (1 TO 9, NO DECIMAL)
2

ENTER 2 PARAMETERS FOR EACH OF THE
2 EXPONENTIAL TERMS...

COEFFICIENT    EXCRETORY HALF-LIFE
----------     ----------
0.8 0.25
0.2 7.0

TYPE
1-FOR DISCRETE INTAKES
2-FOR CONTINUOUS INTAKE AT CONSTANT RATE
1

HOW MANY DISCRETE INTAKES? (1 TO 20, NO DECIMAL)
1

ENTER THE  1 TIMES (DAYS) AND THE
CORRESPONDING INTAKES (MICROCURIES)
----------  ----------
0.0 1.0

FOR TABULATION, ENTER (DAYS)
MIN. TIME   INCREMENT   MAX. TIME
----------  ----------  ----------
0.0 5.0 50.0

TYPE 1-FOR INPUT SUMMARY
     2-TO SUPPRESS
1
```

SUMMARY OF INPUTS
EXPONENTIAL MODEL

RADIONUCLIDE -- S-35

CRITICAL ORGAN -- WHOLE BODY

RADIOACTIVE HALF-LIFE	8.700E+01	DAYS
RADIOACTIVE DECAY RATE	7.967E-03	PER DAY
EFF. ABSORBED ENERGY	5.600E-02	MEV
MASS OF CRITICAL ORGAN	7.000E+04	G
BIOLOGICAL CONV. FACTOR	4.096E-05	REMS/MICROCURIE-DAY

PARAMETERS ASSOCIATED WITH EXPONENTIAL TERMS...

	COEFFICIENTS	EXCRETORY HALF-LIVES	EXCRETION RATES
1	8.000E-01	2.500E-01	2.773E+00
2	2.000E-01	7.000E+00	9.902E-02

DISCRETE TIMES AND UPTAKES...

TIME (DAYS)	UPTAKE (MICROCURIES)
0.000E-01	1.000E+00

TABULATION OF DOSE RATE AND DOSE

TIME(DAYS)	RATE (REMS/DAY)	DOSE (REMS)
0.000E-01	4.09600E-05	0.00000E-01
5.000E+00	4.79812E-06	4.35070E-05
1.000E+01	2.81026E-06	6.20869E-05
1.500E+01	1.64598E-06	7.29692E-05
2.000E+01	9.64055E-07	7.93430E-05
2.500E+01	5.64651E-07	8.30762E-05
3.000E+01	3.30718E-07	8.52627E-05
3.500E+01	1.93703E-07	8.65434E-05
4.000E+01	1.13453E-07	8.72934E-05
4.500E+01	6.64496E-08	8.77328E-05
5.000E+01	3.89198E-08	8.79901E-05

TYPE
1-FOR MORE TABULATION
2-TO CHANGE INTAKES
3-TO CHANGE NUCLIDES
4-TO EXIT
4

with each radionuclide on the list and their respective reference organs reside in a direct-access file in the user's disk area of the PDP-10 System. This stored data base is one of the principal features that distinguish the capabilities of INDOS2 from those of INDOS1. Once the user has designated his choice of radionuclide by entering a code number, INDOS2 will retrieve from the disk file the necessary parameter information associated with radionuclide and critical organ, along with information related to the proper mathematical model (exponential, power function, or a mixture of the two). The user, in a dialogue phase, then specifies the pattern of intake (at discrete times, or continuous at a constant rate) and output options.

Inputs to INDOS2 should be in terms of the quantity of material inhaled or ingested into the body; the user indicates whether the mode of intake is inhalation or ingestion, and the program converts the intake to a proportionate uptake in the critical organ. This feature is another major difference between INDOS1 and INDOS2.

Output options for INDOS2 are: (1) a tabulation of time (days), dose rate (rems/day), and dose (rems) in intervals of a specified time increment, and (2) a typewritten graph of dose (rems) vs time (days); either or both may be requested for a given run.

The information which the user must be prepared to supply to INDOS2 during the dialogue phase is summarized below:

Code number of radionuclide (see Appendix C)

Mode of intake

1-ingestion

2-inhalation

Pattern of intake

1-discrete

Number N of discrete intakes

Times t_i (days) and corresponding intakes a_i (μCi)

2-continuous at a constant rate

Initial body burden α (μCi)

Rate of intake into body c (μCi/day)

Output option

1-tabulation

Minimum time, time increment, maximum time (days)

2-graph

Minimum and maximum values for time axis (days)

Three lines of commentary to appear on graph

Option of a typed summary of input and data-base information

After each run, the user will have the option of returning to earlier points in the program for additional tabulation or graphing, for changing radionuclides, or changing modes of intake; or he may end the run.

The following example shows the remote terminal record of a run of INDOS2. A graph is included.

The remarks of subsection 3.1 concerning free-form numeric input and tabulation apply verbatim to INDOS2.

The user's attention is called to two points concerning the graph. (1) The time axis is vertical and time increases downward. The dose axis is horizontal, and the direction of increasing dose is

```
REFERENCE ORGAN RADIATION DOSE CALCULATION
------------------------------------------

ENTER CODE NO. OF NUCLIDE.
323

MODE OF INTAKE...
TYPE
1-FOR INGESTION
2-FOR INHALATION
1

TYPE
1-FOR DISCRETE INTAKES
2-FOR CONTINUOUS INTAKE AT CONSTANT RATE
1

HOW MANY DISCRETE INTAKES? (1 TO 50)
1

ENTER THE  1 TIMES (DAYS) AND THE
CORRESPONDING INTAKES (MICROCURIES)
----------  ----------
0. 1.

TYPE
1-FOR TABULATION
2-FOR GRAPH
1

FOR TABULATION, ENTER (DAYS)
MIN. TIME   INCREMENT   MAX. TIME
----------  ----------  ----------
0. 5. 80.

TYPE 1-FOR INPUT SUMMARY
     2-TO SUPPRESS
1
```

SUMMARY OF INPUTS
EXPONENTIAL MODEL

RADIONUCLIDE	27 CO-60
REFERENCE ORGAN	TOTAL BODY
RADIOACTIVE HALF-LIFE	1.900E+03 DAYS
RADIOACTIVE DECAY RATE	3.648E-04 PER DAY
EFF. ABSORBED ENERGY	1.500E+00 MEV
MASS OF REFERENCE ORGAN	7.000E+04 G
BIOLOGICAL CONV. FACTOR	1.097E-03 REMS/MICROCURIE-DAY
MODE OF INTAKE	INGESTION
UPTAKE FRACTION	3.000E-01

PARAMETERS ASSOCIATED WITH EXPONENTIAL TERMS...

	COEFFICIENTS	EXCRETORY HALF-LIVES	EXCRETION RATES
1	6.500E-01	1.000E+01	6.931E-02
2	3.500E-01	1.000E-05	6.931E+04

DISCRETE TIMES AND INTAKES...

TIME (DAYS)	TOTAL INTAKE TO BODY (MICROCURIES)	UPTAKE (MICROCURIES)
0.000E-01	1.0000E+00	3.0000E-01

TABULATION OF DOSE RATES AND DOSES

RADIONUCLIDE -- 27 CO-60

REFERENCE ORGAN -- TOTAL BODY

MODE OF INTAKE -- INGESTION

TIME (DAYS)	RATE (REMS/DAY)	DOSE (REMS)
0.000E-01	3.2914E-04	0.0000E-01
5.000E+00	1.5100E-04	9.0325E-04
1.000E+01	1.0658E-04	1.5408E-03
1.500E+01	7.5227E-05	1.9908E-03
2.000E+01	5.3097E-05	2.3084E-03
2.500E+01	3.7477E-05	2.5325E-03
3.000E+01	2.6452E-05	2.6908E-03
3.500E+01	1.8670E-05	2.8024E-03
4.000E+01	1.3178E-05	2.8813E-03
4.500E+01	9.3011E-06	2.9369E-03
5.000E+01	6.5649E-06	2.9762E-03
5.500E+01	4.6336E-06	3.0039E-03
6.000E+01	3.2705E-06	3.0234E-03
6.500E+01	2.3084E-06	3.0373E-03
7.000E+01	1.6293E-06	3.0470E-03
7.500E+01	1.1500E-06	3.0539E-03
8.000E+01	8.1168E-07	3.0587E-03

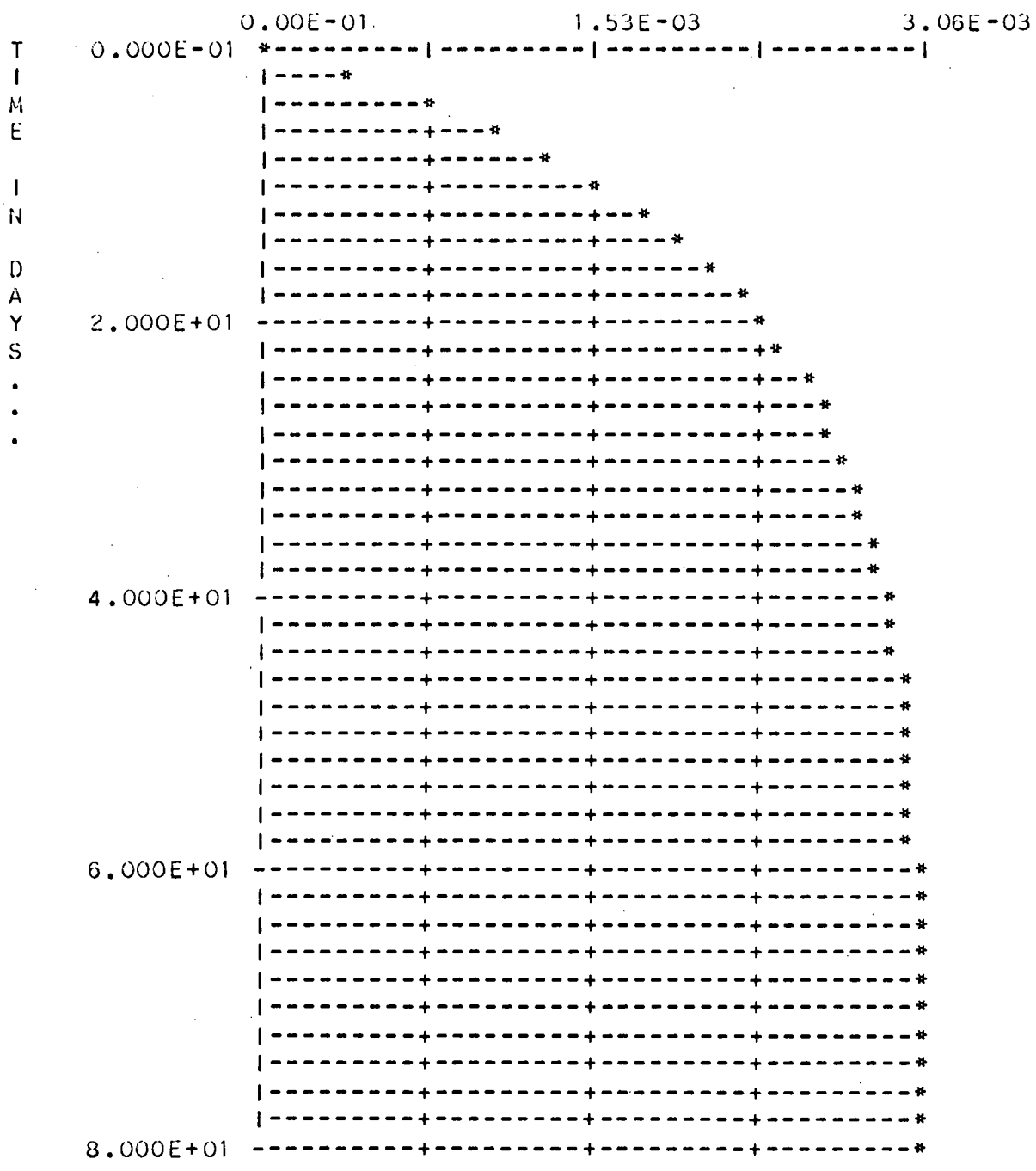
```
TYPE
1-FOR MORE TABULATION
2-TO CHANGE INTAKES
3-TO CHANGE NUCLIDES
4-FOR GRAPH
5-TO EXIT
4

ENTER MIN. AND MAX. TIMES (DAYS) FOR TIME AXIS
TMIN        TMAX
----------  ----------
0. 80.

ENTER 3 LINES OF COMMENTARY TO APPEAR ON GRAPH
(NOT TO EXCEED 40 CHAR. PER LINE)
----------------------------------------
```

PLOT OF RADIATION DOSE AGAINST TIME

RADIONUCLIDE -- 27 CO-60
REFERENCE ORGAN -- TOTAL BODY
INTAKE BY INGESTION

TYPE
1-FOR MORE GRAPHS
2-FOR MORE TABULATION
3-TO CHANGE INTAKES
4-TO CHANGE NUCLIDES
5-TO EXIT

DOSE IN REMS...



to the right. (2) The scales on both axes are always computed in such a way as to keep the graph a fixed size.

3.3 INDOS3

INDOS3 is computationally equivalent to INDOS2. These codes differ only with respect to the output offered and to the dialogue necessary to specify the outputs. INDOS3 provides only punched-card output, which can be used as input to programs in batch-run jobs (e.g., graphing programs). INDOS3 shares the data base of INDOS2; for the user's choice of the radionuclides included in that data-base file (refer to Appendix C), INDOS3 punches at specified time intervals, the time (days), the burden (μCi) of the reference organ, and the dose (rems) to the organ. Burden replaces dose rate because of an observed preference for graphing the former quantity in many instances.

The punched-card deck consists of (1) a title card of 35 characters or fewer, (2) a card containing a single integer NCARD (punched in format I3), which is the number of data cards to follow, and (3) the NCARD number of data cards, each containing time, burden, and dose [format 3(1PE10.3)]. During the dialogue phase, the user writes the title to be punched in the first card and specifies the integer NCARD, which must lie in the range 11 to 501.

The information required of the user of INDOS3 during the dialogue phase is similar to that of INDOS2. The following list gives a specific indication:

Code number of radionuclide (see Appendix C)

Mode of intake

1-ingestion

2-inhalation

Pattern of intake

1-discrete

Number N of discrete intakes

Times t_i (days) and corresponding intakes a_i (μCi)

2-continuous at a constant rate

Initial body burden α (μCi)

Rate of intake into body c (μCi/day)

Option of typed summary of input and data-base information

Minimum and maximum time values to be included (days)

Number of data cards to be punched (range 11 to 501)

Title card (no more than 35 characters)

Option to revise the last three items

After punching, the user is offered the opportunity to change time limits, title, or the number of data cards; to change intake information; to change radionuclides; or to end the run.

The following example consists of the teletype record of a run of INDOS3.

Remarks about free-form input that have been made in connection with INDOS1 (subsection 3.1) are applicable without modification to INDOS3.

```
REFERENCE ORGAN RADIATION DOSE CALCULATION
------------------------------------------

PUNCHED CARD OUTPUT FOR CRT GRAPHICS


ENTER CODE NO. OF NUCLIDE.
330

MODE OF INTAKE...
TYPE
1-FOR INGESTION
2-FOR INHALATION
2

TYPE
1-FOR DISCRETE INTAKES
2-FOR CONTINUOUS INTAKE AT CONSTANT RATE
1

HOW MANY DISCRETE INTAKES? (1 TO 50)
1

ENTER THE  1 TIMES (DAYS) AND THE
CORRESPONDING INTAKES (MICROCURIES)
----------  ----------
0. 1.

TYPE 1-FOR INPUT SUMMARY
     2-TO SUPPRESS
2


ENTER MIN. AND MAX. TIMES (DAYS) FOR TIME AXIS
TMIN        TMAX
----------  ----------
0. 15.

HOW MANY DATA POINTS DO YOU WANT PLOTTED?
MIN. IS 11, MAX. IS 501
51

ENTER TITLE FOR GRAPH (1 LINE, 35 CHAR. OR LESS, DO NOT USE $)
-----------------------------------
NP-239 IN BONE.  1 U-CI INTAKE


YOU HAVE SPECIFIED...

GRAPH TITLE
NP-239 IN BONE.  1 U-CI INTAKE

NO. OF CARDS --  51

TIME RANGE FROM  0.000E-01 TO  1.500E+01

TYPE
1-IF THESE INPUTS ARE CORRECT
2-TO REVISE THEM
1

TYPE
1-TO CHANGE TIME LIMITS, TITLE, OR NO. OF DATA POINTS
2-TO CHANGE INTAKES
3-TO CHANGE NUCLIDES
4-TO EXIT
4
```

3.4 The Numerical Methods

The overall design of the computational subroutines which serve the INDOS codes has been based on the decision to attempt to return answers that are correct to six significant digits and to flag any answers that might not be supported by this precision. Most of the calculations involve straightforward evaluation of algebraic formulas and present no obstacles. Only two special problems seem to warrant discussion in some detail.

The first problem concerns evaluation of expressions of the form e^{-u} and $1 - e^{-u}$ for positive u. In either case, if u is large, a system underflow error results if the condition is not detected and the exponential set to 0 by the program. The result of this expedient is the loss of all significant digits, but this effect is not believed to propagate; in some instances it leads to the outputting of zero dose rates, a situation that is easily interpreted by the user. In the INDOS codes e^{-u} is set to zero when u exceeds 75. On the other hand, if u is small, conventional calculation of $1 - e^{-u}$ with the exponential subroutine leads to cancellation of significant digits and a possible propagated loss of precision which might not be obvious in outputs. Avoiding such a loss is easily managed by using

$$u = \frac{u^3}{3!} - \frac{u^2}{2!}$$

in place of $1 - e^{-u}$ if u is less than 0.01. This handling of exponential expressions has been employed consistently in the subroutines.

The second problem concerns the evaluation of integrals of the form

$$I = \int_{t_1}^{t_2} e^{-\lambda_r t} (t + x)^{-n} \, dt \quad (0 < n < 1),$$

which occur in the power function models. With a change of variable one can show that

$$I = e^{\lambda_r x} \lambda_r^{n-1} \int_{\alpha}^{\beta} e^{-u} u^{-n} \, du ,$$

where $\alpha = \lambda_r (t_1 + x)$ and $\beta = \lambda_r (t_2 + x)$. Thus the problem reduces to evaluating the integral

$$F(\alpha, \beta, n) = \int_{\alpha}^{\beta} e^{-u} u^{-n} \, du . \tag{3.1}$$

The integration indicated in Eq. (3.1) cannot, in general, be carried out in closed form. Three numerical methods have been used, singly and in combination, to approximate the integral.

The first method, applicable when α and β are relatively small, employs the series

$$\sum_{k=0}^{\infty} \frac{(-1)^k \left[\beta^{k-n+1} - \alpha^{k-n+1}\right]}{k! \, (k - n + 1)}$$

which is obtained by expanding the integrand of Eq. (3.1) in powers of u and integrating term by term. This approach is suggested in reference 5 (p. 28). The series is evaluated by subroutine SER; with this

technique a manageable range for α and β is $0 \leq \alpha < \beta \leq 2$, and this range is used by the subroutine INTEG which coordinates the integration.

When $2 \leq \alpha < \beta \leq 20$, a composite sixth-order Newton-Cotes quadrature rule is applied to subintervals of the range $[\alpha,\beta]$; this quadrature rule may be written in the form

$$\int_a^b f(u)\, du = \frac{2h}{45} \sum_{k=0}^{M/4-1} [7f_{4k} + 32f_{4k+1} + 12f_{4k+2} + 32f_{4k+3} + 7f_{4k+4}] - \frac{2(b-a)}{945} h^6 f^{(6)}(\xi)$$

$$(a < \xi < b), \tag{3.2}$$

where M is a multiple of 4 and $h = (b - a)/M$. We have written f_j for $f(u_j)$, where $u_j = a + jh$, $j = 0, \ldots, M$ (see reference 2, p. 73 ff). For this application, $f(u) = e^{-u} u^{-u}$.

Subroutine NEWCO implements the rule (3.2) in such a way that the relative error does not exceed a prescribed tolerance E_{rel} in absolute value. Because of the necessity of using a bound for the absolute value of $f^{(6)}$ over the interval $[a,b]$, it has been found that considerable computational economy is achieved by subdividing the range $[\alpha,\beta]$ into subintervals of no more than unit length, applying (3.2) to each subinterval, and summing the results. Subroutine INTEG applies NEWCO in just this way to that portion of the range of integration that lies in [2,20]. This approach controls the total error if each E_{rel} is suitably chosen and sufficient precision is available to prevent the accumulation of rounding errors.

In the case $20 \leq \alpha < \beta$, an asymptotic series can be used to approximate the integral:

$$F(z, +\infty, n) \sim z^{a-1} e^{-z} \left[1 + \frac{a-1}{z} + \frac{(a-1)(a-2)}{z^2} + \ldots\right],$$

where $a = 1 - n$ [reference 1, p. 263, Eq. (6.5.32)]. Subroutine ASYMP sums the number of terms needed for the desired accuracy.

A master subroutine INTEG coordinates SER, NEWCO, and ASYMP and returns a value of the integral (3.1) for arbitrary α and β. In the event that either limit of integration exceeds 65, INTEG returns a warning flag to the calling program. This is relayed to the mainline and results in the printing of an asterisk beside the corresponding dose and dose rate. For the parameter ranges usually involved, this truncation is not likely to result in loss of precision.

REFERENCES

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Appendix A.

Listing of Computer Codes

```
C ****** INDOS1 ******
C  AUTHORS...   G. G. KILLOUGH
C              EAST TENNESSEE STATE UNIVERSITY
C              DEPARTMENT OF MATHEMATICS
C                  AND DIVISION OF COMPUTER SCIENCE
C              JOHNSON CITY, TENNESSEE
C
C              PAUL S. ROHWER
C              ENVIRONMENTAL SCIENCES DIVISION
C              OAK RIDGE NATIONAL LABORATORY
C              OAK RIDGE, TENNESSEE
C
C **** MAIN PROGRAM ****
C
C       THE INDOS CODES ARE SPECIAL PURPOSE CONVERSATIONAL PROGRAMS
C  WRITTEN TO FUNCTION IN A TIME-SHARING ENVIRONMENT.  THEY HAVE BEEN
C  IMPLEMENTED ON THE ORNL PDP-10.
C
C       INDOS1 COMPUTES DOSE RATE AND DOSE TO AN ORGAN AS FUNCTIONS
C  OF TIME.  THIS DOSE RESULTS FROM DEPOSITION OF A SPECIFIED
C  QUANTITY OF A RADIONUCLIDE IN THE ORGAN.  THE USER MUST SPECIFY
C  ALL PARAMETERS RELATED TO RADIONUCLIDE AND ORGAN, HIS CHOICE OF
C  MATHEMATICAL MODEL (EXPONENTIAL OR POWER FUNCTION), AND INTAKE
C  INFORMATION AS THESE ITEMS ARE REQUESTED BY THE CODE.
C
C       THE TERM 'INTAKE' IN MESSAGES OUTPUTTED BY INDOS1 REFERS TO
C  QUANTITY OF MATERIAL DEPOSITED IN THE ORGAN, NOT TOTAL QUANTITY
C  INTRODUCED INTO THE BODY.
C
C       OUTPUT IS A TABULATION OF TIMES (DAYS), DOSE RATES (REMS/DAY),
C  AND DOSES (REMS).
C
C ******************************************************************
C
      REAL LMBDA,LOG2,MASS,N
C
C  THE DIMENSION OF ARRAYS KNU, TB, AND BETA LIMITS THE NUMBER OF
C  TERMS IN AN EXPONENTIAL MODEL.  IF THIS IS INCREASED BEYOND 9,
C  CERTAIN STATEMENTS IN THE DIALOG PHASE WILL NEED TO BE CHANGED.
C
      REAL K,KNU(9),TB(9),BETA(9)
      INTEGER ERCOD
C
C  THE DIMENSION OF ARRAYS TI AND AI LIMITS THE NUMBER OF DISCRETE
C  INTAKES.  IF THIS IS CHANGED, CERTAIN STATEMENTS IN THE DIALOG
C  PHASE WILL NEED TO BE CHANGED.
C
      DIMENSION NAMN(4),NAMCR(4),TI(20),AI(20)
      DATA IBLNK/' '/,ISTAR/'*'/
      LOG2=ALOG(2.0)
C
C ***** BEGINNING OF DIALOG PHASE.
C
      TYPE 500
500   FORMAT('1CRITICAL ORGAN RADIATION DOSE CALCULATION'/
     $' ----------------------------------------'//)
C
C  INPUT ALPHAMERIC INFORMATION FOR SUBSEQUENT OUTPUT LABELLING...
C  NAME OR FORMULA OF RADIONUCLIDE (20 CHARACTERS OR LESS)
C  AND NAME OF ORGAN (20 CHARACTERS OR LESS).
C
1     TYPE 501
501   FORMAT(' ENTER NAME OR FORMULA OF NUCLIDE (20 CHAR. OR LESS)'/)
```

```
      ACCEPT 502,(NAMN(I),I=1,4)
502   FORMAT(4A5)
      TYPE 503
503   FORMAT(' TYPE NAME OF CRITICAL ORGAN (20 CHAR. OR LESS)'/)
      ACCEPT 502,(NAMCR(I),I=1,4)
C
C  INPUT RADIOACTIVE HALF-LIFE (THALF).  TEST FOR NEGATIVE VALUE.
C
11    TYPE 504
504   FORMAT(' ENTER RADIOACTIVE HALF-LIFE (DAYS)'/)
      ACCEPT 505,THALF
505   FORMAT(3F)
      IF(THALF.GT.0) GO TO 12
      TYPE 506
506   FORMAT(' ?? INPUT ERROR ??  TRY AGAIN.'/)
      GO TO 11
C
C  COMPUTE RADIOACTIVE DECAY RATE (LMBDA).
C
12    LMBDA=LOG2/THALF
C
C  INPUT EFF. ABSORBED ENERGY PER DISINTEGRATION (EPSLN)
C  AND MASS OF ORGAN (MASS).  TEST FOR 0 OR NEGATIVE VALUE.
C
13    TYPE 507
507   FORMAT(' ENTER EPSILON (MEV) AND MASS (G) OF CRITICAL'/
     $' ORGAN'/)
      ACCEPT 505,EPSLN,MASS
      IF(EPSLN.GT.0..AND.MASS.GT.0.) GO TO 14
      TYPE 506
      GO TO 13
C
C  COMPUTE CONVERSION FACTOR (BIFAC) TO CHANGE FROM
C  CUMULATIVE BURDEN (MICROCURIE-DAYS) TO DOSE (REMS).
C
14    BIFAC=51.2*EPSLN/MASS
C
C  INPUT FLAG SETTING (MODEL) FOR CHOICE OF MODEL...
C
C    MODEL = 1   FOR   EXPONENTIAL
C          = 2         POWER FUNCTION
C          = 3         MIXED
C
C  TEST FOR ERRONEOUS VALUE OF MODEL.
C  THEN BRANCH TO APPROPRIATE INPUT SEGMENT.
C
141   TYPE 5071
5071  FORMAT(' TYPE'/' 1-FOR EXPONENTIAL MODEL'/' 2-FOR POWER FUNCTION M
     $ODEL'/' 3-FOR MIXED MODEL'/)
      ACCEPT 510,MODEL
      IF(MODEL.GE.1.AND.MODEL.LE.3) GO TO (1421,15,1423),MODEL
      TYPE 506
      GO TO 141
C
C ****** BEGIN MIXED-MODEL SEGMENT...
C
C  INPUT MIXTURE COEFFICIENT (K).  TEST FOR LESS THAN 0 OR
C  GREATER THAN 1.
C
1423  TYPE 5072
5072  FORMAT(' ENTER COEFFICIENT OF EXPONENTIAL PART OF MIXED MODEL'/)
      ACCEPT 505,K
      IF(K.GT.0..AND.K.LT.1.) GO TO 1421
      TYPE 506
      GO TO 1423
C
```

```
C ****** BEGIN EXPONENTIAL MODEL SEGMENT
C        (ALSO PART OF MIXED MODEL SEGMENT)...
C
C  INPUT NUMBER OF EXPONENTIAL TERMS IN MODEL (M).  TEST
C  FOR LESS THAN 1 OR GREATER THAN 9.
C
1421  TYPE 5073
5073  FORMAT(' HOW MANY EXPONENTIAL TERMS? (1 TO 9, NO DECIMAL)'/)
      ACCEPT 510,M
      IF(M.GE.1.AND.M.LE.9) GO TO 143
      TYPE 506
      GO TO 1421
C
C  INPUT M COEFFICIENTS (KNU(NU)) AND BIOLOGICAL
C  HALF-LIVES (TB(NU)).  TEST EACH FOR 0 OR NEGATIVE.
C
143   TYPE 5074,M
5074  FORMAT(' ENTER 2 PARAMETERS FOR EACH OF THE'/
     $' ',I1,' EXPONENTIAL TERMS...'//
     $' COEFFICIENT',T16,'EXCRETORY HALF-LIFE'/
     $' ----------',T20,'----------'/)
      DO 144 NU=1,M
145   ACCEPT 505,KNU(NU),TB(NU)
      IF(KNU(NU).GT.0..AND.TB(NU).GT.0.) GO TO 146
      TYPE 506
      TYPE 5075
5075  FORMAT(' ----------',T20,'----------'/)
      GO TO 145
C
C  COMPUTE BIOLOGICAL EXCRETION RATE (BETA(NU)).
C
146   BETA(NU)=LOG2/TB(NU)
144   CONTINUE
C
C  COMPUTE SUM (SUM) OF COEFFICIENTS (KNU(NU), NU=1,M).
C  TEST SUM FOR GREATER THAN 1.
C
      SUM=0.
      DO 147 NU=1,M
147   SUM=SUM+KNU(NU)
      IF(SUM.LE.1.) GO TO 148
      TYPE 506
      TYPE 5076
5076  FORMAT(' SUM OF COEFFICIENTS GREATER THAN 1.'/)
      GO TO 143
C
C  IF MODEL IS EXPONENTIAL, BRANCH AROUND POWER FUNCTION SEGMENT.
C  OTHERWISE IT IS MIXED, SO GO INTO POWER FUNCTION SEGMENT.
C
148   GO TO (171,171,15),MODEL
C
C ****** BEGIN POWER FUNCTION MODEL SEGMENT
C        (ALSO PART OF MIXED MODEL SEGMENT)...
C
C  INPUT POWER FUNCTION PARAMETERS SMALL N (N),
C  SMALL X (X), AND CAPITAL A (ACAP).  TEST
C  FOR ERRONEOUS VALUES.
C
15    TYPE 508
508   FORMAT(' ENTER N, X, AND CAPITAL-A FOR POWER FUNCTION'/)
      ACCEPT 505,N,X,ACAP
      IF(N.GE.1..OR.N.LE.0.) GO TO 16
      IF(ACAP.LE.0..OR.X.LT.0.) GO TO 16
      GO TO 171
16    TYPE 506
      GO TO 15
```

```
C
C ****** END OF INPUT PHASE FOR MODEL PARAMETERS.
C
C ****** BEGIN INPUT OF INFORMATION RELATED TO PATTERN OF INTAKE.
C
C  INPUT FLAG SETTING (IM) TO DETERMINE BASIC INTAKE PATTERN...
C
C    IM = 1     FOR     INTAKES AT ONE OR MORE DISCRETE TIMES
C       = 2             CONTINUOUS INTAKE AT A CONSTANT RATE
C
C  TEST FOR ERRONEOUS VALUES OF IM.  THEN BRANCH TO THE APPROPRIATE
C  SEGMENT ACCORDING TO THE VALUE OF IM.
C
171   TYPE 5081
5081  FORMAT(' TYPE'/' 1-FOR DISCRETE INTAKES'/' 2-FOR CONTINUOUS INTAKE
     $ AT CONSTANT RATE'/)
      ACCEPT 510,IM
      IF(IM.EQ.1.OR.IM.EQ.2) GO TO (17,192),IM
      TYPE 506
      GO TO 171
C
C ****** DISCRETE INTAKES INPUT SEGMENT.
C
C  INPUT NUMBER CAPITAL N (NCAP) OF DISCRETE INTAKES.
C  TEST FOR AN ERRONEOUS VALUE (LESS THAN 1 OR GREATER THAN 20).
C
17    TYPE 509
509   FORMAT(' HOW MANY DISCRETE INTAKES? (1 TO 20, NO DECIMAL)'/)
      ACCEPT 510,NCAP
510   FORMAT(I)
      IF(NCAP.LE.20.AND.NCAP.GE.1) GO TO 18
      TYPE 506
      GO TO 17
C
C  INPUT THE DISCRETE TIMES (TI(I)) AND INTAKES (AI(I)), I=1,NCAP.
C  TEST FOR NEGATIVE TIMES AND ZERO OR NEGATIVE INTAKES.
C
18    TYPE 511,NCAP
511   FORMAT(' ENTER THE ',I2,' TIMES (DAYS) AND THE'/
     $' CORRESPONDING INTAKES (MICROCURIES)'/
     $' ----------  ----------'/)
      DO 19 I=1,NCAP
181   ACCEPT 505,TI(I),AI(I)
      IF(TI(I).GE.0..AND.AI(I).GT.0.) GO TO 19
      TYPE 506
      TYPE 5111
5111  FORMAT(' ----------  ----------'/)
      GO TO 181
19    CONTINUE
C
C  BRANCH AROUND CONTINUOUS INTAKES SEGMENT.
C
      GO TO 191
C
C ****** CONTINUOUS INTAKES INPUT SEGMENT.
C
C  INPUT INITIAL CONTENT (A0) AND DAILY INTAKE RATE (C).
C  TEST FOR NEGATIVE VALUES.
C
192   TYPE 5091
5091  FORMAT(' ENTER'/' INITIAL  BODY  BURDEN   UPTAKE RATE'/
     $' ',T7,'(MICRO-CI)',T25,'(MICRO-CI/DAY)'/' ',T7,'----------',
     $T27,'----------'/)
      ACCEPT 505,A0,C
      IF(A0.GE.0..AND.C.GE.0.) GO TO 191
      TYPE 506
```

```
      GO TO 192
C
C ****** BEGIN OUTPUT OPTIONS SEGMENT.
C
C  INPUT MINIMUM TIME (TMIN), TIME INCREMENT (DELT),
C  AND MAXIMUM TIME (TMAX) FOR TABLE OF OUTPUT.
C  TEST FOR ERRONEOUS VALUES.
C
C  NOTE... IF TMIN = TMAX, TABLE IS ONE LINE FOR THAT TIME VALUE.
C          IF DELT = 0., TABLE IS TWO LINES FOR TMIN AND TMAX, IF
C              THESE ARE DIFFERENT.
C
191   TYPE 512
512   FORMAT(' FOR TABULATION, ENTER (DAYS)'/' MIN. TIME',3X'INCREMENT',
     $3X'MAX. TIME'/
     $' ----------  ----------  ----------'/)
      ACCEPT 505,TMIN,DELT,TMAX
      IF(TMIN.LE.TMAX.AND.DELT.GE.0.) GO TO 20
      TYPE 506
      GO TO 191
C
C  INPUT A FLAG SETTING (INSUM) TO ACCEPT OR REJECT
C  A SUMMARY OF INPUTS...
C
C       INSUM = 1                  TO ACCEPT
C             = ANY OTHER VALUE    TO REJECT
C
C  CONTINUE IN SEQUENCE OR BRANCH AROUND ACCORDING TO VALUE OF INSUM.
C
20    TYPE 513
513   FORMAT(' TYPE 1-FOR INPUT SUMMARY'/' ',T7,'2-TO SUPPRESS'/)
      ACCEPT 510,INSUM
      IF(INSUM.NE.1) GO TO 3
C
C ****** OUTPUT A SUMMARY OF INPUT INFORMATION.
C
      TYPE 5130
5130  FORMAT(///' SUMMARY OF INPUTS')
      GO TO (201,202,203),MODEL
201   TYPE 5131
5131  FORMAT(' EXPONENTIAL MODEL'/' ----------- -----'/)
      GO TO 204
202   TYPE 5132
5132  FORMAT(' POWER FUNCTION MODEL'/' ----- -------- -----'/)
      GO TO 204
203   TYPE 5133
5133  FORMAT(' MIXED MODEL'/' ----- -----'/)
204   TYPE 514,(NAMN(I),I=1,4),(NAMCR(I),I=1,4),THALF,LMBDA,EPSLN,
     $          MASS,BIFAC
514   FORMAT('0RADIONUCLIDE -- ',4A5/'0CRITICAL ORGAN -- ',4A5/
     $'0RADIOACTIVE HALF-LIFE',T31,1PE10.3,' DAYS'/
     $'0RADIOACTIVE DECAY RATE',T31,1PE10.3,' PER DAY'/
     $'0EFF. ABSORBED ENERGY',T31,1PE10.3,' MEV'/'0MASS OF CRITICAL ORGA
     $N',T31,1PE10.3,' G'/'0BIOLOGICAL CONV. FACTOR',T31,1PE10.3,' REMS/
     $MICROCURIE-DAY'/)
      GO TO (205,206,205),MODEL
205   TYPE 5134,(NU,KNU(NU),TB(NU),BETA(NU),NU=1,M)
5134  FORMAT('0PARAMETERS ASSOCIATED WITH EXPONENTIAL TERMS...'//
     $' ',T5,'COEFFICIENTS',T19,'EXCRETORY',T32,'EXCRETION'/
     $' ',T19,'HALF-LIVES',T34,'RATES'//(' ',I1,2X,1PE10.3,
     $2(3X,1PE10.3)))
      GO TO (207,206,206),MODEL
206   TYPE 5135,N,X,ACAP
5135  FORMAT('0POWER FUNCTION PARAMETERS...'/
     $'0N',T11,1PE10.3/'0X',T11,1PE10.3/'0CAP. A',T11,1PE10.3/)
207   GO TO (21,22),IM
```

```
21    TYPE 5141,(TI(I),AI(I),I=1,NCAP)
5141  FORMAT('0DISCRETE TIMES AND UPTAKES...'/'0TIME (DAYS)',T21,
     $'UPTAKE (MICROCURIES)'//(' ',1PE11.3,T23,1PE11.3))
      GO TO 3
22    TYPE 5142,A0,C
5142  FORMAT(/'0INITIAL BURDEN',T31,1PE10.3,' MICROCURIES'/
     $'0UPTAKE RATE',T31,1PE10.3,' MICROCURIES/DAY')
C
C ****** BEGIN COMPUTATION AND TABULATION PHASE.
C
C  TYPE HEADINGS FOR TABULAR OUTPUT.
C
3     TYPE 515
515   FORMAT(///' TABULATION OF DOSE RATE AND DOSE'/
     $' ---------- -- ---- ---- --- ----'//
     $' TIME(DAYS)',T16,'RATE (REMS/DAY)',T34,'DOSE (REMS)'/)
C
C  INITIALIZE BEFORE TABULATION LOOP...
C
C      MSG WILL NORMALLY CONTAIN A BLANK CHARACTER, BUT MSG='*'
C      WILL SIGNAL POSSIBLE LOSS OF SIGNIFICANT DIGITS IN OUTPUT
C      DATA.  MSG WILL BE TYPED WITH OUTPUT.
C
C      ICODE = 1 AT END OF LOOP MEANS CONTINUE
C            = 2                MEANS EXIT
C
C      T GOES FROM TMIN TO TMAX IN INCREMENTS OF DELT.
C
      MSG=IBLNK
      ICODE=1
      T=TMIN
C
C  ERCOD IS RESET TO 0 AT BEGINNING OF LOOP EACH TIME.
C  ERCOD = 1 IS A FLAG SET BY COMPUTATIONAL SUBROUTINES IF A
C  POSSIBLE LOSS OF SIGNIFICANT DIGITS IS DETECTED.
C
C  BEGIN LOOP.
C
31    ERCOD=0
C
C  DETERMINE MODEL AND INTAKE PATTERN AND BRANCH TO APPROPRIATE
C  SUBROUTINE FOR COMPUTATION OF BURDEN (QSMAL) AND CUMULATIVE
C  BURDEN (QCAP) AT TIME T.
C
      GO TO (311,312,311),MODEL
311   GO TO (3111,3112),IM
C
C  CALL SUBROUTINE FOR DISCRETE INTAKES, EXPONENTIAL MODEL.
C
3111  CALL DIEX(T,NCAP,TI,AI,LMBDA,M,KNU,BETA,QSMAL,QCAP)
      GO TO 314
C
C  CALL SUBROUTINE FOR CONTINUOUS INTAKES, EXPONENTIAL MODEL.
C
3112  CALL CIEX(T,A0,C,LMBDA,M,KNU,BETA,QSMAL,QCAP)
C
C  IF MODEL IS MIXED, SAVE QSMAL AND QCAP FROM EXPONENTIAL
C  SUBROUTINE AND CALL APPROPRIATE POWER FUNCTION SUBROUTINE.
C
314   GO TO (313,313,3141),MODEL
3141  QS=QSMAL
      QC=QCAP
312   GO TO (3121,3122),IM
C
C  CALL SUBROUTINE FOR DISCRETE INTAKES, POWER FUNCTION.
C
```

```
3121  CALL DIPF(T,NCAP,TI,AI,LMBDA,N,ACAP,X,QSMAL,QCAP,ERCOD)
      GO TO 315
C
C  CALL SUBROUTINE FOR CONTINUOUS INTAKES, POWER FUNCTION.
C
3122  CALL CIPF(T,A0,C,LMBDA,N,ACAP,X,QSMAL,QCAP,ERCOD)
315   GO TO (313,313,316) , MODEL
C
C  FOR MIXED MODEL COMPUTE COMBINATION OF EXPONENTIAL AND
C  POWER FUNCTION CONTRIBUTIONS.
C
316   QSMAL=K*QS + (1.-K)*QSMAL
      QCAP=K*QC + (1.-K)*QCAP
C
C  COMPUTE DOSE RATE (DRATE) AND DOSE (DOSE).
C
313   DRATE=BIFAC*QSMAL
      DOSE=BIFAC*QCAP
C
C  IF POSSIBLE LOSS OF SIGNIFICANT DIGITS HAS BEEN DETECTED,
C  CHANGE VALUE OF MSG FROM BLANK TO '*'.  TYPE DRATE AND DOSE,
C  LABELLED BY MSG.
C
      IF(ERCOD.GT.0) MSG=ISTAR
      TYPE 516,T,DRATE,MSG,DOSE,MSG
516   FORMAT(' ',1PE10.3,T17,1PE12.5,A1,T33,1PE12.5,A1)
C
C  A NORMAL TABLE HAS TWO OR MORE ENTRIES WITH DELT POSITIVE.
C  BRANCH IF THIS TABLE IS NOT NORMAL.
C
      IF(.NOT.(TMIN.LT.TMAX.AND.DELT.GT.0.)) GO TO 32
C
C  NORMAL CASE.  INCREMENT T AND TEST.
C
      T=T+DELT
      IF(T.LT.TMAX) GO TO 31
C
C  INCREMENTED T GREATER THAN OR EQUAL TO TMAX.  IF ICODE = 2
C  SIGNALS THAT THIS IS LAST PASS, EXIT.  OTHERWISE, NEXT
C  PASS SHOULD BE LAST, SO RESET ICODE=2, T=TMAX, AND BRANCH
C  TO BEGINNING OF LOOP.
C
      IF(ICODE.EQ.2) GO TO 33
      ICODE=2
      T=TMAX
      GO TO 31
C
C  ABNORMAL CASE.
C
32    IF(TMIN.EQ.TMAX) GO TO 33
C
C  TMIN IS LESS THAN TMAX.  RESET ICODE=2 TO SIGNAL LAST PASS
C  NEXT TIME THROUGH.  MAKE DELT POSITIVE SO THAT NEXT PASS
C  FINISHES AS NORMAL CASE.  RESET T=TMAX AND RETURN TO
C  BEGINNING OF LOOP.
C
      ICODE=2
      DELT=TMAX-TMIN
      T=TMAX
      GO TO 31
C
C  INPUT FLAG SETTING (IANS) TO INDICATE USER OPTION...
C
C       IANS = 1   FOR    ADDITIONAL TABULATION
C            = 2          CHANGING INTAKE PATTERN OR PARAMETERS
C            = 3          CHANGING RADIONUCLIDES
```

```
C             = 4           ENDING RUN
C
C  TEST FOR ERRONEOUS VALUE OF IANS.  BRANCH TO APPROPRIATE OPTION.
C
33    TYPE 517
517   FORMAT(///' TYPE'/' 1-FOR MORE TABULATION'/' 2-TO CHANGE INTAKES'/
     $' 3-TO CHANGE NUCLIDES'/' 4-TO EXIT'/)
      ACCEPT 510,IANS
      IF(IANS.GE.1.AND.IANS.LE.4) GO TO (191,171,1,34),IANS
      TYPE 506
      GO TO 33
34    CALL EXIT
C
C ***********************************************************************
      END
```

```
C ****** INDOS2 ******
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C
C ****** MAIN PROGRAM ******
C
C       THE INDOS CODES ARE SPECIAL PURPOSE CONVERSATIONAL PROGRAMS
C  WRITTEN TO FUNCTION IN A TIME-SHARING ENVIRONMENT.  THEY HAVE BEEN
C  IMPLEMENTED ON THE ORNL PDP-10.
C
C       INDOS2 COMPUTES DOSE RATE AND DOSE TO AN ORGAN AS FUNCTIONS
C  OF TIME.  THIS DOSE RESULTS FROM DEPOSITION OF A SPECIFIED
C  QUANTITY OF ANY ONE OF SEVERAL RADIONUCLIDES IN THE ORGAN, AND
C  THE ORGAN IS THE ONE WHICH IS REGARDED AS CRITICAL FOR THE
C  RADIONUCLIDE SELECTED.  ONCE THE USER DESIGNATES HIS CHOICE OF
C  RADIONUCLIDE, INDOS2 SECURES PARAMETER VALUES ASSOCIATED WITH
C  THE MATERIAL AND ITS CRITICAL ORGAN FROM A DIRECT-ACCESS FILE
C  STORED IN THE USER'S DISK AREA.  THIS STORED DATA BASE IS ONE
C  FEATURE WHICH DISTINGUISHES THE CAPABILITIES OF INDOS2 FROM THOSE
C  OF INDOS1.
C
C       A SECOND DISTINCTION IS THE MEANING OF THE TERM 'INTAKE.'
C  FOR INDOS2, THIS TERM REFERS TO THE QUANTITY OF MATERIAL INHALED
C  OR INGESTED INTO THE BODY (THE USER CHOOSES THE ROUTE OF INTAKE).
C  INDOS2 CONVERTS THE INTAKE INTO A PROPORTIONATE DEPOSITION IN THE
C  CRITICAL ORGAN FOR THE CALCULATIONS.
C
C       AT THE USER'S OPTION, INDOS2 IS CAPABLE OF OUTPUTTING A
C  TYPEWRITTEN GRAPH OF THE DOSE VS. TIME.  STANDARD OUTPUT IS A
C  TABULATION OF TIMES (DAYS), DOSE RATES (REMS/DAY), AND DOSES
C  (REMS).
C
C ***************************************************************
C
C  THE DIMENSION OF ARRAYS KNU, TB, AND BETA LIMITS THE NUMBER OF
C  TERMS IN AN EXPONENTIAL MODEL.  INCREASING THIS BEYOND 9 REQUIRES
C  CHANGING CERTAIN OUTPUT FORMATS.
C
C  THE DIMENSION OF ARRAYS TI, AI, AND AA LIMITS THE NUMBER OF
C  DISCRETE INTAKES.  INCREASING THIS BEYOND 99 REQUIRES CHANGING
C  CERTAIN OUTPUT FORMATS.
C
C  THE ARRAYS NAMN, NAMCR, AVENUE, IBAR, IBORD, LINE, CMMNTS, DOSE,
C  AND TIME ARE OF CRITICAL SIZE AND SHOULD NOT BE REDIMENSIONED.
C
      REAL LMBDA,LOG2,MASS,N,K,KNU(9)
      INTEGER ERC
      INTEGER HYPHEN
      DIMENSION TB(9),BETA(9),NAMN(4),NAMCR(4),
     $          AVENUE(2,2),
     $          TI(50),AI(50),AA(50)
      DIMENSION IBAR(41),IBORD(2),LINE(41),CMMNTS(3,8),DOSE(41),
     $         TIME(41)
      DATA IBLNK/' '/,ISTAR/'*'/,AVENUE/'INGES','INHAL','TION ','ATION'/
      DATA IBORD/'-----','----I'/,HYPHEN/'-'/,IPLUS/'+'/,ICHAR/'I'/,
```

```
     $      TIME/'T','I','M','E',' ','I','N',' ','D','A','Y','S','.',
     $           '.','.',26*' '/
      LOG2=ALOG(2.0)
      TYPE 500
500   FORMAT('1REFERENCE ORGAN RADIATION DOSE CALCULATION'/
     $' ----------------------------------------'//)
C
C  INPUT AN INTEGER CODE NUMBER (NCODE) TO SELECT THE DESIRED RADIO-
C  NUCLIDE FOR CALCULATION.
C
1     TYPE 501
501   FORMAT(' ENTER CODE NO. OF NUCLIDE.'/)
      ACCEPT 502,NCODE
502   FORMAT(I)
C
C  SPECIFY TWO DIRECT-ACCESS DATA FILES...
C
C *** INDEX.DAT ***
C  SERVES AS AN INDEX FOR THE MAIN DATA FILE NUCPAR.DAT.  EACH
C  RECORD IN INDEX.DAT CONTAINS (1) THE CODE NUMBER OF A RADIO-
C  NUCLIDE (5 CHARACTERS) AND (2) A POINTER (10 CHARACTERS) TO
C  THE PHYSICAL RECORD OF NUCPAR.DAT WHICH BEGINS THE LOGICAL
C  RECORD CONTAINING DATA ON THE RADIONUCLIDE AND ITS CRITICAL
C  ORGAN.  THUS EACH PHYSICAL RECORD OF INDEX.DAT IS 15 CHARAC-
C  TERS.  THE ASSOCIATED FORTRAN VARIABLE FOR THIS FILE IS INDX.
C
C *** NUCPAR.DAT ***
C  CONTAINS THE DATA BASE FOR THE RADIONUCLIDES AVAILABLE TO
C  INDOS2.  EACH PHYSICAL RECORD OF THE FILE IS 10 CHARACTERS,
C  BUT THE INFORMATION IN THE FILE IS ORGANIZED INTO LOGICAL
C  RECORDS OF VARIABLE LENGTH, EACH LOGICAL RECORD CORRESPONDING
C  TO A RADIONUCLIDE.  A LOGICAL RECORD CONTAINS THE NAME OF
C  THE RADIONUCLIDE (20 CHARACTERS), THE NAME OF ITS CRITICAL
C  ORGAN (20 CHARACTERS), THE RADIOACTIVE HALF-LIFE, EFFECTIVE
C  ABSORBED ENERGY, MASS OF THE CRITICAL ORGAN, FRACTIONS OF
C  INTAKE REACHING CRITICAL ORGAN FROM INGESTION AND INHALATION,
C  RESPECTIVELY, AND AN INTEGER CODE TO IDENTIFY THE MODEL.
C  THE FOREGOING QUANTITIES REQUIRE 10 CHARACTERS EACH.  THE
C  REMAINDER OF THE FILE CONTAINS INFORMATION APPROPRIATE TO
C  THE PARTICULAR MODEL, NAMELY...
C
C       FOR EXPONENTIAL MODEL, THE NUMBER OF EXPONENTIAL TERMS
C  (10 CHARACTERS) AND FOR EACH TERM A COEFFICIENT AND BIOLOGICAL
C  HALF-LIFE (10 CHARACTERS EACH).
C
C       FOR POWER FUNCTION MODEL, THE PARAMETERS SMALL N, SMALL
C  X, AND CAPITAL A (10 CHARACTERS EACH).
C
C       FOR MIXED MODEL, THE MIXTURE COEFFICIENT CAPITAL K (10
C  CHARACTERS), THE NUMBER OF EXPONENTIAL TERMS (10 CHARACTERS)
C  AND FOR EACH TERM A COEFFICIENT AND BIOLOGICAL HALF-LIFE
C  (10 CHARACTERS EACH), THEN THE POWER FUNCTION PARAMETERS
C  SMALL N, SMALL X, AND CAPITAL A.
C
C  THE ASSOCIATED FORTRAN VARIABLE FOR NUCPAR.DAT IS MAIN.
C
      CALL DEFINE FILE (1,15,INDX,'INDEX.DAT',0,0)
      CALL DEFINE FILE (2,10,MAIN,'NUCPAR.DAT',0,0)
C
C  COMPARE INPUTTED CODE NUMBER NCODE WITH EACH CODE NUMBER
C  (NCO) IN FILE INDEX.DAT.  IF EQUALITY IS DETECTED, READ
C  CORRESPONDING POINTER (MAIN) TO LOCATE RECORD IN NUCPAR.DAT.
C  IN CASE OF DISK I/O ERROR, GIVE USER OPTION OF TRYING THE
C  READ OPERATION AGAIN, TRYING A DIFFERENT CODE NUMBER, OR
C  CALLING EXIT.
111   INDX=1
```

```
11     READ(1'INDX,5025,ERR=12,END=13) NCO,MAIN
5025   FORMAT(I5,I10)
       IF(NCO-NCODE) 11,14,11
12     TYPE 503
503    FORMAT(//' A DISK I-O ERROR HAS OCCURRED.  TYPE'/
      $' 1-TO TRY AGAIN'/' 2-TO TRY A DIFFERENT NUCLIDE'/
      $' 3-TO CALL EXIT'/)
       ACCEPT 502,IANS
       IF(IANS.GE.1.AND.IANS.LE.3) GO TO (111,1,34),IANS
       TYPE 506
506    FORMAT(' ?? INPUT ERROR ??  TRY AGAIN.'/)
       GO TO 12
C
C  IF CODE NUMBER WAS NOT FOUND IN FILE INDEX.DAT, ADVISE USER
C  AND BRANCH TO BEGINNING TO ALLOW HIM TO TRY ANOTHER.
C
13     TYPE 504
504    FORMAT(//' THERE IS NO SUCH CODE NO. IN THE FILE.'/
      $' TRY ANOTHER.'/)
       GO TO 1
C
C  INPUT FROM DATA FILE NUCPAR.DAT...
C
C        THE NAME (ALPHAMERIC) OF THE RADIONUCLIDE (NAMN(I),I=1,4)
C
C        THE NAME (ALPHAMERIC) OF THE CRITICAL ORGAN
C        (NAMCR(I),I=1,4)
C
C        RADIOACTIVE HALF-LIFE (THALF)
C
C        EFFECTIVE ABSORBED ENERGY PER DISINTEGRATION (EPSLN)
C
C  MASS OF CRITICAL ORGAN (MASS)
C
C        FRACTIONS OF INTAKE REACHING CRITICAL ORGAN BY
C        INGESTION (FW) AND BY INHALATION (FA)
C
C        CODE (MODEL) TO INDICATE WHICH MODEL...
C
C           MODEL = 1  FOR EXPONENTIAL
C                 = 2       POWER FUNCTION
C                 = 3       MIXED
C
C  IN CASE OF DISK I/O ERROR, RETURN TO START OF PROGRAM.
C
14     READ(2'MAIN,5051,ERR=15) (NAMN(I),I=1,4),(NAMCR(I),I=1,4),
      $    THALF,EPSLN,MASS,FW,FA,MODEL
5051   FORMAT(4(2A5/),5(F10.0/),I10)
505    FORMAT(3F)
C
C  COMPUTE CONVERSION FACTOR (BIFAC) TO CHANGE FROM CUMULATIVE
C  BURDEN (MICROCURIE-DAYS) TO DOSE (REMS).
C
       BIFAC=51.2*EPSLN/MASS
C
C  COMPUTE RADIOACTIVE DECAY RATE (LMBDA).
C
       LMBDA=LOG2/THALF
C
C  BRANCH TO APPROPRIATE INPUT SEGMENT ACCORDING TO VALUE OF
C  MODEL.
C
       GO TO (161,162,16),MODEL
15     TYPE 507
507    FORMAT(//' A FATAL DISK I-O ERROR HAS OCCURRED.'/
      $' RETURN TO START OF PROGRAM'/)
```

```
      GO TO 1
C
C ****** MIXED MODEL ******
C
C  INPUT MIXTURE COEFFICIENT (K) FROM FILE NUCPAR.DAT.
C
16     READ(2'MAIN,508,ERR=15) K
508   FORMAT(F10.0)
C
C ****** EXPONENTIAL (OR MIXED) MODEL ******
C
C  INPUT FROM FILE NUCPAR.DAT THE NUMBER (M) OF EXPONENTIAL TERMS
C  AND FOR EACH TERM (NU=1,M) A COEFFICIENT (KNU(NU)) AND A
C  BIOLOGICAL HALF-LIFE (TB(NU)).
C
161   READ(2'MAIN,5099,ERR=15)M,(KNU(NU),TB(NU),NU=1,M)
5099  FORMAT(I10/(F10.0))
C
C  FOR NU=1,M COMPUTE BIOLOGICAL DECAY RATES (BETA(NU)).
C
      DO 163 NU=1,M
163   BETA(NU)=LOG2/TB(NU)
C
C  IF MODEL IS EXPONENTIAL, BRANCH AROUND POWER FUNCTION SEGMENT.
C  OTHERWISE IT IS MIXED, SO CONTINUE IN SEQUENCE.
C
      IF(MODEL-1) 162,170,162
C
C ****** POWER FUNCTION (OR MIXED) MODEL ******
C
C  INPUT FROM FILE NUCPAR.DAT THE POWER FUNCTION PARAMETERS
C  SMALL N (N), SMALL X (X), AND CAPITAL A (ACAP).
C
162   READ(2'MAIN,508,ERR=15) N,X,ACAP
C
C ****** BEGIN USER DIALOG PHASE...
C
C  INPUT A CODE (IAV) TO CHOOSE BETWEEN INGESTION (IAV=1) AND
C  INHALATION (IAV=2).  TEST FOR ERRONEOUS VALUE.  SET FORTRAN
C  VARIABLE FF EQUAL TO FW OR FA ACCORDING TO VALUE OF IAV.
C
170   TYPE 5080
5080  FORMAT(' MODE OF INTAKE...'/' TYPE'/' 1-FOR INGESTION'/' 2-FOR INH
     $ALATION'/)
      ACCEPT 502,IAV
      IF(IAV.EQ.1.OR.IAV.EQ.2) GO TO (1701,1702),IAV
      TYPE 506
      GO TO 170
1701  FF=FW
      GO TO 171
1702  FF=FA
171   TYPE 5081
5081  FORMAT(' TYPE'/' 1-FOR DISCRETE INTAKES'/' 2-FOR CONTINUOUS INTAKE
     $ AT CONSTANT RATE'/)
C
C  INPUT CODE (IM) FOR BASIC PATTERN OF INTAKE...
C
C       IM = 1  FOR INTAKES AT ONE OR MORE DISCRETE TIMES
C          = 2  FOR CONTINUOUS INTAKE AT A CONSTANT RATE
C
C  TEST FOR ERRONEOUS VALUES OF IM.  THEN BRANCH TO THE APPROPRIATE
C  SEGMENT ACCORDING TO VALUE OF IM.
C
      ACCEPT 510,IM
      IF(IM.EQ.1.OR.IM.EQ.2) GO TO (17,192),IM
      TYPE 506
```

```
      GO TO 171
C
C ****** DISCRETE INTAKES INPUT SEGMENT.
C
C  INPUT NUMBER CAPITAL N (NCAP) OF DISCRETE INTAKES.  TEST FOR AN
C  ERRONEOUS VALUE (LESS THAN 1 OR GREATER THAN 50).
C
17    TYPE 509
509   FORMAT(' HOW MANY DISCRETE INTAKES? (1 TO 50)'/)
      ACCEPT 510,NCAP
510   FORMAT(I)
      IF(NCAP.LE.50.AND.NCAP.GE.1) GO TO 18
      TYPE 506
      GO TO 17
C
C  INPUT THE DISCRETE TIMES (TI(I)) AND INTAKES (AI(I)), I=1,NCAP.
C  TEST FOR ERRONEOUS NEGATIVE TIMES AND ZERO OR NEGATIVE INTAKES.
C
18    TYPE 511,NCAP
511   FORMAT(' ENTER THE ',I2,' TIMES (DAYS) AND THE'/
     $' CORRESPONDING INTAKES (MICROCURIES)'/
     $' ----------  ----------'/)
      DO 19 I=1,NCAP
181   ACCEPT 505,TI(I),AI(I)
      IF(TI(I).GE.0..AND.AI(I).GT.0.) GO TO 182
      TYPE 506
      TYPE 5111
5111  FORMAT(' ----------  ----------'/)
      GO TO 181
C
C  COMPUTE DEPOSITIONS IN CRITICAL ORGAN (AA(I),I=1,NCAP) RESULTING
C  FROM CORRESPONDING INTAKES.
C
182   AA(I)=FF*AI(I)
19    CONTINUE
C
C  BRANCH AROUND CONTINUOUS INTAKES INPUT SEGMENT.
C
      GO TO 2001
C
C ****** CONTINUOUS INTAKES INPUT SEGMENT.
C
C  INPUT INITIAL BODY BURDEN (A0) AND DAILY RATE OF INTAKE INTO
C  BODY (C).  TEST FOR ERRONEOUS NEGATIVE VALUES.
C
192   TYPE 5091
5091  FORMAT(' ENTER'/' INITIAL  BODY  BURDEN   INTAKE RATE'/
     $' ',T7,'(MICRO-CI)',T25,'(MICRO-CI/DAY)'/' ',T7,'----------',
     $T27,'----------'/)
      ACCEPT 505,A0,C
      IF(A0.GE.0..AND.C.GE.0.) GO TO 190
      TYPE 506
      GO TO 192
C
C  COMPUTE INITIAL BURDEN (A0A) OF CRITICAL ORGAN AND DAILY RATE
C  OF DEPOSITION (CA) IN CRITICAL ORGAN.
C
190   A0A=FF*A0
      CA=FF*C
C
C ****** BEGIN OUTPUT OPTIONS SEGMENT.
C
C  INPUT CODE (IGT) TO CHOOSE BETWEEN TABULATION (IGT=1) OR GRAPH
C  OF DOSE VS. TIME (IGT=ANY OTHER VALUE).
C
2001  TYPE 5121
```

```
5121  FORMAT(' TYPE'/' 1-FOR TABULATION'/' 2-FOR GRAPH'/)
      ACCEPT 502,IGT
      IF(IGT.NE.1) GO TO 20
C
C ****** TABULATION PHASE.
C
C  INPUT MINIMUM TIME (TMIN), TIME INCREMENT (DELT), AND MAXIMUM
C  TIME (TMAX) FOR OUTPUT TABLE.  TEST FOR ERRONEOUS VALUES.
C
C  NOTE... IF TMIN = TMAX, TABLE IS ONE LINE FOR THAT TIME VALUE.
C          IF DELT = 0., TABLE IS TWO LINES FOR TMIN AND TMAX IF
C              THESE ARE DIFFERENT.
C
191   TYPE 512
512   FORMAT(' FOR TABULATION, ENTER (DAYS)'/
     $' MIN. TIME',3X'INCREMENT',3X'MAX. TIME'/
     $' ----------  ----------  ----------'/)
      ACCEPT 505,TMIN,DELT,TMAX
      IF(TMIN.LE.TMAX.AND.DELT.GE.0.) GO TO 20
      TYPE 506
      GO TO 191
C
C  INPUT FLAG SETTING (INSUM) TO ACCEPT (INSUM=1) OR REJECT
C  (INSUM = ANY OTHER VALUE) A SUMMARY OF INPUTS.
C
20    TYPE 513
513   FORMAT(' TYPE 1-FOR INPUT SUMMARY'/' ',T7,'2-TO SUPPRESS'/)
      ACCEPT 510,INSUM
      IF(INSUM.NE.1) GO TO 301
C
C ****** OUTPUT A SUMMARY OF INPUT INFORMATION.
C
      TYPE 5130
5130  FORMAT(///' SUMMARY OF INPUTS')
      GO TO (201,202,203),MODEL
201   TYPE 5131
5131  FORMAT(' EXPONENTIAL MODEL'/' ----------- -----'/)
      GO TO 204
202   TYPE 5132
5132  FORMAT(' POWER FUNCTION MODEL'/' ----- -------- -----'/)
      GO TO 204
203   TYPE 5133
5133  FORMAT(' MIXED MODEL'/' ----- -----'/)
204   TYPE 514,(NAMN(I),I=1,4),(NAMCR(I),I=1,4),THALF,LMBDA,EPSLN,
     $          MASS,BIFAC,(AVENUE(IAV,I),I=1,2),FF
514   FORMAT('0RADIONUCLIDE',T31,4A5/'0REFERENCE ORGAN',T31,4A5/
     $'0RADIOACTIVE HALF-LIFE',T31,1PE10.3,' DAYS'/
     $'0RADIOACTIVE DECAY RATE',T31,1PE10.3,' PER DAY'/
     $'0EFF. ABSORBED ENERGY',T31,1PE10.3,' MEV'/'0MASS OF REFERENCE ORG
     $AN',T31,1PE10.3,' G'/'0BIOLOGICAL CONV. FACTOR',T31,1PE10.3,' REMS
     $/MICROCURIE-DAY'/'0MODE OF INTAKE',T31,2A5/'0UPTAKE FRACTION',
     $T31,1PE10.3)
      GO TO (205,206,205),MODEL
205   TYPE 5134,(NU,KNU(NU),TB(NU),BETA(NU),NU=1,M)
5134  FORMAT(/'0PARAMETERS ASSOCIATED WITH EXPONENTIAL TERMS...'//
     $' ',T5,'COEFFICIENTS',T19,'EXCRETORY',T32,'EXCRETION'/
     $' ',T19,'HALF-LIVES',T34,'RATES'//(' ',I1,2X,1PE10.3,
     $2(3X,1PE10.3)))
      GO TO (207,206,206),MODEL
206   TYPE 5135,N,X,ACAP
5135  FORMAT(/'0POWER FUNCTION PARAMETERS...'/
     $'0N',T11,1PE10.3/'0X',T11,1PE10.3/'0CAP. A',T11,1PE10.3/)
207   GO TO (21,22),IM
21    TYPE 5141,(TI(I),AI(I),AA(I),I=1,NCAP)
5141  FORMAT(/'0DISCRETE TIMES AND INTAKES...'/'0TIME (DAYS)',T16,'TOTAL
     $ INTAKE',T35,'UPTAKE'/' ',T19,'TO BODY'/
```

```
     $' ',T16,'(MICROCURIES)',T32,'(MICROCURIES)'//(' ',1PE10.3,T17,
     $1PE11.4,T33,1PE11.4))
      GO TO 301
22    TYPE 5142,A0,A0A,C,CA
5142  FORMAT('0INITIAL BURDENS...'/'0INTAKE',T31,1PE10.3,' MICROCURIES'/
     $'0UPTAKE',T31,1PE10.3,' MICROCURIES'//'0CONSTANT RATES...'/
     $'0INTAKE RATE',T31,1PE10.3,' MICROCURIES/DAY'/'0UPTAKE RATE',T31,
     $1PE10.3,' MICROCURIES/DAY')
301   IF(IGT.NE.1) GO TO 4
C
C ****** BEGIN COMPUTATION AND TABULATION PHASE.
C
C  TYPE HEADINGS FOR TABULAR OUTPUT.
C
3     TYPE 515,(NAMN(I),I=1,4),(NAMCR(I),I=1,4),(AVENUE(IAV,I),I=1,2)
515   FORMAT(///' TABULATION OF DOSE RATES AND DOSES'/
     $' ---------- -- ---- ----- --- -----'//
     $' RADIONUCLIDE -- ',4A5//' REFERENCE ORGAN -- ',4A5//
     $' MODE OF INTAKE -- ',2A5///
     $' TIME (DAYS)  RATE (REMS/DAY)   DOSE  (REMS)'/)
C
C  INITIALIZE BEFORE TABULATION LOOP...
C
C      MSG WILL NORMALLY CONTAIN A BLANK CHARACTER, BUT MSG='*'
C      WILL SIGNAL POSSIBLE LOSS OF SIGNIFICANT DIGITS IN OUTPUT
C      DATA.  MSG WILL BE TYPED ON EACH LINE OF TABLE.
C
C      ICODE = 1  AT END OF LOOP MEANS CONTINUE
C            = 2                 MEANS EXIT.
C
C      T GOES FROM TMIN TO TMAX IN INCREMENTS OF DELT.
C
      MSG=IBLNK
      ICODE=1
      T=TMIN
C
C  ERC IS RESET TO 0 EACH TIME THROUGH LOOP.  ERC=1 IS A FLAG SET
C  BY COMPUTATIONAL SUBROUTINES IF A POSSIBLE LOSS OF SIGNIFICANT DIGITS
C  IS DETECTED.
C
31    ERC=0
C
C  BEGIN LOOP...
C  CHOOSE COMPUTATIONAL SUBROUTINE ACCORDING TO MODEL AND INTAKE
C  PATTERN.
C
      GO TO (311,312,311),MODEL
311   GO TO (3111,3112),IM
C
C  CALL SUBROUTINE FOR DISCRETE INTAKES, EXPONENTIAL MODEL.
C
3111  CALL DIEX(T,NCAP,TI,AA,LMBDA,M,KNU,BETA,QSMAL,QCAP)
      GO TO 314
C
C  CALL SUBROUTINE FOR CONTINUOUS INTAKES, EXPONENTIAL MODEL.
C
3112  CALL CIEX(T,A0A,CA,LMBDA,M,KNU,BETA,QSMAL,QCAP)
C
C  IF MODEL IS MIXED, SAVE VALUES OF QSMAL AND QCAP FROM EXPONENTIAL
C  SUBROUTINE AND CALL APPROPRIATE POWER FUNCTION SUBROUTINE.
C
314   GO TO (313,313,3141),MODEL
3141  QS=QSMAL
      QC=QCAP
312   GO TO (3121,3122),IM
C
```

```
C  CALL SUBROUTINE FOR DISCRETE INTAKES, POWER FUNCTION.
C
3121  CALL DIPF(T,NCAP,TI,AA,LMBDA,N,ACAP,X,QSMAL,QCAP,ERC)
      GO TO 315
C
C  CALL SUBROUTINE FOR CONTINUOUS INTAKES, POWER FUNCTION.
C
3122  CALL CIPF(T,AOA,CA,LMBDA,N,ACAP,X,QSMAL,QCAP,ERC)
315   GO TO (313,313,316) , MODEL
C
C  FOR MIXED MODEL, COMPUTE COMBINATION OF EXPONENTIAL AND
C  POWER FUNCTION CONTRIBUTIONS.
C
316   QSMAL=K*QS + (1.-K)*QSMAL
      QCAP=K*QC + (1.-K)*QCAP
C
C  COMPUTE DOSE RATE (DRATE) AND DOSE (DOS).
C
313   DRATE=BIFAC*QSMAL
      DOS=BIFAC*QCAP
C
C  IF POSSIBLE LOSS OF SIGNIFICANT DIGITS HAS BEEN DETECTED, CHANGE
C  VALUE OF MSG FROM BLANK TO '*' AND TYPE DRATE AND DOSE, LABELLED
C  BY MSG.
C
      IF(ERC.GT.0) MSG=ISTAR
      TYPE 516,T,DRATE,MSG,DOS,MSG
516   FORMAT(' ',1PE10.3,T17,1PE11.4,A1,T33,1PE11.4,A1)
C
C  WE CONSIDER A TABULATION NORMAL IF THE TABLE HAS TWO OR MORE LINES
C  AND DELT IS POSITIVE.  BRANCH IF THIS TABULATION IS NOT NORMAL.
C
      IF(.NOT.(TMIN.LT.TMAX.AND.DELT.GT.0.)) GO TO 32
C
C  NORMAL CASE.  INCREMENT T AND TEST.
C
      T=T+DELT
      IF(T.LT.TMAX) GO TO 31
C
C  INCREMENTED T GREATER THAN OR EQUAL TO TMAX.  IF ICODE=2 SIGNAL THAT
C  THIS IS LAST PASS, EXIT.  OTHERWISE, NEXT PASS WILL BE LAST, SO
C  RESET ICODE=2, T=TMAX, AND BRANCH TO BEGINNING OF LOOP.
C
      IF(ICODE.EQ.2) GO TO 33
       ICODE=22
      T=TMAX
      GO TO 31
C
C  ABNORMAL CASE.
C
32    IF(TMIN.EQ.TMAX) GO TO 33
C
C  TMIN IS LESS THAN TMAX.  RESET ICODE=2 TO SIGNAL LAST PASS NEXT TIME
C  AROUND.  MAKE DELT POSITIVE SO THAT NEXT PASS FINISHES AS NORMAL
C  CASE.  RESET T=TMAX AND RETURN TO BEGINNING OF LOOP.
C
      ICODE=2
      DELT=TMAX-TMIN
      T=TMAX
      GO TO 31
C
C  INPUT CODE (IANS) TO INDICATE USER OPTION...
C
C     IANS = 1  FOR  ADDITIONAL TABULATION
C          = 2  TO CHANGE INTAKE PATTERN
C          = 3  TO CHANGE RADIONUCLIDES
```

```
C           = 4  TO BRANCH TO GRAPH PHASE
C           = 5  TO CALL EXIT
C
C  TEST FOR ERRONEOUS VALUE.  BRANCH TO APPROPRIATE OPTION.
C
33     TYPE 517
517    FORMAT(///' TYPE'/' 1-FOR MORE TABULATION'/' 2-TO CHANGE INTAKES'/
      $' 3-TO CHANGE NUCLIDES'/' 4-FOR GRAPH'/' 5-TO EXIT'/)
       ACCEPT 510,IANS
       IF(IANS.GE.1.AND.IANS.LE.5) GO TO (191,170,1,4,34),IANS
       TYPE 506
       GO TO 33
34     CALL EXIT
C
C ****** GRAPH PHASE.
C
C  INPUT MINIMUM TIME (TMIN) AND MAXIMUM TIME (TMAX) FOR TIME AXIS.
C  TEST FOR ERRONEOUS VALUES.
C
4      TYPE 600
600    FORMAT(/' ENTER MIN. AND MAX. TIMES (DAYS) FOR TIME AXIS'/
      $' TMIN',T14,'TMAX'/' ----------  ----------'/)
       ACCEPT 505,TMIN,TMAX
       IF(TMIN.GE.0..AND.TMAX.GT.TMIN) GO TO 41
       TYPE 506
       GO TO 4
C
C  SET UP AN ARRAY OF 41 CHARACTERS AS FOLLOWS...
C
C    I---------+---------+---------+---------+
C
C  INDEXED FROM 1 TO 41 BEGINNING WITH 'I'.
C
41     DO 42 I=2,41
42     IBAR(I)=HYPHEN
       DO 43 I=11,41,10
43     IBAR(I)=IPLUS
       IBAR(1)=ICHAR
C
C  COMPUTE INCREMENT (DELT) TO GIVE GRAPH 41 ABSCISSAS.
C
       DELT=(TMAX-TMIN)/40.
C
C  BEGIN DOSE CALCULATION LOOP.
C
       T=TMIN
       DO 44 ITIME=1,41
C
C  BRANCH TO APPROPRIATE COMPUTATIONAL SUBROUTINE ACCORDING TO MODEL
C  AND PATTERN OF INTAKES.
C
       GO TO (711,712,711),MODEL
711    GO TO (7111,7112),IM
C
C  CALL SUBROUTINE FOR DISCRETE INTAKES, EXPONENTIAL MODEL.
C
7111   CALL DIEX(T,NCAP,TI,AA,LMBDA,M,KNU,BETA,QSMAL,QCAP)
       GO TO 714
C
C  CALL SUBROUTINE FOR CINTINUOUS INTAKES, EXPONENTIAL MODEL.
C
7112   CALL CIEX(T,AOA,CA,LMBDA,M,KNU,BETA,QSMAL,QCAP)
C
C  IF MODEL IS MIXED, SAVE VALUE OF QCAP FROM EXPONENTIAL SUBROUTINE
C  AND CALL APPROPRIATE POWER FUNCTION SUBROUTINE.
C
```

```
714    GO TO (713,713,7141),MODEL
7141   QC=QCAP
712    GO TO (7121,7122),IM
C
C  CALL SUBROUTINE FOR DISCRETE INTAKES, POWER FUNCTION.
C
7121   CALL DIPF(T,NCAP,TI,AA,LMBDA,N,ACAP,X,QSMAL,QCAP,ERC)
       GO TO 715
C
C  CALL SUBROUTINE FOR CONTINUOUS INTAKES, POWER FUNCTION.
C
7122   CALL CIPF(T,AOA,CA,LMBDA,N,ACAP,X,QSMAL,QCAP,ERC)
715    GO TO (713,713,716),MODEL
C
C  FOR MIXED MODEL, COMPUTE COMBINATION OF EXPONENTIAL AND POWER
C  FUNCTION CONTROUBTIONS.
C
716    QCAP=K*QC + (1.-K)*QCAP
C
C  COMPUTE DOSE AND STORE IN ARRAY (DOSE(ITIME)).
C
713    DOSE(ITIME)=BIFAC*QCAP
       T=T+DELT
44     CONTINUE
C
C  IF NO DOSE HAS ACCUMULATED, TYPE ERROR MESSAGE AND BYPASS TYPING
C  GRAPH.
C
       IF(DOSE(1).EQ.DOSE(41)) GO TO 63
C
C  INPUT ARRAY OF ALPHAMERIC INFORMATION (CMMNTS(I,J),J=1,8, I=1,3)
C  TO BE TYPED UNDER GRAPH AS 3 LINES OF COMMENTARY.
C
       TYPE 608
608    FORMAT(' ENTER 3 LINES OF COMMENTARY TO APPEAR ON GRAPH'/
      $' (NOT TO EXCEED 40 CHAR. PER LINE)'/
      $' ----------------------------------------'/)
       ACCEPT 609,((CMMNTS(I,J),J=1,8),I=1,3)
609    FORMAT(8A5)
C
C  TYPE GRAPH TITLE INFORMATION AND DOSE AXIS.
C
       TYPE 601,(NAMN(I),I=1,4),(NAMCR(I),I=1,4),(AVENUE(IAV,I),I=1,2)
601    FORMAT('1',T17,'PLOT OF RADIATION DOSE AGAINST TIME'/
      $' ',        T17,'----------------------------------'//
      $' ',T17,'RADIONUCLIDE -- ',4A5/' ',T17,'REFERENCE ORGAN -- ',4A5/
      $' ',T17,'INTAKE BY ',2A5//' ',T17,'DOSE IN REMS...'/)
       DMIN=DOSE(1)
       DMAX=DOSE(41)
       DMEAN=0.5*(DMIN+DMAX)
       TYPE 602,DMIN,DMEAN,DMAX,TIME(1),TMIN,ISTAB,
      $          IBORD,IBORD,IBORD,IBORD
602    FORMAT(' ',2X,3(11X,1PE9.2)/' ',A1,1PE13.3,1X,A1,4(2A5))
C
C  COMPUTE NUMBER OF SPACES PER REM OF DOSE (SPUNIT).
C
       SPUNIT=40./(DMAX-DMIN)
       T=TMIN
C
C  ENTER PLOTTING LOOP.
C
       DO 61 ITIME=2,41
       T=T+DELT
C
C  COMPUTE NUMBER OF ORDINATE SPACES NEEDED TO REPRESENT DOSE (NSP).
C
```

```
      NSP=1+IFIX(0.5 + SPUNIT*(DOSE(ITIME)-DMIN))
C
C  MOVE POSITIONS 1 TO NSP OF ARRAY IBAR INTO ARRAY LINE.
C  IF NUMBER OF LINE TO BE PRINTED IS A MULTIPLE OF 10, BRANCH
C  TO LABEL ABSCISSA WITH CURRENT VALUE OF TIME.
C
      DO 45 I=1,NSP
45    LINE(I)=IBAR(I)
      IF((ITIME-1)/10*10.EQ.(ITIME-1)) GO TO 5
C
C  OTHERWISE PUT AN ASTERISK IN POSITION CORRESPONDING TO POINT TO BE
C  PLOTTED AND TYPE LINE.  CONTINUE LOOP.
C
      LINE(NSP)=ISTAR
      TYPE 603,TIME(ITIME),(LINE(I),I=1,NSP)
603   FORMAT(' ',A1,14X,41A1)
      GO TO 61
C
C  MAKE TICK MARK (HYPHEN) ON TIME AXIS, PLACE ASTERISK IN POSITION
C  CORRESPONDING TO POINT TO BE PLOTTED, AND TYPE CURRENT TIME.
C  TYPE LINE.
C
5     LINE(1)=HYPHEN
      LINE(NSP)=ISTAR
      TYPE 604,TIME(ITIME),T,(LINE(I),I=1,NSP)
604   FORMAT(' ',A1,1PE13.3,1X,41A1)
61    CONTINUE
C
C  TYPE COMMENTS FOLLOWING GRAPH.
C
      TYPE 605,((CMMNTS(I,J),J=1,8),I=1,3)
605   FORMAT(//(' ',T17,8A5))
      IGT = 1
C  OFFER USER OPTION ACCORDING TO INPUT CODE NUMBER (IANS)...
C
C       IANS = 1     FOR MORE GRAPHS
C            = 2     FOR FURTHER TABULATION
C            = 3     TO CHANGE INTAKE PATTERN
C            = 4     TO CHANGE RADIONUCLIDES
C            = 5     TO CALL EXIT
C
C  TEST IANS FOR ERRONEOUS VALUE AND BRANCH TO INDICATED OPTION.
C
62    TYPE 606
606   FORMAT('1TYPE'/' 1-FOR MORE GRAPHS'/' 2-FOR MORE TABULATION'/
     $' 3-TO CHANGE INTAKES'/' 4-TO CHANGE NUCLIDES'/' 5-TO EXIT'/)
      ACCEPT 510,IANS
      IF(IANS.GE.1.AND.IANS.LE.5) GO TO (4,191,170,1,34),IANS
      TYPE 506
      GO TO 62
C
C  ERROR MESSAGE FOR SUPPRESSION OF GRAPH IN ABSENCE OF DOSE
C  ACCUMULATION.
C
63    TYPE 607
607   FORMAT(//' ** ERROR CONDITION -- NO ACCUMULATED DOSE **'/
     $         ' **             GRAPH SUPPRESSED             **')
      GO TO 33
C
C ***********************************************************************
      END
```

```
C ****** INDOS3 ******
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C
C ****** MAIN PROGRAM ******
C
C       INDOS3 COMPUTES BURDEN AND DOSE TO AN ORGAN AS FUNCTIONS
C  OF TIME.  THIS DOSE RESULTS FROM DEPOSITION OF A SPECIFIED
C  QUANTITY OF ANY ONE OF SEVERAL RADIONUCLIDES IN THE ORGAN, AND
C  THE ORGAN IS THE ONE WHICH IS REGARDED AS CRITICAL FOR THE
C  RADIONUCLIDE SELECTED.  COMPUTATIONALLY, INDOS3 IS IDENTICAL TO
C  INDOS2, AND THESE CODES ACCESS THE SAME DIRECT-ACCESS FILES.
C  THE CODES DIFFER ONLY IN THE FORM OF OUTPUT.  INDOS3 PROVIDES
C  PUNCHED-CARD OUTPUT WHICH CAN SERVE AS INPUT TO OTHER CODES
C  SUCH AS GRAPHICAL PROGRAMS.  EXPLANATORY COMMENTS ARE INCLUDED ONLY
C  AT POINTS WHERE INDOS3 DIFFERS SUBSTANTIALLY FROM INDOS2.
C
C ***********************************************************************
C
C  THE DIMENSION OF ARRAYS KNU, TB, AND BETA LIMITS THE NUMBER OF
C  TERMS IN AN EXPONENTIAL MODEL.  INCREASING THIS BEYOND 9 REQUIRES
C  CHANGING CERTAIN OUTPUT FORMATS.
C
      REAL LMBDA,LOG2,MASS,N,K,KNU(9)
      INTEGER ERC
C  THE DIMENSION OF ARRAYS TI, AI, AND AA LIMITS THE NUMBER OF
C  DISCRETE INTAKES.  INCREASING THIS BEYOND 99 REQUIRES CHANGING
C  CERTAIN OUTPUT FORMATS.
C
C  ARRAY INCHAR IS USED FOR 35 CHARACTERS WHICH WOULD SERVE AS A GRAPH
C  TITLE.  THIS DIMENSION COULD BE INCREASED TO 80 IF THE APPROPRIATE
C  STATEMENTS WERE CHANGED.  ARRAYS DOSE, BURDEN, AND TIME HAVE BEEN
C  ARBITRARILY DIMENSIONED 501.  THIS IS THE MAXIMUM NUMBER OF DATA
C  CARDS THAT WILL BE PUNCHED ON A GIVEN PASS.  THIS DIMENSION CAN BE
C  INCREASED IF THE APPROPRIATE STATEMENTS ARE MODIFIED.
C
C  THE ARRAYS NAMN, NAMCR, AND AVENUE ARE OF CRITICAL SIZE AND SHOULD
C  NOT BE REDIMENSIONED.
C
      DIMENSION TB(9),BETA(9),NAMN(4),NAMCR(4),
     $          AVENUE(2,2),
     $          TI(50),AI(50),AA(50)
      DIMENSION INCHAR(35),DOSE(501),BURDEN(501),TIME(501)
      DATA AVENUE/'INGES','INHAL','TION ','ATION'/,
     $     IPUNCH/7/
      LOG2=ALOG(2.0)
      TYPE 500
500   FORMAT('1REFERENCE ORGAN RADIATION DOSE CALCULATION'/
     $' ----------------------------------------'//
     $' PUNCHED CARD OUTPUT FOR CRT GRAPHICS'//)
C  INPUT AN INTEGER CODE NUMBER (NCODE) TO SELECT THE DESIRED RADIO-
C  NUCLIDE FOR CALCULATION.
1     TYPE 501
501   FORMAT(' ENTER CODE NO. OF NUCLIDE.'/)
C
```

```
      ACCEPT 502,NCODE
502   FORMAT(I)
C
C
C  SPECIFY TWO DIRECT-ACCESS DATA FILES...
C
C *** INDEX.DAT ***
C
C *** NUCPAR.DAT ***
      CALL DEFINE FILE (1,15,INDX,'INDEX.DAT',0,0)
      CALL DEFINE FILE (2,10,MAIN,'NUCPAR.DAT',0,0)
111   INDX=1
11    READ(1'INDX,5025,ERR=12,END=13) NCO,MAIN
5025  FORMAT(I5,I10)
      IF(NCO-NCODE) 11,14,11
12    TYPE 503
503   FORMAT(//' A DISK I-O ERROR HAS OCCURRED.  TYPE'/
     $' 1-TO TRY AGAIN'/' 2-TO TRY A DIFFERENT NUCLIDE'/
     $' 3-TO CALL EXIT'/)
      ACCEPT 502,IANS
      IF(IANS.GE.1.AND.IANS.LE.3) GO TO (111,1,34),IANS
      TYPE 506
506   FORMAT(' ?? INPUT ERROR ??  TRY AGAIN.'/)
      GO TO 12
13    TYPE 504
504   FORMAT(//' THERE IS NO SUCH CODE NO. IN THE FILE.'/
     $' TRY ANOTHER.'/)
      GO TO 1
14    READ(2'MAIN,5051,ERR=15) (NAMN(I),I=1,4),(NAMCR(I),I=1,4),
     $    THALF,EPSLN,MASS,FW,FA,MODEL
5051  FORMAT(4(2A5/),5(F10.0/),I10)
505   FORMAT(3F)
      BIFAC=51.2*EPSLN/MASS
      LMBDA=LOG2/THALF
      GO TO (161,162,16),MODEL
15    TYPE 507
507   FORMAT(//' A FATAL DISK I-O ERROR HAS OCCURRED.'/
     $' RETURN TO START OF PROGRAM'/)
      GO TO 1
16     READ(2'MAIN,508,ERR=15) K
508   FORMAT(F10.0)
161   READ(2'MAIN,5099,ERR=15)M,(KNU(NU),TB(NU),NU=1,M)
5099  FORMAT(I10/(F10.0))
      DO 163 NU=1,M
163   BETA(NU)=LOG2/TB(NU)
      IF(MODEL-1) 162,170,162
162   READ(2'MAIN,508,ERR=15) N,X,ACAP
170   TYPE 5080
5080  FORMAT(' MODE OF INTAKE...'/' TYPE'/' 1-FOR INGESTION'/' 2-FOR INH
     $ALATION'/)
      ACCEPT 502,IAV
      IF(IAV.EQ.1.OR.IAV.EQ.2) GO TO (1701,1702),IAV
      TYPE 506
      GO TO 170
1701  FF=FW
      GO TO 171
1702  FF=FA
171   TYPE 5081
5081  FORMAT(' TYPE'/' 1-FOR DISCRETE INTAKES'/' 2-FOR CONTINUOUS INTAKE
     $ AT CONSTANT RATE'/)
      ACCEPT 510,IM
      IF(IM.EQ.1.OR.IM.EQ.2) GO TO (17,192),IM
      TYPE 506
      GO TO 171
17    TYPE 509
509   FORMAT(' HOW MANY DISCRETE INTAKES? (1 TO 50)'/)
```

```
      ACCEPT 510,NCAP
510   FORMAT(I)
      IF(NCAP.LE.20.AND.NCAP.GE.1) GO TO 18
      TYPE 506
      GO TO 17
18    TYPE 511,NCAP
511   FORMAT(' ENTER THE ',I2,' TIMES (DAYS) AND THE'/
     $' CORRESPONDING INTAKES (MICROCURIES)'/
     $' ----------  ----------'/)
      DO 19 I=1,NCAP
181   ACCEPT 505,TI(I),AI(I)
      IF(TI(I).GE.0..AND.AI(I).GT.0.) GO TO 182
      TYPE 506
      TYPE 5111
5111  FORMAT(' ----------  ----------'/)
      GO TO 181
182   AA(I)=FF*AI(I)
19    CONTINUE
      GO TO 2001
192   TYPE 5091
5091  FORMAT(' ENTER'/' INITIAL  BODY  BURDEN   INTAKE RATE'/
     $' ',T7,'(MICRO-CI)',T25,'(MICRO-CI/DAY)'/' ',T7,'----------',
     $T27,'----------'/)
      ACCEPT 505,A0,C
      IF(A0.GE.0..AND.C.GE.0.) GO TO 190
      TYPE 506
      GO TO 192
190   A0A=FF*A0
      CA=FF*C
2001  CONTINUE
20    TYPE 513
513   FORMAT(' TYPE 1-FOR INPUT SUMMARY'/' ',T7,'2-TO SUPPRESS'/)
      ACCEPT 510,INSUM
      IF(INSUM.NE.1) GO TO 301
      TYPE 5130
5130  FORMAT(///' SUMMARY OF INPUTS')
      GO TO (201,202,203),MODEL
201   TYPE 5131
5131  FORMAT(' EXPONENTIAL MODEL'/' ----------- -----'/)
      GO TO 204
202   TYPE 5132
5132  FORMAT(' POWER FUNCTION MODEL'/' ----- -------- -----'/)
      GO TO 204
203   TYPE 5133
5133  FORMAT(' MIXED MODEL'/' ----- -----'/)
204   TYPE 514,(NAMN(I),I=1,4),(NAMCR(I),I=1,4),THALF,LMBDA,EPSLN,
     $          MASS,BIFAC,(AVENUE(IAV,I),I=1,2),FF
514   FORMAT('0RADIONUCLIDE',T31,4A5/'0REFERENCE ORGAN',T31,4A5/
     $'0RADIOACTIVE HALF-LIFE',T31,1PE10.3,' DAYS'/
     $'0RADIOACTIVE DECAY RATE',T31,1PE10.3,' PER DAY'/
     $'0EFF. ABSORBED ENERGY',T31,1PE10.3,' MEV'/'0MASS OF REFERENCE ORG
     $AN',T31,1PE10.3,' G'/'0BIOLOGICAL CONV. FACTOR',T31,1PE10.3,' REMS
     $/MICROCURIE-DAY'/'0MODE OF INTAKE',T31,2A5/'0UPTAKE FRACTION',
     $T31,1PE10.3)
      GO TO (205,206,205),MODEL
205   TYPE 5134,(NU,KNU(NU),TB(NU),BETA(NU),NU=1,M)
5134  FORMAT(/'0PARAMETERS ASSOCIATED WITH EXPONENTIAL TERMS...'//
     $' ',T5,'COEFFICIENTS',T19,'EXCRETORY',T32,'EXCRETION'/
     $' ',T19,'HALF-LIVES',T34,'RATES'//(' ',I1,2X,1PE10.3,
     $2(3X,1PE10.3)))
      GO TO (207,206,206),MODEL
206   TYPE 5135,N,X,ACAP
5135  FORMAT(/'0POWER FUNCTION PARAMETERS...'/
     $'0N',T11,1PE10.3/'0X',T11,1PE10.3/'0CAP. A',T11,1PE10.3/)
207   GO TO (21,22),IM
21    TYPE 5141,(TI(I),AI(I),AA(I),I=1,NCAP)
```

```
5141  FORMAT(/'0DISCRETE TIMES AND INTAKES...'/'0TIME (DAYS)',T16,'TOTAL
     $ INTAKE',T35,'UPTAKE'/' ',T19,'TO BODY'/
     $' ',T16,'(MICROCURIES)',T32,'(MICROCURIES)'//(' ',1PE10.3,T17,
     $1PE11.4,T33,1PE11.4))
      GO TO 301
22    TYPE 5142,A0,A0A,C,CA
5142  FORMAT('0INITIAL BURDENS...'/'0INTAKE',T31,1PE10.3,' MICROCURIES'/
     $'0UPTAKE',T31,1PE10.3,' MICROCURIES'//'0CONSTANT RATES...'/
     $'0INTAKE RATE',T31,1PE10.3,' MICROCURIES/DAY'/'0UPTAKE RATE',T31,
     $1PE10.3,' MICROCURIES/DAY')
301   CONTINUE
C
C  ACCEPT MINIMUM AND MAXIMUM TIME VALUES (TMIN, TMAX) FOR PUNCHED-CARD
C  DATA.  TEST FOR ERRONEOUS VALUES.
C
4     TYPE 600
600   FORMAT(/' ENTER MIN. AND MAX. TIMES (DAYS) FOR TIME AXIS'/
     $' TMIN',T14,'TMAX'/' ----------  ----------'/)
      ACCEPT 505,TMIN,TMAX
      IF(TMIN.GE.0..AND.TMAX.GT.TMIN) GO TO 41
      TYPE 506
      GO TO 4
C
C  INPUT NUMBER (NCARD) OF DATA CARDS TO BE PUNCHED FOR THE INTERVAL
C  TMIN,TMAX.  TEST FOR INCORRECT VALUE.  IF NCARD EXCEEDS 501, RESET
C  VALUE TO 501.
C
41    TYPE 601
601   FORMAT(' HOW MANY DATA POINTS DO YOU WANT PLOTTED?'/
     $' MIN. IS 11, MAX. IS 501'/)
      ACCEPT 502,NCARD
      IF(NCARD.LT.11) NCARD=11
      IF(NCARD.GT.501) NCARD=501
C
C  INPUT UP TO 35 CHARACTERS TO BE PUNCHED INTO A CARD.  THIS CAN SERVE
C  AS GRAPH TITLE IF CARDS ARE USED AS INPUT TO A PLOTTING PROGRAM.
C
      TYPE 602
602   FORMAT(' ENTER TITLE FOR GRAPH (1 LINE, 35 CHAR. OR LESS, DO NOT U
     $SE $)'/' ----------------------------------'/)
      ACCEPT 603,(INCHAR(I),I=1,35)
603   FORMAT(80A1)
C
C  GIVE RESUME OF GRAPH TITLE CHARACTERS, NCARD, TMIN, TMAX.  ALLOW
C  USER TO REVISE THESE IF HE WISHES.
C
      TYPE 604,(INCHAR(I),I=1,35),NCARD,TMIN,TMAX
604   FORMAT('0YOU HAVE SPECIFIED...'/'0GRAPH TITLE'/' ',35A1/
     $'0NO. OF CARDS -- ',I3/'0TIME RANGE FROM ',1PE10.3,' TO ',1PE10.3/
     $/' TYPE'/' 1-IF THESE INPUTS ARE CORRECT'/' 2-TO REVISE THEM'/)
      ACCEPT 502,IANS
      IF(IANS.NE.1) GO TO 4
C
C  COMPUTE TIME INCREMENT (DELT).
C
      DELT=(TMAX-TMIN)/FLOAT(NCARD-1)
C
C  COMPUTE DOSE (DOSE(ITIME)) AND ORGAN BURDEN (BURDEN(ITIME)).
C
      T=TMIN
      DO 44 ITIME=1,NCARD
      GO TO (711,712,711),MODEL
711   GO TO (7111,7112),IM
7111  CALL DIEX(T,NCAP,TI,AA,LMBDA,M,KNU,BETA,QSMAL,QCAP)
      GO TO 714
7112  CALL CIEX(T,A0A,CA,LMBDA,M,KNU,BETA,QSMAL,QCAP)
```

```
714    GO TO (713,713,7141),MODEL
7141   QC=QCAP
       QS=QSMAL
712    GO TO (7121,7122),IM
7121   CALL DIPF(T,NCAP,TI,AA,LMBDA,N,ACAP,X,QSMAL,QCAP,ERC)
       GO TO 715
7122   CALL CIPF(T,AOA,CA,LMBDA,N,ACAP,X,QSMAL,QCAP,ERC)
715    GO TO (713,713,716),MODEL
716    QCAP=K*QC + (1.-K)*QCAP
       QSMAL=K*QS + (1.-K)*QSMAL
713    DOSE(ITIME)=BIFAC*QCAP
       BURDEN(ITIME)=QSMAL
       TIME(ITIME)=T
       T=T+DELT
44     CONTINUE
C
C  IF NO DOSE HAS ACCUMULATED, BRANCH TO TYPE ERROR MESSAGE AND
C  SUPPRESS PUNCHING.
C
       IF(DOSE(1).EQ.DOSE(NCARD)) GO TO 63
C
C  PUNCH CARD FILE IN FOLLOWING FORMATS...
C
C    FIRST CARD -- UP TO 35-CHARACTER TITLE FOR DATA SET
C    SECOND CARD -- VALUE OF NCARD (I3)
C    EACH REMAINING CARD -- TIME, DOSE, BURDEN (3(1PE10.3))
C
       WRITE(IPUNCH,603) INCHAR
       WRITE(IPUNCH,606) NCARD,(TIME(I),DOSE(I),BURDEN(I),I=1,NCARD)
606    FORMAT(I3/(3(1PE10.3)))
C
C  INPUT A VALUE (IANS) TO INDICATE USER OPTION...
C
C    IANS = 1  TO CHANGE PUNCHING SPECIFICATIONS
C         = 2  TO CHANGE INTAKE PATTERNS
C         = 3  TO CHANGE RADIONUCLIDES
C         = 4  TO CALL EXIT
C
C  TEST FOR ERRONEOUS VALUE AND BRANCH ACCORDING TO VALUE OF IANS.
C
62     TYPE 605
605    FORMAT(' TYPE'/' 1-TO CHANGE TIME LIMITS, TITLE, OR NO. OF DATA PO
      $INTS'/' 2-TO CHANGE INTAKES'/' 3-TO CHANGE NUCLIDES'/' 4-TO EXIT'/
      $)
       ACCEPT 502,IANS
       IF(IANS.GE.1.AND.IANS.LE.4) GO TO (4,170,1,34),IANS
       TYPE 506
       GO TO 62
34     CALL EXIT
63     TYPE 607
607    FORMAT(//' ** ERROR CONDITION -- NO ACCUMULATED DOSE **'/
      $          ' **              GRAPH SUPPRESSED            **')
       GO TO 62
C
C ***********************************************************************
       END
```

```
      SUBROUTINE CIEX(T,A,C,LMBDA,M,KNU,BETA,QSMAL,QCAP)
C ***********************************************************************
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C *                                                                     *
C *                                                                     *
C * CIEX STANDS FOR CONTINUOUS INTAKE, EXPONENTIAL MODEL.               *
C *                                                                     *
C * INPUT PARAMETERS ARE...                                             *
C *                                                                     *
C *   T............TIME (DAYS)                                          *
C *                                                                     *
C *   A............INITIAL BURDEN (MICROCURIES) OF ORGAN                *
C *                                                                     *
C *   C............RATE (MICROCURIES/DAY) OF DEPOSITION OF              *
C *                RADIONUCLIDE INTO ORGAN                              *
C *                                                                     *
C *   LMBDA........RADIOACTIVE DECAY RATE (FRACTION/DAY) OF             *
C *                RADIONUCLIDE                                         *
C *                                                                     *
C *   M............SIZE OF ARRAYS KNU, BETA                             *
C *                                                                     *
C *   KNU..........ARRAY OF M FRACTIONAL COEFFICIENTS GOVERNING THE     *
C *                DISTRIBUTION OF THE RADIONUCLIDE ENTERING THE BODY   *
C *                TO THE VARIOUS COMPARTMENTS                          *
C *                                                                     *
C *   BETA.........ARRAY OF M EXCRETION RATES (FRACTION/DAY), EACH      *
C *                RATE BEING ASSOCIATED WITH A COMPARTMENT OF THE      *
C *                MODEL                                                *
C *                                                                     *
C *                                                                     *
C * OUTPUT PARAMETERS...                                                *
C *                                                                     *
C *   QSMAL........BURDEN (MICROCURIES) OF THE ORGAN AT TIME T          *
C *                                                                     *
C *   QCAP.........CUMULATIVE BURDEN (MICROCURIE-DAYS) OF THE ORGAN     *
C *                AT TIME T                                            *
C *                                                                     *
C *                                                                     *
C * SUBROUTINE CIEX EVALUATES EQS. (2.40) AND (2.41)                    *
C *                                                                     *
C *                                                                     *
C * SUBROUTINES CALLED...                                               *
C *                                                                     *
C *   NONE                                                              *
C *                                                                     *
C ***********************************************************************
      REAL LMBDA,KNU(M)
      DIMENSION BETA(M)
C
C  COMPUTE EMLT = EXP(-LMBDA*T)   IF  LMBDA*T IS LESS THAN OR = 75.
C
C               = 0.              OTHERWISE (UNDERFLOW)
C
      U=LMBDA*T
```

```
      IF(U.GT.75.) GO TO 10
      EMLT=EXP(-U)
      GO TO 11
10    EMLT=0.0
11    TEMPK=1.0
C
C  INITIALIZE FOR SUMMATION...
C
      SUM1=0.0
      SUM2=0.0
      SUM3=0.0
      SUM4=0.0
C
C  COMPUTE SUMS, NU=1,M
C
      DO 2 NU=1,M
      RATE=LMBDA+BETA(NU)
      V=BETA(NU)*T
C
C  COMPUTE  TERM1 = KNU(NU)*EXP(-BETA(NU)*T)   IF  BETA(NU)*T  IS LESS
C                                              THAN OR = 75.
C
C                 = 0.                         OTHERWISE (UNDERFLOW)
C
      IF(V.GT.75.) GO TO 21
      TERM1=KNU(NU)*EXP(-V)
      GO TO 22
21    TERM1=0.0
22    TERM3=KNU(NU)/RATE
C
C  IN THE FOLLOWING SEQUENCE, TERM2 AND TERM4 DEPEND ON THE QUANTITY
C  1. - EXP(-RATE*T).  TO AVOID UNDERFLOW AND POSSIBLE CANCELLATION OF
C  SIGNIFICANT DIGITS, THIS QUANTITY IS CALCULATED AS
C
C     TEMP = 1.                                IF RATE*T EXCEEDS 75.
C                                              (UNDERFLOW CASE)
C
C          = W + W**3/6. - W**2/2.             IF W (= RATE*T) IS LESS
C                                              THAN OR = 0.01 (LOSS OF
C                                              SIGNIFICANT DIGITS CASE)
C
C          = 1. - EXP(-RATE*T)                 OTHERWISE
C
      W=RATE*T
      IF(W.GT.17.0) GO TO 231
      IF(W.LE.0.01) GO TO 232
      GO TO 23
231   TERM2=TERM3
      TERM4=TERM2/RATE
      GO TO 24
232   TEMP=W+W**3/6.0-W**2/2.0
      TERM2=TERM3*TEMP
      TERM4=TERM2/RATE
      GO TO 24
23    TEMP=1.0-EXP(-W)
      TERM2=TERM3*TEMP
      TERM4=TERM2/RATE
C
C  ACCUMULATE TERMS INTO SUMS...
C
24    TEMPK=TEMPK-KNU(NU)
      SUM1=SUM1+TERM1
      SUM2=SUM2+TERM2
      SUM3=SUM3+TERM3
      SUM4=SUM4+TERM4
2     CONTINUE
```

```
C
C  THE QUANTITY 1. - EXP(-LMBDA*T) IS COMPUTED WITH CONSIDERATIONS
C  SIMILAR TO THOSE OUTLINED IN A PREVIOUS COMMENT
C
      IF(U.GT.17.0) GO TO 41
      IF(U.LE.0.01) GO TO 42
      GO TO 43
41    TEMPE=1.0
      GO TO 44
42    TEMPE=U + U**3/6.0 - U**2/2.0
      GO TO 44
43    TEMPE=1.0 - EXP(-U)
44    TKEL=TEMPK*TEMPE/LMBDA
C
C  COMPUTE QSMAL AND QCAP.
C
      QSMAL=A*EMLT*(TEMPK + SUM1) + C*(TKEL + SUM2)
      QCAP = A*(TKEL + SUM2) + C*((TEMPK/LMBDA + SUM3)*T
     1                            - TKEL/LMBDA - SUM4)
      RETURN
      END
```

```
      SUBROUTINE CIPF(T,A0,C,LMBDA,N,ACAP,X,QSMAL,QCAP,ERCOD)
C ***********************************************************************
C * AUTHORS... G. G. KILLOUGH                                           *
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C *            OAK RIDGE, TENNESSEE                                     *
C *                                                                     *
C *                                                                     *
C * CIPF STANDS FOR CONTINUOUS INTAKE, POWER FUNCTION MODEL.            *
C *                                                                     *
C * INPUT PARAMETERS...                                                 *
C *                                                                     *
C *   T............TIME (DAYS)                                          *
C *                                                                     *
C *   A0...........INITIAL BURDEN (MICROCURIES) IN ORGAN                *
C *                                                                     *
C *   C............RATE (MICROCURIES/DAY) OF DEPOSITION OF              *
C *                RADIONUCLIDE INTO ORGAN                              *
C *                                                                     *
C *   LMBDA........RADIOACTIVE DECAY RATE (FRACTION/DAY) OF             *
C *                RADIONUCLIDE                                         *
C *                                                                     *
C *   N (REAL),                                                         *
C *   ACAP, X......POWER FUNCTION PARAMETERS FOR EXCRETION-RATE         *
C *                MODEL                                                *
C *                                                                     *
C *                E(T) = N/(T+X)*QSMAL(T) ...                          *
C *                                                                     *
C *                ACAP IS A DISTRIBUTION FACTOR BETWEEN COMPARTMENTS   *
C *                                                                     *
C *                                                                     *
C * OUTPUT PARAMETERS...                                                *
C *                                                                     *
C *   QSMAL........BURDEN (MICROCURIES) OF THE ORGAN AT TIME T          *
C *                                                                     *
C *   QCAP.........CUMULATIVE BURDEN (MICROCURIE-DAYS) OF THE ORGAN     *
C *                AT TIME T                                            *
C *                                                                     *
C *   ERCOD........INTEGER FLAG RELAYED TO CALLING PROGRAM FROM         *
C *                SUBROUTINE INTEG.  ERCOD=1 MEANS A POSSIBLE LOSS     *
C *                OF ACCURACY IN INTEGRATION PROCESS                   *
C *                                                                     *
C *                                                                     *
C * SUBROUTINE CIPF EVALUATES EQS. (2.42) AND (2.43)                    *
C *                                                                     *
C *                                                                     *
C * SUBROUTINES CALLED...                                               *
C *                                                                     *
C *   INTEG........EVALUATES THE INTEGRAL OF EXP(-U)*U**(-N) DU         *
C *                                                                     *
C ***********************************************************************
      INTEGER ERCOD
      REAL N,LMBDA
      ERCOD=0
      XL=LMBDA*X
C
C  COMPUTE EXP(-LMBDA*T) AND 1.-EXP(-LMBDA*T) WITH SAME REGARD FOR
```

```
C  UNDERFLOW AND CANCELLATION OF SIGNIFICANT DIGITS AS IN PREVICUS
C  SUBROUTINES CIEX AND DIEX.
C
      U=LMBDA*T
      ELT=0.
      IF(U.LE.75.) ELT=EXP(-U)
      IF(U.LE.17..AND.U.GE.0.01) TEMPE=1.-EXP(-U)
      IF(U.GT.17.) TEMPE=1.0
      IF(U.LT.0.01) TEMPE=U+U**3/6.-U**2/2.
      IF(X) 1,1,2
1     ONAXN=0.
      GO TO 3
2     ONAXN=1.-ACAP*X**(-N)
3     CALL INTEG(XL,XL+U,N,FNT,ERCOD)
      FNT=FNT*EXP(XL)/LMBDA**(1.-N)
      FACT=ONAXN*TEMPE/LMBDA + ACAP*FNT
      IF(T+X) 31,32,31
31    QSMAL=A0*ELT*(ONAXN+ACAP*(T+X)**(-N))+C*FACT
      GO TO 33
32    QSMAL=A0
33    QCAP=A0*FACT+C*(ONAXN*(T-TEMPE/LMBDA)/LMBDA
     $ +ACAP*((T+X-(1.-N)/LMBDA)*FNT-(X**(1.-N)-ELT*(X+T)**(1.-N)
     $)/LMBDA))
      RETURN
      END
```

```
      SUBROUTINE DIEX(T,N,TI,AI,LMBDA,M,KNU,BETA,QSMAL,QCAP)
C ***********************************************************************
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C *            OAK RIDGE, TENNESSEE                                     *
C *                                                                     *
C *                                                                     *
C * DIEX STANDS FOR DISCRETE INTAKES, EXPONENTIAL MODEL.                *
C *                                                                     *
C * INPUT PARAMETERS...                                                 *
C *                                                                     *
C *   T............TIME (DAYS)                                          *
C *                                                                     *
C *   N............NUMBER OF INTAKES                                    *
C *                                                                     *
C *   TI...........ARRAY OF N TIMES (DAYS) AT WHICH INTAKES OCCUR       *
C *                                                                     *
C *   AI...........ARRAY OF N CONTRIBUTIONS TO BURDEN (MICROCURIES) OF *
C *                ORGAN DUE TO INTAKES AT RESPECTIVE TIMES TI          *
C *                                                                     *
C *   LMBDA........RADIOACTIVE DECAY RATE (FRACTION/DAY) OF            *
C *                RADIONUCLIDE                                         *
C *                                                                     *
C *   M............SIZE OF ARRAYS KNU, BETA                             *
C *                                                                     *
C *   KNU..........REAL ARRAY OF M FRACTIONAL COEFFICIENTS GOVERNING   *
C *                THE DISTRIBUTION OF THE RADIONUCLIDE ENTERING THE   *
C *                BODY TO THE VARIOUS COMPARTMENTS                     *
C *                                                                     *
C *   BETA.........ARRAY OF M EXCRETION RATES (FRACTION/DAY), EACH     *
C *                RATE BEING ASSOCIATED WITH A COMPARTMENT OF THE     *
C *                MODEL                                                *
C *                                                                     *
C * OUTPUT PARAMETERS...                                                *
C *                                                                     *
C *   QSMAL........BURDEN (MICROCURIES) OF THE ORGAN AT TIME T          *
C *                                                                     *
C *   QCAP.........CUMULATIVE BURDEN (MICROCURIE-DAYS) OF THE ORGAN    *
C *                AT TIME T                                            *
C *                                                                     *
C *                                                                     *
C * SUBROUTINE DIEX EVALUATES EQS. (2.28) AND (2.29)                    *
C *                                                                     *
C *                                                                     *
C * SUBROUTINES CALLED...                                               *
C *                                                                     *
C *   NONE                                                              *
C *                                                                     *
C ***********************************************************************
C  COMPUTE TEMPK
C
      REAL LMBDA,KNU(M)
      DIMENSION BETA(M),TI(N),AI(N)
      TEMPK=1.0
      DO 1 NU=1,M
      TEMPK=TEMPK-KNU(NU)
```

```
1     CONTINUE
C
C  INITIALIZE FOR SUMMATION OVER THE TI(J), J=1,N...
C  TERMS ARE 0. WHEN T IS LESS THAN TI(J)
C
      QSMAL=0.0
      QCAP=0.0
      DO 2 J=1,N
      IF(T-TI(J)) 24,20,20
C
C  COMPUTE SUM1...
C
20    SUM1=0.0
      DO 21 NU=1,M
C
C  FOR TERM OF SUM1, COMPUTE KNU(NU)*EXP(-BETA(NU)*(T-TI(J)))
C                            IF BETA(NU)*(T-TI(J)) IS LESS THAN OR = 75.
C
C                     OTHERWISE, TERM IS 0. (UNDERFLOW)
C
      U=BETA(NU)*(T-TI(J))
      IF(U-75.) 23,23,21
23    SUM1=SUM1+KNU(NU)*EXP(-U)
21    CONTINUE
C
C  DEAL WITH EXP(-LMBDA*(T-TI(J)) IN MANNER OF PREVIOUS REMARK.
C  ACCUMULATE QSMAL
C
      U=LMBDA*(T-TI(J))
      IF(U-180.) 22,22,24
22    QSMAL=QSMAL+AI(J)*EXP(-U)*(TEMPK+SUM1)
24    IF(T-TI(J)) 2,2,25
C
C  COMPUTE 1. - EXP(-LMBDA*(T-TI(J)) IN A MANNER SIMILAR TO THAT
C  EMPLOYED IN SUBROUTINE CIEX, TO AVOID UNDERFLOW AND POSSIBLE
C  CANCELLATION OF SIGNIFICANT DIGITS.
C
25    U=LMBDA*(T-TI(J))
      IF(U-17.0) 27,27,26
26    TEMPE=1.0
      GO TO 290
27    IF(U-0.01) 28,28,29
28    TEMPE=U+U**3/6.0-U**2/2.0
      GO TO 290
29    TEMPE=1.0-EXP(-U)
C
C  COMPUTE SUM2, DEALING WITH 1. - EXP(-(LMBDA+BETA(NU))*(T-TI(J))) AS
C  INDICATED IN PREVIOUS REMARK.
C
290   SUM2=0.0
      DO 299 NU=1,M
      U=(LMBDA+BETA(NU))*(T-TI(J))
      IF(U-17.) 292,292,291
291   SUM2=SUM2+KNU(NU)/(LMBDA+BETA(NU))
      GO TO 299
292   IF(U-0.01) 293,293,294
293  0 SUM2=SUM2+KNU(NU)/(LMBDA+BETA(NU))*
     2       (U+U**3/6.0-U**2/2.0)
      GO TO 299
294  0 SUM2=SUM2+KNU(NU)/(LMBDA+BETA(NU))*
     1       (1.0-EXP(-U))
299   CONTINUE
C
C  ACCUMULATE QCAP
C
      QCAP=QCAP+AI(J)*(TEMPK*TEMPE/LMBDA+SUM2)
2     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DIPF(T,NCAP,TI,AI,LMBDA,N,ACAP,X,QSMAL,QCAP,ERCOD)
C ***********************************************************************
C * AUTHORS... G. G. KILLOUGH                                           *
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C *            OAK RIDGE NATIONAL LABORATORY                            *
C *            OAK RIDGE, TENNESSEE                                     *
C *                                                                     *
C *                                                                     *
C * DIPF STANDS FOR DISCRETE INTAKES, POWER FUNCTION MODEL.             *
C *                                                                     *
C * INPUT PARAMETERS...                                                 *
C *                                                                     *
C *  T............TIME (DAYS)                                           *
C *                                                                     *
C *  NCAP.........NUMBER OF INTAKES                                     *
C *                                                                     *
C *  TI...........ARRAY OF NCAP TIMES (DAYS) AT WHICH INTAKES OCCUR     *
C *                                                                     *
C *  AI...........ARRAY OF NCAP CONTRIBUTIONS TO BURDEN (MICROCURIES)   *
C *               OF ORGAN DUE TO INTAKES AT RESPECTIVE TIMES TI        *
C *                                                                     *
C *  LMBDA........RADIOACTIVE DECAY RATE (FRACTION/DAY) OF              *
C *               RADIONUCLIDE                                          *
C *                                                                     *
C *  N (REAL),                                                          *
C *  ACAP, X......POWER FUNCTION PARAMETERS FOR EXCRETION-RATE          *
C *               MODEL                                                 *
C *                                                                     *
C *               E(T) = N/(T+X)*QSMAL(T) ...                           *
C *                                                                     *
C *               ACAP IS A DISTRIBUTION FACTOR BETWEEN COMPARTMENTS    *
C *                                                                     *
C *                                                                     *
C * OUTPUT PARAMETERS...                                                *
C *                                                                     *
C *  QSMAL........BURDEN (MICROCURIES) OF THE ORGAN AT TIME T           *
C *                                                                     *
C *  QCAP.........CUMULATIVE BURDEN (MICROCURIE-DAYS) OF THE ORGAN      *
C *               AT TIME T                                             *
C *                                                                     *
C *  ERCOD........INTEGER FLAG RELAYED TO CALLING PROGRAM FROM          *
C *               SUBROUTINE INTEG.  ERCOD=1 MEANS A POSSIBLE LOSS      *
C *               OF ACCURACY IN INTEGRATION PROCESS                    *
C *                                                                     *
C *                                                                     *
C * SUBROUTINE DIPF EVALUATES EQS. (2.30) AND (2.31)                    *
C *                                                                     *
C *                                                                     *
C * SUBROUTINES CALLED...                                               *
C *                                                                     *
C *  INTEG........EVALUATES THE INTEGRAL OF EXP(-U)*U**(-N) DU          *
C *                                                                     *
C ***********************************************************************
      REAL N,TI(NCAP),AI(NCAP),LMBDA
      INTEGER ERCOD,ERC
C
C  INITIALIZE FOR SUMMATION OVER THE TI(J), J=1,NCAP
```

```
C
      QSMAL=0.
      QCAP=0.
      ERCOD=0
      XL=LMBDA*X
      IF(X) 1,1,3
1     ONAXN=0.
      GO TO 4
3     ONAXN=1.-ACAP*X**(-N)
4     DO 2 J=1,NCAP
      U=LMBDA*(T-TI(J))
      IF(T.LT.TI(J).OR.U.GT.75..) GO TO 21
      IF(X.EQ.0..AND.T.EQ.TI(J)) GO TO 5
      QSMAL=QSMAL + AI(J)*EXP(-U)*(ONAXN + ACAP*
     $       (T-TI(J)+X)**(-N))
      GO TO 21
5     QSMAL=QSMAL + AI(J)
C
C  COMPUTE 1. - EXP(-LMBDA*(T-TI(J)) IN A MANNER WHICH AVOIDS UNDERFLOW
C  AND LOSS OF SIGNIFICANT DIGITS THROUGH CANCELLATION, AS IN PREVIOUS
C  SUBROUTINES CIEX, DIEX, AND CIPF
C
21    IF(T.LE.TI(J)) GO TO 2
      IF(U.LE.17..AND.U.GE.0.01) TEMPE=1.-EXP(-U)
      IF(U.GT.17.) TEMPE=1.0
      IF(U.LT.0.01) TEMPE=U+U**3/6.-U**2/2.
      CALL INTEG(XL,XL+U,N,FNT,ERC)
      FNT=FNT*EXP(XL)/LMBDA**(1.-N)
      IF(ERCOD.LT.ERC) ERCOD=ERC
      QCAP=QCAP + AI(J)*(TEMPE*ONAXN/LMBDA
     $           + ACAP*FNT)
2     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE INTEG(A,B,N,INTGL,ERCOD)
C ***********************************************************************
C * AUTHORS... G. G. KILLOUGH                                           *
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C *            OAK RIDGE, TENNESSEE                                     *
C *                                                                     *
C *                                                                     *
C * SUBROUTINE INTEG EVALUATES THE INTEGRAL FROM U=A TO U=B OF THE      *
C * FUNCTION EXP(-U)*U**(-N).                                           *
C *                                                                     *
C * INPUT PARAMETERS...                                                 *
C *                                                                     *
C *   A............LOWER LIMIT OF INTEGRATION.  IF A IS NEGATIVE, THE   *
C *                SUBROUTINE USES ZERO IN PLACE OF A                   *
C *                                                                     *
C *   B............UPPER LIMIT OF INTEGRATION.  IF B EXCEEDS 65., THE   *
C *                SUBROUTINE USES 65. IN PLACE OF B                    *
C *                                                                     *
C *   N............POWER FUNCTION PARAMETER, ASSUMED TO LIE IN (0.,1.)  *
C *                                                                     *
C *                                                                     *
C * OUTPUT PARAMETERS...                                                *
C *                                                                     *
C *   INTGL........REAL VALUE OF THE INTEGRAL                           *
C *                                                                     *
C *   ERCOD........INTEGER FLAG TO INDICATE POSSIBLE LOSS OF PRECISION.*
C *                IN PRESENT VERSION ERCOD=1 IS RETURNED ONLY WHEN     *
C *                UPPER LIMIT OF INTEGRATION EXCEEDS 65.  OTHERWISE    *
C *                ERCOD=0 IS RETURNED                                  *
C *                                                                     *
C *                                                                     *
C * SUBROUTINES CALLED...                                               *
C *                                                                     *
C *   SER..........USES A SERIES FOR THE PART OF THE INTEGRATION RANGE *
C *                FROM 0. TO 2.                                        *
C *                                                                     *
C *   NEWCO........APPLIES SIXTH-ORDER COMPOSITE NEWTON-COTES           *
C *                QUADRATURE RULE TO THE PART OF THE INTEGRATION       *
C *                RANGE BETWEEN 2. AND 20.                             *
C *                                                                     *
C *   ASYMP........USES AN ASYMPTOTIC SERIES TO APPROXIMATE THE INTE-   *
C *                GRAL OVER THE PART OF ITS RANGE BETWEEN 20. AND 65. *
C *                                                                     *
C ***********************************************************************
      REAL N, INTGL
      INTEGER ERCOD
      DATA EREL/.5E-8/
      ERCOD=0
C
C   COMPUTE A1 AS THE LARGER OF A AND 20.
C
      IF(A-20.) 1,1,11
1     A1=20.
      GO TO 2
11    A1=A
C
```

```
C    COMPUTE B1 AS THE SMALLER OF B AND 65.
C
2      IF(B-65.) 21,21,22
21     B1=B
       GO TO 3
C
C    SINCE B EXCEEDS 65., SET ERCOD=1 TO INDICATE TRUNCATION OF THE
C    INTEGRAL.
C
22     B1=65.
       ERCOD=1
C
C    APPLY ASYMPTOTIC SERIES TO THE RANGE FROM 20. TO 65.
C
3      CALL ASYMP(A1,B1,N,EREL,INTGL)
C
C    COMPUTE A1 AS THE LARGER OF A AND 2.
C
       IF(A-2.) 31,31,32
31     A1=2.
       GO TO 4
32     A1=A
C
C    COMPUTE B1 AS THE SMALLER OF B AND 20.
C
4      IF(B-20.) 33,33,34
33     B1=B
       GO TO 5
34     B1=20.
C
C    WORKING BACKWARD FROM UPPER TO LOWER LIMIT OF THAT PART OF THE
C    RANGE LYING BETWEEN 2. AND 20., APPLY COMPOSITE NEWTON-COTES RULE
C    TO SUBINTERVALS OF NO MORE THAN UNIT LENGTH AND SUM THESE PARTIAL
C    CONTRIBUTIONS.
C
5      IF(A1-(B1-1.)) 52,51,51
51     CALL NEWCO(A1,B1,N,EREL,ANS)
       INTGL=INTGL+ANS
       GO TO 6
52     CALL NEWCO(B1-1.,B1,N,EREL,ANS)
       INTGL=INTGL+ANS
       B1=B1-1.
       GO TO 5
C
C    COMPUTE A1 AS THE LARGER OF A AND 0.
C
6      IF(A) 61,61,62
61     A1=0.
       GO TO 63
62     A1=A
C
C    COMPUTE B1 AS THE SMALLER OF B AND 2.
C
63     IF(B-2.) 64,64,65
64     B1=B
       GO TO 66
65     B1=2.
C
C    APPLY SERIES METHOD TO CALCULATE INTEGRAL OVER SUBRANGE BETWEEN 0.
C    AND 2.
C
66     CALL SER(A1,B1,N,EREL,ANS)
       INTGL=INTGL+ANS
       RETURN
       END
```

```
      SUBROUTINE ASYMP(A,B,N,EREL,INTGL)
C ***********************************************************************
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C *            OAK RIDGE NATIONAL LABORATORY                            *
C *            OAK RIDGE, TENNESSEE                                     *
C *                                                                     *
C * SUBROUTINE ASYMP USES THE ASYMPTOTIC SERIES                         *
C *                                                                     *
C *   EXP(-Z)*Z**(-N)*(1. - N/Z + N*(N+1.)/Z**2 - + ...),               *
C *                                                                     *
C * WHICH, FOR LARGE Z, REPRESENTS THE INTEGRAL FROM U=Z TO INFINITY    *
C * OF EXP(-U)*U**(-N) DU.  THE SERIES IS EVALUATED AT Z=A AND Z=B,     *
C * AND THE DIFFERENCE OF THE RESULTS IS RETURNED AS INTGL.             *
C * SUMMATION CONTINUES UNTIL EITHER (1) THE NEXT TERM EXCEEDS THE      *
C * CURRENT TERM IN ABSOLUTE VALUE OR (2) THE NEXT TERM DOES NOT        *
C * PRODUCE IN THE SUM A RELATIVE CHANGE WHICH EXCEEDS EREL IN          *
C * ABSOLUTE VALUE.  IF Z IS 20.0 OR MORE, THE SERIES                   *
C * APPROXIMATES THE INTEGRAL FROM Z TO INFINITY TO AT LEAST 6          *
C * SIGNIFICANT DIGITS.                                                 *
C *                                                                     *
C * INPUT PARAMETERS...                                                 *
C *                                                                     *
C *   A............LOWER LIMIT OF INTEGRATION (SHOULD BE AT LEAST 20.)  *
C *                                                                     *
C *   B............UPPER LIMIT OF INTEGRATION (IF B EXCEEDS A, THIS     *
C *                SUBROUTINE RETURNS THE VALUE 0. FOR INTGL.  THIS     *
C *                FEATURE IS ESSENTIAL TO THE LOGIC OF SUBROUTINE      *
C *                INTEG)                                               *
C *                                                                     *
C *   N............POWER FUNCTION PARAMETER                             *
C *                                                                     *
C *   EREL.........RELATIVE ERROR TOLERANCE.  ASYMPTOTIC SERIES DOES    *
C *                NOT PERMIT ARBITRARY ACCURACY.  SUPERFLUOUS          *
C *                SUMMATION IS AVOIDED BY STOPPING WHEN THE NEXT       *
C *                TERM DOES NOT EXCEED EREL IN ABSOLUTE VALUE          *
C *                                                                     *
C * OUTPUT PARAMETER...                                                 *
C *                                                                     *
C *   INTGL........REAL VALUE OF INTEGRAL FROM U=A TO U=B OF            *
C *                EXP(-U)*U**(-N) DU                                   *
C *                                                                     *
C * SUBROUTINES CALLED...                                               *
C *                                                                     *
C *   NONE                                                              *
C *                                                                     *
C ***********************************************************************
      REAL N, INTGL
C
C   IF B IS GREATER THAN OR EQUAL TO A, RETURN THE VALUE 0.
C
      IF(B-A) 1,1,2
1     INTGL=0.
      RETURN
2     Z=A
      IRET=1
C
```

```
C    BRANCH TO SUMMATION ROUTINE WITH Z=A.  IRET IS A RETURN ADDRESS
C    VARIABLE
C
       GO TO 3
21     INTGL=SUM
       Z=B
       IRET=2
C
C    BRANCH TO SUMMATION ROUTINE WITH Z=B
C
       GO TO 3
22     INTGL=INTGL-SUM
       RETURN
C
C    SUMMATION ROUTINE...
C
3      IF(Z-65.) 32,31,31
31     SUM=0.
       GO TO 4
32     SUM=1.-N/Z
       TERM1=N*(N+1.)/Z**2
       TERM2=-TERM1*(N+2.)/Z
       K=2
325    IF(ABS(TERM1)-EREL) 41,41,33
33     IF(ABS(TERM1)-ABS(TERM2)) 41,34,34
34     SUM=SUM+TERM1
       TERM1=TERM2
       K=K+1
       TERM2=-TERM2*(N+FLOAT(K))/Z
       GO TO 325
41     SUM=SUM*Z**(-N)*EXP(-Z)
C
C    EXIT FROM SUMMATION ROUTINE
C
4      GO TO (21,22),IRET
       END
```

```
      SUBROUTINE NEWCO(ALPHA,BETA,N,EREL,INTGL)
C ***********************************************************************
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C *            OAK RIDGE, TENNESSEE                                     *
C *                                                                     *
C * SUBROUTINE NEWCO APPLIES THE COMPOSITE SIXTH-ORDER NEWTON-COTES     *
C * QUADRATURE RULE OF EQ. (3.2) TO APPROXIMATE THE INTEGRAL FROM       *
C * U=ALPHA TO U=BETA OF EXP(-U)*U**(-N) DU.  THE NUMBER OF SUBDIVI-    *
C * SIONS OF THE INTERVAL ALPHA TO BETA IS CHOSEN IN SUCH A WAY THAT    *
C * THE RELATIVE TRUNCATION ERROR DOES NOT EXCEED EREL IN ABSOLUTE      *
C * VALUE.                                                              *
C *                                                                     *
C * INPUT PARAMETERS...                                                 *
C *                                                                     *
C *   ALPHA........LOWER LIMIT OF INTEGRATION                           *
C *                                                                     *
C *   BETA.........UPPER LIMIT OF INTEGRATION (IF BETA EXCEEDS ALPHA,   *
C *                THIS SUBROUTINE RETURNS THE VALUE 0. FOR INTGL.      *
C *                THIS FEATURE IS ESSENTIAL TO THE LOGIC OF            *
C *                SUBROUTINE INTEG)                                    *
C *                                                                     *
C *   N............POWER FUNCTION PARAMETER                              *
C *                                                                     *
C *   EREL.........RELATIVE TRUNCATION ERROR TOLERANCE                  *
C *                                                                     *
C * OUTPUT PARAMETER...                                                 *
C *                                                                     *
C *   INTGL........REAL VALUE OF THE INTEGRAL FROM U=ALPHA TO U=BETA    *
C *                OF EXP(-U)*U**(-N) DU                                *
C *                                                                     *
C * SUBROUTINES CALLED...                                               *
C *                                                                     *
C *   NONE                                                              *
C *                                                                     *
C ***********************************************************************
      REAL N, INTGL
      F(T)=EXP(-T)*T**(-N)
      P6(T)=((((((N+5.)/T+6.)*(N+4.)/T+15.)*(N+3.)/T+20.)*(N+2.)/T+15.)
     $      *(N+1.)/T+6.)*N/T+1.
C
C   D6F(T) IS THE SIXTH DERIVATIVE OF THE FUNCTION F(T)
C
      D6F(T)=F(T)*P6(T)
C
C   IF BETA IS LESS THAN OR EQUAL TO ALPHA, RETURN THE VALUE 0.
C
      IF(BETA-ALPHA) 1,1,2
1     INTGL=0.
      RETURN
C
C   COMPUTE NUMBER M OF SUBINTERVALS NECESSARY TO CONTROL RELATIVE
C   TRUNCATION ERROR
C
2     M=IFIX(1.+(BETA-ALPHA)*(2.0*D6F(ALPHA)/(945.0*EREL*F((ALPHA+BETA)/
     $      2.)))**(1./6.))
```

```
C
C   COMPUTE M4 = THE SMALLEST INTEGER FOR WHICH 4*M4 IS GREATER THAN
C   OR EQUAL TO M.  USE 4*M4 IN PLACE OF M SINCE THE NUMBER OF
C   SUBINTERVALS MUST BE A MULTIPLE OF 4
C
      M4=M/4
      IF(4*M4-M) 21,22,22
21    M4=M4+1
C
C   COMPUTE H = LENGTH OF EACH SUBINTERVAL
C
22    H=(BETA-ALPHA)/(FLOAT(4*M4))
C
C   INITIALIZE FOR SUMMATICN LOOP
C
      F0=F(BETA)
      X=BETA+4.0*H
      INTGL=0.
      I=0
C
C   SUMMATION LOOP...
C
3     I=I+1
      X=X-4.0*H
      INTGL=INTGL+7.0*F0+32.0*F(X-H)+12.0*F(X-2.0*H)+32.0*F(X-3.0*H)
      F0=F(X-4.0*H)
      INTGL=INTGL+7.0*F0
      IF(I-M4) 3,4,4
4     INTGL=INTGL*(2.0*H/45.0)
      RETURN
      END
```

```
      SUBROUTINE SER(A,B,N,EREL,INTGL)
C ***********************************************************************
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C *                                                                     *
C *                                                                     *
C * SUBROUTINE SER SUMS THE SERIES                                      *
C *                                                                     *
C *   SUM FROM K=0 TO INFINITY OF (-1)**K*(B**(K-N+1) - A**(K-N+1))     *
C *          /((K-FACTORIAL)*(K-N+1)),                                  *
C *                                                                     *
C * WHICH REPRESENTS THE INTEGRAL FROM U = A TO U = B OF THE            *
C * FUNCTION EXP(-U)*U**(-N) DU (SEE SECTION 3.4).                      *
C *                                                                     *
C * INPUT PARAMETERS...                                                 *
C *                                                                     *
C *   A............LOWER LIMIT OF INTEGRATION                           *
C *                                                                     *
C *   B............UPPER LIMIT OF INTEGRATION (IF B EXCEEDS A, THIS     *
C *                SUBROUTINE RETURNS THE VALUE 0. FOR INTGL.  THIS     *
C *                FEATURE IS ESSENTIAL TO THE LOGIC OF SUBROUTINE      *
C *                INTEG)                                               *
C *                                                                     *
C *   N............POWER FUNCTION PARAMETER                              *
C *                                                                     *
C *   EREL.........RELATIVE ERROR TOLERANCE.  SUMMATION CEASES WHEN     *
C *                THE FIRST TERM NOT TAKEN IS LESS THAN OR EQUAL IN    *
C *                ABSOLUTE VALUE TO EREL AS A FRACTION OF THE          *
C *                ACCUMULATED SUM                                      *
C *                                                                     *
C * OUTPUT PARAMETER...                                                 *
C *                                                                     *
C *   INTGL........REAL VALUE OF THE INTEGRAL FROM U=A TO U=B OF        *
C *                EXP(-U)*U**(-N) DU                                   *
C *                                                                     *
C * SUBROUTINES CALLED...                                               *
C *                                                                     *
C *   NONE                                                              *
C *                                                                     *
C ***********************************************************************
      REAL N, INTGL
C
C   RETURN VALUE 0. IF B IS LESS THAN OR EQUAL TO A
C
      IF(B-A) 1,1,2
1     INTGL=0.
      RETURN
2     X=B
      IRET=1
C
C   BRANCH TO SUMMATION ROUTINE TO EVALUATE B-PART OF SERIES.
C   IRET IS A RETURN ADDRESS VARIABLE
C
      GO TO 3
21    INTGL=SUM*B**(1.0-N)
```

```
      X=A
      IRET=2
C
C   BRANCH TO SUMMATION ROUTINE TO EVALUATE A-PART OF SERIES
C
      GO TO 3
22    INTGL=INTGL-SUM*A**(1.0-N)
      RETURN
C
C   BEGINNING OF SUMMATION ROUTINE...
C
3     IF(X) 31,31,32
31    SUM=0.
      GO TO 4
32    SUM=1.0/(1.0-N)
      TERM=1.
      K=0
33    K=K+1
      TERM=TERM*(-X)/FLOAT(K)
      SUM=SUM+TERM/(FLOAT(K+1)-N)
      IF(ABS(TERM/SUM)-EREL) 4,4,33
C
C   EXIT FROM SUMMATION ROUTINE
C
4     GO TO (21,22),IRET
      END
```

Appendix B

Organization of Data File NUCPAR.DAT

ORGANIZATION OF DATA FILE NUCPAR.DAT

I/O: formatted

Physical records: 10 characters

Logical records: variable

Format	Number of Characters	Content of physical record
2A5 2A5	10 10	Name of radionuclide (formula)
2A5 2A5	10 10	Name of critical organ
1PE10.3	10	Radoiactive half-life
1PE10.3	10	Effective absorbed energy per disintegration
1PE10.3	10	Mass of critical organ
1PE10.3 1PE10.3	10 10	FW, FA -- fractions of intake reaching crit. org.
I10	10	Integer code to identify model: 1-exponential; 2-power function; 3-mixed
1-exponential model		
I10	10	Integer M (1 to 9) giving number of exponential terms
1PE10.3	20M	Coefficients and biological half-lives
2-power function model		
1PE10.3	10	N
1PE10.3	10	X
1PE10.3	10	ACAP

3-mixed model

1PE10.3	10	Coefficient K of exponential term
I10	10	Integer M (1 to 9) giving number of exponential terms
1PE10.3	20M	Coefficients of exponential terms and corresponding biological half-lives
1PE10.3	10	N
1PE10.3	10	X
1PE10.3	10	ACAP

The above outline shows the actual order of information within a logical record. No special character is written to falg the beginning or end of a logical record.

ORGANIZATION OF FILE INDEX.DAT

I/O = formatted
Physical records = 15 characters
Logical records = 15 characters

INDEX.DAT serves as an index of NUCPAR.DAT. Each record of INDEX.DAT contains two integers. The first represents the code number of a radionuclide, and the second gives the number of the physical record in NUCPAR.DAT where the information about the radionuclide begins. Each record of INDEX.DAT may be read in format I5, I10.

Appendix C.

Dosimetric Information from ICRP Publications 2, 6, 10, and 10A

APPENDIX C

Dosimetric Information from ICRP Publications 2, 6, 10, and 10A

Code No.	Radionuclide	Reference organ	Radioactive half-life (days)	Eff. absorbed energy (MeV)	Mass of reference organ (g)	Uptake fractions		Exponential parameters		Power function parameters		
						Ingestion	Inhalation	Coefficients	Excretory half-lives (days)	n	x	A
303	1 H-3 (oxide)	Body tissue	4.5×10^3	0.01	4.3×10^4	1.0	1.0	1.0	10.0			
3141	6 C-14 (a) $NaHCO_3$-CO_2 and carboxyl-labelled fatty acids	Bone	2.03×10^6	0.27	$7. \times 10^3$	0.3	0.24	1.0	0.4			
3142	6 C-14 (b) C2-labelled glycine and acetate	Total body	2.03×10^6	0.054	$7. \times 10^4$	1.0	0.75	0.2	0.12			
								0.2	0.9			
								0.3	6.0			
								0.3	35.0			
312	11 Na-22	Total body	950.	1.6	$7. \times 10^4$	1.0	0.75	0.49	8.5			
								0.51	13.5			
								0.27×10^{-2}	445.			
310	15 P-32	Bone	14.2	3.5	$7. \times 10^3$	0.375	0.32	1.0	257.			
318	16 S-35	Total body	87.	0.056	$7. \times 10^4$	1.0	0.75	0.8	0.25			
								0.2	7.0			
317	17 Cl-36	Total body	1.1×10^8	0.26	$7. \times 10^4$	1.0	0.75	1.0	10.0			
311	20 Ca-45	Bone	165.	0.43	$7. \times 10^3$	0.54	0.5			0.15	0.0	1.0
308	26 Fe-59	Spleen	45.	0.34	150.	$2. \times 10^{-3}$	$6. \times 10^{-3}$	1.0	700.			
323	27 Co-60	Total body	1.9×10^3	1.5	$7. \times 10^4$	0.3	0.4	0.65	10.			
								0.35	$1. \times 10^{-5}$*			
325	30 Zn-65	Total body	245.	0.32	$7. \times 10^4$	0.1	0.3	0.25	14.			
								0.75	380.			
332	37 Rb-86	Total body	18.7	0.70	$7. \times 10^4$	1.0	0.75	0.1	4.			
								0.9	95.			
346	38 Sr-85	Total body	65.	0.33	$7. \times 10^4$	0.3	0.4	1.0	2.4	0.2	0.0	1.0
38	38 Sr-89	Bone	51.	2.8	$7. \times 10^3$	0.3‡	0.4‡			0.2	0.0	0.5
42	38 Sr-90	Bone	$1. \times 10^4$	5.5	$7. \times 10^3$	0.3‡	0.4‡			0.2	0.0	0.5
191	52 Te-132	Total body	3.25	1.9	$7. \times 10^4$	0.25	0.38	0.5	0.5			
								0.5	20.			
187	53 I-131	Thyroid	8.04	0.23	20.	0.3	0.23	1.0	100.			
210	55 Cs-137	Total body	1.1×10^4	0.59	$7. \times 10^4$	1.0	0.75	0.15	1.0			
								0.85	115.			
221	56 Ba-140	Bone	12.8	4.2	$7. \times 10^3$	0.035	0.19			0.2	0.0	1.0
238	58 Ce-144	Bone	285.	6.3	$7. \times 10^3$	$3. \times 10^{-5}$	0.075	1.0	3750.			
288	79 Au-198	Kidneys	2.7	0.41	300.	0.1‡	0.3‡	0.03	1.59			
								0.97	$1. \times 10^{-5}$*			
347	84 Po-210	Kidneys	138.4	55.	300.	0.06	0.25	0.1	40.			
								0.9	$1. \times 10^{-5}$*			
348	88 Ra-226	Bone	5.913×10^5	110.	$7. \times 10^3$	0.3	0.4	0.54	0.398			
								0.29	4.95			
								0.11	57.75			
								0.04	693.			
								0.02	5330.8			
349	90 Th-232	Bone	5.15×10^{12}	270.	$7. \times 10^3$	$7. \times 10^{-5}$	0.18	1.0	7.3×10^4			
352	90 Th-228	Bone	700.	970.	$7. \times 10^3$	$7. \times 10^{-5}$	0.18	1.0	7.3×10^4			
353	92 U-233	Bone	5.9×10^7	250.	$7. \times 10^3$	1.1×10^{-3}	0.028			0.5	0.0	1.0
354	92 U-234	Bone	9.1×10^7	240.	$7. \times 10^3$	1.1×10^{-3}	0.028			0.5	0.0	1.0
330	93 Np-239	Bone	2.3	0.98	$7. \times 10^3$	4.5×10^{-5}	0.11	0.5	25.			
								0.5	$7. \times 10^4$			
281	94 Pu-239	Bone	8.92×10^6	270.	$7. \times 10^3$	2.4×10^{-5}	0.2	0.0†	1.0†			
283	94 Pu-241	Bone	4.7×10^3	14.	$7. \times 10^3$	2.4×10^{-5}	0.2	0.0†	1.0†			

*A dummy exponential term is used to gain the effect of fractional coefficients whose sum is less than unity without the introduction of a non-excretory compartment. For Co-60 the effect is no greater than 1/10,000 of one per cent of a 50-year dose; in the case of Au-198, the contribution of this term is less than 1/1000 of one per cent of a 50-year dose; and with Po-210, the dummy term contributes less than 2/10,000 of one per cent of a 50-year dose. It should be pointed out, however, that initial dose rates will be influenced by the dummy terms.

†This arrangement permits total retention in a non-excretory compartment. Any positive numbers could be used for the excretory half-lives.

‡Represents uptake to blood.

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