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On Estimating Dose Rates to Organs As a Function of Age Following Internal Exposure to Radionuclides

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Criteria and Standards Division
Office of Radiation Programs
U.S. Environmental Protection Agency
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Health and Safety Research Division

ON ESTIMATING DOSE RATES TO ORGANS AS A FUNCTION OF AGE
FOLLOWING INTERNAL EXPOSURE TO RADIONUCLIDES

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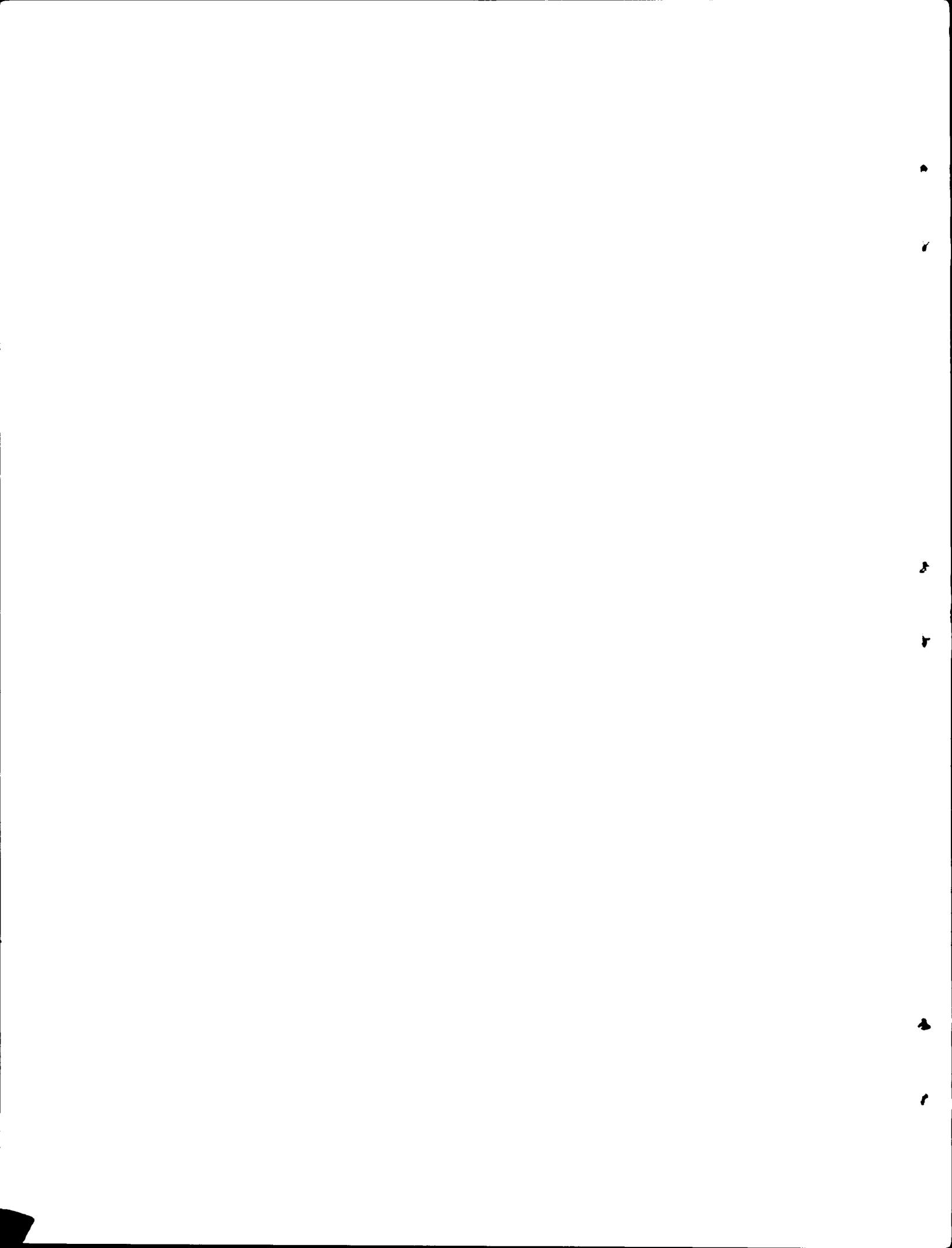
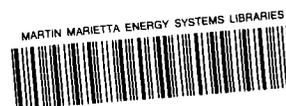
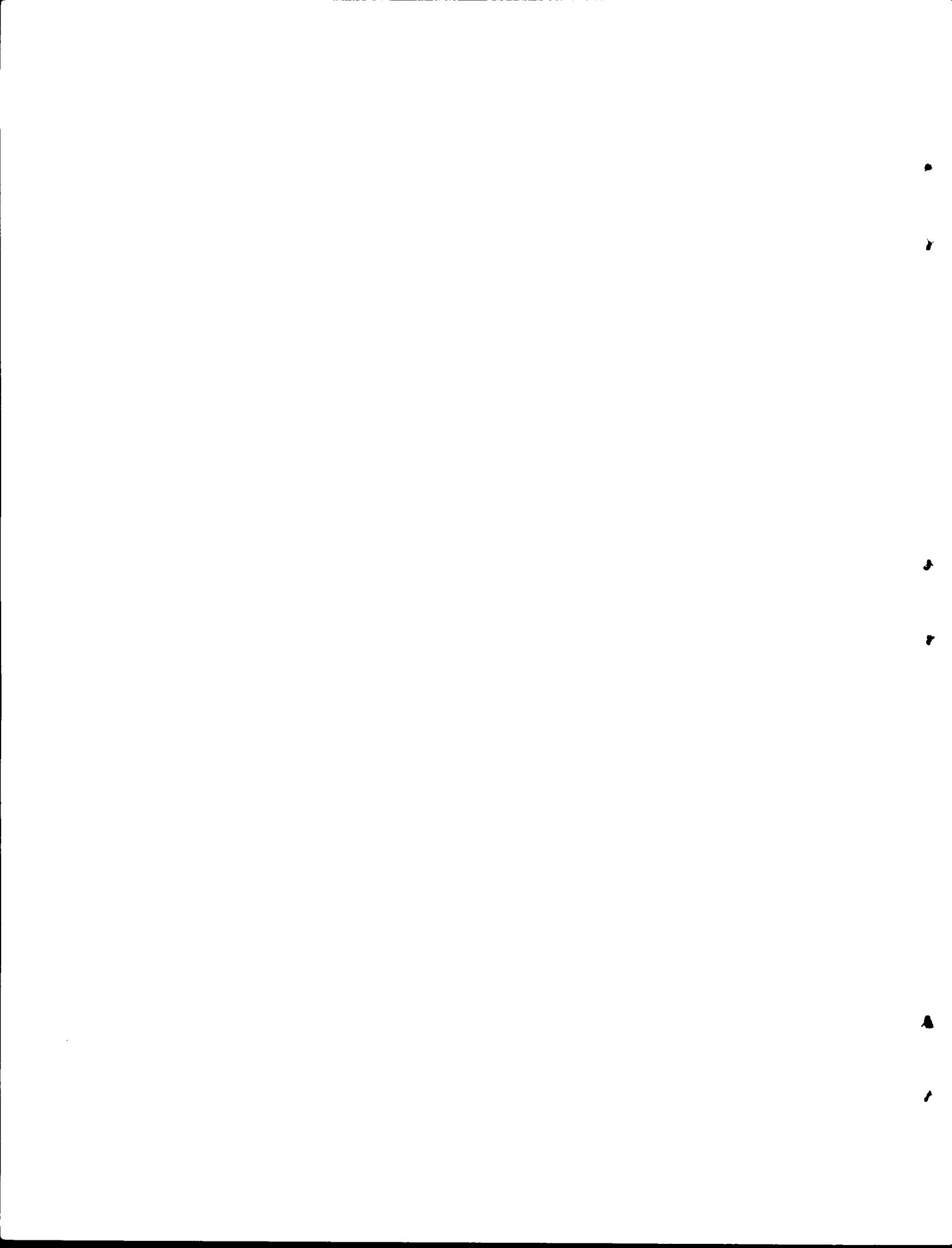


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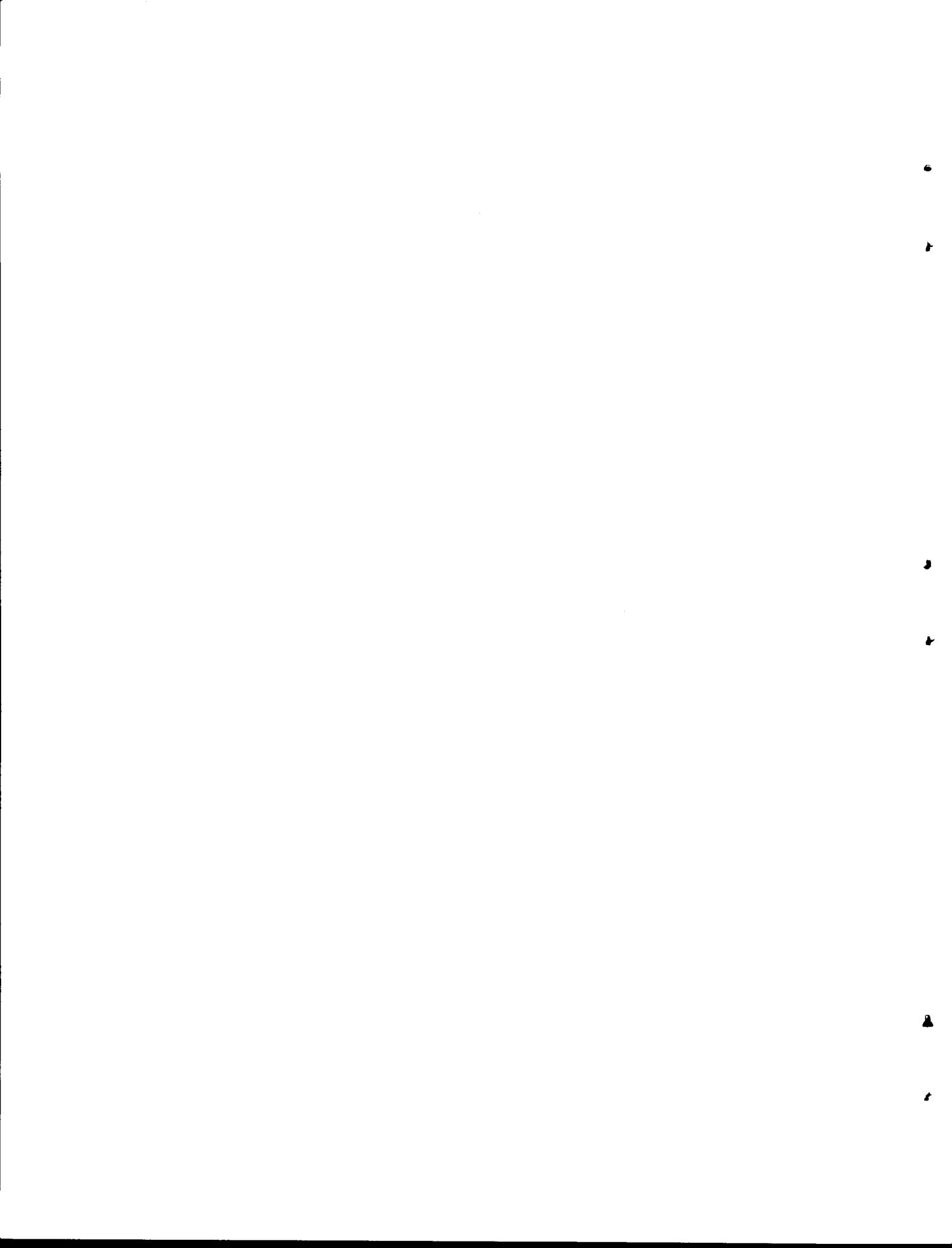


HIGHLIGHTS

This report describes a method for estimating dose rates as a function of age to radiosensitive organs and tissues in the human body at arbitrary times during or after internal exposure to radioactive material. Essentially any internal exposure pathway may be considered, including inhalation, ingestion, and direct entry into the bloodstream or a body organ through an open wound or an injection. The exposure may be either acute or chronic; in the case of a chronic exposure, variable intake rates as a function of time may be considered.

As far as practical, we have attempted to retain the uniformity and simplicity of the "standard adult" models while identifying the significant changes that occur with age. Unfortunately, many metabolic models for adults consist of components which are derived from fits to experimental animal or human data and which are only vaguely identified with physiological mechanisms. Nuclide-specific data for nonadults generally are too sparse to allow meaningful extensions of such models to children by empirical fitting methods. In some cases it has been possible to modify existing adult models so that all model components correspond to physically identifiable processes or subsections of the body, and to incorporate age-dependence into these models through largely physiological considerations. In addition to introducing the capability of estimating age-dependent dose rates, the present methods allow improved estimates of the distribution of activity of some radionuclides even in the adult.

At present there are few, if any, radionuclides for which sufficient metabolic information is available to allow full use of all features of the methodology. The intention has been to construct the methodology and the accompanying computer code (called AGEDOS) so that: (1) full use can be made of the relatively sparse age-dependent, nuclide-specific data now available; (2) full use can be made of the generally plentiful age-dependent physiological information; (3) dose rates estimated for adults are derived from models that are at least as detailed and accurate, and sometimes more detailed and accurate, than previous models; (4) constantly accumulating metabolic information can be incorporated with minimal alterations in the AGEDOS code.



1. INTRODUCTION

The Significance of Age-Dependent Radiation Dosimetry

Protection standards for internal exposure to radionuclides traditionally have been based on metabolic models and parameters developed for the average adult. This approach evolved at a time when most potentially hazardous exposures to radionuclides were occupationally derived and, hence, delivered to adults. In addition, because most available nuclide-specific metabolic data for both humans and animals are for adults, the complex problem of modeling the behavior of radionuclides in the human body has been simplified considerably by ignoring effects of age.

In recent years emphasis in radiation protection has shifted somewhat to environmental contamination and to public rather than occupational exposures. Moreover, there is increasing evidence that, for some radionuclides and exposure situations, neonates, young children, or adolescents may experience significantly higher organ concentrations and subsequent doses than adults. For example, measurements of strontium-90 in tens of thousands of human skeletons have indicated that infants and young children tend to accumulate considerably higher concentrations of this bone-seeking radionuclide than adults.¹⁻³ Results of other studies of age-dependent organ doses in humans and animals also suggest that adult models may not adequately represent all age groups.⁴

The significance attached to the age-dependence of organ doses from a given exposure depends on the interpretation of these doses in terms of subsequent risk. An index of risk commonly applied to radiation exposures is the dose commitment to a population, which is converted to risk by assuming that each member of the population incurs the same risk from a given dose. With this measure of risk, elevated doses received by relatively small subgroups of the population will often appear insignificant because they do not make a large difference in the estimated total risk (cf. Ref. 5).

As with the exposure-dose relationship, however, there is increasing evidence of significant age-dependence in the dose-response relationship for radiation, particularly with regard to potential cancers.

For example, epidemiological studies of Japanese A-Bomb survivors indicate that leukemogenic effects are most pronounced in persons who are very young or very old at the time of exposure.^{6,7} These studies also indicate large variations in risk with age at exposure for non-leukemogenic cancers, although the basic pattern of risk as a function of age depends on the particular risk hypothesis chosen to interpret the data.⁶ Studies of females irradiated for diagnostic purposes, as well as studies of A-Bomb survivors, indicate that the period of highest risk for breast cancer occurs for females irradiated as adolescents or young adults. These and other investigations suggest that exposures may arise for which the concept of population dose will not provide a conservative approach to radiation protection. Moreover, because of the indicated potentially multiplicative effect of elevated dose and elevated response at certain ages, these studies also demonstrate the inadequacies inherent in the "standard man" approach to radiation dosimetry, particularly for identifying critical members of the population.

Implementation of Age-Dependent Dosimetric Methods

This report describes a method designed to estimate dose rates, as a function of age, to radiosensitive organs and tissues in the human body at arbitrary times during or after internal exposure to radioactive material. Essentially any internal exposure pathway may be considered, including inhalation, ingestion, and direct entry into the bloodstream or a body organ through an open wound or an injection. The exposure may be either acute or chronic; in the case of a chronic exposure variable intake rates as a function of time may be considered.

In our modeling efforts an attempt has been made to retain the uniformity and basic features of the present adult models while identifying the significant changes that occur with age. At some points this intention had to be balanced with the requirement that any model for nonadults be a continuous extension of the corresponding model for adults. Unfortunately, many adult dosimetric models consist of components which are derived from fits to experimental animal or human data and which are only vaguely identified with physiological mechanisms. Nuclide-specific data for nonadults generally are too sparse to allow meaningful

extensions of such models to children by empirical fitting methods. In some cases it has been possible to modify existing adult models so that all model components correspond to physically identifiable processes or subsections of the body, and to incorporate age-dependence into these models through largely physiological considerations. As discussed in later sections, this method has been applied with some apparent success to retention and translocation of some radionuclides by the skeleton.

In addition to introducing the capability of estimating age-dependent dose rates, the present methods allow improved estimates of the distribution of activity of some radionuclides even in the adult. In particular, separate consideration is given to some structures often ignored or only implicitly considered in radiation dosimetry, such as the blood, cortical and trabecular bone surfaces, cortical and trabecular bone volumes, and bone marrow.

At present there are few, if any, radionuclides for which sufficient metabolic information is available to allow full use of all features of the methodology. The intention has been to construct the methodology and the accompanying computer code (called AGEDOS) so that:

- (1) full use can be made of the relatively sparse age-dependent, nuclide-specific data now available;
- (2) full use can be made of the generally plentiful age-dependent physiological information;
- (3) dose rates estimated for adults are derived from models that are at least as detailed and accurate, and sometimes more detailed and accurate, than previous models.
- (4) constantly accumulating metabolic information can be incorporated with minimal alterations in the AGEDOS code.

2. AN OVERVIEW OF THE AGEDOS METHODOLOGY

Definitions and Background Information

Radioactive materials may be taken into the body through inhalation, ingestion, contact with open wounds, or injection directly into blood or tissue. Whatever the pathway, internally deposited radionuclides are distributed among various organs and tissues and/or excreted from the body through a variety of complex processes. During its sojourn in the body, a radionuclide may release energy during radioactive decay. If this energy is deposited in sensitive cells or tissues, damage may occur and eventually contribute to a deleterious biological effect such as carcinogenesis or mutagenesis.

The index commonly used to estimate the potential for a given health effect due to exposure to radiation is the absorbed dose, which is defined as the ratio of the energy, $\Delta\varepsilon$, deposited in a specified tissue, to the mass, Δm , of that tissue. The present methodology is designed to estimate the dose per unit time (dose rate) to various radiosensitive organs and tissues at arbitrary times during or after internal exposure to a radionuclide.

The dose rates estimated by the computer code AGEDOS reflect the metabolic and physiological changes that may occur due to the growth process during or after exposure to a radionuclide. For example, in the case of ingestion of a radionuclide one may consider variation with age in the fraction of activity absorbed into the bloodstream from the small intestine, the fraction taken from the bloodstream by various systemic organs, and the biological half-times of the radionuclide in various compartments of these organs, among other factors. Moreover, an attempt has been made to account for the differences with age in the amounts of energy deposited in various organs and tissues due to radioactive decay at a given location. Such differences will arise from the changes during growth in the masses and geometries of body organs and tissues.

The Matrix of Dose Rates Calculated by AGEDOS

Throughout this report the notation $\dot{D}_I(b, b + T)$ is used for the dose rate to a specified tissue of a person of age $b + T$ due to an intake I either occurring at, or beginning at, age b . If the intake I is an acute intake of k units occurring at age b , then the notation will be $\dot{D}_{kU}(b, b + T)$, where U denotes a unit intake and the real number k properly scales the intake. If the intake I is a chronic intake beginning at age b , then I is a function of the time t and the exposed person's age between $t = 0$ (corresponding to age b) and $t = T$ (corresponding to age $b + T$).

The principal task of the computer code AGEDOS is to calculate a matrix of dose rates $\dot{D}_U(B, B + S)$ for an acute unit intake U , for selected beginning ages B , and for selected times $S \geq 0$ (see Table 1). As described later, this matrix may be used to estimate dose rates $\dot{D}_I(b, b + T)$ for essentially arbitrary intake I , beginning age b , and subsequent age $b + T$.

In the AGEDOS code, the "acute unit intake" U is actually represented as an initial activity already in the stomach, lungs, blood, or other organs. To allow development of a dosimetric data base with maximum flexibility, we designed the code to estimate dose rates to all organs beginning with an initial unit activity in the tracheobronchial, nasal-pharyngeal, or pulmonary region of the lungs, with no initial activity in the other two regions. The user of the data base could then perform arithmetic operations to compute dose rates corresponding to arbitrary deposition fractions in the three regions. However, the user of the AGEDOS code has the option of specifying simultaneous initial activities in all regions of the lung.

The beginning ages B (that is, ages at which acute intakes are considered) used in AGEDOS are 0, 100, 365, 1825, 3650, 5475, and 7300 days. Thus, to choose one example, dose rates to the various organs are calculated at ages subsequent to age 1825 days under the assumption that a unit acute intake occurred at age 1825 days (only). The set of beginning ages is somewhat arbitrary but is designed with the intent that no period of rapid metabolic and physiological changes be completely ignored.

Table 1. The matrix of dose rates to a specified tissue illustrative of the matrix calculated by AGEDOS.^a

$\dot{D}_U(0, 0)^b$	$\dot{D}_U(100, 0)$	$\dot{D}_U(365, 0)$	$\dot{D}_U(1825, 0)$	$\dot{D}_U(3650, 0)$	$\dot{D}_U(5475, 0)$	$\dot{D}_U(7300, 0)$
$\dot{D}_U(0, 0.01)$	$\dot{D}_U(100, 0.01)$	$\dot{D}_U(365, 0.01)$	$\dot{D}_U(1825, 0.01)$	$\dot{D}_U(3650, 0.01)$	$\dot{D}_U(5475, 0.01)$	$\dot{D}_U(7300, 0.01)$
$\dot{D}_U(0, 0.1)$	$\dot{D}_U(100, 0.1)$	$\dot{D}_U(365, 0.1)$	$\dot{D}_U(1825, 0.1)$	$\dot{D}_U(3650, 0.1)$	⋮	⋮
$\dot{D}_U(0, 1.0)$	$\dot{D}_U(100, 1.0)$	$\dot{D}_U(365, 1.0)$	$\dot{D}_U(1825, 1.0)$	⋮	⋮	⋮
$\dot{D}_U(0, 10.0)$	$\dot{D}_U(100, 10.0)$	$\dot{D}_U(365, 10.0)$	⋮	⋮	⋮	⋮
$\dot{D}_U(0, 100.0)$	$\dot{D}_U(100, 100.0)$	⋮	⋮	⋮	⋮	⋮
$\dot{D}_U(0, 365.0)$	⋮	⋮	⋮	⋮	⋮	⋮
$\dot{D}_U(0, 730.0)$	⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮	⋮
$\dot{D}_U(0, 7300.0)$	⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮	⋮
$\dot{D}_U(0, T_{end})$	⋮	⋮	⋮	⋮	⋮	⋮

^aThe matrix actually generated by AGEDOS is based on a much finer time grid than is illustrated here.

^bEach value $\dot{D}_U(B, S)$ is the dose rate at time S (age B + S) following an acute unit intake U at time 0 (age B).

The set of times T following the acute intake at which dose rates are to be calculated will be referred to as the "time grid system." The time grid system should include relatively densely spaced times shortly after exposure to properly describe the rapid changes in dose rates that may occur in some organs immediately following an acute intake. At relatively long times after the acute intake, the times in the time grid system may become more widely spaced. However, one must keep in mind that information concerning dose rates due to arbitrary intake patterns will be inferred from the dose rates that are estimated assuming acute intakes. Hence it is essential to obtain as accurate a description as possible of the dose rate curve for an acute intake.

Of course, the desire for accuracy must be balanced somewhat with considerations of computing time and storage requirements. Although the optimal time grid system will vary with the radionuclide and with the particular metabolic models used, we have found that a convenient time grid system for most applications consists of the times (in days): 0, 0.001, 0.002, ..., 0.01, 0.02, ..., 0.1, 0.2, ..., 1.0, 2.0, ..., 10.0, 20.0, ..., 100.0, 150.0, 200.0, 250.0, 300.0, 365.0, 450.0, 540.0, 630.0, 730.0, 830.0, 930.0, 1095.0, 1460.0, and so forth, continuing at intervals of 365.0 days until a specified ending time is reached. This time grid system is now incorporated in the AGEDOS computer code but may be changed easily by the user who prefers a different grid. For ease of exposition, the relatively coarse time grid system indicated in the first column of Table 1 will be used in the illustrations in the following section.

Estimating Dose Rates for Arbitrary Intake Patterns

Assume that a person becomes exposed to a radionuclide at age b and time $t = 0$ and experiences an intake pattern $I(t)$ until age $b + T$. The function $I(t)$ may take any nonnegative values, including zero, as t varies from 0 to T . The problem is to estimate the dose rate $\dot{D}_I(b, b + T)$ to a specified organ, assuming that the dose rates to that organ due to an acute unit intake are known for each of the beginning ages and subsequent times used in AGEDOS (see the illustration in Table 1). The age at initial exposure, b , may be any nonnegative

integral multiple of 365 days (including zero), and the value T may be any of the times in the T grid system.

The basic approach for estimating $\dot{D}_I(b, b + T)$ may be described in terms of a few conceptual steps, using the illustrative time grid system indicated in Table 1:

- (1) The age interval from b to b + T is divided into N subintervals by the decreasing values b + T - 0.01, b + T - 0.1, b + T - 1.0, b + T - 10.0, b + T - 100.0, b + T - 365.0, b + T - 730.0, b + T - 1095.0, and so forth, until the age b is attained. A_1 will denote the subinterval from b + T - 0.01 to b + T, A_2 the subinterval from b + T - 0.1 to b + T - 0.01, and so forth, until one reaches the subinterval A_N whose left endpoint is b (Fig. 1). The smaller distances between values near the age b + T are required because of the potentially rapid changes in dose rates at age b + T corresponding to intakes just prior to that age.
- (2) The dose rate at age b + T due to the total intake between ages b and b + T is viewed as a sum of several dose rates at b + T:

$$\dot{D}_I(b, b + T) = \sum_{j=1}^N \dot{D}_{I_j}(b_j, b + T),$$

where

I_j is the intake over the interval A_j ;

b_j is the left endpoint of A_j ;

$$\dot{D}_{I_j}(b_j, b + T) = \dot{D}_{I_j}[b_j, b_j + (b - b_j + T)].$$

Thus the intake I_j agrees with I on the interval A_j but is zero elsewhere.

- (3) Each value $\dot{D}_{I_j}(b_j, b + T)$ is replaced by an approximation in terms of acute intakes, assuming I_j does not already represent an acute intake. Thus the value $\dot{D}_I(b, b + T)$ is now to be approximated by a sum of the form

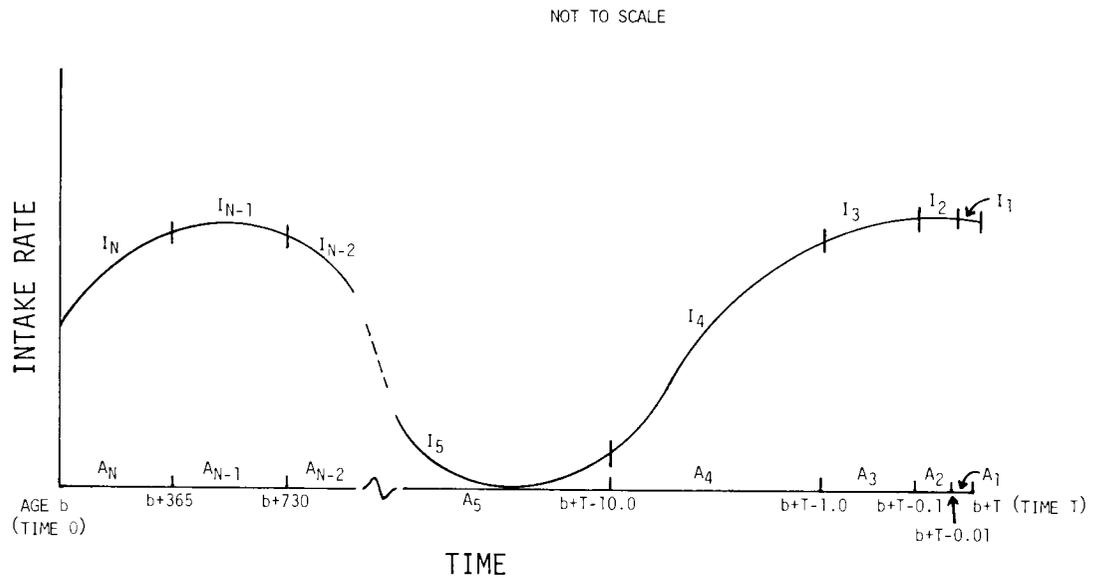


Figure 1. The interval from age b to age $b+T$ is divided into N subintervals by the decreasing values $b+T-0.01$, $b+T-0.1$, $b+T-1.0$, and so forth. The resulting intervals are denoted A_1, A_2, \dots, A_N . The restriction of the intake rate I to the subinterval A_j is denoted by I_j . The dose rate at age $b+T$ due to the intake on A_j is approximated by a dose rate that would result from an acute intake at the left endpoint of A_j . The latter dose rate is obtained by interpolating between appropriate dose rates stored by AGEDOS.

$$\sum_{j=1}^N \dot{D}_{a_j U}(b_j, b + T) ,$$

where

U is an acute unit intake;

a_j is the integral of I_j over A_j ;

$$\dot{D}_{a_j U}(b_j, b + T) = \dot{D}_{a_j U}[b_j, b_j + (b - b_j + T)] .$$

Note that $\dot{D}_{a_j U}(b_j, b + T) = a_j \dot{D}_U(b_j, b + T)$. It is convenient, and usually conservative, to assume that the acute intake occurred at age b_j .

- (4) The value $\dot{D}_U(b_j, b + T)$ represents a dose rate from an acute unit intake. In most cases this dose rate will not be among those calculated by AGEDOS and stored in the basic matrix of dose rates (Table 1). However, $\dot{D}_U(b_j, b + T)$ can be approximated by linear interpolation between two of the dose rates stored in that matrix. In fact, $\dot{D}_U(b_j, b + T)$ can be rewritten as $\dot{D}_U[b_j, b_j + (b - b_j + T)]$, and the points b_j have been chosen so that $b - b_j + T$ is among the times after intake considered in the basic dose rate matrix. One simply chooses consecutive beginning ages B_1 and B_2 considered in the basic matrix and satisfying $B_1 \leq b_j \leq B_2$, and interpolates:

$$\begin{aligned} \dot{D}_U(b_j, b + T) &\approx a \dot{D}_U[B_1, B_1 + (b - b_j + T)] \\ &\quad + (1 - a) \dot{D}_U[B_2, B_2 + (b - b_j + T)] \end{aligned}$$

where

$$a = (B_2 - b_j) / (B_2 - B_1) .$$

The calculation of $\dot{D}_I(b, b + T)$ for ages b not considered in the basic AGEDOS matrix is therefore a straightforward but tedious process. A relatively short computer code, CONVOL, has been developed to perform this calculation. The user simply supplies the values for b and T and the desired intake rate function I (as a step function). A listing of the CONVOL code is given in the Appendix, along with a listing of the AGEDOS code.

The General Scheme for Estimating the Distribution of Activity of Radionuclides in the Body

For modeling purposes the complex behavior of radionuclides is simplified conceptually by viewing the body as a set of compartments. A compartment may be any subdivision of the body which is distinguishable on anatomical, physiological, or physical bases, and which is to be considered separately for purposes of estimating activity or dose. For ease of exposition we shall use the terms "compartment" and "organ" interchangeably, even though some of the compartments considered in this report may represent only a portion of a structure usually considered to be an organ, and some compartments may represent portions of the body usually not associated with organs. Examples of compartments used in this study are the stomach, the pulmonary region of the lung, the entire blood supply, and the surface of trabecular (spongy) bone.

Within a compartment there may be more than one "pool" of activity. We define a pool as any fraction of the activity within a compartment that has a biological half-time distinguishable from the half-time(s) of the remainder of activity within the compartment. The definitions of pool, compartment, and organ vary considerably in the literature; we have chosen definitions that are convenient for our purposes.

The major compartments used in our study, and the movement of activity among these compartments, are indicated schematically in Fig. 2. Activity entering the body by ingestion is assumed to originate in the stomach compartment, and activity entering through inhalation is assumed to originate in a compartment within the lung (either the tracheobronchial, pulmonary, or nasal-pharyngeal region). From the stomach the activity is viewed as passing in series through the small intestine, the upper large intestine, and the lower large intestine, from which it may be excreted. (Exceptions such as noble gases and tritium may be treated as in the previous RADRISK methodology.) Also, activity reaching the small intestine may be absorbed through the wall into the bloodstream, from which it may be taken in parallel into any of several compartments within the skeleton, liver, kidney, thyroid gland, and other tissues. Activity in the lungs may reach the bloodstream directly, or it may enter blood indirectly through the stomach or lymphatic system. The respiratory system, gastrointestinal tract, and

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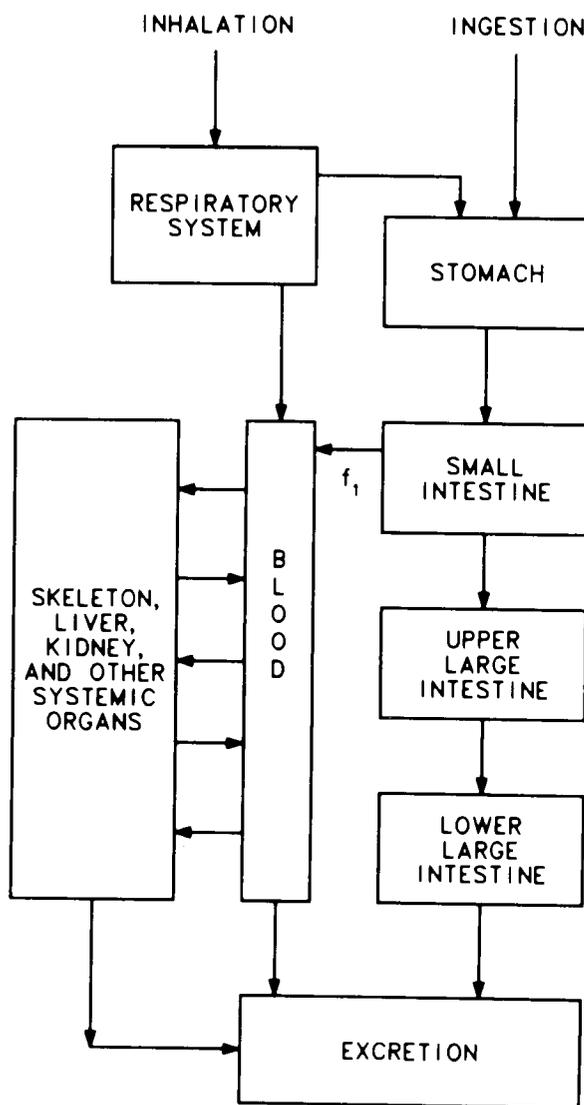


Figure 2. The major compartments considered in AGEDOS, and the movement of activity among these compartments, are indicated schematically. Various subcompartments in the respiratory system, skeleton, and other compartments are also considered.

selected systemic compartments are discussed in detail in a later section.

In all calculations performed with AGEDOS, it is assumed that only the first nuclide in a chain of radioactive species is taken into the body. The formation and dynamics within the body of daughters in the chain are considered explicitly, however.

Throughout, $A_{iq}(t)$ denotes the activity of the i th species of the chain in a compartment indexed by subscript q . If we consider $A_{iq}(t)$ over an interval that is small enough for changes with age to be neglected, the time rate of change of $A_{iq}(t)$ may be modeled by a system of differential equations of the form

$$\dot{A}_{ik} = -(\lambda_i^R + \lambda_{ik}^B) A_{ik} + c_{ik} \left(\lambda_i^R \sum_{j=1}^{i-1} B_{ij} \sum_{r=1}^{L_j} A_{jr} + p_i \right) , \quad (1)$$

$$k = 1, \dots, L_i ,$$

where compartment q is assumed to have L_i separate pools of activity, and where

A_{ik} = activity of species i in the k th pool,

λ_i^R = radioactive decay constant for species i (day^{-1}) ($\ln 2$ divided by the radioactive half-life (days) of species i),

λ_i^B = rate coefficient (time^{-1}) for biological removal of species i from the compartment,

L_j = number of exponential terms in the retention function for species j ,

B_{ij} = branching ratio of the nuclide j to species i ,

p_i = inflow rate of i th species into the compartment.

The subsystem described by these L_i equations can be interpreted as a biological compartment in which the fractional retention of species i is governed by the function

$$R_i(t) = \sum_{k=1}^{L_i} c_{ik} \exp[-(\lambda_i^R + \lambda_{ik}^B)(t)] .$$

The subscript k in Eq. (1) represents the k th term of the retention function, and the coefficients c_{ik} can be thought of as "pathway fractions," that is, the fractions associated with the various pools of activity within the compartment. (For purposes of age-dependent metabolic modeling it is desirable, but not essential, that a sufficient number of anatomical compartments be identified that retention in each compartment can be approximated with a single exponential term.)

If the inflow rates p_i into the compartment remained constant, then the explicit solutions $A_{ik}(t)$, of Eq. (1) would be^{10,11}

$$A_{ik}(t) = \begin{cases} D_{1k} + H_{1k} \exp(-\lambda_{1k}t) & \text{if } i = 1, \\ D_{ik} + H_{ik} \exp(-\lambda_{ik}t) + \sum_{j=1}^{i-1} \sum_{m=1}^{L_j} G_{ikjm} \exp(-\lambda_{jm}t) & \text{if } i > 1, \end{cases}$$

where the coefficients D_{ik} , H_{ik} , and G_{ikjm} may be calculated from the following recursions:

$$D_{ik} = \begin{cases} c_{1k} p_1 / \lambda_{1k} & \text{if } i = 1, \\ (c_{ik} / \lambda_{ik}) \left[\lambda_i^R \sum_{j=1}^{i-1} B_{ij} \sum_{m=1}^{L_j} D_{jm} + p_i \right] & \text{if } i > 1, \end{cases}$$

$$H_{ik} = \begin{cases} A_{1k}(0) - D_{1k} & \text{if } i = 1, \\ A_{ik}(0) - D_{ik} - c_{ik} \lambda_i^R \sum_{j=1}^{i-1} \sum_{m=1}^{L_j} (E_{ijm} + B_{ij} H_{jm}) \\ \quad \times (\lambda_{ik} - \lambda_{jm})^{-1} & \text{if } i > 1, \end{cases}$$

and

$$G_{ikjm} = c_{ik} \lambda_i^R (E_{ijm} + B_{ij} H_{jm}) (\lambda_{ik} - \lambda_{jm})^{-1}, \quad i > 1,$$

where

$$E_{ijm} = \begin{cases} \sum_{r=j+1}^{i-1} B_{ir} \sum_{\mu=1}^{L_r} G_{r\mu jm} & \text{if } j \leq i - 2 \\ 0 & \text{if } j = i - 1 \end{cases}.$$

The following recursion is used to calculate the E_{ijm} .

$$E_{ijm} = \begin{cases} 0 & \text{if } i = 2 \\ \sum_{r=j+1}^{i-1} B_{ir} \lambda_r^R \sum_{\mu=1}^{L_r} c_{r\mu} (E_{rjm} + B_{rj} H_{jm}) (\lambda_{r\mu} - \lambda_{jm})^{-1} & , \\ \text{for } j = 1, \dots, i - 2, \text{ and } i > 2 \end{cases}.$$

An obvious problem in using Eq. (1) as a model of the rate of change of activity of a radionuclide in a compartment is that the inflow rate, p_i , of species i will not remain constant with time. Moreover, since changes with age in the uptake and retention of radionuclides by a compartment are being considered, it cannot be assumed that the biological removal rates, λ_{ik}^B , and "pathway fractions," c_{ik} , remain constant over an extended period.

These problems are handled by dividing the time interval over which dose rates are to be considered into relatively small subintervals over which all parameters in Eq. (1) may be treated as constant. The length of these subintervals vary from a fraction of a day at times close to the initial acute intake of the radionuclide to one year at times very remote from intake. These lengths were chosen through considerations of the potential rates of change with time of the inflow rate, biological removal rate, and pathway fractions. The problem is essentially that of approximating a continuous function by a step function; this requires shorter steps over intervals of rapid change than over intervals of little change. At times close to an acute intake, a close approximation of the inflow rate into some compartments may require steps that are only a

small fraction of a day. Also, the removal rates and pathway fractions for very young children may change significantly over periods of a year or more, so that steps shorter than one year may be required for the first year or two of life.

The inflow rate p_i on each subinterval is taken to be that constant inflow rate which would yield the total activity of the radionuclide that flows out of the feeding compartments during the same subinterval. (Of course, if a portion of the outflow from the feeding compartments proceeds along another pathway, that portion is not included in the calculation of p_i .) For example, the inflow rate p_i to the small intestine from the stomach during a subinterval of length 0.01 days is taken to be $\lambda_s \tilde{A}_s / 0.01$, where λ_s is the outflow rate coefficient (day^{-1}) from the stomach to the small intestine, and \tilde{A}_s is the integrated activity of the radionuclide in the stomach during the same time interval.

The values of biological half-times and pathway fractions used on each subinterval are determined by linear interpolation of the values input for ages 0, 100, 365, 1825, 3650, 5475, and 7300 days. For example, if the calculation is for a person of age 500 days at the beginning of the subinterval, then the half-times and pathway fractions used on that subinterval are determined by linear interpolation from the values input for ages 365 days and 1825 days.

Converting from Activity to Dose Rates

In the preceding section we discussed a general scheme for estimating the distribution of activity in the body as a function of time after intake of a radionuclide. The activity of a radionuclide in a compartment is a measure of the energy being emitted in that compartment at time t . In this section we discuss how one may relate the estimated activities of a radionuclide in all compartments at time t to the dose rate to a specific organ at time t . The problem is to estimate the fraction of the energy emitted by decay of the radionuclide in each compartment ("source organ") that is absorbed by the specified ("target") organ. This absorbed fraction is incorporated into the calculation through the use of dosimetric S-factors.^{12,13} The S-factor $S(X \leftarrow Y)$ is defined for our use as the average dose rate to target organ X from one

unit of activity of the radionuclide uniformly distributed in source organ (or compartment) Y. The units for S-factors depend on the units used for activity and time; thus the S-factor units may be rad/ μ Ci-day or Gy/Bq-s, for example.

The dose rate $[DR_i(X)](t)$ to target organ X at time t due to radionuclide species i in source organs Y_1, Y_2, \dots, Y_M is estimated to be

$$[DR_i(X)](t) = \sum_{k=1}^M [DR_i(X \leftarrow Y_k)](t) ,$$

where

$$[DR_i(X \leftarrow Y_k)](t) = S_i(X \leftarrow Y_k) A_{ik}(t) .$$

In the preceding equation $A_{ik}(t)$ is the activity, at time t, of species i in source organ Y_k .

The dose rate to target organ X from a unit activity of a nuclide in source organ Y due to emissions of type m may be calculated from the expression

$$S_m(X \leftarrow Y) = c \sum f_m E_m \Phi_m(X \leftarrow Y) ,$$

where

c = a constant that depends on the units of dose, energy, and time being used,

f_m = intensity of decay event (number per disintegrations),

E_m = average energy of decay event (MeV),

$\Phi_m(X \leftarrow Y)$ = specific absorbed fraction = fraction of emitted energy from source organ Y absorbed by target organ X per gram of X,

and where the summation is taken over all events of type m. In the following paragraphs we discuss briefly the estimation of the absorbed fractions $\Phi_m(X \leftarrow Y)$ for photon emissions and beta, positron, electron, and alpha decays. More complete descriptions can be found in Refs. 12 and 13.

The S-factor is similar in concept to the SEE factor (specific effective energy) used by ICRP Committee 2 in their recent Publication 30.¹⁴ The SEE factor includes a quality factor for the radiation emitted during the transformation. The S-factor as used in the AGEDOS analysis does not include consideration of the quality factor. The two quantities are related as

$$SEE_m(X \leftarrow Y) = k \sum Q_m S(X \leftarrow Y)_m$$

where

- Q_m = the appropriate quality factor for the mth radiation type
- k = a constant that depends on the units used in the S-factor and SEE factor.

It should be evident that the value $S_m(X \leftarrow Y)$ is a function of the age of the individual, because the specific absorbed fraction $\Phi_m(X \leftarrow Y)$ used to calculate $S_m(X \leftarrow Y)$ may depend on the relative geometries of X and Y as well as the mass of the target organ X.¹⁵ We first discuss the determination of S-factors for various radiation types for a fixed age, and we later describe the introduction of age-dependence into the S-factors.

PHOTON EMISSIONS

There are two principal computational procedures available for estimating specific absorbed fractions for photon emissions: The "Monte Carlo method"¹² and the "point-source kernel method."¹⁶ Each of these will be discussed briefly.

The Monte Carlo method is a computerized approach for estimating the probability of a photon interaction within target organ X after emission from source organ Y. This method is carried out as follows¹² for all combinations of source and target organs and for several (usually 12) photon energies. The body is represented by an idealized phantom in which the internal organs are assigned masses, shapes, positions, and attenuation coefficients based on their chemical composition. A mass attenuation coefficient μ_0 is chosen, where μ_0 is greater than or equal to the mass attenuation coefficients for any region of the body.

The photon begins its course from organ Y in a randomly chosen direction, and a potential site of an interaction is chosen by taking the distance traveled as $-\ln r/\mu_0$, where r is a random number distributed between 0 and 1. The point on the line at this distance from the photon's starting point and in the direction of the photon's path is tested to determine the region of the body containing this point. The computer randomly selects either a favorable or an unfavorable outcome; the probability of a favorable outcome is μ_i/μ_0 , where μ_i is the total mass attenuation coefficients for the i th region. If the outcome is unfavorable, then it is assumed that no interaction occurs, and the photon proceeds another randomly chosen distance along the same line of flight and the game is repeated. If the outcome is favorable, then it is assumed that an interaction occurs. With each interaction, an artificial "weight" of the photon (initially set at unity) is reduced by an amount equal to the expectation of absorption which the photon would have in the actual physical processes. The flight of the photon is terminated (1) if it escapes the body; (2) if its energy falls below a cutoff value -- typically 4 keV; or (3) if its weight falls below 10^{-5} ; in the latter two cases, the energy is considered to be totally absorbed. The energy deposition for an interaction is determined according to a standard equation.¹²

The second procedure for estimating specific absorbed fractions for photon emissions involves integration of a point-source kernel $\Phi(x)$, where x is the distance from the point source. The function Φ is composed of inverse-square and exponential attenuation factors that reflect the loss of energy from photon interactions and a build-up factor that reflects the contribution of scattered photons to dose:¹⁶

$$\Phi(x) = \mu_{en}/\rho \cdot 1/(4\pi x^2) \cdot e^{-\mu x} \cdot B_{en}(\mu x) ,$$

where

$\Phi(x)$ = the point-isotropic specific absorbed fraction,

μ_{en} = the linear energy-absorption coefficient,

μ = the linear attenuation coefficient,

ρ = the density of the medium,

x = the distance from the source,

$B_{en}(\mu x)$ = the energy-absorption build-up factor.

One must integrate this kernel over all distances $x = |u - v|$ corresponding to pairs of points (u,v) , where u lies in the source organ Y and v lies in the target organ X .

Both the Monte Carlo method and the point-kernel method may involve significant sources of error, depending on the energy and the organs under consideration.¹⁷ The Monte Carlo method is a probabilistic approach and produces significant errors in situations where few interactions are expected to occur, such as cases involving target organs which are relatively small or remote from important sources of activity. The point-source kernel method technically is valid only for a homogeneous, unbounded medium. Hence this method may lead to large errors in cases involving significant variations in composition or density of body tissue, or in cases where target organs or important sources of activity lie near a boundary of the body. Cristy and Eckerman¹⁸ have been able to reduce errors in calculations of absorbed fractions by making extensive use of the geometrical reciprocity theorem and by developing correction factors for values generated by the point-kernel method. That is, they use a weighted average of $\Phi_m(X \leftarrow Y)$ and the reciprocal $\Phi_m(Y \leftarrow X)$ produced by the Monte Carlo method, but replace this value with the corrected point-kernel value if the former is statistically unreliable.

BETA, POSITRON, AND ELECTRON DECAY

Beta particles, positrons, and discrete electrons are usually not sufficiently energetic to contribute significantly to cross-irradiation doses of targets separated from a source organ. Thus, it is generally assumed that $\Phi_m(X \leftarrow X)$ is just the inverse of the mass of organ X , and if source and target are separated, $\Phi_m(X \leftarrow Y) = 0$. Exceptions occur when the source and target are in close proximity, which is the case, for example, with various skeletal tissues. Absorbed fractions for cross irradiations among skeletal tissues are computed as a function of energy, using a method described by Eckerman.¹⁹

ALPHA PARTICLE DECAY

The energy of alpha particles and their associated recoil nuclei is generally assumed to be absorbed in the source organ. Therefore, $\Phi_{\alpha}(X \leftarrow X)$ is taken to be the inverse of the organ mass, and $\Phi_{\alpha}(X \leftarrow Y) = 0$ if X and Y are separated. Special calculations are performed for active marrow and endosteal cells in bone, based on a method of Thorne.²⁰

CALCULATION OF S-FACTORS FOR DIFFERENT AGE GROUPS

For non-penetrating radiations the calculation of age-dependent specific absorbed fractions (and hence of S-factors) is straightforward. Since all emitted energy is assumed to be absorbed by the source organ, the only age-dependent variable in this case is the mass of the organ. The problem is considerably more complex for penetrating radiations, however, because the changing shapes and relative positions of the organs must be taken into account in this case in the development of specific absorbed fractions.

Specific absorbed fractions for photon emissions of various energies have been calculated by Cristy and Eckerman¹⁸ for age groups 0, 1, 5, 10, and 15 years. These absorbed fractions were calculated using a combination of the Monte Carlo and point-source kernel methods as described earlier, but using different mathematical phantoms of the human body for each age group. An external view of these mathematically represented phantoms, together with comparative cross-sections of the middle trunk regions of the newborn and adult phantoms, are shown in Fig. 3.²¹ Results of Cristy and Eckerman¹⁸ indicate that the specific absorbed fractions vary substantially with age for some energies, source organs, and target organs (see Fig. 4).

Specific absorbed fractions for adults (age 20 years) are taken from Ref. 12. To avoid discontinuities in calculated doses, S-factors for any non-adult age are calculated from those for ages 0, 1, 5, 10, 15, and 20 years by linear interpolation.

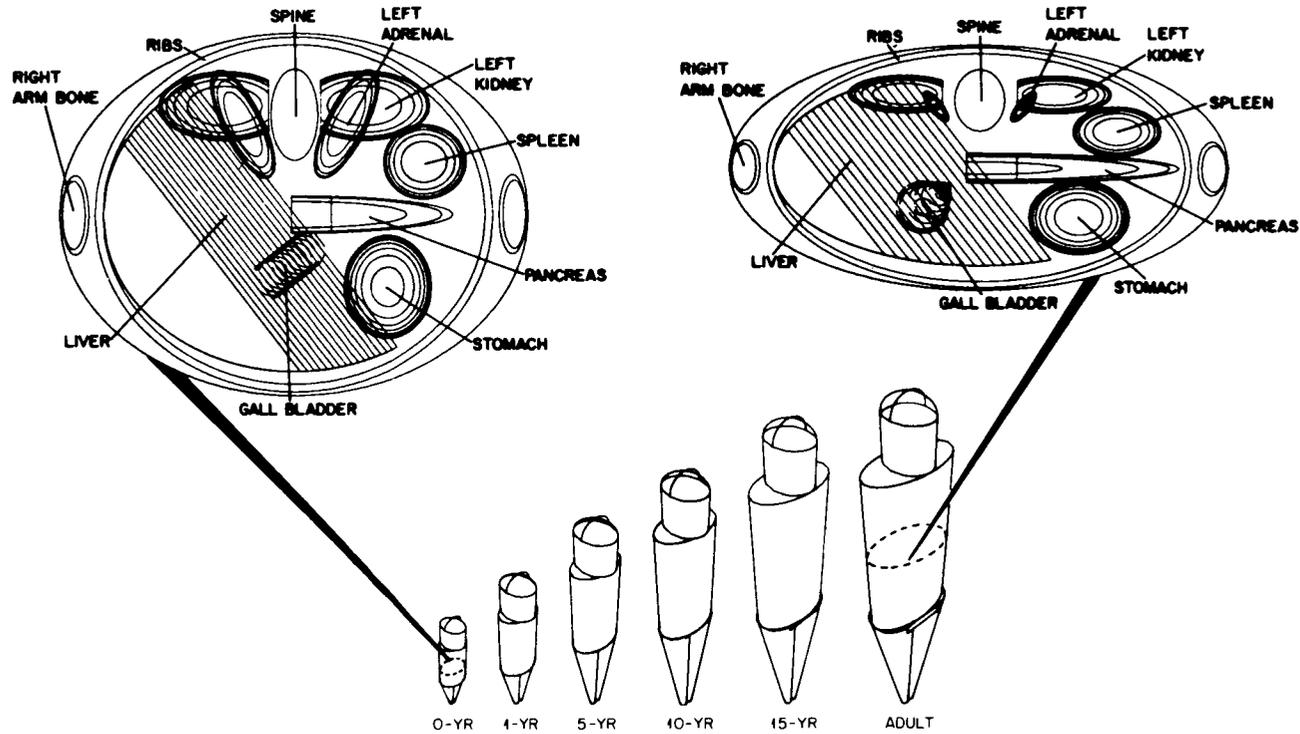
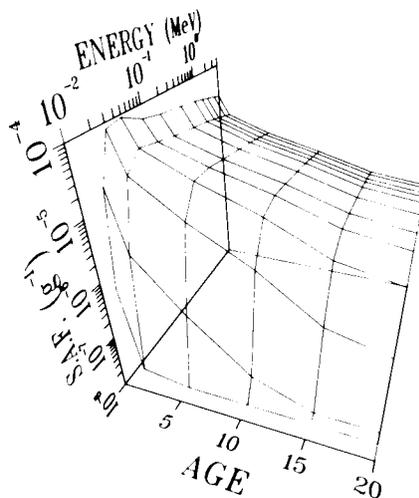
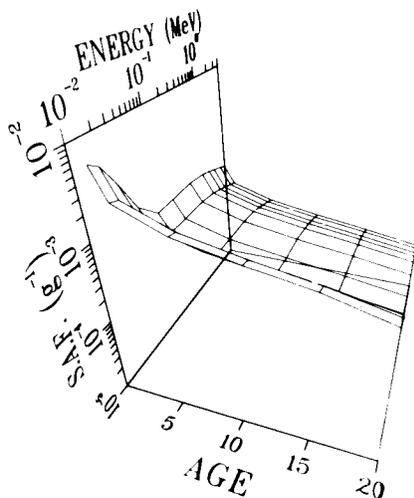


Figure 3. An external view of the mathematically represented phantoms of Cristy, together with comparative cross-sections of the middle trunk regions of the newborn and adult phantoms.²¹

LIVER -to- OVARIES



LIVER -to- LIVER



LUNGS -to- BREAST

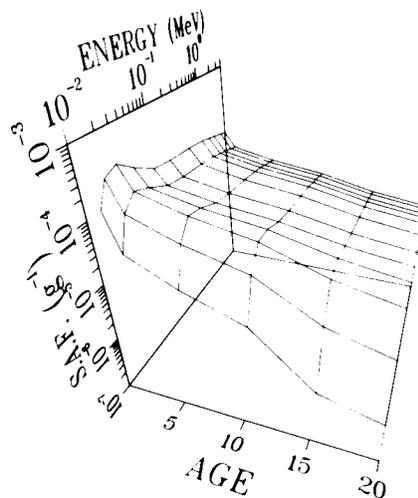


Figure 4. (M. Cristy) The notation "Y-to-X" indicates that Y is the source organ and X is the target organ. The figures show the specific absorbed fractions (SAF's) for photons for various source and target organs, energies, and ages. A typical pattern at all energies is that the SAF (the fraction of energy emitted from within Y that is absorbed by X per gram of X) decreases with age. The effects of the changes with age in the geometries and masses of organs are most marked for low-energy photons.

3. DIFFERENCES WITH AGE IN THE TRANSLOCATION AND RETENTION OF NUCLIDES IN THE BODY

In this section we discuss potential differences with age in the respiratory and gastrointestinal tracts, the skeleton, and certain other tissues. Since some of the possible differences with age mentioned in the discussions of the respiratory and gastrointestinal tracts are not strongly supported by experimental evidence at this time, we recommend the use of adult models for both regions (with the exception of f_1 , the fraction absorbed from the small intestine) until more conclusive evidence to the contrary is available. Changes with age in the skeleton and other systemic organs and tissues are discussed with regard to metabolic models for strontium, plutonium and other actinides, and cesium.

The Respiratory Tract

The lung model used in AGEDOS for particulate deposition and retention is the Task Group Lung Model (TGLM) for adults developed for the International Commission on Radiation Protection (ICRP).²² The ICRP model views the lung as divided into four major regions: nasal-pharynx (NP), tracheobronchial (TB), pulmonary region (P), and lymphatic tissue (L). Each of the NP, TB, and P regions is assigned a deposition fraction depending on the size (the activity median aerodynamic diameter or AMAD) of the particle carrying the nuclides. The biological clearance half-times for the NP, TB, P, and L regions are assumed to be a function of the solubility properties of the particles carrying the nuclides.

To investigate changes with age in the functions of the lung it is helpful to view the lung as a series of symmetrically bifurcating channels as described by the adult lung model of Weibel.²³ Particles carried by inhaled air deposit in the lung airways by processes including diffusion, impaction, and sedimentation. The activity of a radionuclide deposited in a given region of the lung is thought to be controlled by the diameters and numbers of airways in the various regions, the respiratory rate, the volume of air taken in during each breath, and the particle diameter. The net effect of the changes with age in these quantities on the deposition fractions in the NP, TB, and P regions have been estimated using different models.^{24,25} It is suggested by these models that there is little variation with age in the deposition

fractions for those particle sizes usually considered (mean particle size one micron or less with a geometric standard deviation of about 2.8), but there could be a strong age dependence in the relative fractions of very large particles (10 microns) deposited in the TB and P regions. This is viewed as a result of the changing deposition patterns in the NP region, which might retain nearly all of the extremely large particles that enter. Thus, changes in the NP region of a few percent could lead to large relative changes in the percentages of activity deposited in the remaining regions.

A radionuclide deposited in any of the three primary regions may decay, depositing its energy in the local tissue and (for penetrating radiations) other tissues of the body. Competing with radioactive decay, however, are biological processes that may translocate the material from the lung into the bloodstream, lymphatic system, or gastrointestinal tract. Some material in the TB region is carried to the stomach by a slowly flowing mucociliary blanket lining the tracheo-bronchial passages. It has been conjectured²⁴ that the mucal blanket may flow more rapidly in young children than in adults, so that the probability of a given radioactive atom undergoing decay while in the TB region would increase with age. However, even if there were changes with age in the rate at which material is carried from the TB region to the stomach, this would not cause substantial differences in estimates of dose except perhaps for inhaled radionuclides with half-times of a few minutes.

There is a strong age dependence in the volume of air inhaled, which increases from near 20 ml/sec at birth to near 300 ml/sec in adults. This and other suggested changes with age in the functions of the respiratory tract are illustrated in Fig. 5.

The Gastrointestinal (GI) Tract

Material ingested or reaching the stomach via the mucociliary blanket moves in sequence through the stomach, small intestine, upper large intestine, and lower large intestine. The adult model most commonly used for radiation protection depicts an exponential removal from each compartment, characterized by a single removal rate that depends

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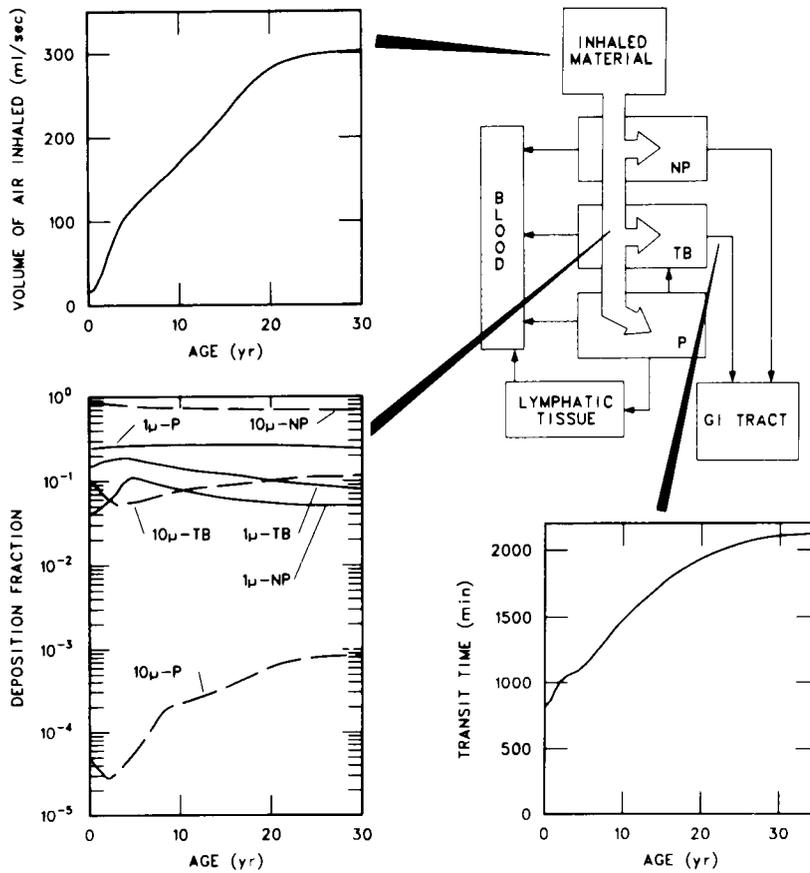


Figure 5. Potentially significant changes with age that may affect the deposition of radioactive material in the lung and its subsequent relocation.

only on the compartment.²⁶ Little information is available concerning these four removal constants as a function of age in humans. Results of experiments with rats suggest that the half-time for removal from the two segments comprising the large intestine may increase with age, primarily because of the increasing tract length. Transit times for the stomach and small intestine may be shortest in the very young because of the elevated liquid content of the diet of infants.²⁷

Radionuclides flowing through the GI tract may be absorbed into the bloodstream from any of the four major compartments, although the fractions absorbed from the stomach and large intestines are usually considered negligible compared with the fraction from the small intestine. The fraction from the small intestine, denoted f_1 , varies considerably between radionuclides and between the foodstuffs to which they are attached. Experimental studies suggest that the f_1 value for some radionuclides may be orders of magnitude higher in newborns than in adult mammals, with largest relative changes with age occurring for those nuclides with small adult f_1 values.²⁷

For many radionuclides there appears to be a rapid decrease in the f_1 value in the first year of life. This may be related somewhat to the dramatic change in diet during the first year of life, which could significantly affect both the removal rate from the small intestine to the upper large intestine and the absorption rate from the small intestine to the bloodstream. The removal rate from the small intestine to the bloodstream comprises three processes mediated by the epithelial wall of the intestine. Material is removed from the contents of the small intestine to the epithelial wall with a removal rate affected by the composition of the contents. From the wall a radionuclide may be absorbed into the bloodstream or may return to the intestinal contents due to sloughing of the cells of the wall. The rate of cell sloughing remains near zero until weaning, at which time the introduction of hard food into the diet creates a shearing force that sharply accelerates the cell sloughing process.²⁷

For some radionuclides it may be reasonable to assume that absorption through the wall of the small intestine in mammals is a relatively non-selective process not governed by the body's needs. Under this assumption one modeler has attempted to estimate the changes in f_1 in

human infants by extrapolating from measured values in rats, with the extrapolation based on comparison of the three processes mentioned in the preceding paragraph.²⁷

Typical changes in f_1 (in humans) predicted from this approach are illustrated in Fig. 6 for two classes of radionuclides, namely, those with small adult f_1 values (upper curves) and those with relatively large f_1 values (lower curve). While such models may be instructive in a broad, qualitative sense, there are sufficient differences in the digestive and absorptive processes in the GI tracts of rats and humans to leave any quantitative extrapolations extremely uncertain. For example, data obtained for rats indicate that the transfer rate from intestinal contents to the epithelial wall may be increased significantly just prior to weaning. Neonatal rats possess very poorly developed immune systems and may require this increased uptake to supplement the intake of antibodies. Since human immune systems are much better developed at birth, changes in epithelial uptake prior to weaning may not be comparable for rats and humans.²⁷

Recent work has indicated that the wall of the small intestine is a more selective tissue than was previously thought, and absorption of nutrients is controlled by the body's needs to a greater extent than had been believed.^{28,29} It has been known for some time that the fraction of calcium or iron absorbed depends on the body's needs for these elements, so the f_1 value for these elements and for chemically similar elements such as strontium and radium (in the case of calcium) and plutonium (in the case of iron) may change as the need for calcium or iron changes during various stages of life. Recent results have indicated the change with age in the absorbed fraction of some trace elements such as zinc and manganese may also reflect a homeostatic adaptation to the age-related shift in the element supply status.³⁰ In the case of some essential elements such as potassium and chemically similar radioelements such as rubidium and cesium, absorption into the bloodstream is nearly complete at all ages,³¹ so that changes with age and any possible homeostatic adaptations in absorption are not discernable.

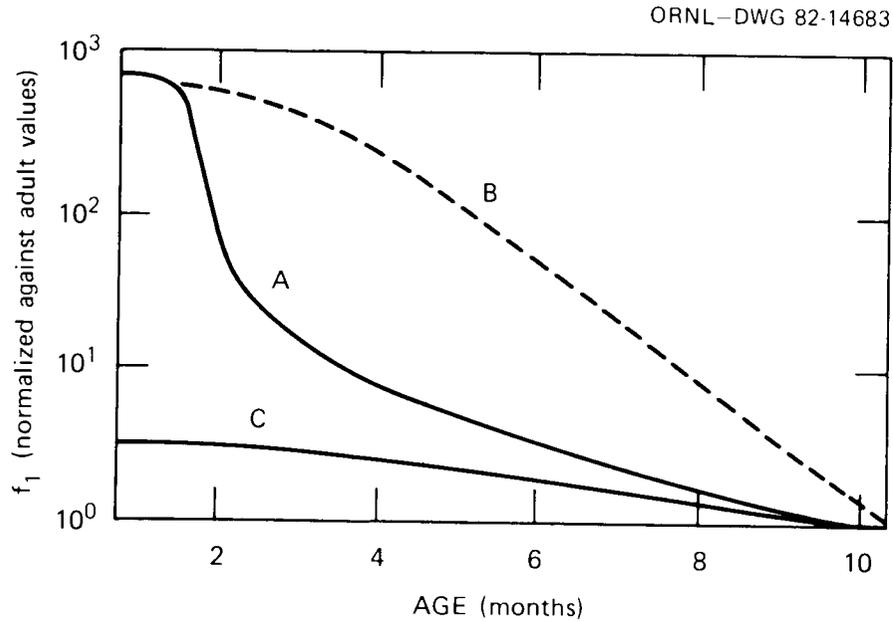


Figure 6. One modeler has attempted to estimate changes with age in the absorbed fraction f_1 in humans by scaling from experimental data for rats.²⁷ For poorly absorbed radionuclides the changes with age estimated in this way would be represented by a curve such as A or B. If the f_1 value for adults is relatively large (say, 0.2 or higher), then the decrease with age in f_1 cannot be nearly as marked but might be represented by curve C, for example.

Examples of Metabolic Models for Radioelements Reaching the Bloodstream

Activity reaching the bloodstream through the respiratory or gastrointestinal tract may be excreted through the intestines, kidneys, or skin, or it may be allotted among the various organs and tissues of the body. Except for the absorption fraction f_1 , retention and translocation of radionuclides by the respiratory and GI tracts do not appear to depend a great deal on the special properties of the radionuclides. Once a nuclide reaches the bloodstream, however, its special characteristics may play an important role in determining its course. Because of the large number of nuclides and organs to be considered and the relatively small amount of nuclide-specific age-dependent data available, it may be many years before there is a fairly complete set of age-dependent models for systemic organs.

In order to examine some of the problems involved in age-dependent modeling of nuclide retention in systemic organs, we shall look in some detail at metabolic models for strontium, plutonium and other actinides, and cesium. It will be apparent from the description of these models that a large amount of effort has been devoted to obtaining a detailed model of the skeleton. This is because of the high degree of radiosensitivity of the skeleton and its propensity to accumulate a great many radionuclides. The ICRP identifies the radiosensitive tissues in the skeleton as the haemotopoietic stem cells of the bone marrow, the endosteal cells lining bone surfaces, and certain epithelial cells close to bone surfaces.^{31,32} Because of the heterogeneous distribution of these cells in the skeleton, it is important to characterize the distribution of a radionuclide within the skeleton, as well as the removal time from various locations.

To account for the very different behavior of various radionuclides with respect to the skeleton, it was convenient to develop two separate general schemes to describe the uptake, translocation, and retention of elements by the skeletal system. One scheme (Fig. 7) applies specifically to the so-called "bone-volume seeking" radionuclides and the other scheme (Fig. 8) to the so-called "bone surface seeking" radionuclides, but the patterns are general enough so that skeletal metabolism of many radionuclides should be describable in terms of one of the two models. In the first model possible local or systemic recirculation of radionuclides is not treated explicitly but may be introduced implicitly

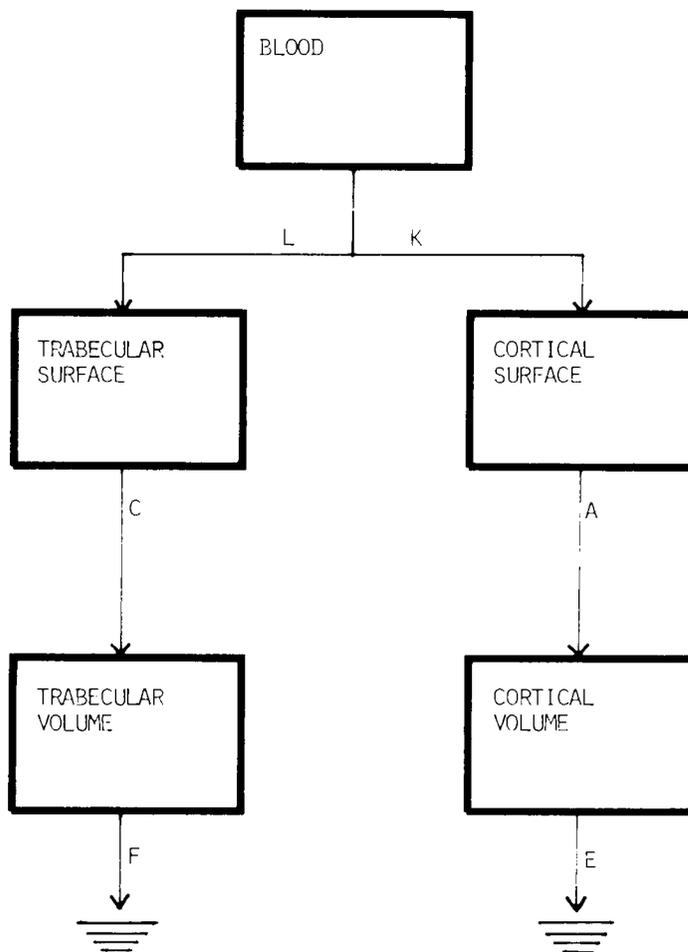


Figure 7. Compartments and pathways in the skeleton as represented in the model for bone-volume seeking elements such as calcium and strontium.

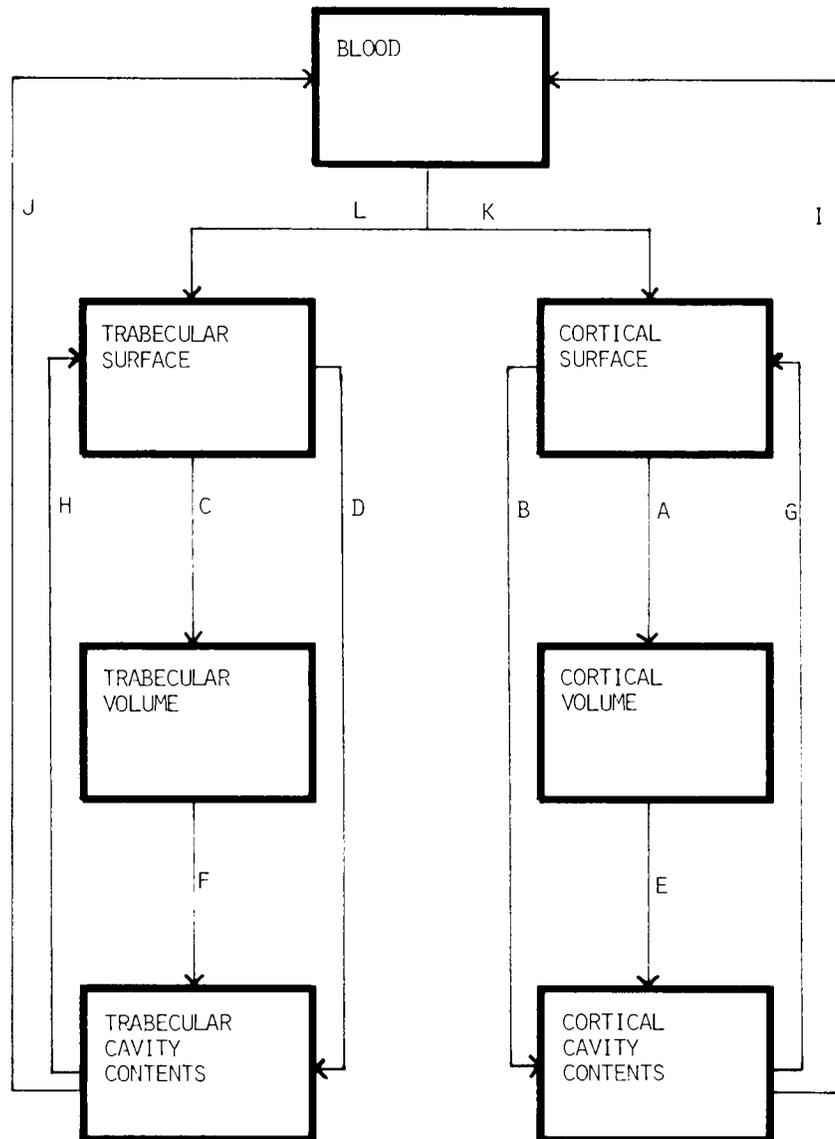


Figure 8. Compartments and pathways in the skeleton as represented in the model for bone-surface seeking elements such as plutonium, americium, and curium.

within parameter values. In the second model recirculation is treated explicitly. Both models assume that activity in the bloodstream can enter the bone volume only after depositing on bone surfaces. The relative fractions moving by each pathway in each model and the removal rate from each of the regions may vary with the radionuclide. In many cases it is possible to estimate the pathway fractions and the removal rates from a knowledge of the mechanisms involved. This will be illustrated for a bone-volume seeking radioelement (strontium) and for bone-surface seeking radioelements (plutonium, americium, and curium). In addition, an age-dependent metabolic model will be described for a radioelement (cesium) which is not considered a bone-seeker.

AN AGE-DEPENDENT METABOLIC MODEL FOR STRONTIUM

Because of the chemical similarities of strontium and calcium, strontium tends to follow the calcium pathways in the body and deposits to a large extent in the skeleton.³² In fact, the fraction of ingested Sr eventually reaching the skeleton at a given age depends largely on the skeletal needs for calcium at that age, although the body is able to discriminate somewhat against Sr in favor of Ca after the first few weeks of life.^{1, 32-34} This discrimination possibly occurs at all membranes, but it is well established that there is discrimination by the gut and kidneys.

Metabolism of Sr by humans may be described using two principal organs: skeleton and remaining tissue. There is a relatively large body of information on age dependence of uptake and retention of Sr by the skeleton, whereas little is known concerning age dependence of Sr in other tissues. Since the integrated activity of Sr in the skeleton appears to be orders of magnitude higher than the integrated activity in the remaining tissues, only minor errors should be introduced by applying an adult retention model for Sr in remaining tissue to all age groups; we shall apply a retention model for "Other" similar to that in ICRP 30.¹⁴ Our age-dependent model for Sr in the skeleton is taken from Ref. 1.

For purposes of modeling the transport of Sr by the skeleton, it suffices to view the mineralized skeleton as consisting of two main compartments: trabecular (cancellous, spongy) and cortical (compact) bone. Two subcompartments, surface and volume, will be considered within each of these main compartments. The four subcompartments of mineralized skeleton and the movement of Sr among these compartments are shown schematically in Fig. 7. Strontium in blood may enter bone volume only after passing through bone surface, and Sr is considered as leaving the body directly from bone volume. While recycling of Sr from bone surface and volume to blood is not considered explicitly, these processes may be incorporated implicitly to some extent in removal rates.

In the mature skeleton trabecular and cortical bone are reasonably distinct both in appearance and in retention of strontium. However, in the nonadult, it appears that these two compartments become less and less differentiated with decreasing age, particularly in their uptake and retention of strontium. We assume that there are no differences in uptake and retention properties between the two compartments until some time during the second year of life and that differences remain fairly small throughout childhood. For the maturing skeleton, the cortical bone compartment is described more accurately as "cortical bone and its precursors" and the trabecular bone compartment as "trabecular bone and its precursors," respectively, with emphasis on the final bone type rather than on the precursor. For example, bone originally laid down as spongy bone but later transformed to cortical bone by either a compaction of trabeculae or a filling in of interstices between trabeculae would be considered as part of the cortical compartment throughout its existence.

Measurements have indicated that compact bone comprises about four-fifths of the adult mineralized skeleton and cancellous bone about one-fifth, by volume, by mass, and by calcium content.³² Limited information from the literature suggests that the mass of compact bone does not have a significantly different rate of increase with increasing age from that of the entire skeleton, particularly after the age of 5 or 6 years.¹ We assume that, at all ages, compact bone comprises 80% and cancellous bone the remaining 20% of the mass of the bone volume. The error inherent in this assumption probably increases with decreasing age

below age 20 years; fortunately, this error will be largely negated by other assumptions in the model. In particular, we assume that there are only small differences in the uptake and turnover rates of Sr in compact and cancellous bone during the first few years of life, so that the concentration of Sr in the skeleton does not depend strongly on the relative masses of the two compartments at early ages.¹

Bone volume

The fraction of ingested Sr eventually taken up by bone volume is assumed to be equal to the fraction of ingested calcium taken up by the bone times a discrimination factor $k(t)$ at age t years. Moreover, the uptake fraction as a function of age for calcium is assumed to be controlled by the changes in skeletal calcium:

$$C'(t) = -[0.8 a(t) + 0.2 b(t)]C(t) + m(t)A(t) ,$$

where t is age in years; $m(t)$ is the uptake fraction for calcium; $a(t)$ and $b(t)$ are the removal rates for calcium from compact and cancellous bone, respectively; $A(t)$ is the average amount of calcium per year ingested (taken as 365 g for all ages); $C(t)$ is the calcium content of the skeleton in grams, and $C'(t)$ is the rate of change of $C(t)$ with respect to t . Therefore, $m(t)$ would be given by

$$m(t) = [(0.8 a(t) + 0.2 b(t))C(t) + C'(t)]/A(t) .$$

The total uptake $u(t)$ of Sr by bone volume at age t is estimated from $m(t)$ by the formula

$$u(t) = k(t)m(t) .$$

The uptake fractions $r(t)$ and $s(t)$ for Sr by cortical bone and trabecular bone, respectively, are estimated by decomposing $u(t)$ into the components dictated by the hypothesized turnover rates and growth rates of the respective compartments. Thus,

$$r(t) = 0.8 k(t)[a(t)C(t) + C'(t)]/A(t) ,$$

and

$$s(t) = 0.2 k(t)[b(t)C(t) + C'(t)]/A(t) .$$

To solve the above equations, we shall require separate estimates of $C(t)$, $a(t)$, $b(t)$, and $k(t)$. At age t years, the calcium content $C(t)$ of the skeleton is roughly approximated by^{1,35}

$$C(t) = 28.0 + 86.828 t - 16.5105 t^2 + 1.5625 t^3 \\ - 0.04114 t^4, 0 \leq t \leq 19.3 ,$$

$$C(t) = -0.3070 t^2 + 23.35 t + 742.2, 19.3 < t \leq 55 ,$$

$$C(t) = 1098 \exp [-0.01(t-55)], 55 < t .$$

The removal rates $a(t)$ and $b(t)$ for cortical and trabecular bone, and the discrimination factor $k(t)$, are listed in Table 2 for selected ages t . Estimates for $a(t)$ are based on tetracycline data of Frost³⁶ for the sixth human rib. Estimates for $b(t)$ are based on turnover rates found by Bennett and co-workers^{37,38} for the vertebrae, together with the

Table 2. Parameters used in model for strontium uptake and removal by skeleton

Age	Removal rate (yr ⁻¹)		Sr/Ca discrimination factor, k	f ₁	f' ₂ (Bone surface)	f' ₂ (Compact bone surface)	f' ₂ (Cancellous bone surface)
	Compact bone	Cancellous bone					
Newborn	3.725	3.725	0.900	0.686	0.686	0.549	0.137
100 days	2.991	2.991	0.704	0.615	0.615	0.492	0.123
1 year	1.045	1.045	0.411	0.428	0.428	0.342	0.086
5 years	0.563	0.662	0.200	0.285	0.285	0.219	0.066
10 years	0.325	0.481	0.200	0.333	0.333	0.251	0.082
15 years	0.187	0.349	0.200	0.384	0.384	0.279	0.105
Adult ^a	0.03	0.18	0.200	0.215	0.215	0.090	0.125

^aAverages for ages 30-50 yr.

assumption that cortical and trabecular bone turnover rates vary in a parallel fashion in adults. Also, it is assumed that $a(t) = b(t)$ for ages ≤ 1.5 years. Values for $k(t)$ are based on studies of the observed ratios of Sr to Ca in diet and in the skeleton.^{33,34} Also given in Table 2 are estimates of $f_1(t)$, the fraction of ingested Sr absorbed into the blood at age t , and $f'_2(t)$, the fraction of Sr reaching the blood that is deposited in bone volume. Values for f_1 and f'_2 are estimated from the equation $u(t) = f_1(t)f'_2(t)$ by assuming $f_1(t) = f'_2(t)$. Although this assumption leads to a crude approximation, any resulting error will appear only in the estimated concentration of Sr in remaining tissue, since it is the product $f_1 f'_2$ that is used in estimating the Sr concentration in the skeleton.

Bone surface

In this model, bone surface is viewed as a transfer compartment for transporting Ca and Sr from blood to bone volume and is identified with the skeletal pool of rapidly exchangeable calcium.¹ While it may be helpful to think of bone surface as that part of the mineralized skeleton lying within some small distance (say, 1 μm) of the anatomical surfaces of bone, some studies have suggested that the readily exchangeable calcium may not be uniformly distributed on anatomical surfaces of bone but may be located principally in areas of present and recent sites of bone formation or resorption (cf. Refs. 32, 39, 40).

Estimates of the mass of calcium in the exchangeable pool are usually less than 10 grams for adults, and a value of 4 grams was used in ICRP 20.³² We assume that the mass at any age is proportional to the amount of skeletal calcium deposited each day at that age; the proportionality constant is obtained from the assumption that the average of the varying masses between ages 30 and 80 years is 4 grams. Hence the mass of calcium in the bone surface compartment at any age is assumed to depend on the amount of skeletal growth and renewal at any age, and the masses are normalized to the ICRP adult value, which we assume is an average value for ages 30 to 80. These assumptions lead to estimates of 3 to 10 grams of calcium for the mass of this surface compartment for most ages,¹ although the estimates are slightly higher for periods of

rapid growth and remodeling and slightly lower during the mid-30's, when turnover rates may be lowest. The proportionality constant derived from our assumptions is 20.6 days. The removal rate constant for calcium from the bone surface, when rounded to one decimal place, was calculated to be 0.1 per day for all ages. This value agrees with the removal rate of calcium from blood, soft tissue, and bone surface used in the ICRP adult model for alkaline earths.³² In that model, a removal rate of 0.25 per day was assumed for Sr. In the present model, there is assumed to be no difference in removal processes from the bone for calcium and strontium, so that the removal rate of 0.1 per day is also used for Sr.

AGE-DEPENDENT METABOLIC MODELS FOR PLUTONIUM, AMERICIUM, AND CURIUM

The models for Pu, Am, and Cm are very similar. All compartments and rate constants (except for removal from blood) are the same in all three models, but some of the compartmental fractions differ in these models. We shall describe the model at length for Pu and then briefly describe differences in the models for Am and Cm.

Similarities Between Pu and Fe

Apparently Pu and Fe bear sufficient chemical resemblance that Pu is able to penetrate some iron transport and storage systems. It has been shown that Pu(IV) in blood serum complexes with transferrin, the iron-transport protein.^{41,42} Thus Pu will partially trace the iron pathway, with the result that a substantial fraction of systemic Pu is carried to the bone marrow and to the liver.⁴³⁻⁵¹ Apparently much of the Pu is released from transferrin at these sites.⁴³⁻⁵¹ It has been shown that Pu(IV) may transfer from transferrin to ferritin, the major iron storage protein in the liver, in vitro at physiological pH, and that the ferritin complex may be more stable than the transferrin complex.⁵² In the skeleton, Pu may be released mainly at sites of developing red cells.⁵¹

Plutonium that has deposited in the liver and other soft tissue may continue to follow the iron pathway, although the time course may be much different for the two elements.⁵³⁻⁵⁵ Plutonium that has reached the skeleton behaves very differently from Fe; its movement is governed by

fairly complicated processes of bone resorption and addition.^{46,47} Because the total metabolic behavior of Pu is not closely related to that of any essential element, any retention model for Pu as a function of age will involve much larger uncertainties than our model for Sr, for example. Still, there is sufficient information concerning the metabolism of Pu by mammals to justify a detailed examination of potential differences with age in doses to radiosensitive tissues following intake of this radioelement.

The Initial Distribution of Pu in the Body

Retention and translocation of Pu that has reached the bloodstream can be modeled using three principal compartments: skeleton, liver, and remaining tissue. Approximately 80% of Pu in the bloodstream is divided between the skeleton and liver, and approximately 20% goes to remaining tissue and excretion.⁴⁴ In experiments with beagles, the division of Pu between skeleton and liver was age-dependent, with skeletal uptake being near 70% in juveniles and 40-60% in adults.^{49,56,57} Langham et al.⁴⁵ estimated that, in persons injected with Pu, approximately 66% was deposited in the skeleton and 23% in the liver. Durbin⁴⁴ reanalyzed the human data to account for the non-uniformity of Pu in samples of bone; she estimated that about 49% was in the skeleton and 31% in the liver at 4 to 457 days after injection. A few years ago, a major portion of the skeleton of one of the injected persons, a young woman injected at age 18 years and dying 17 months later (case HP-4), was analyzed and found to contain about 55% of the injected amount.⁵⁸ Since there was ample time for a small portion of the Pu to be translocated from the skeleton before this woman's death, the fraction originally deposited in her skeleton may have been higher than 55%.

Our model relies on both the human and beagle data. We assume that skeletal uptake remains at 70% until age 15 yr, when the skeletal percentage begins declining linearly to a value of 50% by age 30 yr and remains at 50% thereafter. At all ages, the sum of the skeletal and hepatic fractions is assumed to be 80%, with 20% going to remaining tissue and excretion.

Uptake and Translocation of Pu by the Skeleton

To describe retention of Pu in the skeleton, it is convenient to view the skeleton as consisting of a cortical compartment and a trabecular compartment. Each of these is further divided into three subcompartments: bone surface, bone volume, and a transfer compartment. The transfer compartment, which includes the bone marrow, may receive Pu that is removed from bone surface or volume; Pu may reside in this compartment temporarily before being returned either to the bloodstream or to bone surfaces (Fig. 8). Because of the large amount of recycling of Pu among the skeletal compartments, blood, and other organs, recycling is considered explicitly in the model.

In the following discussion, the indicated pathways correspond to the arrows in Fig. 8.

Pathways K and L. Plutonium is deposited initially on bone surfaces, with highest deposition being at sites with red (hematopoietic) marrow and lowest deposition at sites of yellow (fatty) marrow.⁵⁹ Since red marrow is more highly vascularized than yellow marrow, the degree of vascularity at a given skeletal site may be a determining factor in the initial distribution of Pu.^{59,60} In the adult, nearly all of the red marrow is in trabecular bone,⁶¹ and deposition on trabecular bone may be greater than on cortical bone. In children, some or all of the marrow in cortical bone is active,⁶¹ and a more uniform distribution on cortical and trabecular bones is expected. It is assumed that 50% of the initial deposit in the skeleton of nonadults is on trabecular surfaces and 50% is on cortical surfaces, and that 60% of the initial deposit in the adult skeleton is on trabecular surfaces and 40% is on cortical surfaces. These estimates are crude and involve some arbitrariness but reflect the following considerations. There is at least as much trabecular surface in the skeleton as cortical surface, and possibly more.^{62,63} Thus, if Pu deposited uniformly on all surfaces, then at least 50% of the initial deposit in the skeleton should be assigned to trabecular surfaces. Since it is known that Pu deposits more heavily in areas of active marrow, and almost all active marrow in adults is in trabecular bone, then it seems reasonable to assign more than 50% of the initial

deposit to trabecular surfaces of the adult skeleton. On the other hand, data of Larsen et al.⁵⁸ suggest that trabecular bone may not contain any more Pu than cortical bone after 1.3 years in a 65-year-old man. Although there has been time for some translocation to occur, the turnover rate for trabecular bones in humans is probably not high enough to have led to a massive relocation during 1.3 years.

Pathways A, B, C, and D. Bone surfaces labeled with Pu may remain unchanged, or they may be buried by formation of new bone (A and C) or resorbed by osteoclasts (B and D).^{46,47} The rate of removal from surfaces by burial or resorption depends on the age of the individual and on the bone surface type (trabecular or cortical). To estimate rate constants for pathways A, B, C, and D, it is necessary to understand the relationship between bone formation and bone resorption. There are two somewhat different pictures of this relationship presented in the literature. Some authors describe bone addition and resorption as occurring on opposite sides of a bone (or bone trabecula), so that the bone is pictured as continually "drifting" in a given direction.^{64,65} Other authors describe resorption and addition as occurring in the same location; first an area of bone is excavated by osteoclasts, and then the same area is refilled with osteoid which is later mineralized.⁶⁶ The actual events may involve some combination of these models. Bone "drift" may be the predominant process during growth and perhaps into young adulthood, but may diminish considerably after the skeleton has matured fully, although drift apparently occurs to some extent at all ages.

If bone formation and resorption always occurred on opposite surfaces of a bone segment, then the removal rate for Pu on bone surface would be approximately the sum of the resorption rate λ_1 and the formation rate λ_2 . This situation is assumed for nonadults. On the other hand, if formation represented only the immediate replacement of resorbed bone, then the removal rate would be approximately λ_1 and Pu would be buried in volume only after its resorption by depositing in unmineralized osteoid and moving to the mineralized surface underneath the osteoid. In this model, an intermediate scenario is assumed for adults, with the burial rate in bone volume being $0.5 \lambda_2$, and the removal rate from bone surface being $\lambda_1 + 0.5 \lambda_2$.

The age-dependent resorption rate λ_1 is the same as that for Sr estimated in Table 2. The simplifying assumption is made that $\lambda_1 = \lambda_2$. In older adults λ_1 may be larger than λ_2 , resulting in a net bone loss; however, the difference $\lambda_1 - \lambda_2$ would be small compared with the error already involved in the estimate of λ_1 , so little is lost by assuming $\lambda_1 = \lambda_2$. In children, λ_1 may be smaller than λ_2 , but the assumption that $\lambda_1 = \lambda_2$ adds an element of conservatism to estimates of dose to radiosensitive tissues (assuming our estimate of λ_1 is reasonably accurate). Since more detailed modeling of λ_2 would involve large uncertainties, it would be difficult to justify adjusting the model to account for growth processes not already implicitly considered in the present estimate of λ_2 .

Plutonium resorbed by osteoclasts may be released and concentrated by macrophages in bone cavities, particularly in marrow.⁴⁶ The length of time that Pu remains in these macrophages is not known. In beagles receiving low doses of Pu, peak labeling of macrophages in bone marrow was at two years post injection, and all labeled macrophages had disappeared at four years post injection.⁴⁷ This suggests a half-time in beagles that is short compared with two years. Our model assumes a half time of 90 days. Some fraction of the Pu in resorbed bone may be dissolved and recycled systemically without being taken up by macrophages, and with little or no sojourn time in the marrow. Since our model channels all resorbed Pu through the marrow with the same half-time, the assumed 90-day half-time may be conservative with respect to marrow dose.

Pathways E and F. Pu buried in bone volume may eventually become volume distributed as the bone section "drifts" due to remodeling. The time required for Pu to become volume distributed is assumed to depend on the bone turnover time. If the resorption rate for trabecular bone is k per year, then buried Pu may begin to be resorbed in about $1/k$ years after exposure. (Account must be taken of the fact that k varies with age.) Because of the slow turnover time for cortical bone at most ages, much of the Pu buried in cortical bone of adolescents and adults may never be recycled.

Pathways G, H, I, and J. Autoradiographs suggest that both local (G and H) and systemic (I and J) redeposition onto bone surfaces occurs.^{59,67} If Pu is released in a highly vascularized area and more remote from bone surfaces, then systemic deposition is likely. If Pu is released in a less vascularized area, it is likely that most Pu will be deposited locally. For lack of precise values, it seems reasonable to assume that 50% of the Pu in the transfer compartments is redeposited locally and 50% is carried back to the bloodstream, from where it may still be deposited on bone surfaces. Because of the recycling of Pu from the bloodstream, any error in the assumption of an even split between locally and systemically recycled Pu is automatically adjusted to some extent.

The Model for Pu in the Liver

The retention and removal of Pu by the liver cannot be quantified with much confidence. It is known from animal studies⁵³⁻⁵⁵ that some Pu may leave the liver via blood while some may leave in bile, that Pu is taken up by hepatocytes but later transferred to RE cells, and that Pu may reside for years in the RE system, with the residence time depending to some extent on the iron status of the animals. It is also suggested by autopsies of persons exposed to Pu several years previously that this nuclide may reside for many years in the human liver.

It is not known whether there are differences with age in removal of Pu from the liver. The ICRP model for Pu assumes a biological half-time of 40 years in the liver of adults.⁶⁸ We shall assume that, for all age groups, Pu is retained in the liver with a biological half-time of 10 years. Almost all activity leaving liver will return to blood, but a small amount will reach feces via bile. For computational convenience the small amount in bile is considered to be in a separate soft tissue compartment described later. The half-time of 10 years is somewhat arbitrary but takes into consideration that our model will increase the "apparent" half-time of Pu in the liver considerably since this model considers recirculation and allows the liver to continue to receive Pu removed from skeleton, liver, and soft tissue.

The Model for Pu in Soft Tissue and Excretion

Soft tissue is assumed to consist of two compartments which together receive 20% of the Pu in blood minus the amount rapidly excreted. One soft tissue compartment is associated with excretion pathways such as kidney, bladder, intestines, and biliary pathways. This compartment is assumed to receive 6% of the activity in blood, and activity leaves only via excretion. Although liver is considered separately, for computational convenience we consider activity that may actually leave liver via bile as being channeled through this soft tissue excretion compartment. The second soft tissue compartment is associated with the remaining tissue, that is, all soft tissue not including liver and not lying in a direct excretion pathway. This would include most muscle tissue, lung tissue, and portions of the viscera, for example. This compartment is assumed to receive 10% of the activity in blood, and activity leaving this compartment is recycled to blood. Pu is assumed to leave both soft tissue compartments with a half-time of 500 days, which is based loosely on conclusions reached in Ref. 44.

In addition to activity reaching excretion after a delay in soft tissue, some activity will be rapidly excreted from blood. In this model we assume that 4% of Pu reaching blood is rapidly excreted. Our estimates for the amount excreted are from adult human data.^{44,45,69,70}

Our model for plutonium metabolism is described in great detail in Ref. 71. (The description in that report is only for adults.) Here we have simplified the model in Ref. 71 slightly for computational purposes.

The Modeling for Recycling of Systemic Pu

Pu reaching the bloodstream after removal from skeleton, liver, or soft tissue is assumed to trace the same pathways as the initial deposit in blood. It is assumed that activity leaves blood with a half-time of 0.85 days (cf. Ref. 44).

Adjustments in the Model for Americium and Curium

Plutonium, americium, and curium appear to have very similar metabolic properties, except that plutonium has a much higher affinity for β_1 globulins in blood.⁷² Differences in affinity for proteins may result in a much more rapid clearance of americium and curium from blood, a higher filtration fraction by the kidney, and less propensity to follow the iron pathways as compared with plutonium. Since there is little information on comparative behavior of these elements in humans, the following quantifications of differences were based on results of animal studies.

1. It is suggested by results of Turner and Taylor⁷² that the effective half-time of Am or Cm in blood may be 2 or 3 orders of magnitude lower than that of Pu. We have assumed a half-time of 0.1 days for Am and Cm in blood.
2. Studies of Lloyd and co-workers^{49, 56, 57, 73, 74} suggest that about 80% of Pu, Am, or Cm goes to skeleton and liver, but Pu may have a relatively higher affinity for skeleton and/or Am and Cm a relatively higher affinity for liver. Basing our estimates on these results for dogs, we assume that 80% of Pu, Am, or Cm goes to skeleton plus liver, but that the relative percentages going to skeleton in adults are Pu:Am:Cm = 50%:30%:45%. For newborns, 70% of Pu, Am, or Cm is assumed to go to skeleton, and for persons of 1-15 years of age, the average of the adult and newborn values is applied.
3. The distribution of Am in the skeleton may be more uniform than the distribution of Pu.⁷³ Also, the distributions of Am and Cm in the skeleton appear to be very similar.⁷⁵ We assume that 50% of Am or Cm that goes to skeleton is deposited on trabecular surfaces and 50% is deposited on cortical surfaces at all ages; this compares with a ratio for Pu of 60%:40% for adults and 50%:50% for non-adults.
4. In humans most of the cumulative excretion of actinides appears to be in urine.⁷¹ Experimental evidence for dogs indicates that early urinary excretion of Am or Cm is greater than for Pu,^{49, 56, 57, 73, 74} probably because of the weaker attachment to proteins exhibited by Am

and Cm. We assume that the comparative fractions of rapid excretion of Pu, Am, and Cm in blood are 0.04:0.07:0.06, based on the studies with dogs. Since fecal excretion data for actinides in animals cannot be readily extrapolated to humans, we cannot improve on the simple assumption that fecal excretion of Pu, Am, and Cm are identical in humans. Also, for lack of better information we shall assume that the model for Pu concerning excretion via soft tissue applies to Am and Cm.

All other features of the Pu model are assumed to apply to Am and Cm.

METABOLIC MODEL FOR CESIUM

Cesium tends to follow the movement of potassium in the body but attains a fairly distinct distribution after a few days because of the much slower transport of Cs across cell membranes.⁷⁶ It appears to be the slower entry of Cs into cells that leads to its longer residence time in plasma and its higher short-term excretion rate compared with K. On the other hand, it is apparently the slower transport rate of Cs out of cells, mainly the dark fibers of muscle, that produces a longer effective biological half-time for Cs than K in adults.⁷⁶ The differences in transport rates of Cs and K across cell membranes are sufficiently different that the whole-body retention function for Cs does not closely resemble that for K.

The ICRP 30¹⁴ retention model for cesium in the human body is represented mathematically as a sum of two exponentials:

$$R(t) = a \exp(-0.693t/T_1) + (1 - a) \exp(-0.693t/T_2)$$

where $R(t)$ is the fraction retained in the body at some time t days after an initial time $t = 0$. Cesium is assumed to be rapidly and completely absorbed into the bloodstream from the GI tract, and inhaled cesium is assigned the solubility class D for all compounds. (Both of these assumptions seem reasonable for all age groups.) Of Cs entering the blood, a fraction $a = 0.1$ is assumed to be translocated to an unspecified tissue compartment and retained there with a half-time $T_1 = 2$ days, and the remaining fraction $1 - a = 0.9$ is assumed to be transferred to another unspecified tissue compartment and retained with a half-time $T_2 = 110$ days. Both of these compartments are taken as uniformly distributed throughout the body.

While the ICRP 30 model may represent a reasonable compromise of the different retention patterns of Cs among humans, studies indicate that there is considerable variation in retention times of Cs in humans.⁷⁷⁻⁹⁸ It is generally agreed that whole-body retention of Cs is approximated adequately by the sum of two or three exponentials. For adult human males two terms are generally adequate, but three terms are

often required for adult females and children.⁷⁵ We suspect that the intermediate component, with a typical half-time of two weeks, becomes more apparent for persons who have relatively less dark muscle fiber available to accumulate Cs (or, more precisely, less active transport into muscle fibers). The short-term component may actually be better represented by two sub-components, with perhaps one-third of this amount being excreted very rapidly (within a few hours) and two-thirds being excreted with a half-time of 1-2 days (see Naversten and Liden⁸¹). Thus the short-term component of the ICRP 30 model, a $\exp(-0.693t/T_1)$, may be better represented for some persons by three components with half-times of a few hours, a few days, and a few weeks, respectively.

Despite the differences in membrane transport of Cs and K, the behaviors of these two elements in the body are closely enough aligned that total-body K appears to be a suitable index for predicting whole-body retention of Cs.⁷⁶ Previously, both total body mass and age have been used as indices of variation of $T_{1/2}$ for Cs. A comparison of mass, age, and total body K as indicators of $T_{1/2}$ for Cs can be made from Figs. 9-11 where we have included measurements made on both sexes and several age groups among healthy persons as well as on persons with different muscle diseases.⁷⁸ Both body mass and age appear to correlate reasonably well with the long-term $T_{1/2}$ for Cs for healthy nonadults, but these parameters do not correlate well with $T_{1/2}$ in adults and persons with muscle disease. Thus age and body mass may be only coincidentally related to mechanisms controlling Cs $T_{1/2}$. Total body K, however, appears to be a good predictor of Cs $T_{1/2}$ for dystrophics as well as healthy persons, and for adults as well as children.

For predictive purposes, it is convenient to consider only two major components as in the ICRP 30 model. Assuming that retention is of the general form given in the above equation for $R(t)$, where the first component combines any possible sub-components with very rapid up through intermediate-term excretion, we provide a procedure for estimating a , T_1 , and T_2 .

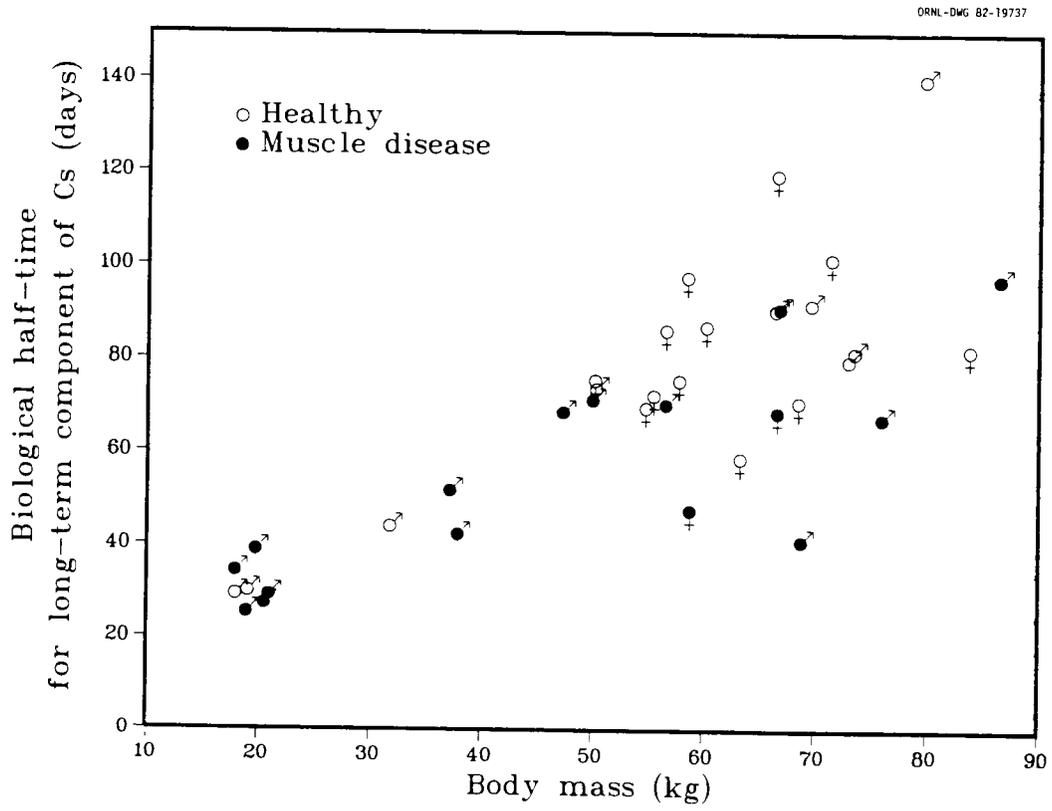


Figure 9. Long-term half-time for Cs vs total body mass.

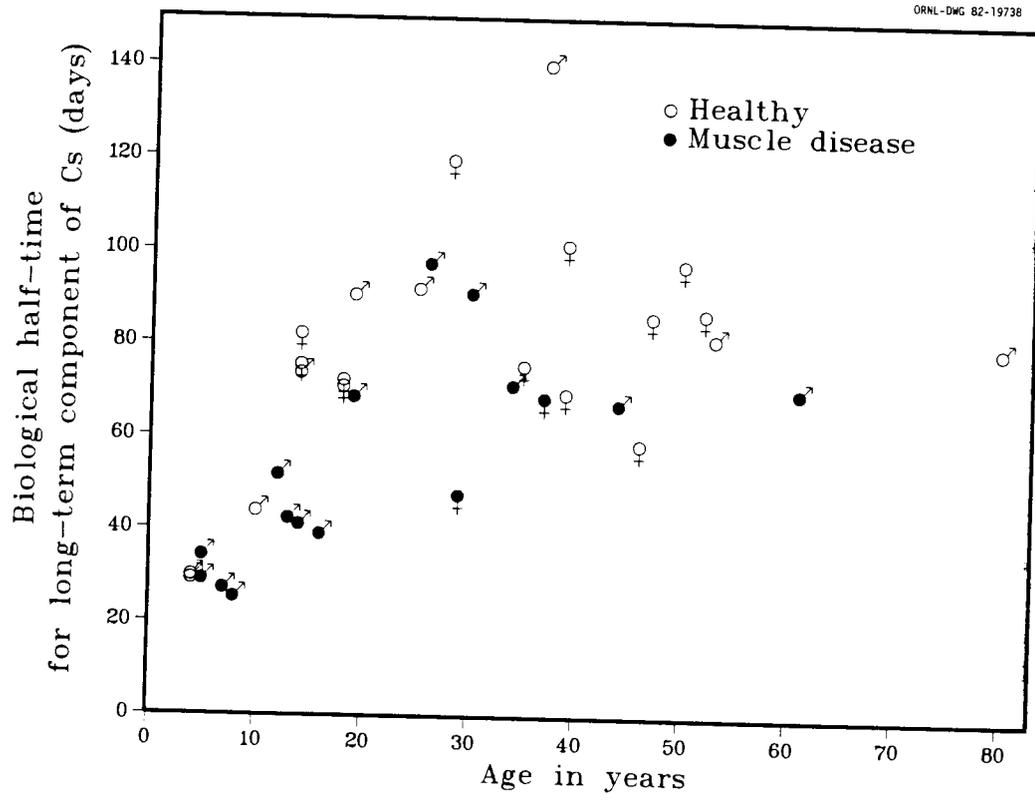


Figure 10. Long-term half-time for Cs vs age.

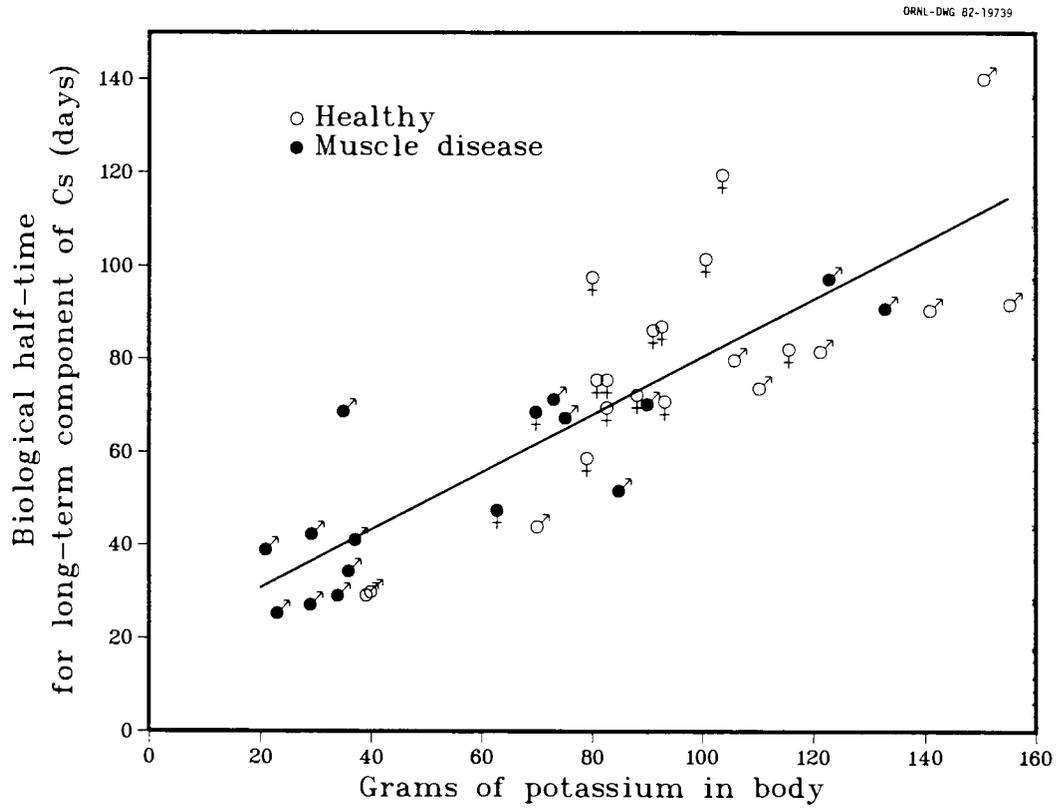


Figure 11. Long-term half-time for Cs vs total body K.

(a) The value a may be estimated by

$$\text{adult males: } a = 0.57 - 0.003A ,$$

$$\text{adult females: } a = 0.36 - 0.002A ,$$

where A is the mass of total body K (g). These equations represent fits to pairs (a, A) for healthy persons (see Ref. 78). As indicated in Fig. 12, the fraction of Cs in the short-term component decreases with total body K , probably because of the higher competition for Cs from dark muscle fiber, which would tend to increase with total body K . The values a and A are more highly correlated for males than females.

(b) The short-term half-time T_1 is estimated using the predicted value a :

$$\text{adult males: } T_1 = 21a - 0.46 ,$$

$$\text{adult females: } T_1 = 6.4a + 4.4 .$$

These equations represent fits to data for healthy persons⁷⁸ (see Fig. 13). Again, the pairs (a, T_1) are better correlated for males than for females.

(c) The long-term half-time T_2 is estimated by:

$$\text{adult males: } T_2 = 0.72A + 1.22 ,$$

$$\text{adult females: } T_2 = 0.73A + 16.2 .$$

These equations represent fits to data for healthy persons.⁷⁸ Once again, the pairs (A, T_2) are better correlated for males than for females. We next derive an age-dependent version of the Cs retention function $R(t)$ given in ICRP 30. This will be accomplished by use of the above equations for males; we are restricting attention to the equations for

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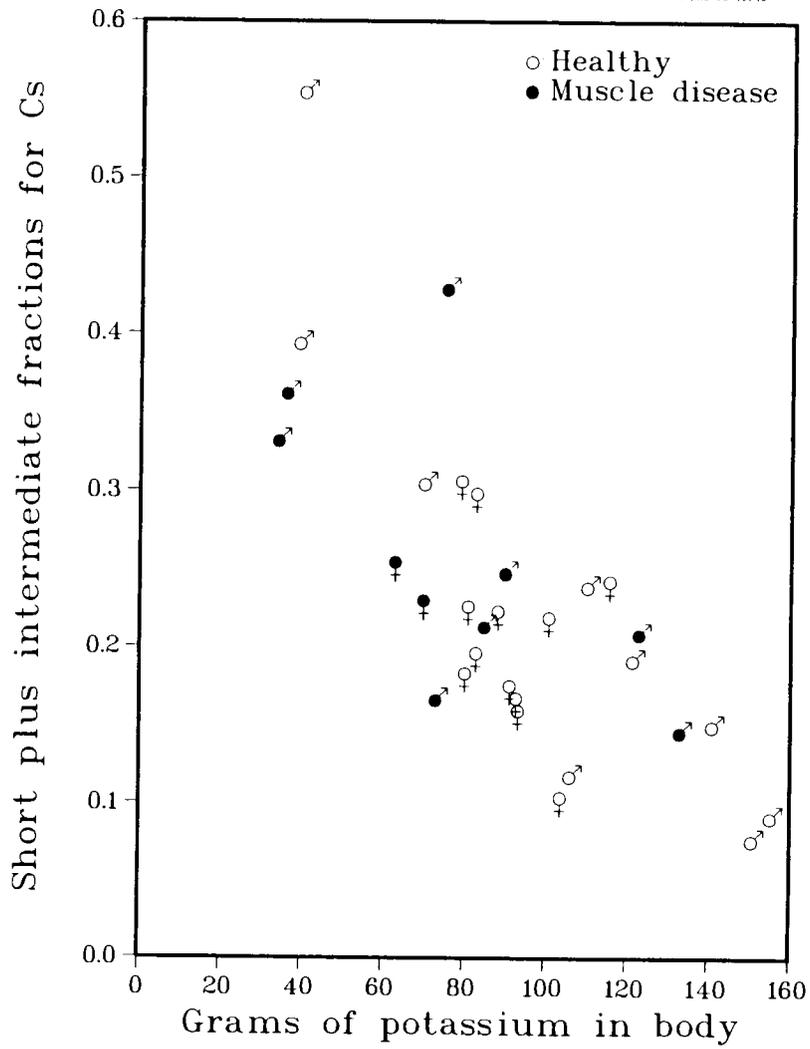


Figure 12. Fraction of Cs excreted over short and/or intermediate term vs total body K.

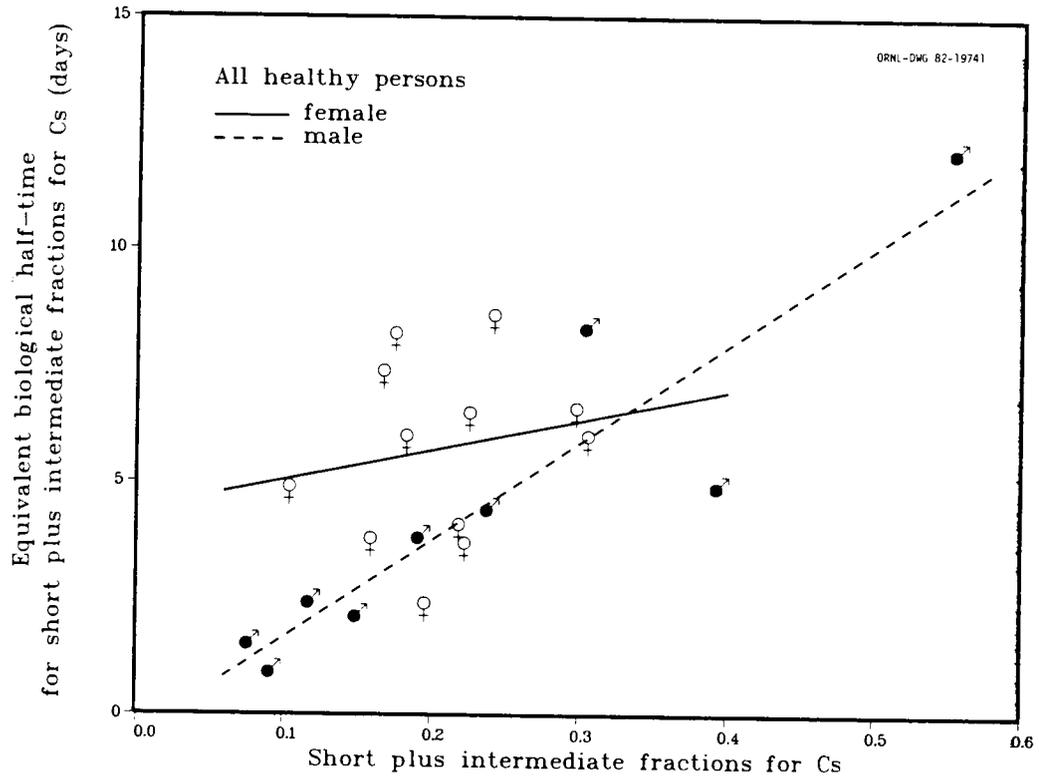


Figure 13. Relation between fraction of Cs excreted over short and/or intermediate term and biological half-time for this Cs.

males because these appear to be much more reliable than the corresponding equations derived for females.

The equations for a and T_1 (for males) can be combined to yield an expression for T_1 as a function of total body K:

$$T_1 = 11.5 - 0.063A ,$$

where, as before, A is the mass of total body K in grams. From this equation, together with the equation for T_2 , it can be seen that $T_2 - T_1$ decreases as A decreases, and that $T_2 = T_1$ at $A = 13.2$ g, which is approximately the potassium content of a five-month-old child (see Ref. 99). Since it does not seem reasonable to allow $T_2 < T_1$, we shall assume that the above equations are valid only for ages five months or greater, and that $T_1 = T_2$ for ages less than five months. Thus the retention function for Cs will reduce to a single term for ages less than five months, and the single biological half-time can be estimated from empirical data. For convenience, we shall consider the age-dependent retention function as having two terms at all ages, although the two half-times are assumed to be identical for ages less than five months. These considerations lead to the estimated values of a , T_1 , and T_2 given in Table 3, for selected ages. Note that, in Table 3, there is an estimated decrease in the half-time of Cs in humans during the first few months of life, but after this period the long-term half-time increases continually to adulthood. The initial decrease in retention time is estimated from the combined empirical data of Wilson and Spiers⁸⁴ and Pendleton *et al.*⁸⁶ The longer half-time of Cs in newborns than in slightly older infants may result from two factors: (1) at birth, essentially all muscle behaves the same as the slow (dark) muscle of older humans, but muscle differentiates into fast and slow muscle during the first few months of life;¹⁰⁰ and (2) there is an increase during the first few months of life in the secretion of aldosterone,¹⁰¹ a hormone that increases the exit rate of potassium (and apparently also cesium) from cells.

Table 3. Estimated compartmental fractions and half-times in the age-dependent retention function for Cs

Age	Total-body K ^a (g)	Short plus intermediate term fraction	Short plus intermediate term T _{1/2} (days)	Long-term fraction	Long-term T _{1/2} (days)
Newborn	5.2	0.50	25	0.50	25
100 days	11.4	0.50	12	0.50	12
1 year	20.8	0.51	10	0.49	16
5 years	42.7	0.44	8.8	0.56	32
10 years	71.0	0.36	7.0	0.64	52
15 years	131.4	0.18	3.2	0.82	96
Adult ^b	150	0.10	2.0	0.90	110

^aEstimated from formula $g\text{ K/kg body weight} = 2.276 - 0.0057 \times \text{Age (years)}$ given by Wagner et al.,¹⁰² together with body weights given in ICRP 23.⁹⁷

^bFractions and half-times are from the ICRP 30 model for Cs. These values agree with our model predictions for a male with total-body K = 150 g, except that our model would predict compartmental fractions of 0.12 and 0.88 rather than 0.10 and 0.90, respectively.

4. A GUIDE FOR USERS OF THE COMPUTER CODE AGEDOS

In this section we collect and briefly summarize the basic concepts underlying the AGEDOS methodology and computer code; we describe in a general fashion the input requirements for the AGEDOS code; we provide samples of input and output for the three radionuclides whose age-dependent metabolic models were described in the preceding section; and we provide an extensive description of the structure of the AGEDOS code. Listings of the codes AGEDOS and CONVOL are given in the Appendix. Recall that CONVOL is the computer code that uses the basic matrix generated by AGEDOS to estimate the dose rates at arbitrary times and ages during or after an arbitrary intake pattern. CONVOL may be easily adapted as a subroutine of AGEDOS, or CONVOL may be used independently of AGEDOS provided a proper matrix of dose rates is available for input into CONVOL. The version of CONVOL given in the Appendix is designed to be used interactively on the PDP-10 computer.

The AGEDOS code shares many features with the dosimetric section of the code RADRISK,¹⁰ which in turn was patterned closely after the code INREM II,¹¹ although RADRISK and INREM II apply only to Reference Man. In particular, the procedure in AGEDOS for calculating activities in a series of time steps is patterned after RADRISK and INREM II, and the routines for solving the differential equations are almost identical in the three codes. The reader who wishes to understand the intricate working parts of the AGEDOS code may find that the documents describing INREM II and RADRISK provide valuable background material.

A Summary of the Basic Concepts Underlying AGEDOS and a General Description of Input Requirements

The body is viewed as a set of compartments as illustrated in Fig. 2. Within a compartment there may be more than one pool of activity, that is, the activity within the compartment may be divided into segments (five or fewer) defined in terms of their biological half-times.

There is assumed to be an acute unit exposure at a given age. This age is selected by the user from seven "basic beginning ages": 0, 100, 365, 1825, 3650, 5475, or 7300 days of age. The user has the option to cycle through all seven basic beginning ages with a single computer run. This cycle would generate a matrix of dose rates analogous to that depicted in Table 1 for each compartment specified by the user. As indicated in Table 1, beginning at age B activities are calculated and corresponding dose rates are stored for all ages B+S, where S ranges over a specified time grid system, until B+S is greater than 85 years.

The acute unit intake is represented as an initial activity in the stomach for ingestion, the NP, TB, and/or P regions of the lungs for inhalation, or any specified compartments for the injection case. It is assumed that only a parent nuclide is ingested, inhaled, or injected, but ingrowth of daughters is considered explicitly.

Instantaneous and integrated activities of the parent and daughter nuclides in the various compartments are calculated in a series of time steps. The first ten steps after the acute intake are typically of length 0.001 day, the next ten steps are of length 0.01 day, and so forth. The numerous steps are needed to adequately approximate a conceptually continuous process in this stepwise fashion. The numerous small time steps near time zero are especially important because of rapid changes in dose rates that can occur soon after an acute intake of activity.

Each time step is defined by a starting time t_1 and an ending time t_2 . For a given pool, the initial activity at time t_1 is the activity calculated at the ending time in the preceding time step. The activity at t_2 in the present time step is calculated from the differential equation (1), using biological rate constants, branching ratios, pathway fractions, and inflow rates calculated as described in the following paragraphs.

All parameters considered to be independent of the radionuclide are specified within the code, usually as block data. This includes, for example, removal rates from the different compartments of the lung and removal rates from the four segments of the GI tract (except absorption to blood). For the most part, such parameters are specified for each of the seven basic beginning ages. Important exceptions are the removal

rate from blood and removal rates from the NP, TB, P, and L regions of the lung; these rates are assumed to be invariant with age.

Radionuclide-dependent data are specified by the user for adults (age 7300 days) and for any or all of the ages 0, 100, 365, 1825, 3650, and 5475 days. The user first selects the source organs that will be considered and then selects an "age grid" consisting of up to seven basic beginning ages (including 7300 days) for which f_1 values and retention data for each source organ will be supplied. For example, the age grid may consist of 365 and 7300 days. Then f_1 values and compartmental retention functions must be supplied for these two ages.

The AGEDOS code automatically supplies metabolic data for each of the basic beginning ages not specified in the age grid. This is done by a "defaulting" process in which data for the next highest specified basic beginning age is supplied to an omitted basic beginning age. For example, if the age grid is {365, 7300}, then the user-supplied data for age 7300 days will be assigned to ages 1825, 3650, and 5475 days, and the user-supplied data for age 365 days will be assigned to ages 0 and 100 days. In some cases it may appear preferable to assign interpolated values to those ages for which data are not available from the literature. In such cases the user would simply start with a larger age grid and would input interpolated values for chosen intermediate basic beginning ages.

For a given step from time t_1 to time t_2 following the acute intake at age B , the code finds two adjacent basic beginning ages B_1 and B_2 bounding $B+t_1$ (unless $B+t_1 \geq 7300$) and interpolates linearly between age-dependent data for ages B_1 and B_2 to produce new parameters to be used in the time step from t_1 to t_2 . If $B+t_1 \geq 7300$, then the parameters for adults are used in this time step. Similarly, S-factors for age $B+t_1$ are calculated by interpolating between S-factors for ages B_1 and B_2 . The change in activity from t_1 to t_2 is calculated by holding constant all physical and metabolic values between times t_1 and t_2 .

AGEDOS requires as input far more information than is presently available for most radionuclides. This has been done so that full use can be made of the fragmentary age-dependent (and, in many cases, adult) data now available. At every point allowance has been made for the fact that required input may not be available, so that the user can always

use "Reference Man" data and can combine this with whatever age-dependent data may be on hand. As one example, the code requires retention functions for both cortical and trabecular bone. Since these data frequently will not be available, the user may simply assign a single retention function for mineralized skeleton to both compartments. In this case, the code will produce estimates of dose rates that are at least as reliable as those generated using previous methods. For nuclides for which additional information concerning retention in cortical and trabecular bone is available, improved estimates of dose rates will be obtained.

As another illustration, the user might have information on retention in an organ for 1-year-olds and adults only. With the AGEDOS approach, the information for 1-year-olds would be used to calculate dose rates only for the first 365 days of life, after which the adult data would be utilized. Thus the age-dependent information, however sparse, would not be completely wasted, and adult metabolic data would be retained at all ages above which no age-dependent information has been developed. Even in the case of a radionuclide for which no age-dependent metabolic information whatever has been developed, an improvement will still be made through the use of age-dependent anatomical data.

AGEDOS Structure

The AGEDOS computer code consists of a main driving program and a series of subroutines as shown schematically in Fig. 14. The code is written in FORTRAN IV and compiled and executed on the IBM 3033, requiring 600K for execution.

Unit 5 is used for data input with the exception of S-factors, which are input on unit 15. Unit 6 is used for the principal line printer output including a summary of input data and tabulations of dose rates. Unit 16 is used to tabulate activities for each radionuclide and source organ at each time step, unit 17 is used to tabulate accumulated activities for each radionuclide and source organ at each time step, and unit 18 is used to tabulate committed dose to each target organ at each time step. Units 25 and 27 are used to output activities and dose

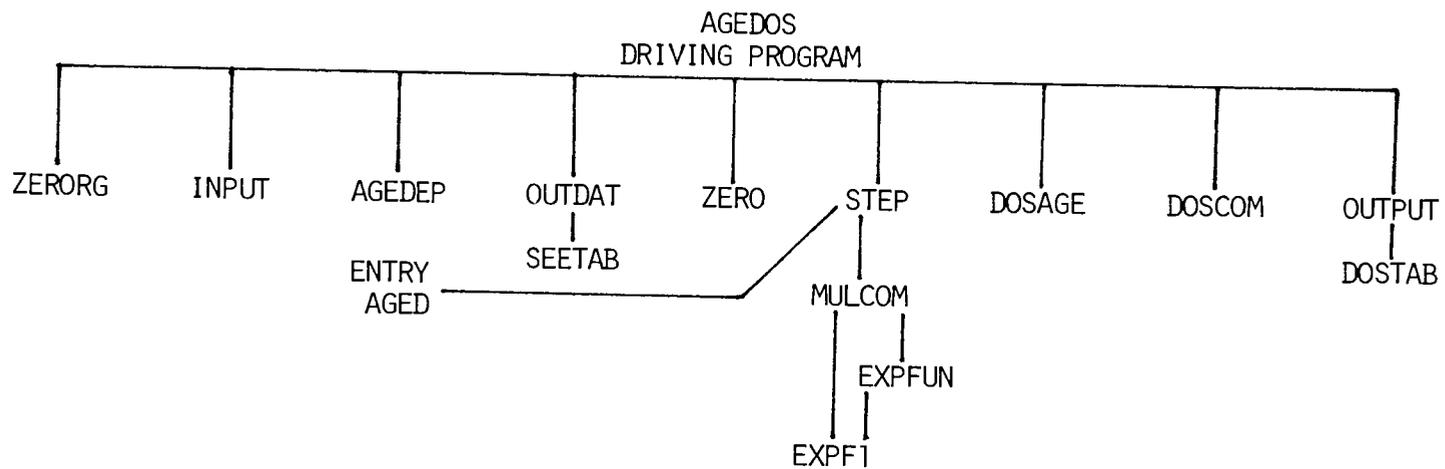


Figure 14. AGEDOS structure.

rates, respectively, at each time step to a disk or tape file for later use by the CONVOL convolution code.

The driving program is responsible for initializing certain parameters and managing the calls to subroutines for initialization of other parameters, data input, calculation of activities and dose rates, and output of results. AGEDOS defines a time grid at which activities and dose rates are calculated; the grid is essentially logarithmic in nature, consisting of the points 0.001, 0.002, ..., 0.01, 0.02, ..., 0.1, 0.2, ..., 1, 2, ..., 10, 20, ..., 100, 150, 200, 250, 300, 365, 450, 540, 630, 730, 830, 930, 1095, 1460, 1825, and 365-day intervals thereafter. The calculation is terminated when all activities are exhausted or when the specified end point is reached.

INPUT DATA REQUIREMENTS FOR AGEDOS

The input to the AGEDOS code consists of 2 separate input streams. The first segment contains all data except the dosimetric S-factors which are contained in a second input stream.

Input to unit 5

1. Number of radionuclide species in chain, number of LET-types present in this chain, number of exposure cases to be considered, flag to indicate whether only adult S-factors will be input from unit 15 (NSAGES=6 means yes; NSAGES=1 means S-factors for ages 0, 365, 1825, 3650, 5475, and 7300 days will be input)
NSPEC,NLET,NCASES,NSAGES (4I4)
2. Names and half-lives of radionuclide species in chain
(NAMNUC(ISPEC), TR(ISPEC), ISPEC=1,NSPEC) (A8, E10.0)
3. Number of branching fractions and branching fraction matrix
NBR (I4)
(JSPEC, ISPEC, BRANCH(ISPEC,JSPEC), IBR=1, NBR) (2I4, E10.0)
branching function from JSPEC to ISPEC
4. Number of source organs other than lungs and GI tract and name of each (if bone is to be included as a source organ, the

- first two organs must be "COR BONE" and "TRA BONE")
 NSOU (I4)
 (NAMSOU(ISOU), ISOU=1, NSOU) (10A8)
5. Number of target organs and name of each
 NTRG (I4)
 (NAMTRG(ITRG), ITRG=1, NTRG) (10A8)
6. Flag for volume or surface deposition in bone for each radionuclide (0 = volume, 1=surface)
 (ISURF(ISPEC), ISPEC=1, NSPEC) (20I4)
7. Number of ages for which metabolic data are to be specified, and age grid
 NAGEM (I4)
 (MAGE(IAGE), IAGE=1, NAGEM) (7I4)
8. For each radionuclide species in the chain (ISPEC=1, NSPEC):
 For each organ (ISOU=1, NSOU):
 Number of compartments in retention function,
 NCOMP(ISPEC, ISOU) (I4)
 For each age in age grid (IAGE=1, NAGEM):
 blood-to-organ transfer fraction
 F2PRA(ISPEC, ISOU, IAGE) (E10.0),
 compartment coefficient and biological half-life
 for each compartment of retention function
 (CA(ISPEC, IC, ISOU, IAGE), TBA(ISPEC, IC,
 ISOU, IAGE), IC=1, NCOMP(ISPEC, ISOU)) (8E10.0)
9. Excretion fraction for each radionuclide species in the chain
 (F2EXCR(ISPEC), ISPEC=1, NSPEC) (8E10.0)
10. Biological half-time (days) for blood for each radionuclide species
 (TBLUD(ISPEC), ISPEC=1, NSPEC) (8E10.0)
11. Fraction of each radionuclide species recycled to blood from each source organ
 For each radionuclide in the chain (ISPEC=1, NSPEC):
 (F2RCYC(ISPEC, ISOU), ISOU=1, NSOU) (8E10.0)

- *12. Exposure mode (1=inhalation, 2=ingestion, 3=injection) and, for inhalation, respiratory clearance category (1=D, 2=W, 3=Y) for each radionuclide species
 MODE, (SOL(ISPEC), ISPEC=1, NSPEC) (20I4)
- *13. GI-to-blood absorption fractions for each of the four GI segments For each radionuclide species in the chain (ISPEC=1, NSPEC):
 For each age in the age grid (IAGE=1, NAGEM):
 (GIFRAC (ISPEC, ISEG, IAGE), ISEG=1,4) (4E10.0)
- *14. Initial age of exposed individual and endpoint of integration
 T0, TEND (I4, E10.0)
- *15. Initial activities in stomach, NP, TB, Pulmonary, Blood and other explicit source organs
 YS0, YNP0, Y1TB0, YBLUD0, (YORG0(ISOU), ISOU=1, NSOU)
 (8E10.0)

Input to Unit 15

For each radionuclide species in the chain (ISPEC=1, NSPEC):
 For each of six** age groups (0, 365, 1825, 3650, 5475, and 7300 days)
 (IAGE = NSAGES, 6):
 For radiation of type ILET (ILET=1, NLET):
 For each target organ (ITRG=1, NTRG):
 S-factors for the specified matrix of source and target organs,
 (S(IAGE, ILET, ISPEC, ISOU, ITRG), ISOU=1, NSSEE***)
 S-factors for source tissues cortical bone surface (ISBONE=1) and trabecular bone surface (ISBONE=2) and target tissues endosteal cells (ITBONE=1) and red marrow (ITBONE=2),
 ((SFSURF(IAGE, ILET, ISPEC, ISBONE, ITBONE), ISBONE=1,2), ITBONE=1,2)

A second outline of input requirements is presented in Table 4 and sample input data sets are shown in Figs. 15 and 16. Sample output is shown in Table 5.

*Repeat for each exposure case, 1 to NCASES.

**Or 1 age group (7300 days) if NSAGES=6.

***When delayed excretion compartment is present NSSEE=NSOU+J-1; otherwise NSSEE=NSOU+J, where J=6 when bone is considered as a source organ, and J=5 otherwise.

Table 4. Input data for AGEDOS

Parameters	Number of values	Number of cards	Data type	Format
<u>Unit 5</u>				
1.* NSPEC,NLET,NCASES,NSAGES	1 for each parameter	1	Integer	4I4
2. (NAMNUC(ISPEC),TR(ISPEC),ISPEC=1,NSPEC)	NSPEC pairs	1 per pair	Alpha, Real	A8, E10.0
3. NBR	1	1	Integer	I4
(JSPEC, ISPEC, BRANCH(ISPEC, JSPEC), IBR=1, NBR)	3	NBR	Integer, Real	2I4, E10.0
4. NSOU	1	1	Integer	I4
(NAMSOU(ISOU), ISOU=1, NSOU)	NSOU	1	Alpha	10A8
5. NTRG	1	1	Integer	I4
(NAMTRG(ITRG), ITRG=1, NTRG)	NTRG	1-3	Alpha	10A8
6. (ISURF(ISPEC), ISPEC=1, NSPEC)	NSPEC	1	Integer	20I4
7. NAGEM	1	1	Integer	I4
(MAGE(IAGE), IAGE=1, NAGEM)	NAGEM	1	Integer	20I4
8. For ISPEC=1, NSPEC: For ISOU=1, NSOU: NCOMP(ISPEC, ISOU)	1	1	Integer	I4
For IAGE=1, NAGEM F2PRA(ISPEC, ISOU, IAGE) (CA(ISPEC, IC, ISOU, IAGE), TBA(ISPEC, IC, ISOU, IAGE), IC=1, NCOMP(ISPEC, ISOU)	1	1	Real	E10.0
9. (F2EXCR(ISPEC), ISPEC=1, NSPEC)	NCOMP pairs	1-2	Real	8E10.0
10. (TBLUD (ISPEC), ISPEC=1, NSPEC)	NSPEC	1-2	Real	8E10.0
11. For ISPEC=1, NSPEC: (F2RCYC(ISPEC, ISOU), ISOU=1, NSOU)	NSPEC	1-2	Real	8E10.0
12.** MODE,(SOL(ISPEC), ISPEC=1, NSPEC)	NSOU	NSPEC	Real	8E10.0
13.** For ISPEC=1, NSPEC: FOR IAGE=1, NAGEM: (GIFRAC(ISPEC, ISEG, IAGE), ISEG=1,4)	NSPEC	1	Integer	20I4
14.** T0, TEND	4	NSPEC x NAGEM	Real	4E10.0
15.** YS0, YNP0, Y1TB0, YP0, YBLUD0, (YORG0(ISOU), ISOU=1, NSOU)	2	1	Integer, Real	I4, E10.0
	NSOU+5	1-2	Real	8E10.0
<u>Unit 15</u>				
For ISPEC=1, NSPEC: For IAGE=NSAGES, 6: For ILET=1, NLET: For ITRG=1, NTRG: (S(IAGE, ILET, ISPEC, ISOU, ITRG), ISOU=1, NSSEE***)	NSSEE***	1-2	Real	8E10.0
((SFSURF(IAGE, ILET, ISPEC, ISBONE, ITBONE), ISBONE=1, 2), ITBONE=1, 2)	4	1	Real	4E10.0

*Numbers in this column correspond to numbers under heading "Input to Unit 5" in text.

**Repeat for each exposure case, 1 to NCASES.

***NSSEE=NSOU+5 when delayed excretion compartment is present; otherwise NSSEE=NSOU+6.

Figure 15. (Continued)

0.520E-09 0.382E-10 0.728E-11 0.112E-10 0.154E-11 0.117E-09 0.122E-09 0.122E-09
 0.287E-03 0.147E-11 0.573E-10 0.684E-10 0.454E-09 0.515E-11 0.529E-11 0.529E-11
 0.287E-02 0.162E-11 0.664E-17 0.929E-17 0.181E-17 0.248E-09 0.167E-09 0.167E-09
 0.287E-03 0.387E-10 0.118E-09 0.921E-10 0.317E-09 0.222E-00 0.333E-02 0.555E-02
 0.0 0.142E-10 0.201E-12 0.363E-12 0.660E-13 0.793E-10 0.102E-09 0.102E-09
 0.287E-03 0.441E-01 0.163E-05 0.539E-09 0.792E-10 0.137E-10 0.174E-10 0.174E-10
 0.900E-10 0.103E-05 0.230E-01 0.432E-08 0.217E-08 0.420E-10 0.389E-10 0.389E-10
 0.287E-03 0.366E-05 0.637E-08 0.417E-01 0.107E-08 0.500E-10 0.440E-10 0.440E-10
 0.287E-02 0.482E-10 0.239E-08 0.548E-09 0.670E-01 0.133E-09 0.119E-09 0.119E-09
 0.178E-12 0.80E-10 0.570E-10 0.227E-10 0.636E-11 0.556E-10 0.813E-10 0.813E-10
 0.287E-03 0.201E-05 0.115E-09 0.371E-09 0.224E-11 0.302E-10 0.384E-10 0.384E-10
 0.173E-05 0.681E-10 0.100E-11 0.156E-11 0.218E-12 0.782E-10 0.990E-10 0.990E-10
 0.287E-03 0.752E-11 0.267E-08 0.194E-08 0.621E-08 0.501E-10 0.436E-10 0.436E-10
 0.287E-03 0.169E-08 0.283E-10 0.487E-10 0.772E-11 0.133E-10 0.157E-10 0.157E-10
 0.287E-02 0.303E-10 0.128E-09 0.104E-09 0.359E-09 0.199E-01 0.330E-08 0.696E-02
 0.0 0.131E-05 0.275E-05 0.262E-10 0.245E-10 0.134E-10 0.321E-10 0.411E-10 0.411E-10
 0.287E-03 0.896E-10 0.203E-11 0.261E-11 0.103E-09 0.283E-11 0.587E-11 0.587E-11
 0.287E-03 0.769E-12 0.224E-14 0.756E-14 0.620E-15 0.644E-11 0.658E-11 0.658E-11
 0.287E-02 0.567E-11 0.155E-08 0.248E-09 0.755E-09 0.843E-11 0.782E-11 0.782E-11
 0.287E-02 0.555E-02 0.270E-08 0.095E-02
 0.112E-09 0.640E-11 0.771E-12 0.970E-12 0.105E-12 0.433E-10 0.401E-10 0.401E-10
 0.106E-03 0.894E-12 0.202E-10 0.122E-10 0.112E-09 0.819E-12 0.600E-12 0.600E-12
 0.106E-03 0.713E-16 0.776E-20 0.123E-19 0.157E-20 0.584E-10 0.428E-10 0.428E-10
 0.106E-03 0.105E-10 0.712E-10 0.243E-10 0.865E-13 0.682E-01 0.102E-02 0.171E-02
 0.0 0.127E-11 0.637E-14 0.135E-13 0.168E-14 0.215E-10 0.242E-10 0.242E-10
 0.106E-03 0.129E-01 0.470E-10 0.160E-09 0.250E-10 0.740E-11 0.505E-11 0.505E-11
 0.106E-03 0.261E-10 0.883E-02 0.145E-08 0.717E-09 0.143E-10 0.851E-11 0.851E-11
 0.106E-02 0.895E-10 0.235E-08 0.163E-01 0.779E-09 0.144E-10 0.816E-11 0.816E-11
 0.106E-03 0.778E-11 0.670E-09 0.166E-09 0.256E-01 0.403E-10 0.249E-10 0.249E-10
 0.106E-03 0.390E-11 0.114E-10 0.518E-11 0.937E-12 0.185E-10 0.176E-10 0.176E-10
 0.106E-03 0.480E-10 0.278E-10 0.742E-10 0.197E-12 0.731E-11 0.825E-11 0.825E-11
 0.652E-02 0.177E-10 0.102E-12 0.159E-12 0.177E-13 0.191E-10 0.213E-10 0.213E-10
 0.106E-03 0.711E-12 0.816E-05 0.640E-09 0.701E-08 0.134E-10 0.771E-11 0.771E-11
 0.106E-03 0.427E-05 0.588E-11 0.815E-11 0.898E-12 0.283E-11 0.282E-11 0.282E-11
 0.106E-03 0.937E-11 0.523E-10 0.416E-10 0.150E-09 0.623E-02 0.120E-08 0.218E-02
 0.0 0.655E-10 0.446E-11 0.371E-11 0.168E-11 0.764E-11 0.867E-11 0.867E-11
 0.106E-03 0.231E-14 0.484E-12 0.206E-12 0.170E-10 0.334E-12 0.642E-12 0.642E-12
 0.106E-03 0.205E-14 0.157E-16 0.282E-16 0.722E-17 0.115E-11 0.111E-11 0.111E-11
 0.106E-03 0.545E-12 0.413E-09 0.542E-10 0.821E-10 0.141E-11 0.834E-12 0.834E-12
 0.106E-03 0.171E-02 0.120E-08 0.312E-02
 0.349E-10 0.144E-11 0.141E-12 0.133E-12 0.992E-14 0.162E-10 0.121E-10 0.121E-10
 0.520E-04 0.538E-14 0.350E-11 0.239E-11 0.227E-10 0.253E-12 0.113E-12 0.113E-12
 0.832E-17 0.786E-20 0.215E-22 0.765E-22 0.298E-23 0.133E-10 0.178E-10 0.178E-10
 0.520E-04 0.308E-11 0.106E-10 0.716E-11 0.273E-10 0.283E-01 0.425E-03 0.708E-03
 0.0 0.251E-12 0.209E-15 0.488E-15 0.455E-16 0.105E-10 0.889E-11 0.889E-11
 0.520E-04 0.622E-02 0.214E-10 0.583E-10 0.434E-11 0.671E-12 0.133E-11 0.133E-11
 0.520E-04 0.754E-11 0.441E-02 0.619E-09 0.700E-09 0.830E-11 0.288E-11 0.288E-11
 0.520E-04 0.314E-10 0.115E-08 0.807E-02 0.180E-09 0.105E-10 0.627E-11 0.627E-11
 0.520E-04 0.181E-11 0.425E-09 0.693E-10 0.128E-01 0.248E-10 0.800E-11 0.800E-11
 0.520E-04 0.109E-11 0.342E-11 0.179E-11 0.196E-12 0.882E-11 0.501E-11 0.501E-11
 0.520E-04 0.115E-10 0.109E-10 0.248E-10 0.173E-13 0.295E-11 0.263E-11 0.263E-11
 0.520E-04 0.488E-11 0.651E-14 0.112E-13 0.797E-15 0.745E-11 0.643E-11 0.643E-11
 0.520E-04 0.780E-12 0.211E-09 0.270E-09 0.840E-09 0.556E-11 0.187E-11 0.187E-11
 0.520E-04 0.170E-05 0.692E-12 0.201E-11 0.670E-13 0.112E-11 0.813E-12 0.813E-12
 0.520E-04 0.364E-11 0.304E-10 0.210E-10 0.804E-10 0.292E-02 0.536E-09 0.102E-02
 0.0 0.221E-10 0.790E-12 0.692E-12 0.224E-12 0.285E-11 0.245E-11 0.245E-11
 0.520E-04 0.484E-16 0.160E-13 0.152E-13 0.724E-11 0.629E-13 0.884E-13 0.884E-13
 0.520E-04 0.405E-16 0.754E-15 0.155E-18 0.111E-19 0.376E-12 0.389E-12 0.389E-12
 0.520E-04 0.494E-12 0.125E-09 0.914E-11 0.128E-10 0.445E-12 0.153E-12 0.153E-12
 0.520E-04 0.708E-02 0.536E-05 0.144E-02

S-factors for Y-90 for age 0 days.

S-factors for Y-90 for age 365 days.

S-factors for Y-90 for age 1825 days.

Figure 15. (Continued)

0.124E-10 0.700E-12 0.211E-13 0.216E-13 0.236E-15 0.888E-11 0.531E-11 0.531E-11
0.310E-04 0.388E-15 0.691E-12 0.603E-12 0.125E-10 0.911E-13 0.298E-13 0.298E-13
0.110E-04 0.105E-21 0.666E-25 0.125E-24 0.672E-25 0.734E-11 0.104E-10 0.104E-10
0.210E-04 0.135E-11 0.529E-11 0.310E-11 0.124E-10 0.167E-01 0.250E-03 0.417E-03
0.0 0.178E-10 0.479E-12 0.645E-17 0.215E-16 0.152E-17 0.649E-11 0.445E-11 0.445E-11
0.310E-04 0.352E-02 0.521E-11 0.246E-10 0.126E-11 0.883E-12 0.232E-12 0.232E-12
0.210E-04 0.258E-11 0.262E-02 0.312E-09 0.159E-09 0.513E-11 0.144E-11 0.144E-11
0.210E-04 0.108E-10 0.648E-09 0.479E-02 0.943E-10 0.529E-11 0.221E-11 0.221E-11
0.170E-04 0.616E-12 0.243E-09 0.311E-10 0.757E-02 0.197E-10 0.463E-11 0.463E-11
0.202E-12 0.637E-12 0.142E-11 0.444E-12 0.407E-13 0.392E-11 0.182E-11 0.192E-11
0.310E-04 0.225E-11 0.764E-11 0.498E-11 0.129E-14 0.169E-11 0.123E-11 0.123E-11
0.210E-04 0.179E-11 0.528E-15 0.956E-15 0.497E-16 0.350E-11 0.244E-11 0.244E-11
0.210E-04 0.119E-12 0.146E-09 0.174E-09 0.424E-09 0.255E-11 0.694E-12 0.694E-12
0.203E-11 0.906E-10 0.142E-12 0.282E-12 0.147E-13 0.592E-12 0.331E-12 0.331E-12
0.310E-04 0.118E-10 0.188E-10 0.112E-10 0.454E-10 0.153E-02 0.320E-09 0.536E-03
0.0 0.113E-10 0.101E-10 0.218E-12 0.206E-13 0.456E-13 0.127E-11 0.899E-12 0.899E-12
0.310E-04 0.129E-17 0.142E-14 0.148E-14 0.109E-11 0.180E-13 0.249E-13 0.249E-13
0.170E-12 0.948E-18 0.419E-21 0.920E-21 0.461E-22 0.181E-12 0.203E-12 0.203E-12
0.310E-04 0.548E-14 0.452E-10 0.307E-11 0.549E-11 0.152E-12 0.423E-13 0.423E-13
0.170E-12 0.418E-03 0.220E-09 0.766E-03 0.111E-16 0.456E-11 0.238E-11 0.238E-11
0.110E-04 0.176E-16 0.181E-12 0.118E-12 0.404E-11 0.223E-13 0.727E-14 0.727E-14
0.181E-04 0.574E-24 0.449E-28 0.201E-27 0.717E-29 0.471E-11 0.632E-11 0.632E-11
0.181E-04 0.221E-11 0.774E-12 0.266E-11 0.125E-11 0.537E-11 0.102E-01 0.153E-03 0.255E-03
0.0 0.177E-11 0.845E-14 0.261E-18 0.767E-18 0.370E-19 0.135E-11 0.932E-12 0.932E-12
0.181E-04 0.177E-11 0.240E-02 0.269E-11 0.973E-11 0.446E-12 0.567E-12 0.255E-12 0.255E-12
0.181E-04 0.100E-11 0.145E-02 0.142E-09 0.731E-10 0.281E-11 0.725E-12 0.725E-12
0.181E-04 0.405E-11 0.337E-09 0.265E-02 0.510E-10 0.347E-11 0.925E-12 0.925E-12
0.144E-17 0.158E-12 0.127E-09 0.115E-10 0.428E-02 0.968E-11 0.210E-11 0.210E-11
0.181E-04 0.316E-12 0.359E-12 0.178E-12 0.918E-14 0.149E-11 0.605E-12 0.605E-12
0.181E-04 0.268E-16 0.145E-02 0.176E-11 0.439E-15 0.890E-12 0.592E-12 0.592E-12
0.144E-02 0.864E-12 0.293E-16 0.577E-16 0.737E-17 0.105E-11 0.651E-12 0.651E-12
0.181E-04 0.119E-14 0.681E-10 0.658E-10 0.216E-09 0.961E-12 0.238E-12 0.238E-12
0.181E-04 0.405E-10 0.315E-13 0.596E-13 0.144E-14 0.258E-12 0.128E-12 0.128E-12
0.181E-04 0.629E-12 0.103E-10 0.495E-11 0.214E-10 0.890E-03 0.196E-09 0.312E-03
0.0 0.388E-11 0.399E-11 0.402E-13 0.454E-13 0.633E-14 0.577E-12 0.354E-12 0.354E-12
0.181E-04 0.104E-15 0.527E-16 0.663E-16 0.418E-12 0.768E-14 0.596E-14 0.596E-14
0.181E-04 0.120E-15 0.535E-24 0.215E-23 0.687E-25 0.152E-12 0.188E-12 0.188E-12
0.181E-04 0.433E-15 0.178E-10 0.191E-11 0.176E-11 0.732E-13 0.186E-13 0.186E-13
0.181E-04 0.255E-03 0.196E-09 0.444E-03 0.109E-16 0.359E-11 0.233E-11 0.233E-11
0.338E-11 0.384E-12 0.534E-15 0.406E-15 0.109E-16 0.359E-11 0.233E-11 0.233E-11
0.148E-04 0.971E-22 0.645E-13 0.465E-13 0.747E-11 0.241E-13 0.738E-14 0.738E-14
0.148E-04 0.940E-25 0.115E-31 0.153E-31 0.782E-33 0.531E-11 0.448E-11 0.448E-11
0.148E-04 0.208E-12 0.159E-11 0.826E-12 0.787E-11 0.312E-03 0.117E-03 0.195E-03
0.0 0.128E-10 0.295E-11 0.437E-11 0.232E-11 0.730E-11 0.236E-11 0.184E-11 0.184E-11
0.148E-04 0.187E-02 0.536E-11 0.935E-11 0.741E-12 0.402E-12 0.393E-12 0.393E-12
0.148E-04 0.845E-12 0.117E-02 0.110E-09 0.691E-10 0.197E-11 0.485E-12 0.485E-12
0.148E-04 0.368E-11 0.735E-09 0.212E-02 0.408E-10 0.222E-11 0.654E-12 0.654E-12
0.148E-04 0.104E-12 0.925E-10 0.907E-11 0.746E-02 0.546E-11 0.195E-11 0.195E-11
0.214E-13 0.154E-12 0.319E-12 0.171E-12 0.480E-14 0.101E-11 0.819E-12 0.819E-12
0.148E-04 0.581E-12 0.652E-12 0.102E-11 0.958E-17 0.383E-12 0.422E-12 0.422E-12
0.148E-04 0.130E-11 0.354E-17 0.431E-17 0.152E-19 0.767E-12 0.716E-12 0.716E-12
0.148E-04 0.388E-15 0.435E-10 0.593E-10 0.146E-09 0.143E-11 0.373E-12 0.373E-12
0.251E-12 0.415E-10 0.151E-13 0.184E-13 0.431E-15 0.136E-12 0.106E-11 0.106E-11
0.148E-04 0.324E-12 0.662E-11 0.347E-11 0.162E-10 0.623E-03 0.147E-09 0.218E-03
0.0 0.303E-11 0.410E-11 0.224E-13 0.188E-13 0.283E-14 0.424E-12 0.177E-11 0.177E-11
0.148E-04 0.691E-21 0.614E-17 0.934E-17 0.919E-13 0.679E-14 0.817E-14 0.817E-14
0.148E-04 0.832E-21 0.407E-25 0.582E-25 0.188E-45 0.299E-12 0.358E-12 0.358E-12
0.148E-04 0.403E-15 0.692E-11 0.461E-12 0.266E-12 0.737E-13 0.188E-13 0.188E-13
0.148E-04 0.117E-03 0.195E-02 0.147E-05 0.312E-03

S-factors for Y-90 for age 3650 days.

S-factors for Y-90 for age 5475 days.

S-factors for Y-90 for adults.

Table 5. ASEDOS output corresponding to input data described in Fig. 15 (ingestion of 1 μ Ci Sr-90 at age 0 days).

LOW-LET DOSE RATES (RAC/DAY):											
TIME (DAYS)	0.0	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010
TARGET											
ADRENALS	0.0	4.74E-07	1.87E-06	4.15E-06	7.29E-06	1.12E-05	1.59E-05	2.14E-05	2.75E-05	3.43E-05	4.18E-05
BL WALL	0.0	4.74E-07	1.87E-06	4.15E-06	7.29E-06	1.12E-05	1.59E-05	2.14E-05	2.75E-05	3.43E-05	4.18E-05
BRAIN	0.0	4.74E-07	1.87E-06	4.15E-06	7.29E-06	1.12E-05	1.59E-05	2.14E-05	2.75E-05	3.43E-05	4.18E-05
BONE SUR	0.0	6.71E-08	5.19E-07	1.62E-06	3.72E-06	7.11E-06	1.21E-05	1.89E-05	2.78E-05	3.91E-05	5.30E-05
BREAST	0.0	4.74E-07	1.87E-06	4.15E-06	7.29E-06	1.12E-05	1.59E-05	2.14E-05	2.75E-05	3.43E-05	4.18E-05
ST WALL	4.73E-01	4.62E-01	4.52E-01	4.41E-01	4.31E-01	4.22E-01	4.12E-01	4.03E-01	3.94E-01	3.85E-01	3.76E-01
SI WALL	0.0	5.79E-03	1.13E-02	1.77E-02	2.40E-02	3.03E-02	3.66E-02	4.29E-02	4.92E-02	5.55E-02	6.18E-02
ULI WALL	0.0	3.21E-05	2.17E-04	2.81E-04	4.94E-04	7.61E-04	1.08E-03	1.45E-03	1.82E-03	2.34E-03	2.85E-03
LLI WALL	0.0	5.21E-07	2.15E-06	5.03E-06	9.29E-06	1.51E-05	2.24E-05	3.16E-05	4.26E-05	5.55E-05	7.05E-05
KIDNEYS	0.0	4.74E-07	1.87E-06	4.15E-06	7.29E-06	1.12E-05	1.59E-05	2.14E-05	2.75E-05	3.43E-05	4.18E-05
LIVER	0.0	4.74E-07	1.87E-06	4.15E-06	7.29E-06	1.12E-05	1.59E-05	2.14E-05	2.75E-05	3.43E-05	4.18E-05
LUNGS	0.0	4.74E-07	1.87E-06	4.15E-06	7.29E-06	1.12E-05	1.59E-05	2.14E-05	2.75E-05	3.43E-05	4.18E-05
OVARIES	0.0	4.74E-07	1.87E-06	4.15E-06	7.29E-06	1.12E-05	1.59E-05	2.14E-05	2.75E-05	3.43E-05	4.18E-05
PANCREAS	0.0	4.74E-07	1.87E-06	4.15E-06	7.29E-06	1.12E-05	1.59E-05	2.14E-05	2.75E-05	3.43E-05	4.18E-05
RED MAR	0.0	3.12E-09	1.86E-08	5.83E-08	1.34E-07	2.56E-07	4.75E-07	6.81E-07	1.00E-06	1.41E-06	1.92E-06
SPLFEN	0.0	4.40E-07	1.74E-06	5.86E-06	6.76E-06	1.20E-05	1.48E-05	1.99E-05	2.55E-05	3.19E-05	3.88E-05
TESTES	0.0	4.74E-07	1.87E-06	4.15E-06	7.29E-06	1.12E-05	1.59E-05	2.14E-05	2.75E-05	3.43E-05	4.18E-05
THYROID	0.0	4.74E-07	1.87E-06	4.15E-06	7.29E-06	1.12E-05	1.59E-05	2.14E-05	2.75E-05	3.43E-05	4.18E-05
UTERUS	0.0	4.74E-07	1.87E-06	4.15E-06	7.29E-06	1.12E-05	1.59E-05	2.14E-05	2.75E-05	3.43E-05	4.18E-05
TIME (DAYS)	0.02C	0.030	0.040	0.050	0.060	0.070	0.080	0.090	0.100	0.200	0.300
TARGET											
ADRENALS	1.44E-04	2.82E-04	4.37E-04	5.99E-04	7.57E-04	9.06E-04	1.04E-03	1.17E-03	1.28E-03	1.79E-03	1.83E-03
BL WALL	1.44E-04	2.82E-04	4.37E-04	5.99E-04	7.57E-04	9.06E-04	1.04E-03	1.17E-03	1.28E-03	1.79E-03	1.83E-03
BRAIN	1.44E-04	2.82E-04	4.37E-04	5.99E-04	7.57E-04	9.06E-04	1.04E-03	1.17E-03	1.28E-03	1.79E-03	1.83E-03
BONE SUR	1.16E-01	2.44E-01	2.44E-01	4.28E-01	6.66E-01	9.50E-01	1.29E-01	1.67E-01	2.08E-01	6.85E-01	1.17E-01
BREAST	1.44E-04	2.82E-04	4.37E-04	5.99E-04	7.57E-04	9.06E-04	1.04E-03	1.17E-03	1.28E-03	1.79E-03	1.83E-03
ST WALL	3.00E-01	2.90E-01	2.80E-01	2.70E-01	2.60E-01	2.50E-01	2.40E-01	2.30E-01	2.20E-01	2.10E-01	2.00E-01
SI WALL	7.91E-02	7.73E-02	7.57E-02	7.41E-02	7.25E-02	7.10E-02	6.95E-02	6.80E-02	6.67E-02	6.53E-02	6.37E-02
ULI WALL	9.89E-02	1.95E-02	3.06E-02	4.22E-02	5.38E-02	6.50E-02	7.55E-02	8.52E-02	9.41E-02	1.04E-01	1.13E-01
LLI WALL	3.59E-04	5.27E-04	1.82E-03	3.04E-03	4.61E-03	6.50E-03	8.69E-03	1.12E-02	1.39E-02	4.85E-02	8.93E-02
KIDNEYS	1.44E-04	2.82E-04	4.37E-04	5.99E-04	7.57E-04	9.06E-04	1.04E-03	1.17E-03	1.28E-03	1.79E-03	1.83E-03
LIVER	1.44E-04	2.82E-04	4.37E-04	5.99E-04	7.57E-04	9.06E-04	1.04E-03	1.17E-03	1.28E-03	1.79E-03	1.83E-03
LUNGS	1.44E-04	2.82E-04	4.37E-04	5.99E-04	7.57E-04	9.06E-04	1.04E-03	1.17E-03	1.28E-03	1.79E-03	1.83E-03
OVARIES	1.44E-04	2.82E-04	4.37E-04	5.99E-04	7.57E-04	9.06E-04	1.04E-03	1.17E-03	1.28E-03	1.79E-03	1.83E-03
PANCREAS	1.44E-04	2.82E-04	4.37E-04	5.99E-04	7.57E-04	9.06E-04	1.04E-03	1.17E-03	1.28E-03	1.79E-03	1.83E-03
RED MAR	1.44E-04	2.82E-04	4.37E-04	5.99E-04	7.57E-04	9.06E-04	1.04E-03	1.17E-03	1.28E-03	1.79E-03	1.83E-03
SPLFEN	1.44E-04	2.82E-04	4.37E-04	5.99E-04	7.57E-04	9.06E-04	1.04E-03	1.17E-03	1.28E-03	1.79E-03	1.83E-03
TESTES	1.44E-04	2.82E-04	4.37E-04	5.99E-04	7.57E-04	9.06E-04	1.04E-03	1.17E-03	1.28E-03	1.79E-03	1.83E-03
THYROID	1.44E-04	2.82E-04	4.37E-04	5.99E-04	7.57E-04	9.06E-04	1.04E-03	1.17E-03	1.28E-03	1.79E-03	1.83E-03
UTERUS	1.44E-04	2.82E-04	4.37E-04	5.99E-04	7.57E-04	9.06E-04	1.04E-03	1.17E-03	1.28E-03	1.79E-03	1.83E-03
TIME (DAYS)	0.40C	0.500	0.600	0.700	0.800	0.900	1.000	2.000	3.000	4.000	5.000
TARGET											
ADRENALS	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
BL WALL	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
BRAIN	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
BONE SUR	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
BREAST	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
ST WALL	1.81E-02	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
SI WALL	6.95E-02	4.26E-03	2.97E-03	2.29E-03	1.93E-03	1.73E-03	1.62E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
ULI WALL	1.39E-01	1.26E-01	1.17E-01	9.92E-02	8.26E-02	7.55E-02	6.97E-02	6.57E-02	6.30E-02	6.15E-02	6.03E-02
LLI WALL	1.38E-01	1.61E-01	1.85E-01	2.10E-01	2.26E-01	2.37E-01	2.45E-01	2.51E-01	2.56E-01	2.60E-01	2.63E-01
KIDNEYS	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
LIVER	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
LUNGS	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
OVARIES	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
PANCREAS	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
RED MAR	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
SPLFEN	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
TESTES	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
THYROID	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
UTERUS	1.76E-03	1.69E-03	1.67E-03	1.58E-03	1.55E-03	1.52E-03	1.51E-03	1.55E-03	1.58E-03	1.54E-03	1.45E-03
TIME (DAYS)	6.00C	7.000	8.000	9.000	10.000	20.000	30.000	40.000	50.000	60.000	70.000
TARGET											
ADRENALS	1.34E-02	1.23E-03	1.17E-03	1.04E-03	9.54E-04	5.69E-04	4.49E-04	3.74E-04	3.15E-04	2.68E-04	2.30E-04
BL WALL	1.34E-02	1.23E-03	1.17E-03	1.04E-03	9.54E-04	5.69E-04	4.49E-04	3.74E-04	3.15E-04	2.68E-04	2.30E-04
BRAIN	1.34E-02	1.23E-03	1.17E-03	1.04E-03	9.54E-04	5.69E-04	4.49E-04	3.74E-04	3.15E-04	2.68E-04	2.30E-04
BONE SUR	2.36E-01	2.26E-01	2.16E-01	2.06E-01	1.97E-01	1.83E-01	1.72E-01	1.61E-01	1.50E-01	1.41E-01	1.32E-01
BREAST	1.34E-02	1.23E-03	1.17E-03	1.04E-03	9.54E-04	5.69E-04	4.49E-04	3.74E-04	3.15E-04	2.68E-04	2.30E-04
ST WALL	1.34E-02	1.23E-03	1.17E-03	1.04E-03	9.54E-04	5.69E-04	4.49E-04	3.74E-04	3.15E-04	2.68E-04	2.30E-04
SI WALL	1.34E-02	1.23E-03	1.17E-03	1.04E-03	9.54E-04	5.69E-04	4.49E-04	3.74E-04	3.15E-04	2.68E-04	2.30E-04
ULI WALL	1.36E-02	1.24E-03	1.17E-03	1.04E-03	9.54E-04	5.69E-04	4.49E-04	3.74E-04	3.15E-04	2.68E-04	2.30E-04
LLI WALL	8.21E-02	2.88E-03	2.14E-03	1.42E-03	1.10E-03	9.54E-04	4.49E-04	3.74E-04	3.15E-04	2.68E-04	2.30E-04
KIDNEYS	1.34E-02	1.23E-03	1.17E-03	1.04E-03	9.54E-04	5.69E-04	4.49E-04	3.74E-04	3.15E-04	2.68E-04	2.30E-04
LIVER	1.34E-02	1.23E-03	1.17E-03	1.04E-03	9.54E-04	5.69E-04	4.49E-04				

Table 5. (Continued)

TIME(DAYS)	770.000	830.000	930.000	1095.000	1460.000	1825.000	2170.000	2555.000	2920.000	3285.000	3650.000
TARGET											
ADRENALS	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
BL WALL	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
BRAIN	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
BONE SUR	1.09E-03	1.06E-04	5.09E-04	7.77E-04	1.47E-04	5.79E-05	2.41E-05	1.35E-05	7.66E-06	4.41E-06	2.62E-06
BFEST	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
ST WALL	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
ULI WALL	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
LLI WALL	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
KIDNEYS	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
LIVER	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
LUNGS	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
OVARIES	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
PANCREAS	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
RED MAP	4.17E-04	7.08E-04	2.95E-04	1.41E-04	5.35E-05	2.95E-05	4.71E-06	4.16E-06	2.93E-06	1.07E-06	5.16E-07
SPLFFN	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
TESTES	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
THYROID	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
UTERUS	6.59E-06	6.08E-06	7.09E-06	2.95E-06	1.63E-06	9.29E-07	6.29E-07	6.14E-07	7.87E-07	2.90E-07	2.14E-07
TIME(DAYS)	4015.000	4280.000	4745.000	5110.000	5475.000	5840.000	6205.000	6570.000	6935.000	7300.000	7665.000
TARGET											
ADRENALS	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
BL WALL	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
BRAIN	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
BONE SUR	1.63E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
BFEST	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
ST WALL	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
ULI WALL	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
LLI WALL	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
KIDNEYS	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
LIVER	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
LUNGS	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
OVARIES	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
PANCREAS	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
RED MAP	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
SPLFFN	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
TESTES	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
THYROID	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
UTERUS	1.60E-07	1.22E-07	9.18E-08	6.85E-08	5.04E-08	3.84E-08	3.38E-08	2.47E-08	1.98E-08	1.58E-08	1.29E-08
TIME(DAYS)	8030.000	8395.000	8760.000	9125.000	9490.000	9855.000	10220.000	10585.000	10950.000	11315.000	11680.000
TARGET											
ADRENALS	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
BL WALL	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
BRAIN	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
BONE SUR	1.13E-08	1.00E-08	1.01E-08	9.52E-09	8.00E-09	6.51E-09	5.88E-09	3.81E-09	3.19E-09	2.81E-09	2.44E-09
BFEST	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
ST WALL	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
ULI WALL	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
LLI WALL	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
KIDNEYS	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
LIVER	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
LUNGS	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
OVARIES	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
PANCREAS	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
RED MAP	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
SPLFFN	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
TESTES	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
THYROID	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
UTERUS	1.07E-08	8.22E-09	7.44E-09	6.20E-09	5.16E-09	4.30E-09	3.88E-09	2.55E-09	2.49E-09	2.07E-09	1.73E-09
TIME(DAYS)	12045.000	12410.000	12775.000	13140.000	13505.000	13870.000	14235.000	14600.000	14965.000	15330.000	15695.000
TARGET											
ADRENALS	1.44E-09	1.20E-09	9.90E-10	8.33E-10	6.94E-10	5.78E-10	4.92E-10	4.01E-10	3.34E-10	2.79E-10	2.32E-10
BL WALL	1.44E-09	1.20E-09	9.90E-10	8.33E-10	6.94E-10	5.78E-10	4.92E-10	4.01E-10	3.34E-10	2.79E-10	2.32E-10
BRAIN	1.44E-09	1.20E-09	9.90E-10	8.33E-10	6.94E-10	5.78E-10	4.92E-10	4.01E-10	3.34E-10	2.79E-10	2.32E-10
BONE SUR	6.29E-09	4.77E-09	5.46E-09	5.17E-09	4.89E-09	4.61E-09	4.33E-09	4.15E-09	3.93E-09	3.72E-09	3.53E-09
BFEST	1.44E-09	1.20E-09	9.90E-10	8.33E-10	6.94E-10	5.78E-10	4.92E-10	4.01E-10	3.34E-10	2.79E-10	2.32E-10
ST WALL	1.44E-09	1.20E-09	9.90E-10	8.33E-10	6.94E-10	5.78E-10	4.92E-10	4.01E-10	3.34E-10	2.79E-10	2.32E-10
ULI WALL	1.44E-09	1.20E-09	9.90E-10	8.33E-10	6.94E-10	5.78E-10	4.92E-10	4.01E-10	3.34E-10	2.79E-10	2.32E-10
LLI WALL	1.44E-09	1.20E-09	9.90E-10	8.33E-10	6.94E-10	5.78E-10	4.92E-10	4.01E-10	3.34E-10	2.79E-10	2.32E-10
KIDNEYS	1.44E-09	1.20E-09	9.90E-10	8.33E-10	6.94E-10	5.78E-10	4.92E-10	4.01E-10	3.34E-10	2.79E-10	2.32E-10
LIVER	1.44E-09	1.20E-09	9.90E-10	8.33E-10	6.94E-10	5.78E-10	4.92E-10	4.01E-10	3.34E-10	2.79E-10	2.32E-10
LUNGS	1.44E-09	1.20E-09	9.90E-10	8.33E-10	6.94E-10	5.78E-10	4.92E-10	4.01E-10	3.34E-10	2.79E-10	2.32E-10
OVARIES	1.44E-09	1.20E-09	9.90E-10	8.33E-10	6.94E-10	5.78E-10	4.92E-10	4.01E-10	3.34E-10	2.79E-10	2.32E-10
PANCREAS	1.44E-09	1.20E-09	9.90E-10	8.33E-10	6.94E-10	5.78E-10	4.92E-10</				

Subroutines. As noted above, AGEDOS comprises a series of subroutines. Subroutines ZERO and ZERORG initialize appropriate parameter values to zero. Subroutine INPUT reads the data for the current problem; subsequent calls to ENTRY INCASE, a second entry point in INPUT, are used to read data for each exposure case. Subroutine OUTDAT prints physical and metabolic data for the current problem common to all exposure cases. Subroutine AGEDEP initializes the arrays of age-dependent physiological and metabolic parameters, based upon available input data; subsequent calls to ENTRY AGED, a second entry point in AGEDEP, determine the appropriate values for age-dependent parameters for the current time for use in subroutine STEP. STEP advances the integration of the differential equations over the current subinterval by repeatedly invoking subroutine MULCOM, which solves the differential equations for each organ. A matrix of dose rates to all target organs at the current time is computed by subroutine DOSAGE, while subroutine DOSCOM computes the committed dose to all target organs. Subroutine OUTPUT prints the results of the current case, tabulating the dose rate and committed dose matrices.

Brief descriptions of each subroutine follow:

INPUT: Called by driving program to input parameters for the current problem, including: number, names, half-lives, and branching ratios of all radionuclides in the chain; number and names of source organs; the age grid for which metabolic data are specified; metabolic data for each source organ and radionuclide; fractional allocation of blood to each source organ; half-time in blood for each radionuclide; fraction of each radionuclide recycled to blood from each source organ; fraction of each radionuclide going to prompt excretion; and S-factors for all radionuclides, source organs, target organs, and ages. Subsequent calls to ENTRY INCASE(ICASE) input parameters for each exposure case: exposure mode; GI uptake fractions; beginning age; time of integration; and initial conditions. Common blocks used are /CASOPT/, /SFACT/, /RADAT/, /ORGDAT/, /NUMBERS/, /NAMES/, /TYME/, /GI/, /AGE/, /SOLUB/, /NOUGHT/, /SURVOL/, /EXCTRM/, /BONSWT/, and /BLOOD/.

INCASE(ICASE): A second entry point to subroutine INPUT called by the driving program to input parameters for each desired exposure case: exposure mode; GI uptake fractions; beginning age; time of integration; and initial conditions.

OUTDAT: Called by driving program to tabulate the physical and metabolic parameters for each radionuclide, including radionuclide names, radiological half-lives, branching ratios, transfer fractions and retention parameters for each source organ and each age, blood allocation and turnover rate, bone deposition assumptions, and S-factors. Common blocks used are /NUMBRS/, /NAMES/, /SFACT/, /RADAT/, /AGE/, /ORGDAT/, /BLOOD/, /EXCTRM/, and /SURVOL/.

SEETAB(IAGE, ILET, IFIRST, LAST, ISPEC): Called by OUTDAT to tabulate the matrix of S-factors for radionuclide ISPEC to all target organs from source organs with indices IFIRST through LAST, at age IAGE, for radiation of LET-type ILET. Common blocks used are /NUMBRS/, /NAMES/, /SFACT/, /AGESEE/, /BONSWT/, and /AGE/.

ZERO: Called by driving program to initialize all parameter values in common blocks /LEVELS/, /CUMACT/, /ACTVTY/, and /DOSES/ to 0.0 for each case.

ZERORG: Called by driving program to initialize all parameter values in common blocks /ORGDAT/ and /GI/ to zero for each radionuclide chain.

AGEDEP(T): Called initially by driving program to set up arrays of metabolic parameters; if data for a particular age are not specified, data for the next higher age for which data are given are used as a default. Data include metabolic models for all source organs, radionuclides and ages, and age-dependent GI-tract absorption fractions. Subsequent calls to ENTRY AGED(T) determine the appropriate values of age-dependent parameters for the current time T. Common blocks used are /AGEMET/, /AGEBON/, /NUMBRS/, /ORGDAT/, /GI/, /AGE/, /AGESEE/, /SOLUB/, and /INTRP/.

AGED(T): A second entry point to subroutine AGEDEP called by STEP to determine the appropriate values of age-dependent parameters for the current time step; parameter values for time $T = (T_0 + T_1) \times 0.5 \times \text{DELT}$ are placed in common block /AGEMET/ for use in subroutine STEP.

STEP(T₀, T₁, T₂, MODE): Called by driving program to advance the integration of the differential equations from time T₁ to T₂ for an individual of beginning age T₀. The principal task of STEP is the organization of data for calls to subroutine MULCOM and storage of the results in appropriate arrays. STEP takes the initial activities from common block /LEVELS/ and returns updated values for the current subinterval; time-integrated activities for the subinterval are stored in /CUMACT/. MODE 1 indicates inhalation, 2 ingestion, and 3 injection cases. Common blocks used are /SWTCHS/, /RADAT/, /LEVELS/, /CUMACT/, /ORGDAT/, /AGEMET/, /AGEBON/, /TGLM/, /EXCTRM/, /BONSWT/, /NUMBERS/, /SURVOL/, /BURBON/, /BLOOD/, /INTRP/, and /MULDAT/.

MULCOM: Called repeatedly by STEP to compute activities and cumulated activities of each radionuclide in the decay chain for the current organ and time step. Common blocks used are /NUMBERS/, /RADAT/, and /MULDAT/.

DOSAGE(T, INDEX): Called by driving program to compute dose rate matrix DOSRAT (ILET, INDEX, ITRG), to all target organs from activities calculated by subroutine STEP for the current time T; also tabulates activities in each source organ on auxiliary output unit if desired. Common blocks are /SWTCHS/, /NUMBERS/, /NAMES/, /ORGDAT/, /LEVELS/, /CUMACT/, /ACTVTY/, /DOSES/, /SFACT/, /CASE/, /TYME/, /INTRP/, /SOLUB/, /SURVOL/, /EXCTRM/, /BONSWT/, and /BLOOD/.

DOSCOM(T): Called by driving program to compute committed dose, DOSE(ILET, ITRG), to all target organs at time T from activities calculated by subroutine STEP; also tabulates committed dose to all target organs and/or accumulated activity in each

source organ at each time step on auxiliary output units if desired. Common blocks used are /NUMBRS/, /NAMES/, /ORGDAT/, /CUMACT/, /ACTVTY/, /DOSES/, /SFACT/, /CASE/, /TYME/, /INTRP/, /SOLUB/, /SURVOL/, /EXCTRM/, /BONSWT/, and /BLOOD/.

OUTPUT: Called by the driving program to print case-specific information for the current problem, including initial activity in each organ, beginning age, GI uptake fractions, respiratory clearance class (for inhalation case), and a matrix of dose rates to all target organs at specified times for low- and high-LET radiation; the dose commitments to each target organ at the end of the integration period are also tabulated. Common blocks used are /NUMBRS/, /NAMES/, /GI/, /AGE/, /STEPS/, /NOUGHT/, /CASE/, /SOLUB/, /TYME/, /ACTVTY/, and /DOSES/.

DOSTAB(ILET, IFIRST, LAST): Called by OUTPUT to tabulate the matrix of dose rates to all target organs for source organs with indices IFIRST through LAST from radiation of LET-type ILET. Common blocks used are /NUMBRS/, /NAMES/, and /DOSES/.

Common Blocks and Parameter Definitions

The transfer of information among subroutines of AGEDOS is accomplished primarily through the following common blocks.

/NUMBRS/ NSPEC, NSOU, NTRG, NLET

NSPEC = number of radionuclide species in the chain

NSOU = number of source organs (excluding lung and GI segments); total source organs NS = NSOU + 6 if bone is included as a source organ, and NS = NSOU + 5 otherwise

NTRG = number of target tissues

NLET = 1 if only low-LET radiation is present
2 if high-LET radiation is present

/NAMES/ NAMNUC(NSPEC), NAMSOU(NSOU), NAMTRG(NTRG)

NAMNUC(ISPEC) = name of radionuclide ISPEC

NAMSOU(ISO) = name of source organ ISO

NAMTRG(ITRG) = name of target organ ITRG

/RADAT/ TR(NSPEC), BRANCH(NSPEC,NSPEC), LMR(NSPEC)

TR(ISPEC) = radiological half-life of species ISPEC (days)

BRANCH(ISPEC,JSPEC) = branching ratio of species JSPEC to species ISPEC (JSPEC < ISPEC)

LMR(ISPEC) = radiological removal rate of species ISPEC (day⁻¹)

/CASOPT/ NCASES, LAST

NCASES = number of cases considered in this problem

LAST = Logical switch to indicate end of input data

/TYME/ T0, TEND

T0 = age at beginning of exposure

TEND = time limit for current case

/STEPS/ NTIMES

NTIMES = number of times for which dose rates have been computed for current case

/CASE/ ICASE

ICASE = number of the current exposure case under consideration

/BLOOD/ LBLUD(NSPEC), TBLUD(NSPEC)

TBLUD(ISPEC) = biological half-life (days) for species ISPEC in blood

LBLUD(ISPEC) = clearance rate (day⁻¹) from blood for species ISPEC

/SURVOL/ ISURF(NSPEC)

ISURF(ISPEC) = 0 if species ISPEC is a bone volume seeker, 1 if it is a bone surface seeker

/EXCTRM/ NSSEE, OTHEXC

NSSEE = number of source organs for which S-factors are input (when delayed excretion compartment is present NSSEE=NSOU+5; otherwise NSSEE=NSOU+6)

OTHEXC = logical flag to indicate presence of delayed excretion compartment in current chain

/BONSWT/ NOBONE

NOBONE = logical switch to indicate inclusion of bone tissues as explicit source organs (if NOBONE = .TRUE., the standard bone model in AGEDOS is bypassed)

/ORGDAT/ NCOMP(NSPEC,NSOU), C(NSPEC,NC,NSOU,NAGEP), LMBDAB(NSPEC,NC,NSOU,NAGEP), F2PRIM(NSPEC,NSOU,NAGEP), TBA(NSPEC,NC,NSOU,NAGEP), F2EXCR(NSPEC), F2RCYC(NSPEC,NORG)

F2PRIM(ISPEC, ISOU, IAGE)

= transfer fraction of species ISPEC from blood to source organ ISOU (excluding lungs and GI segments)

NCOMP(ISPEC, ISOU), C(ISPEC, IC, ISOU, IAGE), LMBDAB(ISPEC, IC, ISOU, IAGE)

= parameters specifying the fractional retention function for nuclide species ISPEC in source organ ISOU at age IAGE. NCOMP is the number of terms in the retention function, and C and LMBDAB (REAL) are the coefficient and biological removal rate constant (day^{-1} , respectively, of term IC ($1 \leq IC \leq NCOMP$)). The form is

NCOMP (ISPEC, ISOU)

$$\sum_{IC=1} C(ISPEC, IC, ISOU) * \exp(-LMBDAB(ISPEC, IC, ISOU) * T)$$

The function shown has not been corrected for radioactive decay.

TBA(ISPEC, IC, ISOU, IAGE)

= biological half-life (days) of term IC in the retention function for species ISPEC in source organ ISOU at age IAGE

F2EXCR(ISPEC) = transfer fraction of species ISPEC from blood to excretion

F2RCYC(ISPEC, IORG) = fraction of species ISPEC returned to blood from source organ IORG

/SOLUB/ MODE, SOL(NSPEC)

MODE = mode of intake (1 = inhalation, 2 = ingestion, 3 = injection)

SOL(ISPEC) = respiratory clearance class of species ISPEC (if MODE=1) (1=class D, 2= class W, 3 = class Y)

/SWTCHS/ SNP, STB1, SP, SL, STB2(2), SLUNG, SST, SSI, SULI, SLLI, SGI, SBLUD, SSURF

= logical switches to indicate exhaustion of activity (i.e., if ".TRUE.") from nasal-pharynx (respiratory pathways A and B), tracheobronchial region (C,D), pulmonary region (E, F, G, H), respiratory lymph (I, J), TB feedback pathways (K, L), lung (i.e., all of the preceding are .TRUE.), stomach, small intestine, lower large intestine, total GI-tract, blood, and bone surface

/TGLM/ LMA(NSPEC), LMB(NSPEC), LMC(NSPEC), LMD(NSPEC), LME(NSPEC), LMF(NSPEC), LMG(NSPEC), LMH(NSPEC), LMI(NSPEC), FA(NSPEC), FB(NSPEC), FC(NSPEC), FD(NSPEC), FE(NSPEC), FF(NSPEC), FG(NSPEC), FH(NSPEC), FI(NSPEC)

LMA(ISPEC)...LMI(ISPEC)

= clearance rate coefficients (day^{-1}) for respiratory pathways a through i, respectively

FA(ISPEC)...FI(ISPEC)
 = deposition fractions for respiratory pathways a through i for species ISPEC

/GI/ LMGIA(4,NAGEP), LMABA(NSPEC,4,NAGEP), GIFRAC(NSPEC,4,NAGEP)
 LMGIA(ISEG,IAGE) = clearance rate coefficient (day^{-1}) for segment ISEG of the GI tract at age IAGE
 LMABA(ISPEC, ISEG, IAGE)
 = absorption rate coefficient (day^{-1}) of species ISPEC from segment ISEG and age IAGE
 GIFRAC(ISPEC, ISEG, IAGE)
 = GI-tract-to-blood transfer fraction for species ISPEC in segment ISEG at age IAGE

/AGEBON/ ALAMA(NAGEP), ALAMB(NAGEP), ALAMC(NAGEP), ALAMD(NAGEP), ALAME(NAGEP), ALAMF(NAGEP), ALAMY(NAGEP), ALAMR(NAGEP), VLAMAC
 ALAMA(IAGE)...ALAMF(IAGE)
 = age-dependent removal rates (day^{-1}) for pathways A through F of the bone model at age IAGE
 ALAMY(IAGE), ALAMR(IAGE)
 = age-dependent removal rates (day^{-1}) for cortical marrow (bone pathways G and I) and trabecular marrow (bone pathways H and J) at age IAGE
 VLAMAC = removal rate (day^{-1}) for pathways A and C of the bone model for volume-seeking radionuclides

/AGEMET/ LMG I(4), LMAB(NSPEC,4), C(NSPEC,NC,NSOU), LMBDAB(NSPEC,NC,NSOU), F2PRIM(NSPEC,NSOU), LAMDAA, LAMDAB, LAMDAC, LAMDAD, LAMD AE, LAMD AF, LAMD AY, LAMD AR
 LMG I(ISEG) = clearance rate (day^{-1}) for segment ISEG of the GI tract at current age
 LAMB(ISPEC, ISEG) = absorption rate (day^{-1}) of species ISPEC from GI segment ISEG at current age
 C(ISPEC, IC, ISOU), LMBDAB(ISPEC, IC, ISOU)
 = coefficient and biological removal rate (day^{-1}) of term IC of fractional retention function for nuclide ISPEC in source organ ISOU
 F2PRIM(ISPEC, ISOU)
 = transfer fraction of species ISPEC from blood to source organ ISOU
 LAMDAA...LAMDAR = clearance rates (day^{-1}) for pathways A through F of the bone model, cortical marrow (pathways G and I), and trabecular marrow (pathways H and J)

/NOUGHT/ YSØ, YNPØ, Y1TBØ, YPØ, YBLUDØ, YORGØ(NSOU)
 YSØ...YORGØ(ISOU)
 = initial activity in stomach, NP, TB, pulmonary, blood, and other source organs. (For ingestion case YSØ is nonzero and all other initial conditions are zero; for inhalation

YNP \emptyset , Y1TB \emptyset , and/or YP \emptyset are nonzero and others set to zero; for injection, YBLUD \emptyset and/or YORG \emptyset (ISOU) are nonzero.)

/AGE/ MPHYS(NAGEP), MAGE(NAGEP), NAGEP, NAGEM

NAGEP = number of ages for which physiological parameters (e.g., bone model, lung models) are specified (=7)

MPHYS(1...NAGEP)

= age grid for which physiological parameters are specified (0, 100, 365, 1825, 3650, 5475, and 7300 days)

NAGEM = number of ages for which certain metabolic parameters (uptake fractions, retention function parameters, and GI-to-blood transfer fractions) are input

MAGE(1...NAGEM) = age grid for which these metabolic parameters are input

/AGESEE/ MSEE(NAGEP-(thel), NSEE

MSEE(IAGE) = age grid for which S-factors are input (normally 0, 365, 1825, 3650, 5475 and 7300 days)

NSEE = number of ages for which S-factors are given

/INTRP/ SRPLAT, IPS

SRPLAT = interpolation fraction for S-factor data for current age

$$= \frac{T - MSEE(IPS-1)}{MSEE(IPS) - MSEE(IPS-1)}$$

IPS = pointer to S-factors for current age

/BURBON/ CBURY, TBURY

CBURY, TBURY = $\sum \text{DELT} \times \text{LAMDAE}$, $\sum \text{DELT} \times \text{LAMDAF}$ = measure of radionuclide burial in cortical and trabecular bone

/MULDAT/ DELT, LMB(NSPEC,NC), C(NSPEC,NC), P(NSPEC,NC), A \emptyset (NSPEC,NC), A(NSPEC,NC), AW(NSPEC,NC), NCTEMP(NSPEC)

Parameters defining differential equations for solution in subroutine MULCOM for current organ.

DELT = length of current subinterval (days)

C(ISPEC,IC), LMB(ISPEC,IC)

= coefficient and biological removal rate (day^{-1}) of the term IC of the fractional retention function for nuclide ISPEC in the current source organ

P(ISPEC,IC) = inflow vector of nuclide ISPEC in compartment IC of the current organ

A \emptyset (ISPEC,IC) = initial activity of nuclide ISPEC in compartment IC at the beginning of the current subinterval

A(ISPEC,IC) = activity of nuclide ISPEC in compartment IC

AW(ISPEC,IC) = time-integrated activity of nuclide ISPEC in compartment IC for the current subinterval

NCTEMP(ISPEC) = number of compartments in current source organ for nuclide ISPEC

/LEVELS/ YNP(NSPEC,2) Y1TB(NSPEC,2), Y2TB(NSPEC,2), YP(NSPEC,4), YL(NSPEC,2), YS(NSPEC), YSI(NSPEC), YULI(NSPEC), YLLI(NSPEC), YBLUD(NSPEC), YCSUR(NSPEC), YTSUR(NSPEC), YREDM(NSPEC), YYELM(NSPEC), YORG(NSPEC,NC,NSOU), YEXCR(NSPEC)

YNP(ISPEC, IPATH), ... YEXCR(ISPEC)

= activity in lungs (pathways a through l), GI segments, blood, bone transfer compartment, cortical bone surface, trabecular bone surface, red marrow, yellow marrow, other explicit source organs (if bone is included as a source organ, the first 2 organs in YORG must be cortical bone and trabecular bone), and excretion

/ACTVITY/ ACT(NSPEC,NTIMES,NORG), AWIGL(NSPEC,NORG), AW(NSPEC,NORG)

ACT(ISPEC, ITIME, IORG)

= activity in the lungs, GI segments, blood, cortical bone surface, trabecular bone surface, cortical bone volume, trabecular bone volume, red marrow, yellow marrow, other explicit source organs, and total body

AWIGL(ISPEC, IORG)

= integrated activity of nuclide ISPEC in source IORG over current time step

AW(ISPEC, IORG) = accumulated activity of radionuclide ISPEC in source organ IORG

/CUMACT/ YNPW(NSPEC,2), Y1TBW(NSPEC,2), Y2TBW(NSPEC,2), YPW(NSPEC,4), YWL(NSPEC,2), YSW(NSPEC), YSIW(NSPEC), YULIW(NSPEC), YLLIW(NSPEC), YBLUDW(NSPEC), YCSURW(NSPEC), YTSURW(NSPEC), YREDMW(NSPEC), YYELMW(NSPEC), YORGW(NSPEC,NC,NSOU), YEXCRW(NSPEC)

YNPW(ISPEC, IPATH), ... YEXCRW(ISPEC)

= time-integrated activity for the current subinterval in lung compartments (pathways a through l), GI segments, blood, bone transfer compartment, cortical bone surface, trabecular bone surface, red marrow, yellow marrow, other explicit source organs (if bone is included as a source organ, the first 2 organs in YORGW must be cortical and trabecular bone), and excretion

/SFACT/ S(NAGEP,NLET,NSPEC,NS,NTRG), NSAGES, SFSURF(NAGEP,NLET,NSPEC,2,2)

S(IAGE, ILET, ISPEC, ISOU, ITRG)

= average dose rate (rad/ μ Ci) to target organ ITRG due to a unit activity of radionuclide ISPEC uniformly distributed in source organ ISOU for age IAGE and LET-type ILET (1 for low-LET, 2 for high-LET)

NSAGES = flag to indicate that only adult S-factors are provided for cases when $T_0 \geq 7300$ (NSAGES=6 when only adult S-factors are given; otherwise values for all ages must be provided)

SFSURF(IAGE, ILET, ISPEC, ISOU, ITRG)

= as defined for S(IAGE, ILET, ISPEC, ISBONE, ITBONE) for source tissues cortical bone surface (ISBONE=1) and trabecular bone surface (ISBONE=2) and target tissues red marrow (ITBONE=1) and endosteal cells (ITBONE=2)

/DOSES/ DOSRAT(NLET,NTIMES,NTRG), DOSTIM(NTIMES), DOSE(NLET,NTRG)

DOSRAT(ILET, ITIME, ITRG)

= dose rate to target organ ITRG at time DOSTIM(ITIME) for
LET-type ILET

DOSTIM(ITIME) = time (days) at which current dose estimates are computed

DOSE(ILET, ITRG) = committed dose to target organ ITRG for low-LET (ILET=1) or
high-LET (ILET=2) radiation

5. CONCLUSIONS

The AGEDOS methodology allows estimates of dose rates, as a function of age, to radiosensitive organs and tissues in the human body at arbitrary times during or after internal exposure to radioactive material. Presently there are few, if any, radionuclides for which sufficient metabolic information is available to allow full use of all features of the methodology. The intention has been to construct the methodology so that optimal information can be gained from a mixture of the limited amount of age-dependent, nuclide-specific data and the generally plentiful age-dependent physiological data now available. Moreover, an effort has been made to design the methodology so that constantly accumulating metabolic information can be incorporated with minimal alterations in the AGEDOS computer code.

The significance attached to age-dependent radiation dosimetry must ultimately be judged in terms of identified risk to different age groups. Some preliminary analyses performed by the authors, using the AGEDOS code in conjunction with age-dependent risk factors developed from the A-bomb survivor data and other studies, has indicated that the doses and subsequent risks of eventually experiencing radiogenic cancers may vary substantially with age for some exposure scenarios and may be relatively invariant with age for other scenarios. Whatever the ultimate conclusions are regarding the influence of age on the risk from exposure to a given radionuclide, it is essential that those conclusions be reached only after thorough analysis of the available age-dependent data. We believe that the AGEDOS methodology provides a convenient and efficient means for performing the internal dosimetry that is necessary for such analyses.



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APPENDIX

APPENDIX: Listings of the computer codes AGEDOS and CONVOL

AGEDOS

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C-----
C
C  AGEDOS..
C
C  COMPUTES AGE-DEPENDENT ORGAN ELRDENS AND DCSE RATES TO VARIOUS TARGET ORGANS
C  FROM INTERNALLY DEPOSITED (INHALED, INGESTED, OR INJECTED) RADIOACTIVITY.
C-----
C
C  LOGICAL SNP,STR1,SP,SL,STR2,SLUNG,SST,SSI,SULI,SLLI,
C  $ SGI,SBLUD,SSURF,SEND,LAST
C  DOUBLE PRECISION NAMNUC,NAMSOU,NAMTRG
C  REAL LMA,LMP,LMC,LMD,LME,LMF,LMG,LMH,LMI,LMBDAB,TGRID(76)
C  INTEGER SOL,TC
C  COMMON /CASOP1/ NCASES, LAST
C  COMMON /NAMES/ NAMNUC(12),NAMSOU(10),NAMTRG(24)
C  COMMON /SWTCHS/ SNP,STR1,SP,SL,STR2(2),SLUNG,
C  $ SST,SSI,SULI,SLLI,SGI,SBLUD,SSURF
C  COMMON /TYME/ TO,TEND
C  COMMON /NUMBR$/ NSPEC,NSOL,NTRG,NLET
C  COMMON /STEPS/ IDCSE
C  COMMON /CUMACT/ YNPW(12,2),Y1TBW(12,2),Y2TBW(12,2),YPW(12,4),
C  $ YLW(12,2),YSW(12),YSIW(12),YULIW(12),YLLIW(12),
C  $ YBLUDW(12),YCSURW(12),YTSURW(12),YREDMW(12),YYELMW(12),
C  $ YORGW(12,5,10),YEXCRW(12)
C  COMMON /LEVEL$/ YNP(12,2),Y1TB(12,2),Y2TB(12,2),YP(12,4),
C  $ YL(12,2),YS(12),YSI(12),YULI(12),YLLI(12),YBLUD(12),
C  $ YCSUR(12),YTSUR(12),YREDM(12),YYELM(12),YCRG(12,5,10),
C  $ YEXCR(12)
C  COMMON /AGE/ MPHYS(7),MAGE(7),NAGEP,NAGEM
C  COMMON /ORGDAT/ NCOMP(12,10),C(12,5,10,7),
C  $ LMBDAB(12,5,10,7),F2PRIM(12,10,7),TBA(12,5,10,7),F2EXCR(12),
C  $ F2RCYC(12,10)
C  COMMON /TGLM/ LMA(12),LMB(12),LMC(12),LMD(12),LME(12),
C  $ LMF(12),LMG(12),LMH(12),LMI(12),FA(12),FB(12),
C  $ FC(12),FD(12),FE(12),FF(12),FG(12),FH(12),
C  $ FI(12)
C  COMMON /NOUGHT/ YSO,YNP0,Y1TB0,YP0,YBLUD0,YCRG0(10)
C  COMMON /SOLUB/ MCDE,SOL(12)
C  COMMON /CASE/ ICASE
C  DIMENSION TLMA(3),TLMB(3),TLMC(3),TLMC(3),TLMF(3),TLMF(3),
C  $ TLMG(3),TLMH(3),TLMI(3),
C  $ TFA(3),TFB(3),TFC(3),TFD(3),TFE(3),TFF(3),TFG(3),TFH(3),TFI(3)
C
C  TGRID SPECIFIES THE INITIAL 75 TIME STEPS (DAYS) OF THE CALCULATION.
C  DATA TGRID/0.0,0.001,0.002,0.003,0.004,0.005,0.006,0.007,0.008,
C  $ 0.009,0.01,0.02,0.03,0.04,0.05,0.06,0.07,0.08,0.09,0.1,0.2,0.3,
C  $ 0.4,0.5,0.6,0.7,0.8,0.9,1.0,2.0,3.0,4.0,5.0,6.0,7.0,8.0,9.0,10.,
C  $ 20.,30.,40.,50.,60.,70.,80.,90.,100.,150.,200.,250.,300.,365.,
C  $ 450.,540.,630.,730.,830.,930.,
C  $ 1095.,1460.,1925.,2190.,2555.,2920.,3295.,3650.,4015.,
C  $ 4380.,4745.,5110.,5475.,5840.,6205.,6570.,6935.,7300./
C
C  THE FOLLOWING ARE COMPARTMENTAL DEPOSITION FRACTIONS AND REMOVAL RATES
C  FOR THE ICRP TGLM LUNG MODEL.
C  DATA TLMA/3*69.31472/,
C  $ TFA/0.5,0.1,0.01/,
C  $ TLMB/69.31472,2*1.732868/,
C  $ TFB/0.5,0.9,0.99/,
C  $ TLMC/3*69.31472/,
C  $ TFC/0.95,0.5,0.01/,
C  $ TLMG/3*3.456736/,
C  $ TFD/0.05,0.5,0.99/,
C  $ TLME/1.386294E-2,1.386294E-3/,
C  $ TFE/0.8,0.15,0.05/,
C  $ TLMF/0.0,2*C.6931472/,
C  $ TFF/0.0,2*0.4/,
C  $ TLMG/0.0,1.386294E-2,1.386294E-3/,
C  $ TFG/0.0,2*0.4/,
C  $ TLMH/1.386294E-2,1.386294E-3/,
C  $ TFH/0.2,0.05,0.15/,
C  $ TLMI/1.386294E-2,6.931472E-4/,
C  $ TFI/2*1.0,0.5/

```

```

      CALL STAY
C
      LAST=.FALSE.
C
C SET SYSTEM ROUTINE PGMMSK TO IGNORE UNDERFLOWS AND LOSS OF SIGNIFICANCE.
      CALL PGMMSK(1,1,C,0)
C
      DO 160 INUC=1,100
         ICASE=1
C
C SET METABOLIC PARAMETERS INITIALLY TO ZERO
      CALL ZFRORG
C
C READ INPUT DATA FOR CURRENT NUCLIDE.
      CALL INPUT
      IF (LAST) GO TO 170
      10  CALL INCASE(ICASE)
C
C INITIALIZE METABOLIC PARAMETER ARRAYS
      CALL AGFDEP(0,C)
C
C OUTPUT CASE-INDEPENDENT DATA
      IF (ICASE .EQ. 1) CALL CUTDAT
C
C SOL(ISPEC)=1,2, OR 3 IF THE SOLUBILITY CLASS IS D,W, OR Y, RESP.
C THE FOLLOWING DETERMINES THE LUNG PARAMETERS TO BE SENT TO STEP
C VIA THE COMMON BLOCK TGLM.
      IF (MODE .GT. 1) GO TO 20
      DO 20 ISPEC=1,NSPEC
         J=SOL(ISPEC)
         LMA(ISPEC)=TLMA(J)
         FA(ISPEC)=TFA(J)
         LMB(ISPEC)=TLMB(J)
         FR(ISPEC)=TFB(J)
         LMC(ISPEC)=TLMC(J)
         FC(ISPEC)=TFC(J)
         LMD(ISPEC)=TLD(J)
         FD(ISPEC)=TFD(J)
         LME(ISPEC)=TLE(J)
         FE(ISPEC)=TFE(J)
         LMF(ISPEC)=TLMF(J)
         FF(ISPEC)=TFF(J)
         LMG(ISPEC)=TLMG(J)
         FG(ISPEC)=TFG(J)
         LMH(ISPEC)=TLMH(J)
         FH(ISPEC)=TFH(J)
         LMI(ISPEC)=TLMI(J)
         FI(ISPEC)=TFI(J)
      20  CONTINUE
C
C ZERO ACTIVITY ARRAYS.
      CALL ZERO
C
C INITIALIZE AGE-DEPENDENT PARAMETERS..
      CALL AGED(FLDAT(10))
C
C SWITCHES SNP, ..., SBLUD INDICATE EXHAUSTION OF THEIR RESPECTIVE
C COMPARTMENTS. SEND INDICATES FINAL EXHAUSTION OF ALL FEEDER
C COMPARTMENTS. SET ALL SWITCHES INITIALLY TO FALSE.
      SNP=.FALSE.
      STB1=.FALSE.
      SP=.FALSE.
      SL=.FALSE.
      STR2(1)=.FALSE.
      STB2(2)=.FALSE.
      SLUNG=.FALSE.
      IF (MODE .EQ. 1) GO TO 30
         SNP=.TRUE.
         STB1=.TRUE.
         SP=.TRUE.
         SL=.TRUE.
         STR2(1)=.TRUE.
         STB2(2)=.TRUE.
         SLUNG=.TRUE.
      30  SST=.FALSE.
         SSI=.FALSE.
         SULT=.FALSE.
         SLLI=.FALSE.
         SGI=.FALSE.
         IF (MODE .LT. 2) GO TO 35
            SST=.TRUE.
            SSI=.TRUE.
            SULT=.TRUE.
            SLLI=.TRUE.
            SGI=.TRUE.
      35  SBLUD=.FALSE.
         SSURF=.FALSE.
         SEND=.FALSE.

```

```

C
C CONSIDER INITIAL ACTIVITY IN NP, TR, AND PUL REGIONS OF THE LUNGS,
C IN THE STOMACH, IN BLOOD, AND/CP IN OTHER SOURCE ORGANS,
C AS SPECIFIED IN THE INPUT DATA.
  IF (MODE .EQ. 2) GO TO 60
  IF (MODE .EQ. 3) GO TO 70
  YNP(1,1)=FA(1)*YNP0
  YNP(1,2)=FB(1)*YNP0
  YITB(1,1)=FC(1)*YITB0
  YITB(1,2)=FC(1) * YITR0
  YP(1,1)=FE(1)*YP0
  YP(1,2)=FF(1)*YP0
  YP(1,3)=FG(1)*YP0
  YP(1,4)=FH(1)*YP0
  GO TO 90
60  YS(1)=YS0
  GO TO 90
70  YBLUD(1)=YBLUD0
  DO 80 ISOU=1,NSCU
    YORG(1,1,ISOU)=YORG0(1,ISOU)
80  CONTINUE
90  CONTINUE
C
C COMPUTE DOSE RATES AT TIME ZFRC..
  CALL DOSAGE(0.0,1)
C
C DETERMINE TIME-STEPS FOR SUBCLTIME STEP.
  NSTEPS=75 + IFIX((TEND-7300.)/365.)
  IDOSE=1
  DO 120 INTERV=1,NSTEPS
C
C IF ALL FEEDER COMPARTMENTS ARE EXHAUSTED AND ACTIVITIES ARE NEAR ZERO.
C HALT CALCULATIONS.
  IF (SLUNG .AND. SGT .AND. SPLUD) SEND=.TRUE.
  IF (.NOT.SEND) GO TO 100
  DO 94 IORG=1,NSCU
    DO 96 ISPEC=1,NSPEC
      NC=NCMP(ISPEC,IORG)
      DO 94 IC=1,NC
        IF (YORG(ISPEC,IC,IORG) .GT. 1.0E-20) GO TO 100
94  CONTINUE
96  CONTINUE
98  CONTINUE
  GO TO 130
100 CONTINUE
C
C FOR AGES LESS THAN 20 YEARS USE TIME STEPS DEFINED IN TGRID ARRAY.
  IF (INTERV .LE. 75) T1=TGRID(INTERV)
  IF (INTERV .LE. 75) T2=TGRID(INTERV+1)
C
C FOR AGES GREATER THAN 20 USE TIME STEPS OF 1 YEAR.
  IF (INTERV .GT. 75) T1=T2
  IF (INTERV .GT. 75) T2=T1 + 365.
C
C IF T2 IS GREATER THAN THE END TIME TEND, END CALCULATIONS.
  IF (T2 .GT. TEND) GO TO 130
C
C COMPUTE ACTIVITY IN EACH SOURCE ORGAN. T0 IS AGE AT BEGINNING OF EXPOSURE.
  CALL STEP(T0,T1,T2,MODE)
C
C COMPUTE DOSE RATES TO EACH ORGAN.
  IDOSE=IDOSE+1
  CALL DOSAGE(T2,IDOSE)
C
C COMPUTE COMMITTED DOSE AT T2..
  CALL DOSC(M(T2))
120 CONTINUE
130 CALL OUTPUT
  ICASE=ICASE+1
  IF (NCASES .GE. ICASE) GO TO 10
160 CONTINUE
170 CALL EXIT
  STOP
  END
C

```

```

-----
C      BLOCK DATA
-----
C
C      PHYSIOLOGICAL PARAMETERS ARE SPECIFIED FOR THE FOLLOWING 7 AGES IN MPHYS.
COMMON /AGE/ MPHYS(7),MAGE(7),NAGEP,NAGEM
DATA NAGEP/7/,
$ MPHYS/0,100,365,1825,3650,5475,7300/
COMMON /AGESEE/ MSEE(6),NSEF
DATA MSEE/0,365,1825,3650,5475,7300/
DATA NSEE/6/

C
C      LMGIA ARE TURNOVER RATES FOR THE 4 SEGMENTS OF THE GI TRACT FOR EACH OF
C      THE 7 AGES SPECIFIED IN MPHYS.
REAL LMGIA,LMABA,LM4A
COMMON /GI/ LMGIA(4,7),LMARA(12,4,7),CIFRAC(12,4,7)
DATA LMGIA/24,.6,.1,846134,1.0,24,.6,.1,846134,1.0,
$ 24,.6,.1,846134,1.0,24,.6,.1,846134,1.0,24,.6,.1,846134,1.0,
$ 24,.6,.1,846134,1.0,24,.6,.1,846134,1.0/

C
C      REMOVAL RATES FOR AGE DEPENDENT BCNF MODEL.
C      ALAMQ DENOTES THE AGE-DEPENDENT REMOVAL RATES FOR PATHWAY 'Q'.
COMMON /AGERON/ ALAMA(7),ALAMB(7),ALANC(7),ALAMD(7),ALAME(7),
$ ALAMF(7),ALAMY(7),ALAMR(7),VLAMAC
DATA ALAMA/.0102,.00822,.00288,.00153,.000904,.000521,.0000821/,
$ ALAMB/.0102,.00822,.00288,.00153,.000904,.000521,.0000821/,
$ ALANC/.0102,.00822,.00288,.00181,.00132,.000959,.000493/,
$ ALAMD/.0102,.00822,.00288,.00181,.00132,.000959,.000493/,
$ ALAME/.0102,.00822,.00288,.00153,.000904,.000521,.0000821/,
$ ALAMF/.0102,.00822,.00288,.00181,.00132,.000959,.000493/,
$ ALAMY/7*C,CC77/,
$ ALAMR/7*C,CC77/,
$ VLAMAC/0.1/
END

C
-----
C      SUBROUTINE ZERO
-----
C
C      INITIALIZE DOSE AND ACTIVITY ARRAYS TO ZERO.
C
COMMON /LEVELS/ A(864)
COMMON /CUMACT/ B(864)
COMMON /ACTVITY/ C(36432)
COMMON /DOSES/ F(7398)

C
DO 10 I=1,864
  A(I)=0.0
  B(I)=0.0
10 CONTINUE
DO 20 I=1,7398
  F(I)=0.0
20 CONTINUE
DO 30 I=1,36432
  C(I)=0.0
30 CONTINUE
RETURN
END

C
-----
C      SUBROUTINE ZEROORG
-----
C
C      INITIALIZE METABOLIC PARAMETER ARRAYS TO ZERO.
C
REAL LMGIA,LM4A
COMMON /ORGDA1/ N(120),A(13572)
COMMON /GI/ LMGIA(4,7),G(672)
DO 10 I=1,120
  N(I)=0
10 CONTINUE
DO 20 I=1,13572
  A(I)=0.0
20 CONTINUE
DO 30 I=1,672
  G(I)=0.0
30 CONTINUE
RETURN
END

```

```

-----
C      SUBROUTINE INFLT
-----
C
C      INPUT DATA FOR CURRENT RADIONUCLIDE CHAIN.
C      DATA FOR EACH EXPOSURE CASE ARE INPUT IN ENTRY INCASE(ICASE).
C      SIGNAL EXIT IF END-OF-FILE CARD IS DETECTED BY FIRST READ STATEMENT.
C
      LOGICAL LAST,CTHEXC,NOBCNE
      DOUBLE PRECISION NAMNUC,NAMSCOU,NAMTRG,NAMEXC,NAMCOR
      INTEGER TO,SOL
      REAL LMGIA,LMEDA,LMABA,LMR,LBLUD
      COMMON /CASOPT/ NCASES,LAST
      COMMON /SFACT/ S(7,2,12,16,24),NSAGES,SFSURF(7,2,12,2,2)
      COMMON /RADAT/ TR(12),BRANCH(12,12),LMR(12)
      COMMON /ORGDAT/ NCOMP(12,10),CA(12,5,10,7)
      $  LMBDA(12,5,10,7),F2PRA(12,10,7),TEA(12,5,10,7),F2EXCR(12),
      $  F2RCYC(12,10)
      COMMON /NAMES/ NAMNUC(12),NAMSCOU(10),NAMTRG(24)
      COMMON /NUMBRE/ NSPEC,NSOL,NTRG,NLET
      COMMON /TYME/ TO,TEND
      COMMON /GI/ LMGIA(4,7),LMABA(12,4,7),GIFRAC(12,4,7)
      COMMON /AGE/ MPHYS(7),MAGE(7),NAGEM,NAGEM
      COMMON /SOLUB/ MCCE,SOL(12)
      COMMON /NOUGHT/ YEO,YNPO,YITBO,YPO,YBLUDO,YCRGO(10)
      COMMON /SURVOL/ ISURF(12)
      COMMON /BLOOD/ LBLUD(12),TBLUD(12)
      COMMON /EXCTR#/ NSSEE,OTHEXC
      COMMON /BONSWT/ NOBONE
      DATA NAMCOR/BHCOR BCNE /
      DATA NAMEXC/BOTH-EXCR /
      DATA IN /5/, IN2 /15/
C
C      READ NUMBER OF SPECIES IN CHAIN.
      READ(IN,1000,END=160) NSPEC,NLET,NCASES,NSAGES
C
C      READ NAMES AND HALF-LIVES OF NUCLIDES IN CHAIN.
      DO 10 ISPEC=1,NSPEC
        READ(IN,1010) NAMNUC(ISPEC),TR(ISPEC)
        LMR(ISPEC)=0.6931472/TR(ISPEC)
      10 CONTINUE
C      INITIALIZE MATRIX OF BRANCHING RATIOS TO ZERO.
      DO 30 ISPEC=1,NSPEC
        DO 20 JSPEC=1,NSPEC
          BRANCH(ISPEC,JSPEC)=0.0
        20 CONTINUE
      30 CONTINUE
C
C      READ THE NUMBER NBR OF NON-ZERO BRANCHING RATIOS TO FOLLOW.
      READ(IN,1000) NBR
      IF (NBR .EQ. 0) GO TO 40
      DO 40 IBR=1,NBR
        READ(IN,1020) JSPEC,ISPEC,BRANCH(ISPEC,JSPEC)
      40 CONTINUE
C
C      READ THE NUMBER NSOU AND NAMES NAMSCU OF SOURCE ORGANS.
      READ(IN,1000) NSOU
      READ(IN,1030) (NAMSCU(ISCU),ISOU=1,NSOU)
      NOBONE=.FALSE.
      IF (NAMSCU(1) .NE. NAMCOR) NOBONE=.TRUE.
      OTHEXC=.FALSE.
      IF (NAMSCU(NSOU) .EQ. NAMEXC) OTHEXC=.TRUE.
      NSSEF=NSOU+6
      IF (NOBONE) NSSEF=NSOU+5
      IF (OTHEXC) NSSEF=NSSEF-1
C
C      READ THE NUMBER NTRG AND NAMES NAMTRG OF TARGET ORGANS.
      READ(IN,1000) NTRG
      READ(IN,1030) (NAMTRG(ITRG),ITRG=1,NTRG)
C
C      SPECIFY WHETHER SURFACE OR VOLUME DEPOSITION MODEL IN BCNE IS TO BE USED.
      READ(IN,1000) (ISURF(ISPEC),ISPEC=1,NSPEC)
C
C      SPECIFY NO. OF AGES NAGEM FOR WHICH METABOLIC PARAMETERS WILL
C      BE ENTERED.
      READ(IN,1000) NAGEM
C
C      SPECIFY THE AGE GRID MAGE TO BE USED WITH METABOLIC DATA.
C      THERE ARE NAGEM AGES, WHERE NAGEM IS AT MOST 7. AGES MUST BE SELECTED
C      FROM THE SET 0, 100, 365, 1825, 3650, 5475, AND 7300 DAYS.
C      DATA FOR ADULTS (AGE 7300 DAYS) MUST ALWAYS BE SPECIFIED.
      READ(IN,1000) (MAGE(IAGE),IAGE=1,NAGEM)

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C
C FOR EACH AGE AND SPECIES IN THE CHAIN, READ METABOLIC DATA FOR ORGANS.
  DO 80 ISPEC=1,NSPEC
    DO 70 ISOU=1,NSOU
      READ(IN,1000) NCOMP(ISPEC,ISOU)
      NCTEMP=NCCMP(ISPEC,ISOU)
      DO 60 IAGE=1,NAEM
        DO 50 JAGE=1,7
          IF (MAGE(IAGE) .NE. MPHYS(JAGE)) GO TO 50
          READ(IN,1040) F2PRA(ISPEC,ISOU,JAGE)
          READ(IN,1040) (CA(ISPEC,IC,ISCU,JAGE),
            $ TBA(ISPEC,IC,ISCU,JAGE),IC=1,NCTEMP)
          GO TO 60
        50 CONTINUE
      60 CONTINUE
    70 CONTINUE
  80 CONTINUE
C
C INPUT EXCRETION FRACTION FOR EACH NUCLIDE..
  READ(IN,1040) (F2EXCR(ISPEC),ISPEC=1,NSPEC)
C
C INPUT BIOLOGICAL HALF-LIFE FOR EACH RADIONUCLIDE IN BLOOD..
  READ(IN,1040) (TBLUD(ISPEC),ISPEC=1,NSPEC)
  DO 90 ISPEC=1,NSPEC
    IF (TBLUD(ISPEC) .EQ. 0.0) TBLUD(ISPEC)=0.25
    LBLUD(ISPEC)=0.6931472/TBLUD(ISPEC)
  90 CONTINUE
C
C INPUT FRACTION OF ACTIVITY FROM EACH ORGAN RECYCLED TO BLOOD..
  DO 95 ISPEC=1,NSPEC
    READ(IN,1040) (F2RCYC(ISPEC,ISCU),ISCU=1,NSOU)
  95 CONTINUE
C
C READ IN SEE VALUES..
  IF (NSAGES .NE. 6) NSAGES=1
  DO 140 ISPEC=1,NSPEC
    DO 130 IAGE=NSAGES,6
      DO 120 ILET=1,NLET
        DO 110 ITRG=1,NTRG
          READ(IN2,1040) (S(IAGE,ILET,ISPEC,ISOU,ITRG),ISOU=1,NSSEE)
          DO 100 ISCU=1,NSSEE
            S(IAGE,ILET,ISPEC,ISCU,ITRG)=
              $ S(IAGE,ILET,ISPEC,ISOU,ITRG)*51.15
          100 CONTINUE
        110 CONTINUE
        READ(IN2,1040) ((SFSURF(IAGE,ILET,ISPEC,ISBONE,ITBONE),
          $ ISBONE=1,2),ITRCNE=1,2)
        $ SFSURF(IAGE,ILET,ISPEC,1,1)=SFSURF(IAGE,ILET,ISPEC,1,1)*
          $ 51.15
        $ SFSURF(IAGE,ILET,ISPEC,1,2)=SFSURF(IAGE,ILET,ISPEC,1,2)*
          $ 51.15
        $ SFSURF(IAGE,ILET,ISPEC,2,1)=SFSURF(IAGE,ILET,ISPEC,2,1)*
          $ 51.15
        $ SFSURF(IAGE,ILET,ISPEC,2,2)=SFSURF(IAGE,ILET,ISPEC,2,2)*
          $ 51.15
      120 CONTINUE
    130 CONTINUE
  140 CONTINUE
C
C END OF CASE-INDEPENDENT DATA
C
  GO TO 170
160 LAST=.TRUE.
170 RETURN
C
C-----
C ENTRY INCASE(ICASE)
C-----
C
C INPUT CASE DESCRIPTIONS FOR EACH EXPOSURE CASE.
C
C READ INTAKE MODE (1=INHALATION, 2=INGESTION, 3=INJECTION) AND
C SOLUBILITY CLASS FOR EACH NUCLIDE IF CASE IS INHALATION.
  READ(IN,1000) MODE,(SOL(ISPEC),ISPEC=1,NSPEC)
C

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C READ GI-TRACT UPTAKE FRACTIONS
C USE SAME AGE DOMAIN FOR ALL SEGMENTS AND SPECIES
  DO 210 ISPEC=1,NSPEC
    DO 200 IAGE=1,NAGEM
      DO 180 ISEG=1,4
        GIFRAC(ISPEC,ISEG,IAGE)=0.0
180      CONTINUE
          DO 190 JAGE=1,7
            IF (MAGE(IAGE) .NE. MPHYS(JAGE)) GO TO 190
            READ(IN,1C40) (GIFRAC(ISPEC,ISEG,JAGE),ISEG=1,4)
            GO TO 200
190      CONTINUE
200      CONTINUE
210      CONTINUE
C
C READ INITIAL AGE OF INDIVIDUAL AND TIME OF INTEGRATION.
  READ(IN,1050) T0,TEND
C
C READ INITIAL CONDITIONS FOR STOMACH, LUNGS, BLOOD, AND OTHER ORGANS.
  READ(IN,1040) YSO,YNPO,YITBC,YPO,YRLUD0,(YORGO(I),I=1,NSOU)
  RETURN
C
1000 FORMAT(20I4)
1010 FORMAT(A8,E10.3)
1020 FORMAT(2I4,F10.0)
1030 FORMAT(10A8)
1040 FORMAT(8E10.0)
1050 FORMAT(I4,E10.0)
  END
C
-----
C SUBROUTINE OUTDAT
-----
C
C PRINTS OUT CASE-INDEPENDENT INFORMATION
C
  LOGICAL OTHXC
  INTEGER OUT
  REAL LMBDA,LMR
  DOUBLE PRECISION NAMNUC,NAMSCU,NAMTRG,NAME1,NAME2,BLANK,
  $ BONDEP(2)
  COMMON /NUMBR5/ NSPEC,NSOU,NTRG,NLET
  COMMON /NAMES/ NAMNUC(12),NAMSCU(10),NAMTRG(24)
  COMMON /SFACT/ S(7,2,12,16,24),NSAGES,SFSURF(7,2,12,2,2)
  COMMON /RADAT/ TR(12),BRANCH(12,12),LMR(12)
  COMMON /AGE/ MPHYS(7),MAGE(7),NAGEP,NAGEM
  COMMON /ORGDAT/ NCCMP(12,10),CA(12,5,10,7),LMBDA(12,5,10,7),
  $ F2PRA(12,10,7),TBA(12,5,10,7),F2FXCR(12),F2RCYC(12,10)
  COMMON /BLOOD/ LBLUD(12),TBLUD(12)
  COMMON /SURVOL/ ISURF(12)
  COMMON /EXCTR5/ NSSEE,OTHXC
  DATA BONDEP/8FVOLUME /,8HSURFACE /
  DATA BLANK/8H /
  DATA OUT/6/
C
C PRINT NUCLIDE NAMES AND HALF-LIVES..
  WRITE(OUT,200C) NAMNUC(1)
  DO 10 ISPEC=1,NSPEC
    WRITE(OUT,2C10) NAMNUC(ISPEC),TR(ISPEC)
  10 CONTINUE
C
C PRINT TABLE OF BRANCHING RATIOS..
  IF (NSPEC .EQ. 1) GO TO 30
  WRITE(OUT,202C)
  DO 20 JSPEC=1,NSPEC
    DO 20 ISPEC=1,NSPEC
      IF (BRANCH(ISPEC,JSPEC) .NE. 0.0) WRITE(OUT,2030) NAMNUC(JSPEC),
  $ NAMNUC(ISPEC),BRANCH(ISPEC,JSPEC)
  20 CONTINUE
  30 CONTINUE
C
C PRINT TABLE OF METABOLIC PARAMETERS FOR EACH NUCLIDE AND SOURCE ORGAN..
  WRITE(OUT,204C)
  DO 60 ISOU=1,NSOU
    DO 50 ISPEC=1,NSPEC
      DO 40 IAGE=1,NAGEM
        NC=NCCMP(ISPEC,ISOU)
        NAME1=NAMSCU(ISOU)
        NAME2=NAMNUC(ISPEC)
        IF (ISPEC .NE. 1 .OR. IAGE .NE. 1) NAME1=BLANK
        IF (IAGE .NE. 1) NAME2=BLANK
        WRITE(OUT,2C50) NAME1,NAME2,MAGE(IAGE),
  $ F2PRA(ISPEC,ISOU,IAGE),
  $ (CA(ISPEC,IC,ISOU,IAGE),TBA(ISPEC,IC,ISOU,IAGE),IC=1,NC)
  40 CONTINUE
  50 CONTINUE
  60 CONTINUE

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C
C PRINT FRACTION OF ACTIVITY IN EACH ORGAN RECYCLED TO BLOOD..
  WRITE(OUT,206C)
  DO 65 ISPEC=1,NSPEC
    WRITE(OUT,2065) NAMNUC(ISPEC),(NAMSCU(ISOU),F2RCYC(ISPEC,ISOU),
      $ ISOU=1,NSCU)
  65 CONTINUE
C
C PRINT BONE DEPOSITION ASSUMPTIONS, BLOOD HALF-TIME, AND EXCRETION FRACTION
C FOR EACH NUCLIDE.
  WRITE(OUT,207C) (NAMNUC(ISPEC),BCNDP(ISURF(ISPEC)+1),
    $ TBLUD(ISPEC),F2EXCR(ISPEC),ISPEC=1,NSPEC)
C
C TABULATE S-FACTORS FOR ALL NUCLIDES, SOURCES, TARGETS, AND
C AGE GROUPS.
  DO 90 ISPEC=1,NSPEC
    DO 80 IAGE=NSAGES,6
      DO 70 ILET=1,ILET
        IFIRST=1
        LAST=13
        IF (NSSEF .LT. LAST) LAST=NSSEE
        CALL SEETAB(IAGE,ILET,IFIRST,LAST,ISPEC)
        IF (LAST .EQ. NSSFE) GO TO 70
        IFIRST=14
        LAST=26
        IF (NSSFE .LT. LAST) LAST=NSSEF
        CALL SEETAB(IAGE,ILET,IFIRST,LAST,ISPEC)
      70 CONTINUE
    80 CONTINUE
  90 CONTINUE
C
2000 FORMAT(' ',T63,'ACFDOS'/' ',T63,'-----/' ' ',T18,'AGE-',
  $ 'DEPENDENT ESTIMATES OF DOSE RATE TO SELECTED TARGET ORGANS',
  $ ' FROM INTERNAL RADIONUCLIDE EXPOSURES'/
  $ 'ORADIONUCLIDE: ',A8/' ',21('-')/'0 ',T15,'RADIOACTIVE'/
  $ ' ',T16,'HALF-LIFE'/' NUCLIDE',T17,'(DAYS)')
2010 FORMAT(' ',A8,T15,1PG10.3)
2020 FORMAT(' BRANCHING RATIOS: ',T21,'FRM',T31,'TO',T41,'FRACTION')
2030 FORMAT(' ',T21,A8,T31,A8,T40,1PG10.3)
2040 FORMAT('0 ',T40,'COMPARTMENT DEPOSITION FRACTIONS (C) AND ',
  $ ' BIOLOGICAL HALF-TIMES (TB, DAYS)'/
  $ ' ',T35,93('-')/' ORGAN',T10,'NUCLIDE',
  $ 'T19,'AGE',T23,'F2-PRIME',T35,'C1',T45,'TB1',T55,'C2',
  $ 'T65,'TB2',T75,'C3',T85,'TB3',T95,'C4',T105,'TB4',T115,
  $ 'C5',T125,'TB5'/)
2050 FORMAT(' ',A8,T10,A8,T18,I4,11(1PG10.2))
2060 FORMAT('/0 ',T33,'FRACTION OF ACTIVITY'/' NUCLIDE',T15,'ORGAN',T33,
  $ 'RECYCLED TO BLOOD')
2065 FORMAT(' ',A8,(' ',T15,A8,T30,F10.5))
2070 FORMAT('/0 ',T33,'HALF-TIME',T53,'EXCRETION'/'T15,'BONE',T33,
  $ 'IN BLOOD',T53,'FRACTION'/' NUCLIDE',T15,'DEPOSITION',T33,
  $ '(DAY)',T53,'FRM BLOOD'/'(' ',A8,T15,A8,T30,F10.5,T50,F10.5))
  RETURN
  END
C
C-----
C SUBROUTINE SEETAB(IAGE,ILET,IFIRST,LAST,ISPEC)
C-----
C
C AFTER PRINTING A HEADING AND THE NAMES OF SOURCES (IFIRST TO LAST)
C THIS SUBROUTINE PRINTS S-FACTORS FOR ALL TARGET ORGANS FOR
C THESE SOURCES.
C ILET INDICATES HIGH OR LOW LET RADIATION: ILET=1 DENOTES LOW LET
C RADIATION, ILET=2 DENOTES HIGH LET.
C
  LOGICAL NORONE
  INTEGER OUT
  DOUBLE PRECISION NAMNUC,NAMSCU,NAMTRG,NAMS(6),NAMSUR,NAMMAR
  COMMON /NAMES/ NAMNUC(12),NAMSCU(10),NAMTRG(24)
  COMMON /NUMBRS/ NSPEC,NSCU,NTRG
  COMMON /SFACT/ S(7,2,12,16,24),NSAGES,SFSURF(7,2,12,2,2)
  COMMON /AGESEF/ MSFE(6),NSEF
  COMMON /AGE/ MPHYS(7),MAGE(7),NAGFP,NAGEM
  COMMON /BONSWT/ ACONE
  DATA NAMS/8HLLNGS ,8HST CONT ,8HSI CONT ,8HULI CONT,8HLLI CONT,
  $ 8HRED MAR /
  DATA NAMSUR/8PHONE SUR/, NAMMAR/8HRED MAR /
  DATA OUT /6/
C
C PRINT HEADING
  IF (ILET .EQ. 1) WRITE (OUT,2000) NAMNUC(ISPEC),MSEE(IAGE)
  IF (ILET .EQ. 2) WRITE (OUT,2010) NAMNUC(ISPEC),MSEE(IAGE)

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C
C PRINT NAMES OF SOURCES
  LASTM6=LAST-6
  IFIRM6=IFIRST-6
  LASTM5=LAST-5
  IFIRM5=IFIRST-5
  IF (NOBONE) GO TO 5
  IF (IFIRST.NE. 1) WRITE(OUT,2020) (NAMSOU(ISOU),ISOU=IFIRM6,
$ LASTM6)
  IF (IFIRST.EQ. 1) WRITE(OUT,2020) (NAMS(IS),IS=1,6),
$ (NAMSOU(ISOU),ISOU=IFIRST,LASTM6)
  GO TO 6
5 IF (IFIRST.NE. 1) WRITE(OUT,2020) (NAMSOU(ISO),ISOU=IFIRM5,
$ LASTM5)
  IF (IFIRST.EQ. 1) WRITE(OUT,2020) (NAMS(IS),IS=1,5),
$ (NAMSOU(ISO),ISOU=IFIRST,LASTM5)
6 CONTINUE

C
C PRINT S-FACTORS FOR THIS SPECIES FOR SOURCE ORGANS IFIRST TO LAST
C AND FOR ALL TARGET ORGANS
  DO 10 ITRG=1,NTRG
    WRITE(OUT,2030)NAMTRG(ITRG),(S(IAGE,ILET,ISPEC,ISOU,ITRG),
$ ISOU=IFIRST,LAST)
    IF (NOBONE) GO TO 10
    IF (NAMTRG(ITRG).EQ. NAMSUR) WRITE(OUT,2040)
$ (SFSURF(IAGE,ILET,ISPEC,IS,1),IS=1,2)
    IF (NAMTRG(ITRG).EQ. NAMMAR) WRITE(OUT,2040)
$ (SFSURF(IAGE,ILET,ISPEC,IS,2),IS=1,2)
  10 CONTINUE

C
2000 FORMAT(// ' ',T37,'LOW-LET S FACTORS (RAD/MICROCURIE-DAY) FOR ',A8/
$ ' ',T55,'AGE : ',I4,' DAYS'/
$ 'OTARGET',T55,'SOURCE ORGANS'/' ORGANS')
2010 FORMAT(// ' ',T37,'HIGH-LET S FACTORS (RAD/MICROCURIE-DAY) FOR ',
$ A8/ ' ',T55,'AGE : ',I4,' DAYS'/
$ 'OTARGET',T55,'SOURCE ORGANS'/' ORGANS')
2020 FORMAT('0',T13,A8,11(1X,A8))
2030 FORMAT(' ',A8,T12,1P13G9.2)
2040 FORMAT(' (SURFACE)',T66,1P2G9.2)
  RETURN
  END

```

```

C
C-----
C SUBROUTINE AGEDEP(T)
C-----
C
C INITIAL CALL TO AGEDEP SETS UP DEFAULTS; SUBSEQUENT CALLS TO ENTRY AGED
C RETURN TO STEP THE AGE-DEPENDENT PARAMETERS FOR THE T1-T2 TIME FRAME.
C
  INTEGER SOL
  REAL LMGIA,LMABA,LMBDA,LMGI,LMAE,LMBDAB,
$ LAMDA, LAMDA, LAMDAC, LAMDA, LAMDAE, LAMDAF, LAMDAR, LAMDAR
  COMMON /AGEME/ LMGIA(4),LMABA(12,4),C(12,5,10),
$ LMBDAB(12,5,10),F2PRIM(12,10),
$ LAMDA, LAMDA, LAMDAC, LAMDA,
$ LAMDAE, LAMDAF, LAMDAR, LAMDAR
  COMMON /AGEBON/ ALAMA(7),ALAMB(7),ALAMC(7),ALAMD(7),ALAME(7),
$ ALAMF(7),ALAMY(7),ALAMR(7),VLAMAC
  COMMON /NUMBRS/ NSPEC,NSOU,NTRG,NLET
  COMMON /ORGDAT/ NCOMP(12,10),CA(12,5,10,7),
$ LMBDA(12,5,10,7),F2PRA(12,10,7),TBA(12,5,10,7),F2EXCR(12),
$ F2RCYC(12,10)
  COMMON /GI/ LMGIA(4,7),LMABA(12,4,7),GIFRAC(12,4,7)
  COMMON /AGE/ MPHYS(7),MAGE(7),NAGEP,NAGEM
  COMMON /AGESEE/ MSEE(6),NSEE
  COMMON /SOLUB/ MDCF,SOL(12)
  COMMON /INTRP/ SRPLAT,IPS

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C
C IF DATA FOR A PARTICULAR AGE ARE NOT SPECIFIED, DEFAULT
C TO THE NEXT HIGHER AGE GROUP FOR WHICH DATA ARE GIVEN.
C

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C GI TO BLOOD ABSORPTION FRACTIONS..
  DO 70 ISPEC=1,NSPEC
    DO 60 ISEG=1,4
      DO 50 IAGE=1,7
        IF (GIFRAC(ISPEC,ISEG,IAGE).NE. 0.0) GO TO 50
        DO 40 JAGE=IAGE,7
          IF (GIFRAC(ISPEC,ISFG,JAGE).EQ. 0.0) GO TO 40
          GIFRAC(ISPEC,ISEG,IAGE)=GIFRAC(ISPEC,ISEG,JAGE)
        GO TO 50
      40 CONTINUE
    50 CONTINUE
  60 CONTINUE
  70 CONTINUE

```

```

C
C ABSORPTION RATES FROM GI SEGMENTS..
  DO 100 ISPEC=1,NSPEC
    DO 90 ISEG=1,4
      DO 80 IAGE=1,7
        TEMP=AMINI(GIFRAC(ISPEC,ISEG,IAGE),0.99)
        LMABA(ISPEC,ISEG,IAGE)=LMGIA(ISEG,IAGE)*TEMP/(1.0-TEMP)
      80 CONTINUE
    90 CONTINUE
  100 CONTINUE
C
C METABOLIC MODELS FOR EACH SOURCE ORGAN (ABSORPTION FRACTION, F2PRA,
C COMPARTMENTAL DEPOSITION FRACTIONS, CA, AND BIOLOGICAL HALF-TIMES,TBA)..
  DO 140 ISPEC=1,NSPEC
    DO 130 ISOU=1,NSCU
      DO 120 IAGE=1,7
        IF (F2PRA(ISPEC,ISOU,IAGE) .NE. 0.0) GO TO 120
        DO 110 JAGE=IAGE,7
          IF (F2PRA(ISPEC,ISOU,JAGE) .EQ. 0.0) GO TO 110
          F2PRA(ISPEC,ISOU,IAGE)=F2PRA(ISPEC,ISOU,JAGE)
          GO TO 120
        110 CONTINUE
      120 CONTINUE
    130 CONTINUE
  140 CONTINUE
  DO 230 ISPEC=1,NSPEC
    DO 180 IORG=1,NSCU
      NCA=NCOMP(ISPEC,IORG)
      DO 170 IC=1,NCA
        DO 160 IAGE=1,7
          IF (CA(ISPEC,IC,IORG,IAGE) .NE. 0.0) GO TO 160
          DO 150 JAGE=IAGE,7
            IF (CA(ISPEC,IC,IORG,JAGE) .EQ. 0.0) GO TO 150
            CA(ISPEC,IC,IORG,IAGE)=CA(ISPEC,IC,IORG,JAGE)
            TBA(ISPEC,IC,IORG,IAGE)=TBA(ISPEC,IC,IORG,JAGE)
            GO TO 160
          150 CONTINUE
        160 CONTINUE
      170 CONTINUE
    180 CONTINUE
  230 CONTINUE
C
C CONVERT HALF-TIMES TO CLEARANCE RATES..
  DO 270 ISPEC=1,NSPEC
    DO 260 IORG=1,NSCU
      NCA=NCOMP(ISPEC,IORG)
      DO 250 IC=1,NCA
        DO 240 IAGE=1,7
          LMBDA(ISPEC,IC,IORG,IAGE)=
          $ 0.6931472/TBA(ISPEC,IC,IORG,IAGE)
        240 CONTINUE
      250 CONTINUE
    260 CONTINUE
  270 CONTINUE
  RETURN
C
C -----
C ENTRY AGED(T)
C -----
C
C ENTRY POINT TO MOVE METABOLIC DATA FOR AGE T=T0+T1+0.5*DELT
C TO COMMON /AGEMET/ FOR USE IN STEP
C
C DETERMINE POINTER (IP) INTO METABOLIC DATA
C
  DO 310 IAGE=1,7
    IF (MPHYS(IAGE) .GT. IFIX(T)) GO TO 320
  310 CONTINUE
  IP=7
  GO TO 330
  320 IP=IAGE
  330 CONTINUE
C
C COMPUTE INTERPOLATION FRACTION, TRPLAT..
  TRPLAT=(T - FLOAT(MPHYS(IP-1)))/
  $ FLOAT(MPHYS(IP)-MPHYS(IP-1))
  IF (T .GE. 7300.) TRPLAT=1.0
C

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C DETERMINE POINTER (IPS) FOR SEE DATA.
  DO 340 IAGE=1,6
    IF (MSEE(IAGE) .GT. IFIX(T)) GO TO 350
340 CONTINUE
  IPS=6
  GO TO 360
350 IPS=IAGE
360 CONTINUE
C
C COMPUTE INTERPOLATION FRACTION, SRPLAT..
  SRPLAT=(T - FLOAT(MSEE(IPS-1)))/
  $   FLOAT(MSEE(IPS)-MSEE(IPS-1))
  IF (T .GE. 7300.) SRPLAT=1.0
C
C INTERPOLATE TO DETERMINE APPROPRIATE PARAMETER VALUES FOR AGE T
C
C AGE-DEPENDENT GI TRACT PARAMETERS
  DO 420 ISEG=1,4
    LMGIA(ISEG)=LMGIA(ISEG,IP-1) +
    $   TRPLAT*(LMGIA(ISEG,IP)-LMGIA(ISEG,IP-1))
    DO 410 ISPEC=1,NSPEC
      LMABA(ISPEC,ISEG)=LMABA(ISPEC,ISEG,IP-1)
      $   +TRPLAT*(LMABA(ISPEC,ISEG,IP)-LMABA(ISPEC,ISEG,IP-1))
    410 CONTINUE
  420 CONTINUE
C
C AGE-DEPENDENT SYSTEMIC ORGAN METABOLIC PARAMETERS..
  DO 450 ISPEC=1,NSPEC
    DO 440 ISOU=1,NSOU
      F2PRIM(ISPEC,ISOU)=F2PRA(ISPEC,ISOU,IP-1)
      $   +TRPLAT*(F2PRA(ISPEC,ISOU,IP)-F2PRA(ISPEC,ISOU,IP-1))
      NCA=NCOMP(ISPEC,ISOU)
      DO 430 IC=1,NCA
        C(ISPEC,IC,ISOU)=CA(ISPEC,IC,ISOU,IP-1)
        $   +TRPLAT*(CA(ISPEC,IC,ISOU,IP)-CA(ISPEC,IC,ISOU,IP-1))
        LMBDAB(ISPEC,IC,ISOU)=LMBDA(ISPEC,IC,ISOU,IP-1)
        $   +TRPLAT*(LMBDA(ISPEC,IC,ISOU,IP)-LMBDA(ISPEC,IC,ISOU,IP-1))
      430 CONTINUE
    440 CONTINUE
  450 CONTINUE
C
C AGE-DEPENDENT PARAMETERS FOR BCNE MODEL..
  LAMCAA=ALAMA(IP-1) + TRPLAT*(ALAMA(IP) - ALAMA(IP-1))
  LAMDAB=ALAMB(IP-1) + TRPLAT*(ALAMB(IP) - ALAMB(IP-1))
  LAMDAC=ALAMC(IP-1) + TRPLAT*(ALAMC(IP) - ALAMC(IP-1))
  LAMDAD=ALAMD(IP-1) + TRPLAT*(ALAMD(IP) - ALAMD(IP-1))
  LAMDAE=ALAME(IP-1) + TRPLAT*(ALAME(IP) - ALAME(IP-1))
  LAMDAF=ALAMF(IP-1) + TRPLAT*(ALAMF(IP) - ALAMF(IP-1))
  LAMDAY=ALAMY(IP-1) + TRPLAT*(ALAMY(IP) - ALAMY(IP-1))
  LAMDAR=ALAMR(IP-1) + TRPLAT*(ALAMR(IP) - ALAMR(IP-1))
460 CONTINUE
  RETURN
  END
C

```

```

-----
C SURROUTINE STEP(TC,T1,T2,WCDE)
-----
C
C ADVANCES THE RESIDENCE TIME INTEGRATION FROM TIME T1 TO T2 (DAYS).
C MODE = 1 FOR INHALATION, = 2 FOR INGESTION, = 3 FOR INJECTION.
C
  LOGICAL SNP,STB1,SP,SL,STB2,SLUNG,SST,SSI,SULI,SLLI,SGI,
  $   SBLUD,SSURF,OTHEXC,NOBONE
  INTEGER NCTEMP(12),TO
  REAL LMG1,LMAB,LMEDA,LMEDAB,LBLUD,
  $   LR(12,5),CTEMP(12,5),PTEMP(12,5),YTEMP0(12,5),YTEMP(12,5),
  $   YTEMPW(12,5),LMA,LMB,LMC,LMD,LME,LMF,LMG,LMH,LMI,LMR,
  $   LAMDAA,LAMDAB,LAMDAC,LAMDAD,LAMDAE,LAMDAF,
  $   LAMDAY,LAMDAR,LBNBLD,YTVCLW(12),YCVCLW(12),IFRAC,JFRAC
  DOUBLE PRECISION T,EXPFUN,EXPF1
  COMMON /SWTCH5/ SNP,STB1,SP,SL,STB2(2),SLUNG,SST,SSI,SULI,
  $   SLLI,SGI,SBLUD,SSURF

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COMMON /RADAT/ TR(12),BRANCH(12,12),LMR(12)
COMMON /LEVELS/ YNP(12,2),Y1TB(12,2),Y2TB(12,2),YP(12,4),YL(12,2),
$ YS(12),YSI(12),YULI(12),YLLI(12),YBLUD(12),
$ YCSUR(12),YTSUR(12),YREDM(12),YYELM(12),YCRG(12,5,10),YEXCR(12)
COMMON /CUMACT/ YNPW(12,2),Y1TBW(12,2),Y2TBW(12,2),YPW(12,4),
$ YLW(12,2),
$ YSW(12),YSIW(12),YULIW(12),YLLIW(12),YRLUDW(12),
$ YCSURW(12),YTSURW(12),YREDMW(12),YYELMW(12),YORGW(12,5,10),
$ YEXCRW(12)
COMMON /ORGDAT/ NCOMP(12,10),CA(12,5,10,7),
$ LMBDA(12,5,10,7),F2PRA(12,10,7),TBA(12,5,10,7),F2EXCR(12),
$ F2RCYC(12,10)
COMMON /AGEMET/ LMGI(4),LMAR(12,4),C(12,5,10),
$ LMBDAB(12,5,10),F2PRIM(12,10),
$ LAMDAE,LAMDAF,LAMDAC,LAMDAD,
$ LAMDAE,LAMDAF,LAMDAY,LAMDAR
COMMON /AGEBON/ ALAMA(7),ALAMB(7),ALAMC(7),ALAMD(7),ALAME(7),
$ ALAMF(7),ALAMY(7),ALAMR(7),VLAMAC
COMMON /TGLM/ LMA(12),LMB(12),LMC(12),LMD(12),LME(12),
$ LMF(12),LMG(12),LMH(12),LMI(12),
$ FA(12),FB(12),FC(12),FD(12),FE(12),FF(12),
$ FG(12),FH(12),FI(12)
COMMON /MULDAT/ DFLT,LB,CTEMP,PTEMP,YTEMPO,
$ YTEMP,YTEMPB,NCTEMP
COMMON /NUMBRS/ NSPEC,NSOL,NTRG,NLET
COMMON /SURVOL/ ISURF(12)
COMMON /BURBON/ CBURY,TBURY
COMMON /BLOOD/ LBLUD(12),TBLUD(12)
COMMON /INTRP/ TRPLAT,IP
COMMON /EXCRW/ NSSEE,OTFXC
COMMON /BONSWT/ NOBONE
IF (T1.EQ. 0.0) CBURY=C.0
IF (T1.EQ. 0.0) TBURY=C.0
ADULT=0.0
IF (TRPLAT.EQ. 1.0 .AND. IP.EQ. 6) ADULT=1.0
DFLT=T2-T1
T=DBLE(0.5*(T1+T2))
CALL AGED(FLOAT(T0) + SNGL(T))
C
C IF THIS CASE IS NOT INHALATION, BRANCH TO INGESTION.
IF (SLUNG) GO TO 130
C
C -----
C RESPIRATORY TRACT (TASK GROUP LUNG MODEL FOR AEROSOLS).
C -----
C
C NASOPHARYNGEAL REGION (A,B)
C -----
C IPATH=1 FOR A
C =2 FOR B
C IF (SNP) GO TO 21
C DO 10 ISPEC=1,NSPEC
C
C INFLOW-RATE VECTOR PTEMP.. INITIALIZE TO ZERO.
C DO 4 IPATH=1,2
C PTEMP(ISPEC,IPATH)=0.0
C 4 CONTINUE
C
C NUMBER OF SUBCOMPARTMENTS..
C NCTEMP(ISPEC)=2
C
C SUBCOMPARTMENT FRACTIONS..
C CTEMP(ISPEC,1)=FA(ISPEC)
C CTEMP(ISPEC,2)=FB(ISPEC)
C
C BIOLOGICAL CLEARANCE COEFFICIENTS..
C LB(ISPEC,1)=LMA(ISPEC)
C LB(ISPEC,2)=LMR(ISPEC)
C
C INITIAL CONDITIONS..
C DO 5 IPATH=1,2
C YTEMPO(ISPEC,IPATH)=YNP(ISPEC,IPATH)
C 5 CONTINUE
C 10 CONTINUE
C
C TEST FOR EXHAUSTION..
C DO 510 ISPEC=1,NSPEC
C DO 509 IPATH=1,2
C IF (PTEMP(ISPEC,IPATH) .GT. 1.0E-20 .OR. YTEMPO(ISPEC,IPATH)
C .GT. 1.0E-20) GO TO 511
C YNP(ISPEC,IPATH)=0.0
C YNPW(ISPEC,IPATH)=0.0
C 509 CONTINUE
C 510 CONTINUE
C SNP=.TRUE.
C GO TO 21
C 511 CONTINUE

```

```

C
C CALL MULCOM
C
C MOVE OUTPUTS FOR A,B PATHWAYS..
  DO 20 ISPEC=1,NSPEC
    DO 15 IPATH=1,2
      YNP(I SPEC,IPATH)=YTEMP(I SPEC,IPATH)
      YNPW(I SPEC,IPATH)=YTEMPW(I SPEC,IPATH)
    15 CONTINUE
  20 CONTINUE
  21 CONTINUE
C
C TRACHEOBRONCHIAL REGION (C,D)
C -----
C IPATH=1 FOR C
C =2 FOR D
C IF (STB1) GO TO 41
C DO 30 ISPEC=1,NSPEC
C
C INFLOW RATE VECTOR..
  DO 24 IPATH=1,2
    PTEMP(I SPEC,IPATH)=0.0
  24 CONTINUE
C
C NUMBER OF SUBCOMPARTMENTS..
  NCTEMP(I SPEC)=2
C
C COMPARTMENT FRACTIONS..
  CTEMP(I SPEC,1)=FC(I SPEC)
  CTEMP(I SPEC,2)=FD(I SPEC)
C
C BIOLOGICAL CLEARANCE COEFFICIENTS..
  LB(I SPEC,1)=LMC(I SPEC)
  LB(I SPEC,2)=LMD(I SPEC)
C
C INITIAL CONDITIONS..
  DO 25 IPATH=1,2
    YTEMPO(I SPEC,IPATH)=YITB(I SPEC,IPATH)
  25 CONTINUE
  30 CONTINUE
C
C TEST FOR EXHAUSTION..
  DO 520 ISPEC=1,NSPEC
    DO 519 IPATH=1,2
      IF (PTEMP(I SPEC,IPATH) .GT. 1.0E-20 .OR. YTEMPO(I SPEC,IPATH)
      $ .GT. 1.0E-20) GO TO 521
      YITB(I SPEC,IPATH)=0.0
      YITBW(I SPEC,IPATH)=0.0
    519 CONTINUE
  520 CONTINUE
  STB1=.TRUE.
  GO TO 41
  521 CONTINUE
C
C CALL MULCOM
C
C MOVE OUTPUTS FOR C,D PATHWAYS..
  DO 40 ISPEC=1,NSPEC
    DO 35 IPATH=1,2
      YITB(I SPEC,IPATH)=YTEMP(I SPEC,IPATH)
      YITBW(I SPEC,IPATH)=YTEMPW(I SPEC,IPATH)
    35 CONTINUE
  40 CONTINUE
  41 CONTINUE
C
C PULMONARY REGION (E,F,G,H)
C -----
C IPATH=1 FOR E
C =2 FOR F
C =3 FOR G
C =4 FOR H
C IF (SP) GO TO 61
C DO 50 ISPEC=1,NSPEC
C
C INFLOW RATE VECTOR..
  DO 44 IPATH=1,4
    PTEMP(I SPEC,IPATH)=0.0
  44 CONTINUE

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C
C NUMBER OF SUBCOMPARTMENTS..
  NCTEMP(ISPEC)=4
C
C SUBCOMPARTMENT FRACTIONS..
  CTEMP(ISPEC,1)=FE(ISPEC)
  CTEMP(ISPEC,2)=FF(ISPEC)
  CTEMP(ISPEC,3)=FG(ISPEC)
  CTEMP(ISPEC,4)=FH(ISPEC)
C
C BIOLOGICAL CLEARANCE COEFFICIENTS..
  LB(ISPEC,1)=LME(ISPEC)
  LB(ISPEC,2)=LMF(ISPEC)
  LB(ISPEC,3)=LMG(ISPEC)
  LB(ISPEC,4)=LMH(ISPEC)
C
C INITIAL CONDITIONS..
  DO 45 IPATH=1,4
    YTEMPO(ISPEC,IPATH)=YF(ISPEC,IPATH)
  45 CONTINUE
  50 CCONTINUE
C
C TEST FOR EXHAUSTION..
  DO 530 ISPEC=1,NSPEC
    DO 529 IPATH=1,4
      IF (PTEMP(ISPEC,IPATH) .GT. 1.0E-20 .OR. YTEMPO(ISPEC,IPATH)
        .GT. 1.0E-20) GO TO 531
      YP(ISPEC,IPATH)=0.0
      YPW(ISPEC,IPATH)=0.0
    529 CONTINUE
  530 CONTINUE
  SP=.TRUE.
  GO TO 61
  531 CCONTINUE
C
  CALL MULCOM
C
C MOVE OUTPUTS FOR E,F,G,H PATHWAYS..
  DO 60 ISPEC=1,NSPEC
    DO 55 IPATH=1,4
      YP(ISPEC,IPATH)=YTEMP(ISPEC,IPATH)
      YPW(ISPEC,IPATH)=YTEMPW(ISPEC,IPATH)
    55 CONTINUE
  60 CONTINUE
  61 CONTINUE
C
C LYMPHATIC TISSUE (I,J)
C -----
C   IPATH=1 FOR I
C   =2 FOR J
C   IF (SL) GO TO E1
C   DO 70 ISPEC=1,NSPEC
C
C INFLOW RATE.. TOTAL OUTFLOW OF PATHWAY H.
  DO 64 IPATH=1,2
    PTEMP(ISPEC,IPATH)=LMH(ISPEC)*YPW(ISPEC,4)/DELT
  64 CONTINUE
C
C NUMBER OF SUBCOMPARTMENTS..
  NCTEMP(ISPEC)=2
C
C SUBCOMPARTMENT FRACTIONS..
  CTEMP(ISPEC,1)=FI(ISPEC)
  CTEMP(ISPEC,2)=1.0-FI(ISPEC)
C
C BIOLOGICAL CLEARANCE COEFFICIENTS..
  LB(ISPEC,1)=LMI(ISPEC)
  LB(ISPEC,2)=1.90F-06
C (THE J SUBCOMPARTMENT IS SUBJECT ONLY TO RADIOACTIVE DECAY IN THE TGLM.
C HOWEVER, TO AVOID COMPUTATIONAL DIFFICULTIES, A CLEARANCE RATE OF 1.90F-6
C PER DAY (CORRESPONDING TO A 1000 YEAR HALF-TIME) IS ARBITRARILY ASSIGNED.)
C
C INITIAL CONDITIONS..
  DO 65 IPATH=1,2
    YTEMPO(ISPEC,IPATH)=YL(ISPEC,IPATH)
  65 CONTINUE
  70 CONTINUE
C

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```

C TEST FOR EXHAUSTION..
  DO 540 ISPEC=1,NSPEC
    DO 539 IPATH=1,2
      IF (PTEMP(ISPEC,IPATH) .GT. 1.0E-20 .OR. YTEMP0(ISPEC,IPATH)
        $ .GT. 1.0E-20) GO TO 541
      YLW(ISPEC,IPATH)=0.0
      YLW(ISPEC,IPATH)=0.0
    539 CONTINUE
    540 CONTINUE
      SL=.TRUE.
      GO TO 81
    541 CONTINUE
C
C CALL MULCOM
C
C MOVE OUTPUTS FOR (I,J) PATHWAYS..
  DO 80 ISPEC=1,NSPEC
    DO 75 IPATH=1,2
      YLW(ISPEC,IPATH)=YTEMP(ISPEC,IPATH)
      YLW(ISPEC,IPATH)=YTEMPW(ISPEC,IPATH)
    75 CONTINUE
    80 CONTINUE
    81 CONTINUE
C
C TRACHEOBRONCHIAL FEEDBACK (K,L)
C -----
C THIS WILL REQUIRE TWO CALLS TO MULCOM..
C (1) INPUT FROM F, OUTPUT K
C (2) INPUT FROM G, OUTPUT L
C PATHWAYS K AND L ARE INDEPENDENT SUBCOMPARTMENTS.
C
C PATHWAY K
C -----
C IF (STB2(1)) GO TO 105
  DO 90 ISPEC=1,NSPEC
C
C INFLOW RATE.. OUTFLOW OF PATHWAY F.
  PTEMP(ISPEC,1)=LMF(ISPEC)*YPW(ISPEC,2)/DELT
C
C NUMBER OF SUBCOMPARTMENTS..
  NCTEMP(ISPEC)=1
C
C SUBCOMPARTMENT FRACTIONS..
  CTEMP(ISPEC,1)=1.0
C
C BIOLOGICAL CLEARANCE COEFFICIENTS..
  LB(ISPEC,1)=LMD(ISPEC)
C
C INITIAL CONDITIONS..
  YTEMP0(ISPEC,1)=Y2TB(ISPEC,1)
  90 CONTINUE
C
C TEST FOR EXHAUSTION..
  DO 95 ISPEC=1,NSPEC
    IF (PTEMP(ISPEC,1) .GT. 1.0E-20 .OR. YTEMP0(ISPEC,1)
      $ .GT. 1.0E-20) GO TO 100
    Y2TB(ISPEC,1)=0.0
    Y2TBW(ISPEC,1)=0.0
    95 CONTINUE
    STB2(1)=.TRUE.
    GO TO 105
  100 CONTINUE
C
C CALL MULCOM
C
C MOVE OUTPUTS FOR K PATHWAY..
  DO 105 ISPEC=1,NSPEC
    Y2TB(ISPEC,1)=YTEMP(ISPEC,1)
    Y2TBW(ISPEC,1)=YTEMPW(ISPEC,1)
  105 CONTINUE
C
C PATHWAY L
C -----
C IF (STB2(2)) GO TO 125
  DO 110 ISPEC=1,NSPEC
C
C INFLOW RATE.. OUTFLOW OF PATHWAY G.
  PTEMP(ISPEC,1)=LMG(ISPEC)*YPW(ISPEC,3)/DELT
C
C NCTEMP, CTEMP, AND LB ARE AS FOR PATHWAY K..
  NCTEMP(ISPEC)=1
  CTEMP(ISPEC,1)=1.0
  LB(ISPEC,1)=LMD(ISPEC)

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C
C INITIAL CONDITIONS..
  YTEMPO(ISPEC,1)=Y2TB(ISPEC,2)
110 CONTINUE
C
C TEST FOR EXHAUSTION..
  DO 115 ISPEC=1,NSPEC
    IF (PTEMP(ISPEC,1) .GT. 1.0E-20 .CR. YTEMPO(ISPEC,1)
      $ .GT. 1.0E-20) GO TC 120
    Y2TB(ISPEC,2)=0.0
    Y2TBW(ISPEC,2)=0.0
115 CONTINUE
    STB2(2)=.TRUE.
    GO TO 125
120 CONTINUE
C
  CALL MULCOM
C
C MOVE OUTPUTS FOR PATHWAY L..
  DO 125 ISPEC=1,NSPEC
    Y2TB(ISPEC,2)=YTEMP(ISPEC,1)
    Y2TBW(ISPEC,2)=YTEMPW(ISPEC,1)
125 CONTINUE
C
C TEST FOR EXHAUSTION OF ALL LUNG COMPARTMENTS..
  IF (SNP .AND. STB1 .AND. STB2(1) .AND. STB2(2) .AND. SP .AND.
    $ SL) SLUNG=.TRUE.
-----
C END OF RESPIRATORY SEGMENT
-----
130 CONTINUE
  IF (SGI) GO TC 22C
-----
C G. I. TRACT
-----
C
C STOMACH (S)
-----
  IF (SST) GO TC 15C
  DO 140 ISPEC=1,NSPEC
C
C INFLOW RATE VECTOR..
  IF (MODE .EQ. 2) FTEMP(ISPEC,1)=0.0
  IF (MODE .EQ. 1) FTEMP(ISPEC,1)=(LMB(ISPEC)*YNPW(ISPEC,2) +
    $ LMD(ISPEC) * Y1TBW(ISPEC,2) +
    $ LMD(ISPEC) * (Y2TBW(ISPEC,1) + Y2TBW(ISPEC,2)))/DELTA
C
C NUMBER OF SUBCOMPARTMENTS, COEFFICIENTS, AND BIOLOGICAL REMOVAL
C COEFFICIENTS.
  NCTEMP(ISPEC)=1
  CTEMP(ISPEC,1)=1.0
  LB(ISPEC,1)=LNGI(1)+LMAB(ISPEC,1)
C
C INITIAL CONDITIONS..
  YTEMPO(ISPEC,1)=YS(ISPEC)
140 CONTINUE
C
C TEST FOR EXHAUSTION..
  DO 570 ISPEC=1,NSPEC
    IF (PTEMP(ISPEC,1) .GT. 1.0E-20 .CR. YTEMPO(ISPEC,1)
      $ .GT. 1.0E-20) GO TC 571
    YS(ISPEC)=0.0
    YSW(ISPEC)=0.0
570 CONTINUE
    SST=.TRUE.
    GO TO 150
571 CONTINUE
C
  CALL MULCOM
C
C MOVE OUTPUTS FOR S..
  DO 150 ISPEC=1,NSPEC
    YS(ISPEC)=YTEMP(ISPEC,1)
    YSW(ISPEC)=YTEMPW(ISPEC,1)
150 CONTINUE
C

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```

C SMALL INTESTINE (SI)
C -----
C IF (SSI) GO TO 170
C DO 160 ISPEC=1,NSPEC
C
C NUMBER OF SUBCOMPARTMENTS, COEFFICIENTS, AND BIOLOGICAL REMOVAL
C COEFFICIENTS (ABSORPTION PLUS EMPTYING)..
C NCTEMP(ISPEC)=1
C CTEMP(ISPEC,1)=1.0
C LB(ISPEC,1)=LMAB(ISPEC,2)+LMGI(2)
C
C INFLOW RATE VECTOR.. OUTFLOW FROM STOMACH.
C PTEMP(ISPEC,1)=LMGI(1)*YSW(ISPEC)/DELT
C
C INITIAL CONDITIONS..
C YTEMPO(ISPEC,1)=YSI(ISPEC)
C 160 CONTINUE
C
C TEST FOR EXHAUSTION..
C DO 580 ISPEC=1,NSPEC
C IF (PTEMP(ISPEC,1) .GT. 1.0E-20 .OR. YTEMFO(ISPEC,1)
C $ .GT. 1.0E-20) GO TO 581
C YSI(ISPEC)=0.0
C YSIW(ISPEC)=0.0
C 580 CONTINUE
C SSI=.TRUE.
C GO TO 170
C 581 CONTINUE
C
C CALL MULCOM
C
C MOVE OUTPUTS FOR SI..
C DO 170 ISPEC=1,NSPEC
C YSI(ISPEC)=YTEMP(ISPEC,1)
C YSIW(ISPEC)=YTEMPW(ISPEC,1)
C 170 CONTINUE
C
C UPPER LARGE INTESTINE (ULI)
C -----
C IF (SULI) GO TO 190
C DO 180 ISPEC=1,NSPEC
C
C NUMBER OF SUBCOMPARTMENTS, COEFFICIENTS, AND BIOLOGICAL REMOVAL
C COEFFICIENTS (ABSORPTION PLUS EMPTYING)..
C NCTEMP(ISPEC)=1
C CTEMP(ISPEC,1)=1.0
C LB(ISPEC,1)=LMAB(ISPEC,3)+LMGI(3)
C
C INFLOW VECTOR.. OUTFLOW FROM SMALL INTESTINE.
C PTEMP(ISPEC,1)=LMGI(2)*YSIW(ISPEC)/DELT
C
C INITIAL CONDITIONS..
C YTEMPO(ISPEC,1)=YULI(ISPEC)
C 180 CONTINUE
C
C TEST FOR EXHAUSTION..
C DO 590 ISPEC=1,NSPEC
C IF (PTEMP(ISPEC,1) .GT. 1.0E-20 .OR. YTEMPO(ISPEC,1)
C $ .GT. 1.0E-20) GO TO 591
C YULI(ISPEC)=0.0
C YULIW(ISPEC)=0.0
C 590 CONTINUE
C SULI=.TRUE.
C GO TO 190
C 591 CONTINUE
C
C CALL MULCOM
C
C MOVE ULI OUTPUTS..
C DO 190 ISPEC=1,NSPEC
C YULI(ISPEC)=YTEMP(ISPEC,1)
C YULIW(ISPEC)=YTEMPW(ISPEC,1)
C 190 CONTINUE
C

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C   LOWER LARGE INTESTINE (LLI)
C   -----
C       IF (SLLI) GO TO 210
C       DO 200 ISPEC=1,NSPEC
C
C   NUMBER OF SUBCOMPARTMENTS, COEFFICIENTS, AND BIOLOGICAL REMOVAL
C   COEFFICIENTS (ABSORPTION PLUS EMPTYING)..
C       NCTEMP(ISPEC)=1
C       CTEMP(ISPEC,1)=1.0
C       LB(ISPEC,1)=LMGI(4)+LMAB(ISPEC,4)
C
C   INFLOW VECTOR.. OUTFLOW FROM UPPER LARGE INTESTINE.
C       PTEMP(ISPEC,1)=LMGI(3)*YULIW(ISPEC)/DELTA
C
C   INITIAL CONDITIONS..
C       YTEMP0(ISPEC,1)=YLLI(ISPEC)
C   200 CONTINUE
C
C   TEST FOR EXHAUSTION..
C   DO 600 ISPEC=1,NSPEC
C       IF (PTEMP(ISPEC,1) .GT. 1.0E-20 .OR. YTEMP0(ISPEC,1)
C           .GT. 1.0E-20) GO TO 601
C       YLLI(ISPEC)=0.0
C       YLLIW(ISPEC)=0.0
C   600 CONTINUE
C       SLLI=.TRUE.
C       GO TO 210
C   601 CONTINUE
C
C       CALL MULCOM
C
C   MOVE OUTPUTS FOR LLI..
C       DO 210 ISPEC=1,NSPEC
C           YLLI(ISPEC)=YTEMP0(ISPEC,1)
C           YLLIW(ISPEC)=YTEMPW(ISPEC,1)
C   210 CONTINUE
C
C   TEST FOR EXHAUSTION OF ALL GI COMPARTMENTS..
C       IF (SST .AND. SSI .AND. SULI .AND. SLLI) SGI=.TRUE.
C   220 CONTINUE
C   -----
C   END OF G.I. TRACT CALCULATION.
C   -----
C
C   -----
C   TRANSFER COMPARTMENT(BLUD)
C   -----
C       IF (SBLUD) GO TO 310
C       DO 300 ISPEC=1,NSPEC
C
C   NUMBER OF SUBCOMPARTMENTS, COEFFICIENTS, AND
C   BIOLOGICAL REMOVAL RATES----INCLUDES REMOVAL DUE TO UPTAKE FROM
C   BLOOD BY SOURCE ORGANS AS WELL AS REMOVAL DUE TO EXCRETION.
C   BOTH REMOVAL PROCESSES ARE ASSUMED TO HAVE SAME REMOVAL CONSTANT:
C   LRLUD=LBLUD*(SUM OF F2PRIMES)+LBLUD*(1-SUM OF F2PRIMES)
C
C       NCTEMP(ISPEC)=1
C       CTEMP(ISPEC,1)=1.0
C       LB(ISPEC,1)=LRLUD(ISPEC)
C
C   INFLOW VECTOR. EITHER FROM G. I. FEEDS(S,SI,ULI,LLI) OR LUNG
C   (NP,TB,P,L) AND GI TRACT FEEDS AND RECYCLING FROM BONE AND SYSTEMIC ORGANS.
C
C       PTEMP(ISPEC,1)=(LMAB(ISPEC,1)*YSW(ISPEC)
C           +LMAB(ISPEC,2)*YSIW(ISPEC)
C           +LMAB(ISPEC,3)*YULIW(ISPEC)
C           +LMAB(ISPEC,4)*YLLIW(ISPEC))/DELTA
C       IF (MODE .EQ. 1) PTEMP(ISPEC,1)=PTEMP(ISPEC,1)
C           +(LMA(ISPEC)*YNPW(ISPEC,1)
C           +LMC(ISPEC)*YITBW(ISPEC,1)
C           +LME(ISPEC)*YPW(ISPEC,1)
C           +LMT(ISPEC)*YLNW(ISPEC,1))/DELTA
C       IF (T1 .EQ. 0.0) GO TO 250
C       IF (ISURF(ISPEC) .EQ. 1) PTEMP(ISPEC,1)=PTEMP(ISPEC,1) +
C           (F2RCYC(ISPEC,1)*LAMDAY*YVELMW(ISPEC) +
C           F2RCYC(ISPEC,2)*LAMDAR*YREDMW(ISPEC))/DELTA
C       INITAL=1
C       IF (ISURF(ISPEC) .EQ. 1) INITAL=3
C       DO 250 IORG=INITAL,NSCU
C           NC=NCOMP(ISPEC,IORG)
C           DO 240 IC=1,NC
C               PTEMP(ISPEC,1)=PTEMP(ISPEC,1) + F2RCYC(ISPEC,IORG)*
C                   YORGW(ISPEC,IC,IORG)*LMBDAB(ISPEC,IC,IORG)/DELTA
C   240 CONTINUE
C   250 CONTINUE

```

```

C
C INITIAL CONDITIONS.
  YTEMPO(ISPEC,1)=YBLUD(ISPEC)
300 CONTINUE
C
C TEST FOR EXHAUSTION..
  DO 610 ISPEC=1,NSPEC
    IF (PTEMP(ISPEC,1) .GT. 1.0E-20 .OR. YTEMPO(ISPEC,1)
      $ .GT. 1.0E-20) GO TO 611
    YBLUD(ISPEC)=0.0
    YBLUDW(ISPEC)=0.0
  610 CONTINUE
    SBLUD=.TRUE.
    GO TO 310
  611 CONTINUE
C
  CALL MULCOM
C
C MOVE OUTPUTS FROM BLOCOD.
  DO 310 ISPEC=1,NSPEC
    YBLUD(ISPEC)=YTEMP(ISPEC,1)
    YBLUDW(ISPEC)=YTEMPW(ISPEC,1)
  310 CONTINUE
C-----
C END OF TRANSFER COMPARTMENT
C-----
C-----
C SKELETAL TISSUES (BONE SURFACE, BONE VOLUME, AND MARROW)
C-----
C
  IF (NOBONE) GO TO 490
  IFRAC=1.0
  JFRAC=1.0
C
C CORTICAL BONE SURFACE
C-----
  DO 400 ISPEC=1,NSPEC
C
C NUMBER OF SUBCOMPARTMENTS, COEFFICIENTS, AND BIOLOGICAL REMOVAL
C COEFFICIENTS.
    NCTEMP(ISPEC)=1
    CTEMP(ISPEC,1)=1.0
    LB(ISPEC,1)=VLAMAC
    IF (ISURF(ISPEC) .EQ. 1) LB(ISPEC,1)=LAMDA A + LAMDAB
    IF (ISURF(ISPEC) .EQ. 1 .AND. ADULT .EQ. 1.0) LB(ISPEC,1)=
      $ 0.5*LAMDA A + LAMDAB
C
C INFLOW VECTOR.. INPUT FROM BLOCOD AND LCCAL REDEPOSITION FROM MARROW.
  PTEMP(ISPEC,1)=F2PRIM(ISPEC,1)*LBLUC(ISPEC)*
  $ YBLUDW(ISPEC)/DELT
  IF (ISURF(ISPEC) .EQ. 1) PTEMP(ISPEC,1)=F2PRIM(ISPEC,1)*
  $ LBLUD(ISPEC)*YBLUDW(ISPEC)/DELT +
  $ (1.0-IFRAC)*LAMDAY*YYELMW(ISPEC)/DELT
C
C INITIAL CONDITIONS..
  YTEMPO(ISPEC,1)=YCSUR(ISPEC)
400 CONTINUE
C
  CALL MULCOM
C
C MOVE OUTPUT FROM CORTICAL SURFACES..
  DO 404 ISPEC=1,NSPEC
    YCSUR(ISPEC)=YTEMP(ISPEC,1)
    YCSURW(ISPEC)=YTEMPW(ISPEC,1)
  404 CONTINUE
C
C TRABECULAR BONE SURFACE
C-----
  DO 405 ISPEC=1,NSPEC
C
C NUMBER OF SUBCOMPARTMENTS, COEFFICIENTS, AND BIOLOGICAL REMOVAL
C COEFFICIENTS.
    NCTEMP(ISPEC)=1
    CTEMP(ISPEC,1)=1.0
    LB(ISPEC,1)=VLAMAC
    IF (ISURF(ISPEC) .EQ. 1) LB(ISPEC,1)=LAMDAC + LAMDAD
    IF (ISURF(ISPEC) .EQ. 1 .AND. ADULT .EQ. 1.0) LB(ISPEC,1)=
      $ 0.5*LAMDAC + LAMDAD

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```

      DO 440 ISPEC=1,NSPEC
C     NUMBER OF SUBCOMPARTMENTS, INTAKE RATES, COEFFICIENTS, REMOVAL RATES,
C     AND INITIAL CONDITIONS..
C
      NCTEMP(ISPEC)=NCOMP(ISPEC,2)
      NC=NCTEMP(ISPEC)
      DO 435 IC=1,NC
        CTEMP(ISPEC,IC)=C(ISPEC,IC,2)
        LB(ISPEC,IC)=LMBDAB(ISPEC,IC,2)
        IF (ISURF(ISPEC) .EQ. 1) LB(ISPEC,IC)=FLAMDA
        PTEMP(ISPEC,IC)=YTSURW(ISPEC)*VLAMAC/DELT
        IF (ISURF(ISPEC) .EQ. 1) PTEMP(ISPEC,IC)=YTSURW(ISPEC)*
          $ LAMDAC/DELT
          $ IF (ISURF(ISPEC) .EQ. 1 .AND. ADULT .EQ. 1.0)
          $ PTEMP(ISPEC,IC)=YTSURW(ISPEC)*0.5*LAMDAC/DELT
        YTEMPO(ISPEC,IC)=YORG(ISPEC,IC,2)
      435 CONTINUE
      440 CONTINUE
C
      CALL MULCOM
C
C     MOVE OUTPUTS FROM TRABECULAR BONE VOLUME..
      DO 450 ISPEC=1,NSPEC
        NC=NCOMP(ISPEC,2)
        YTVOLW(ISPEC)=0.0
        DO 445 IC=1,NC
          YORG(ISPEC,IC,2)=YTEMP(ISPEC,IC)
          YORGW(ISPEC,IC,2)=YTEMPW(ISPEC,IC)
          YTVOLW(ISPEC)=YTVOLW(ISPEC) + YCRGW(ISPEC,IC,2)
        445 CONTINUE
      450 CONTINUE
C
C     OMIT MARROW CALCULATIONS FOR VOLUME DEPOSITION.
      IF (SSURF) GO TO 450
C
C     TRABECULAR (RED) BONE MARROW
C     -----
C     FOR DOSIMETRIC PURPOSES THIS WILL BE IDENTIFIED WITH RED MARROW.
C     HOWEVER, WE MAKE USE OF THE FACT THAT THIS COMPARTMENT ALSO
C     CONTAINS A SIGNIFICANT AMOUNT OF INACTIVE (YELLOW) MARROW.
      DO 460 ISPEC=1,NSPEC
C     NUMBER OF SUBCOMPARTMENTS..
      NCTEMP(ISPEC)=1
C
C     SUBCOMPARTMENT FRACTION..
      CTEMP(ISPEC,1)=1.0
C
C     BIOLOGICAL REMOVAL RATE..
      LB(ISPEC,1)=LAMCAR
C
C     INFLOW VECTOR..
      PTEMP(ISPEC,1)=0.0
      IF (ISURF(ISPEC) .EQ. 1) PTEMP(ISPEC,1)=(LAMDAD*
        $ YTSURW(ISPEC)+FLAMDA*YTVOLW(ISPEC))/DELT
C
C     INITIAL CONDITION..
      YTEMPO(ISPEC,1)=YREDW(ISPEC)
      460 CONTINUE
C
      CALL MULCOM
C
C     MOVE OUTPUTS FROM RED MARROW..
      DO 470 ISPEC=1,NSPEC
        YREDM(ISPEC)=YTEMP(ISPEC,1)
        YREDMW(ISPEC)=YTEMPW(ISPEC,1)
      465 CONTINUE
      470 CONTINUE
C

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```

C CORTICAL (YELLOW) BONE MARROW
C -----
C THIS IS USUALLY IDENTIFIED WITH YELLOW MARROW. HOWEVER, AT EARLY
C AGES THIS COMPARTMENT CONTAINS A SIGNIFICANT AMOUNT OF ACTIVE
C (RED) MARROW.
C DO 480 ISPEC=1, NSPEC
C
C NCTEMP AND CTEMP ARE AS FOR TRABECULAR MARROW.
C
C BIOLOGICAL REMOVAL RATE..
C LR(ISPEC,1)=LAMCAY
C
C INFLOW VECTOR..
C PTEMP(ISPEC,1)=C.0
C IF (ISURF(ISPEC).EQ. 1) PTEMP(ISPEC,1)=(LAMDAB*
C $ YCSURW(ISPEC)+ELAMDA*YCVCLW(ISPEC))/DELT
C
C INITIAL CONDITION..
C YTEMPO(ISPEC,1)=YYELM(ISPEC)
C 480 CONTINUE
C
C CALL MULCOM
C
C MOVE OUTPUTS FROM CORTICAL MARROW..
C DO 490 ISPEC=1, NSPEC
C YYELM(ISPEC)=YTEMP(ISPEC,1)
C YYFLMW(ISPEC)=YTEMPW(ISPEC,1)
C 490 CONTINUE
C
C -----
C END OF SKELETAL TISSUE CALCULATIONS.
C -----
C -----
C OTHER ORGANS
C OTHER SYSTEMIC ORGANS SUCH AS LIVER, KIDNEY, ETC., FOLLOWED BY
C 'OTHER' IN WHICH THE REMAINING FRACTION OF ACTIVITY IN THE BODY
C IS UNIFORMLY DISTRIBUTED, AND A 'DELAYED-EXCRETION' COMPARTMENT
C IF APPROPRIATE.
C -----
C
C KSOU=3
C IF (NOBONE) KSOU=1
C DO 350 IORG=KSOU, NSOU
C DO 330 ISPEC=1, NSPEC
C
C NUMBER OF SUBCOMPARTMENTS, INTAKE RATE, COEFFICIENTS, REMOVAL RATES,
C AND INITIAL CONDITIONS..
C
C NCTEMP(ISPEC)=NCOMP(ISPEC, IORG)
C NC=NCOMP(ISPEC, IORG)
C DO 325 IC=1, NC
C CTEMP(ISPEC, IC)=C(ISPEC, IC, IORG)
C LB(ISPEC, IC)=LMBDAB(ISPEC, IC, IORG)
C PTEMP(ISPEC, IC)=(LBLUD(ISPEC)*YELUDW(ISPEC)*
C $ F2PRIM(ISPEC, IORG))/DELT
C YTEMPO(ISPEC, IC)=YORG(ISPEC, IC, IORG)
C 325 CONTINUE
C 330 CONTINUE
C CALL MULCOM
C
C MOVE OUTPUTS FROM ORGAN IORG..
C DO 340 ISPEC=1, NSPEC
C NC=NCOMP(ISPEC, IORG)
C DO 335 IC=1, NC
C YORG(ISPEC, IC, IORG)=YTEMP(ISPEC, IC)
C YORGW(ISPEC, IC, IORG)=YTEMPW(ISPEC, IC)
C 335 CONTINUE
C 340 CONTINUE
C
C END OF IORG LOOP..
C 350 CONTINUE
C -----
C END OF OTHER ORGANS
C -----
C

```

```

C-----
C EXCRETION COMPARTMENT
C-----
      DO 360 ISPEC=1,NSPEC
        NCTEMP(ISPEC)=1
        LB(ISPEC,1)=1.0E-06
        CTEMP(ISPEC,1)=1.0
        PTEMP(ISPEC,1)=LBLUD(ISPEC)*YELUDW(ISPEC)*F2FXCR(ISPEC)/DEL T
        IF (OTHEXC) PTEMP(ISPEC,1)=PTEMP(ISPEC,1) +
          $ (LMBDAB(ISPEC,1,NSOU)*YORGW(ISPEC,1,NSOU) +
          $ LMBDAB(ISPEC,2,NSOU)*YCRGW(ISPEC,2,NSOU) +
          $ LMBDAB(ISPEC,3,NSOU)*YCRGW(ISPEC,3,NSOU) +
          $ LMBDAB(ISPEC,4,NSOU)*YCRGW(ISPEC,4,NSOU) +
          $ LMBDAB(ISPEC,5,NSOU)*YCRGW(ISPEC,5,NSOU))/DEL T
        YTEMPO(ISPEC,1)=YEXCP(ISPEC)
      360 CONTINUE
      CALL MULCOM
      DO 370 ISPEC=1,NSPEC
        YEXCR(ISPEC)=YTEMP(ISPEC,1)
        YEXCRW(ISPEC)=YEXCRW(ISPEC)+YTEMPW(ISPEC,1)
      370 CONTINUE
C-----
C END OF EXCRETION COMPARTMENT
C-----
      RETURN
      END
C

```

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C-----
C SUBROUTINE MULCOM
C-----
C COMPUTES ACTIVITIES A(I,K) AND CUMULATED ACTIVITIES AW(I,K) OF THE I-TH
C RADIONUCLIDE SPECIES OF A CHAIN DUE TO THE K-TH TERM OF ITS FRACTIONAL
C RETENTION FUNCTION, AS DIRECTED BY SUBROUTINE STEP.
C
      REAL T,LMR,LME(12,5),C(12,5),P(12,5),A0(12,5),A(12,5),AW(12,5)
      DOUBLE PRECISION TA1,TA2,TAW1,TAW2,TFRM
      INTEGER NCOMP(12)
      DOUBLE PRECISION E(950),H(12,5),D(12,5),G
      DOUBLE PRECISION LM(12,5),LX(60)
      DOUBLE PRECISION EXPFUN,EXPF1,EXLI,EXLI1,
      $ TEMP,TEMP1
      COMMON /MULDAT/ T,LMB,C,P,A0,A,AW,NCOMP
      COMMON /RADAT/ TR(12),BRANCH(12,12),LMR(12)
      COMMON /NUMRES/ N,NSOU,NTRG,NLET
C
C THE FOLLOWING INTEGER-VALUED STATEMENT FUNCTION COMPUTES THE INDEX
C OF THE (I,J,M)-TH ENTRY IN THE ARRAY E.
      INDXE(I,J,M)=J+(I-1)*(I-2)/2+(M-1)*NN2
C
      NN2=N*(N-1)/2
      IF(T.GT.0.0) GO TO 30
      DO 20 I=1,N
        NCI=NCOMP(I)
        DO 10 M=1,NCI
          A(I,M)=A0(I,M)
          AW(I,M)=0.0
        10 CONTINUE
      20 CONTINUE
      GO TO 300
      30 CONTINUE
C
C COMPUTE TOTAL LAMPDAS AND STORE IN LINEAR ARRAY LX FOR SEPARATION.
      KOUNT=0
      DO 50 I=1,N
        NCI=NCOMP(I)
        DO 40 M=1,NCI
          KOUNT=KOUNT+1
          LX(KOUNT)=LMR(I)+LMB(I,M)
        40 CONTINUE
      50 CONTINUE
C

```

```

C IF TWO LX(I) ARE NEARLY EQUAL, SEPARATE THEM.
C
C SKIP SEPARATION ROUTINE IF N=1.
  IF(N .EQ. 1) GO TO 90
C
C BEGINNING OF SEPARATION ROUTINE. KCUNT=NC. ELEMENTS IN LX.
  KOUNT1=KOUNT-1
C KODE IS A SWITCH FOR WHICH THE VALUE 1 MEANS ANOTHER
C PASS SHOULD BE MADE.
  KODE=1
  60 IF(KODE .NE. 1) GO TO 90
  KODE=0
C BEGIN PASS.
  DO 80 K=1,KCUNT1
  K1=K+1
  DO 70 L=K1,KOUNT
C IF LX(L) AND LX(K) ARE NEARLY EQUAL. SEPARATE THEM.
  IF(DABS(LX(L)/LX(K)-1.0D0) .GE. 1.0D-6) GO TO 70
  LX(L)=LX(K)*1.00001D0
  KODE=1
  70 CONTINUE
  80 CONTINUE
C RETURN FOR (POSSIBLY) ANOTHER PASS BY MEANS OF BACKWARD-POINTING
C GO TO STATEMENT.
  GO TO 60
C END OF SEPARATION ROUTINE.
  90 CONTINUE
C
C MOVE SEPARATED RATE COEFFICIENTS FROM LX TO LM.
  KOUNT=0
  DO 110 I=1,N
  NCI=NCOMP(I)
  DO 100 M=1,NCI
  KCUNT=KOUNT+1
  LM(I,M)=LX(KCUNT)
  100 CONTINUE
  110 CONTINUE
C
C BEGIN MAIN CALCULATION. I=1 IS HANDLED AS A SPECIAL CASE.
  I=1
  NCI=NCOMP(I)
  DO 120 K=1,NCI
  D(I,K)=DBLE(C(I,K)*P(I,K))/LM(I,K)
  H(I,K)=DBLE(A0(I,K))-D(I,K)
  A(I,K)=SNGL(D(I,K)+H(I,K)*EXPFUN(-DELE(T)*LM(I,K)))
  A#(I,K)=SNGL(D(I,K)*DBLE(T)+H(I,K)*EXPF1(LM(I,K),
  $ DBLE(T)))
  120 CONTINUE
  IF(I .EQ. N) GO TO 300
  DO 230 I=2,N
  I1=I-1
  NCI=NCOMP(I)
  DO 150 K=1,NCI
  TEMP=0.0D0
  DO 140 J=1,I1
  TEMP1=0.0D0
  NCJ=NCOMP(J)
  DO 130 M=1,NCJ
  TEMP1=TEMP1+D(J,M)
  130 CONTINUE
  TEMP=TEMP+DBLE(BRANCH(I,J))*TEMP1
  140 CONTINUE
  D(I,K)=DBLE(C(I,K))/LM(I,K)*(DBLE(LMR(I))*TEMP+P(I,K))
  TEMP=0.0D0
  150 CONTINUE

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```

DO 190 J=1,I1
NCJ=NCOMP(J)
DO 180 M=1,NCJ
IJM=INDEXE(I,J,M)
E(IJM)=C.000
IF(J.GT. I-2) GO TC 180
J1=J+1
DO 170 IR=J1,I1
TEMP1=C.000
NCIR=NCOMP(IR)
DO 160 MU=1,NCIR
IRJM=INDEXE(IR,J,M)
TEMP1=TEMP1+DBLE(C(IR,MU)*LMR(IR))/(LM(IR,MU)-LM(J,M))
*(E(IRJM)+DBLE(BRANCH(IR,J))*H(J,M))
160 CONTINUE
E(IJM)=E(IJM)+DBLE(BRANCH(I,IR))*TEMP1
170 CONTINUE
180 CONTINUE
190 CONTINUE
C
C COMPUTE H(I,K), K=1,.....,NCOMP(I).
DO 220 K=1,NCI
TEMP=0.000
DO 210 J=1,I1
NCJ=NCOMP(J)
DO 200 M=1,NCJ
IJM=INDEXE(I,J,M)
TEMP=TEMP+DBLE(LMR(I))/(LM(I,K)-LM(J,M))
*(E(IJM)+DBLE(BRANCH(I,J))*F(J,M))
200 CONTINUE
210 CONTINUE
H(I,K)=DBLE(A(I,K))-D(I,K)-DBLE(C(I,K))*TEMP
220 CONTINUE
230 CONTINUE
C END OF CALCULATION OF D(I,K), H(I,K), E(I,J,M).
C
C BEGIN COMPUTATION OF A(I,K), AW(I,K)
DO 270 I=2,N
II=I-1
NCI=NCOMP(I)
DO 260 K=1,NCI
EXLI=EXPF(LN(-LM(I,K)*DBLE(T)))
EX1LI=EXPF1(LM(I,K),DBLE(T))
TA1=0.000
TA2=0.000
TAW1=0.000
TAW2=0.000
DO 250 J=1,I1
NCJ=NCOMP(J)
DO 240 M=1,NCJ
IJM=INDEXE(I,J,M)
G=DBLE(C(I,K))*DBLE(LMR(I))/(LM(I,K)-LM(J,M))
*(E(IJM)+DBLE(BRANCH(I,J))*F(J,M))
TERM=G*(EXPFUN(-LM(J,M)*DBLE(T))-EXLI)
IF(TERM.GE. 0.000) TA1=TA1+TERM
IF(TERM.LT. 0.000) TA2=TA2+TERM
TERM=G*(EXPF1(LM(J,M),DBLE(T))-EX1LI)
IF(TERM.GE. 0.000) TAW1=TAW1+TERM
IF(TERM.LT. 0.000) TAW2=TAW2+TERM
240 CONTINUE
250 CONTINUE
TERM=LM(I,K)*D(I,K)*EX1LI+DBLE(A0(I,K))*EXLI
IF(TERM.GE. 0.000) TA1=TA1+TERM
IF(TERM.LT. 0.000) TA2=TA2+TERM
A(I,K)=SINGL(TA1+TA2)
IF(ABS(A(I,K)).LE. 1.E-15*SINGL(TA1-TA2)) A(I,K)=0.0
TERM=D(I,K)*(DBLE(T)-EX1LI)+DBLE(A0(I,K))*EX1LI
IF(TERM.GE. 0.000) TAW1=TAW1+TERM
IF(TERM.LT. 0.000) TAW2=TAW2+TERM
AW(I,K)=SINGL(TAW1+TAW2)
IF(ABS(AW(I,K)).LE. 1.E-15*SINGL(TAW1-TAW2)) AW(I,K)=0.0
260 CONTINUE
270 CONTINUE
300 RETURN
END
C

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C-----
C      DOUBLE PRECISION FUNCTION EXPFUN(T)
C-----
C
C COMPUTES EXP(T).
C
  DOUBLE PRECISION T
  EXPFUN=0.0D0
  IF(T.LT.-180.0D0) GO TO 10
  EXPFUN=DEXP(T)
10 RETURN
  END
C
C-----
C      DOUBLE PRECISION FUNCTION EXPF1(LM,T)
C-----
C
C COMPUTES (1.0 - EXP(-LM * T))/LM.
C
  DOUBLE PRECISION LM,T,LMT,EXPFUN
  LMT=LM*T
  IF(LMT.LT.0.03D0) GO TO 10
  GO TO 20
10 EXPF1=T*(((LMT/7.0D0-1.0D0)*LMT/6.0D0+1.0D0)
  $ *LMT/5.0D0-1.0D0)*LMT/4.0D0+1.0D0)*LMT/3.0D0-1.0D0)
  $ *LMT/2.0D0+1.0D0)
  GO TO 30
20 EXPF1=(1.0D0-EXPFUN(-LMT))/LM
30 RETURN
  END
C
C-----
C      SUBROUTINE DOSAGE(T,INDEX)
C-----
C
C COMPUTE DOSE RATE MATRIX FROM ACTIVITIES CALCULATED BY SUBROUTINE STEP
C FOR TIME T.
C
  LOGICAL OTHEXC,NOBONE
  REAL LMBDA,SF,ACTIV(12,16),LBLUD,ATCT(12)
  DOUBLE PRECISION NAMNUC,NAMSOU,NAMTRG,NAMTOT,NAMEX1,NAMEX2,
  $ NAMMOD(3),NAMSUR,NAMMAR
  INTEGER TO,SOL
  LOGICAL SNP,STB1,STB2,SP,SL,SLUNG,SST,SSI,SULI,SLLI.
  $ SGI,SBLUD,SSURF
  COMMON /SWTCHS/ SNP,STB1,SP,SL,STB2(2),SLUNG,SST,SSI.
  $ SULI,SLLI,SGI,SBLUD,SSURF
  COMMON /NUMRCS/ NSPEC,NSOU,NTRG,NLET
  COMMON /NAMES/ NAMNUC(12),NAMSOU(10),NAMTRG(24)
  COMMON /ORGDAT/ NCOMP(12,10),CA(12,5,10,7),LMBDA(12,5,10,7),
  $ F2PRA(12,10,7),TBA(12,5,10,7),F2EXCR(12),F2RCYC(12,10)
  COMMON /LVELES/ YNP(12,2),Y1TB(12,2),Y2TB(12,2),YP(12,4),YL(12,2),
  $ YS(12),YSI(12),YULI(12),YLLI(12),YBLUD(12),
  $ YCSUR(12),YTSUR(12),YREDM(12),YYELM(12),YORG(12,5,10),YEXCR(12)
  COMMON /CUMACT/ YNPW(12,2),Y1TBW(12,2),Y2TBW(12,2),YPW(12,4),
  $ YLW(12,2),YSW(12),YSIW(12),YULIW(12),YLLIW(12),
  $ YBLUDW(12),YCSURW(12),YTSURW(12),YREDMW(12),
  $ YYELMW(12),YORGW(12,5,10),YEXCRW(12)
  COMMON /ACTVTY/ ACT(12,150,20),AWIGL(12,16),AW(12,20)
  COMMON /DOSES/ DOSRAT(2,150,24),DOSTIM(150),DOSE(2,24)
  COMMON /SFACT/ S(7,2,12,16,24),NSAGES,SFSURF(7,2,12,2,2)
  COMMON /CASE/ KASE
  COMMON /TYME/ TO,TEND
  COMMON /INTRP/ TRPLAT,IP
  COMMON /SOLUB/ MCFE,SOL(12)
  COMMON /SURVOL/ ISURF(12)
  COMMON /BLOOD/ LBLUD(12),TBLUD(12)
  COMMON /EXCTRM/ NSEEE,OTHEXC
  COMMON /BONSWT/ NOBONE
  DATA NAMMOD/8H INHALA,8H INGES ,8H INJEC /
  DATA NAMTOT/8HTOT BODY/, NAMEX1/8HEXCRET /, NAMEX2/8HBODY+EXC/
  DATA NAMSUR/8HZONE SUR/, NAMMAR/8HRED MAR /

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C COMPUTE MATRIX OF DOSE RATES TO ALL TARGET ORGANS AT TIME T.
  DO 130 ILET=1,NLET
    DO 120 ITRG=1,NTRG
      DOSRAT(ILET,INDEX,ITRG)=0.0
      DO 110 ISPEC=1,NSPEC
        DO 100 ISOU=1,NSSEE
          SF=S(IP1,ILET,ISPEC,ISCU,ITRG) + TRPLAT
          *(S(IP,ILET,ISPEC,ISOU,ITRG)-S(IP1,ILET,ISPEC,ISOU,ITRG))
          DOSRAT(ILET,INDEX,ITRG)=DOSRAT(ILET,INDEX,ITRG) +
          SF * ACTIV(ISPEC,ISCU)
        100 CONTINUE
          IF (OTHEXC) DOSRAT(ILET,INDEX,ITRG)=DOSRAT(ILET,INDEX,ITRG)
          + SF * ACTIV(ISPEC,NS)
      C
      C FOR RED MARROW AND BONE SURFACE DOSE RATES, INCLUDE CONTRIBUTION FROM
      C SURFACE-DEPOSITED ACTIVITY.
        IF (NOBCNF) GO TO 110
        IF (NAMTRG(ITRG) .NE. NAMEUR) GO TO 105
          SFCEND=SFSURF(IP1,ILET,ISPEC,1,1) + TRPLAT *
          (SFSURF(IP,ILET,ISPEC,1,1)-SFSURF(IP1,ILET,ISPEC,1,1))
          SFTEND=SFSURF(IP1,ILET,ISPEC,2,1) + TRPLAT *
          (SFSURF(IP,ILET,ISPEC,2,1)-SFSURF(IP1,ILET,ISPEC,2,1))
          DOSRAT(ILET,INDEX,ITRG)=DOSRAT(ILET,INDEX,ITRG) +
          SFCEND*YCSUR(ISPEC) + SFTEND*YTSUR(ISPEC)
        105 IF (NAMTRG(ITRG) .NE. NAMMAR) GO TO 110
          SFCRM=SFSURF(IP1,ILET,ISPEC,1,2) + TRPLAT *
          (SFSURF(IP,ILET,ISPEC,1,2)-SFSURF(IP1,ILET,ISPEC,1,2))
          SFTRM=SFSURF(IP1,ILET,ISPEC,2,2) + TRPLAT *
          (SFSURF(IP,ILET,ISPEC,2,2)-SFSURF(IP1,ILET,ISPEC,2,2))
          DOSRAT(ILET,INDEX,ITRG)=DOSRAT(ILET,INDEX,ITRG) +
          SFCRM*YCSUR(ISPEC) + SFTRM*YTSUR(ISPEC)
        110 CONTINUE
        120 CONTINUE
        130 CONTINUE
      C
      C STORE ACTIVITIES IN ARRAY ACT FOR OUTPUT.
        DO 150 ISPEC=1,NSPEC
          ACT(ISPEC,INDEX,1)=ACTIV(ISPEC,1)
          ACT(ISPEC,INDEX,2)=YS(ISPEC)
          ACT(ISPEC,INDEX,3)=YSI(ISPEC)
          ACT(ISPEC,INDEX,4)=YULI(ISPEC)
          ACT(ISPEC,INDEX,5)=YLLI(ISPEC)
          ACT(ISPEC,INDEX,6)=YBLUD(ISPEC)
        C
        IF (NOBONE) GO TO 145
        C
          ACT(ISPEC,INDEX,7)=YCSUR(ISPEC)
          ACT(ISPEC,INDEX,8)=YTSUR(ISPEC)
          ACT(ISPEC,INDEX,9)=YORG(ISPEC,1,1)+YORG(ISPEC,2,1)
          +YORG(ISPEC,3,1)+YORG(ISPEC,4,1)+YORG(ISPEC,5,1)
          ACT(ISPEC,INDEX,10)=YCRG(ISPEC,1,2)+YCRG(ISPEC,2,2)
          +YCRG(ISPEC,3,2)+YCRG(ISPEC,4,2)+YCRG(ISPEC,5,2)
          ACT(ISPEC,INDEX,11)=YREDM(ISPEC)
          ACT(ISPEC,INDEX,12)=YYELM(ISPEC)
          ACT(ISPEC,INDEX,NSOU+11)=ACT(ISPEC,INDEX,1)+ACT(ISPEC,INDEX,2)
          +ACT(ISPEC,INDEX,3)+ACT(ISPEC,INDEX,4)+ACT(ISPEC,INDEX,5)
          +ACT(ISPEC,INDEX,6)+ACT(ISPEC,INDEX,7)+ACT(ISPEC,INDEX,8)
          +ACT(ISPEC,INDEX,9)+ACT(ISPEC,INDEX,10)+ACT(ISPEC,INDEX,11)
          +ACT(ISPEC,INDEX,12)
          DO 140 IS=3,NSCU
            ACT(ISPEC,INDEX,IS+10)=YORG(ISPEC,1,IS)+YORG(ISPEC,2,IS)
            +YORG(ISPEC,3,IS)+YCRG(ISPEC,4,IS)+YCRG(ISPEC,5,IS)
            ACT(ISPEC,INDEX,NSOU+11)=ACT(ISPEC,INDEX,NSOU+11) +
            ACT(ISPEC,INDEX,IS+10)
          140 CONTINUE
          ATOT(ISPEC)=ACT(ISPEC,INDEX,NSOU+11)+YEXCR(ISPEC)
          GO TO 150
        145 ACT(ISPEC,INDEX,NSOU+7)=ACT(ISPEC,INDEX,1)+ACT(ISPEC,INDEX,2)+
          ACT(ISPEC,INDEX,3)+ACT(ISPEC,INDEX,4)+ACT(ISPEC,INDEX,5)+
          ACT(ISPEC,INDEX,6)
          DO 146 ISOU=1,NSOL
            ACT(ISPEC,INDEX,ISOU+6)=YORG(ISPEC,1,ISOU)+YORG(ISPEC,2,ISOU)+
            YORG(ISPEC,3,ISOU)+YORG(ISPEC,4,ISOU)+YCRG(ISPEC,5,ISOU)
            ACT(ISPEC,INDEX,NSOU+7)=ACT(ISPEC,INDEX,NSOU+7)+
            ACT(ISPEC,INDEX,ISOU+6)
          146 CONTINUE
          ATOT(ISPEC)=ACT(ISPEC,INDEX,NSOU+7)+YEXCR(ISPEC)
        150 CONTINUE

```

```

DOSTIM(INDEX)=T
NS=NSOU+6
IF (NOBONE) NS=NSCU+5
NSOU1=NSOU+1
NSOU2=NSOU+2
NSOU3=NSOU+3
NS1=NS+1
NS2=NS+2
NS3=NS+3
NAMSOU(NSOU1)=NAMTOT
NAMSOU(NSOU2)=NAMEX1
NAMSOU(NSOU3)=NAMEX2
IP1=IP-1
C
C STORE ACTIVITIES IN ARRAY ACTIV
C
C INITIALIZE ARRAY
DO 20 ISPEC=1,NSPEC
  DO 10 ISOU=1,NS
    ACTIV(ISPEC,ISOU)=0.0
  10 CONTINUE
  20 CONTINUE
C
  DO 90 ISPEC=1,NSPEC
C
C RESPIRATORY TRACT
  ACTIV(ISPEC,1)=YNP(ISPEC,1) + YNP(ISPEC,2) +
  $ Y1TB(ISPEC,1) + Y1TB(ISPEC,2) +
  $ Y2TB(ISPEC,1) + Y2TB(ISPEC,2) +
  $ YP(ISPEC,1) + YP(ISPEC,2) + YP(ISPEC,3) + YP(ISPEC,4) +
  $ YL(ISPEC,1) + YL(ISPEC,2)
C
C GI TRACT
  ACTIV(ISPEC,2)=YS(ISPEC)
  ACTIV(ISPEC,3)=YSI(ISPEC)
  ACTIV(ISPEC,4)=YULI(ISPEC)
  ACTIV(ISPEC,5)=YLLI(ISPEC)
C
  IF (NOBONE) GO TO 60
C
C RED MARROW
  ACTIV(ISPEC,6)=YREDM(ISPEC)
C
C CORTICAL AND TRABECULAR BONE.
  ACTIV(ISPEC,7)=YYELM(ISPEC)
  NC=NCOMP(ISPEC,1)
  DO 50 IC=1,NC
    ACTIV(ISPEC,7)=ACTIV(ISPEC,7) + YCRG(ISPEC,IC,1)
  50 CONTINUE
  ACTIV(ISPEC,8)=0.0
  NC=NCOMP(ISPEC,2)
  DO 60 IC=1,NC
    ACTIV(ISPEC,8)=ACTIV(ISPEC,8) + YCRG(ISPEC,IC,2)
  60 CONTINUE
C
C OTHER SOURCE ORGANS
  ACTIV(ISPEC,NS1)=ACTIV(ISPEC,1)+ACTIV(ISPEC,2)+ACTIV(ISPEC,3)+
  $ ACTIV(ISPEC,4)+ACTIV(ISPEC,5)
  IF (.NOT.NOBONE) ACTIV(ISPEC,NS1)=ACTIV(ISPEC,NS1)+ACTIV(ISPEC,6)+
  $ ACTIV(ISPEC,7)+ACTIV(ISPEC,8)+YCSUR(ISPEC)+YTSUR(ISPEC)
  KS=9
  IF (NOBONE) KS=6
  JS=6
  IF (NOBONE) JS=5
  DO 80 ISOU=KS,NS
    NC=NCOMP(ISPEC,ISOU-JS)
    DO 70 IC=1,NC
      ACTIV(ISPEC,ISOU)=ACTIV(ISPEC,ISOU) + YCRG(ISPEC,IC,ISOU-JS)
    70 CONTINUE
    IF (ISOU .EQ. NS) ACTIV(ISPEC,ISOU)=ACTIV(ISPEC,ISOU) +
    $ YBLUD(ISPEC)
    ACTIV(ISPEC,NS1)=ACTIV(ISPEC,NS1)+ACTIV(ISPEC,ISOU)
  80 CONTINUE
  90 CONTINUE
C

```

```

C
C OUTPUT ACTIVITIES IN EACH SOURCE ORGAN TO AUXILIARY OUTPUT UNIT
  IF (T.EQ.0.C) WRITE(16,2001)NAMNUC(1),KASE,NAMMOD(MODE),TO
  IF (NOBONE) GO TO 175
  WRITE(16,2000) T,(NAMSOL(ISO),ISO=1,3)
  DO 160 ISPEC=1,NSPEC
    WRITE(16,2010) NAMNUC(ISPEC),(ACT(ISPEC,INDEX,ISO),ISO=1,13)
  160 CONTINUE
  WRITE(16,2020) (NAMSOU(ISO),ISO=4,NSOU3)
  NS11=NSOU+11
  DO 170 ISPEC=1,NSPEC
    WRITE(16,2010)NAMNUC(ISPEC),(ACT(ISPEC,INDEX,ISO),ISO=14,NS11)
  $   ,YEXCR(ISPEC),ATOT(ISPEC)
  170 CONTINUE
  GO TO 177
  175 WRITE(16,2030) T,(NAMSOU(ISO),ISO=1,NSOU3)
  NSOU7=NSOU+7
  DO 176 ISPEC=1,NSPEC
    WRITE(16,2010) NAMNUC(ISPEC),(ACT(ISPEC,INDEX,ISO),
  $   ISO=1,NSOU7),YEXCR(ISPEC),ATOT(ISPEC)
  176 CONTINUE
  177 IF (SLUNG) GO TO 180
  WRITE (16,2080)
  DO 180 ISPEC=1,NSPEC
    WRITE(16,2050) NAMNUC(ISPEC),YNP(ISPEC,1),YNP(ISPEC,2),
  $   Y1TB(ISPEC,1),Y1TB(ISPEC,2),YP(ISPEC,1),
  $   YP(ISPEC,2),YP(ISPEC,3),YP(ISPEC,4),YL(ISPEC,1),
  $   YL(ISPEC,2),Y2TB(ISPEC,1),Y2TB(ISPEC,2)
  180 CONTINUE
C
2001 FORMAT('1',A8,2X,'CASE',I2,' ( ',A8,' ), BEGINNING ',
  $ 'AGE =',I4,' ',130('-'))
2000 FORMAT('0ORGAN ACTIVITIES (MICROCURIES) AT ',1PE10.3,' DAYS: '/
  $ '0 NUCLIDE',
  $ T14,'LUNGS',T23,'ST CCNT',T32,'SI CCNT',T41,'ULI CONT',T50,
  $ 'LLI CONT',T59,'BLOOD C SURF T SURF ',2(A8,1X),
  $ 'RED MAR YEL MAR ',A8)
2010 FORMAT(' ',A8,1P13E9.2)
2020 FORMAT('0',T14,13(A8,1X))
2030 FORMAT('0ORGAN ACTIVITIES (MICROCURIES) AT ',1PE10.3,' DAYS: '/
  $ '0 NUCLIDE',T14,'LUNGS',T23,'ST CCNT',T32,'SI CCNT',T41,
  $ 'ULI CONT',T50,'LLI CCNT',T59,'BLOOD ',7(A8,1X))
2080 FORMAT('0LUNG PATHWAYS: '/0 NUCLIDE',T14,'A',T23,'B',T32,'C',
  $ T41,'D',T50,'E',T59,'F',T68,'G',T77,'H',T86,'I',T95,'J',T104,
  $ 'K',T113,'L')
2090 FORMAT(' ',A8,1P13E9.2)
  RETURN
  END
C

```

SUBROUTINE DOSECCM(T)

C COMPUTE DOSE COMMITMENT TO ALL TARGET ORGANS AT TIME T..

```

C
  LOGICAL OTHEXC,NOBONE
  REAL LMBDA,SF,LBLUD
  DOUBLE PRECISION NAMNUC,NAMSOU,NAMTRG,NAMSUR,NAMMAR,NAMMOD(3),
  $ NAMEXC,NAMTCT
  INTEGER TO,SOL
  COMMON /NUMBRE/ NSPEC,NSOL,NTRG,NLET
  COMMON /NAMES/ NAMNUC(12),NAMSOU(10),NAMTRG(24)
  COMMON /ORGDAT/ NCOMP(12,10),CA(12,5,10,7),LMBDA(12,5,10,7),
  $ F2PRA(12,10,7),TBA(12,5,10,7),F2EXCR(12),F2RCYC(12,10)
  COMMON /CUMACT/ YNPW(12,2),Y1TBW(12,2),Y2TBW(12,2),YPW(12,4),
  $ YLW(12,2),YEW(12),YSIW(12),YULIW(12),YLLIW(12),
  $ YBLUDW(12),YCSURW(12),YTSURW(12),YREDMW(12),
  $ YYELMW(12),YORGW(12,5,10),YEXCRW(12)
  COMMON /ACTVY/ ACT(12,150,20),AWIGL(12,16),AW(12,20)
  COMMON /DOSES/ DOSRAT(2,150,24),DOSTIM(150),DOSE(2,24)
  COMMON /SFACT/ S(7,2,12,16,24),NSAGES,SFSURF(7,2,12,2,2)
  COMMON /CASE/ KASE
  COMMON /TYME/ TO,TEND
  COMMON /INTRP/ TRPLAT,IP
  COMMON /SOLUB/ MODE,SOL(12)
  COMMON /SURVOL/ ISURF(12)
  COMMON /BLOOD/ LBLUD(12),TBLUD(12)
  COMMON /EXCTR/ NSSEE,OTHEXC
  COMMON /BONSTR/ NOBONE

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DATA NAMMOD/8HINHAL. ,8HINGES. ,8HINJEC. /
DATA NAMSUR/8FONE SUR/, NAMMAR/8HRED MAR /
DATA NAMTOT/8FTOTAL /
DATA NAMEXC/8MEXCRET. /
NSOU2=NSOU+2
NAMSOL(NSOU+1)=NAMTOT
NAMSOU(NSOU2)=NAMEXC
NS=NSOU+6
IF (NOBONE) NS=NSCU+5
IP1=IP-1

C
C STORE ACTIVITIES IN ARRAY AWIGL..
C
C COMPUTE ACTIVITIES..
DO 90 ISPEC=1,NSPEC
C
C RESPIRATORY TRACT
AWIGL(ISPEC,1)=YNPW(ISPEC,1) + YNPW(ISPEC,2) +
$ Y1TBW(ISPEC,1) + Y1TBW(ISPEC,2) +
$ Y2TBW(ISPEC,1) + Y2TBW(ISPEC,2) +
$ YPW(ISPEC,1) + YPW(ISPEC,2) + YPW(ISPEC,3) +
$ YPW(ISPEC,4) + YLW(ISPEC,1) + YLW(ISPEC,2)
C
C GI TRACT
AWIGL(ISPEC,2)=YSW(ISPEC)
AWIGL(ISPEC,3)=YSIW(ISPEC)
AWIGL(ISPEC,4)=YULIW(ISPEC)
AWIGL(ISPEC,5)=YLLIW(ISPEC)
C
IF (NOBONE) GO TO 60
C
C RED MARROW.
AWIGL(ISPEC,6)=YREDMW(ISPEC)
C
C CORTICAL AND TRABECULAR BONE.
AWIGL(ISPEC,7)=YVELMW(ISPEC)
NC=NCOMP(ISPEC,1)
DO 50 IC=1,NC
AWIGL(ISPEC,7)=AWIGL(ISPEC,7) + YCRGW(ISPEC,IC,1)
50 CONTINUE
AWIGL(ISPEC,8)=0.0
NC=NCOMP(ISPEC,2)
DO 60 IC=1,NC
AWIGL(ISPEC,8)=AWIGL(ISPEC,8) + YCRGW(ISPEC,IC,2)
60 CONTINUE
C
C OTHER SOURCE ORGANS
KS=9
IF (NOBONE) KS=8
JS=6
IF (NOBONE) JS=5
DO 80 ISOU=KS,NS
AWIGL(ISPEC,ISOU)=0.0
IF (ISOU.EQ.NS) AWIGL(ISPEC,ISOU)=YBLUDW(ISPEC)
NC=NCOMP(ISPEC,ISOU-JS)
DO 70 IC=1,NC
AWIGL(ISPEC,ISOU)=AWIGL(ISPEC,ISOU)+YCRGW(ISPEC,IC,ISOU-JS)
70 CONTINUE
80 CONTINUE
90 CONTINUE
C
C COMPUTE MATRIX OF DOSE COMMITMENTS TO ALL TARGET ORGANS AT TIME T.
DO 130 ILET=1,NLET
DO 120 ITRG=1,NTRG
DO 110 ISPEC=1,NSPEC
DO 100 ISOU=1,NSSEE
SF=S(IP1,ILET,ISPEC,ISOU,ITRG)+TRPLAT*
$ (S(IP,ILET,ISPEC,ISOU,ITRG)-S(IP1,ILET,ISPEC,ISOU,ITRG))
DOSE(ILET,ITRG)=DCSE(ILET,ITRG) +
$ SF * AWIGL(ISPEC,ISOU)
100 CONTINUE
IF (OTHEXC) DOSE(ILET,ITRG)=DCSE(ILET,ITRG) +
$ SF*AWIGL(ISPEC,NS)
C

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C FOR RED MARROW AND BONE SURFACE DOSE RATES. INCLUDE CONTRIBUTION FROM
C SURFACE-DEPOSITED ACTIVITY.
  IF (NOBCNE) GO TO 110
  IF (NAMTRG(ITRG) .NE. NAMSUR) GC TO 105
  SFCEND=SFSURF(IP1,ILET,ISPEC,1,1) + TRPLAT *
  $   (SFSURF(IP,ILET,ISPEC,1,1)-SFSURF(IP1,ILET,ISPEC,1,1))
  SFTEND=SFSURF(IP1,ILET,ISPEC,2,1) + TRPLAT *
  $   (SFSURF(IP,ILET,ISPEC,2,1)-SFSURF(IP1,ILET,ISPEC,2,1))
  DOSE(ILET,ITRG)=DCSE(ILET,ITRG) +
  $   SFCEND*YCSURW(ISPEC) + SFTEND*YTSURW(ISPEC)
105  IF (NAMTRG(ITRG) .NE. NAMMAR) GC TO 110
  SFCRM=SFSURF(IP1,ILET,ISPEC,1,2) + TRPLAT *
  $   (SFSURF(IP,ILET,ISPEC,1,2)-SFSURF(IP1,ILET,ISPEC,1,2))
  SFTRM=SFSURF(IP1,ILET,ISPEC,2,2) + TRPLAT *
  $   (SFSURF(IP,ILET,ISPEC,2,2)-SFSURF(IP1,ILET,ISPEC,2,2))
  DOSE(ILET,ITRG)=DCSE(ILET,ITRG) +
  $   SFCRM*YCSURW(ISPEC) + SFTRM*YTSURW(ISPEC)
110  CONTINUE
120  CONTINUE
130  CONTINUE
C
C STORE ACCUMULATED ACTIVITIES IN ARRAY AW FOR OUTPUT.
DO 150 ISPEC=1,NSPEC
  AW(ISPEC,1)=AW(ISPEC,1) + YNPW(ISPEC,1) + YNPW(ISPEC,2) +
  $   Y1TBW(ISPEC,1) + Y1TBW(ISPEC,2) +
  $   Y2TBW(ISPEC,1) + Y2TBW(ISPEC,2) +
  $   YPW(ISPEC,1) + YPW(ISPEC,2) + YPW(ISPEC,3) +
  $   YPW(ISPEC,4) + YLW(ISPEC,1) + YLW(ISPEC,2)
  AW(ISPEC,2)=AW(ISPEC,2) + YSW(ISPEC)
  AW(ISPEC,3)=AW(ISPEC,3) + YSIW(ISPEC)
  AW(ISPEC,4)=AW(ISPEC,4) + YULIW(ISPEC)
  AW(ISPEC,5)=AW(ISPEC,5) + YLLIW(ISPEC)
  AW(ISPEC,6)=AW(ISPEC,6) + YBLUDW(ISPEC)
C
  IF (NOBONE) GO TO 145
C
  AW(ISPEC,7)=AW(ISPEC,7) + YCSURW(ISPEC)
  AW(ISPEC,8)=AW(ISPEC,8) + YTSURW(ISPEC)
  AW(ISPEC,9)=AW(ISPEC,9)+YORGW(ISPEC,1,1)+YORGW(ISPEC,2,1)
  $   +YORGW(ISPEC,3,1)+YCRGW(ISPEC,4,1)+YORGW(ISPEC,5,1)
  AW(ISPEC,10)=AW(ISPEC,10)+YORGW(ISPEC,1,2)+YORGW(ISPEC,2,2)
  $   +YORGW(ISPEC,3,2)+YORGW(ISPEC,4,2)+YORGW(ISPEC,5,2)
  AW(ISPEC,11)=AW(ISPEC,11)+YREDMW(ISPEC)
  AW(ISPEC,12)=AW(ISPEC,12)+YYELMW(ISPEC)
  AW(ISPEC,NSCU+11)=AW(ISPEC,1)+AW(ISPEC,2)
  $   +AW(ISPEC,3)+AW(ISPEC,4)+AW(ISPEC,5)
  $   +AW(ISPEC,6)+AW(ISPEC,7)+AW(ISPEC,8)
  $   +AW(ISPEC,9)+AW(ISPEC,10)+AW(ISPEC,11)
  $   +AW(ISPEC,12)
DO 140 IS=3,NSOU
  AW(ISPEC,IS+10)=AW(ISPEC,IS+10)+YCRGW(ISPEC,1,IS)+
  $   YORGW(ISPEC,2,IS)+YCRGW(ISPEC,3,IS)+YCRGW(ISPEC,4,IS)+
  $   YORGW(ISPEC,5,IS)
  AW(ISPEC,NSOU+11)=AW(ISPEC,NSOU+11) +
  $   AW(ISPEC,IS+10)
140  CONTINUE
  GO TO 150
145  AW(ISPEC,NSOU+7)=AW(ISPEC,1)+AW(ISPEC,2)+AW(ISPEC,3)+AW(ISPEC,4)+
  $   AW(ISPEC,5)+AW(ISPEC,6)
  DO 146 ISOU=1,NSCU
  AW(ISPEC,ISCU+6)=AW(ISPEC,ISOU+6)+YORGW(ISPEC,1,ISOU)+
  $   YORGW(ISPEC,2,ISOU)+YCRGW(ISPEC,3,ISOU)+YORGW(ISPEC,4,ISOU)+
  $   YORGW(ISPEC,5,ISOU)
  AW(ISPEC,NSCU+7)=AW(ISPEC,NSCU+7)+AW(ISPEC,ISOU+6)
146  CONTINUE
150  CONTINUE
C
C OUTPUT ACTIVITIES IN EACH SOURCE ORGAN TO AUXILIARY OUTPUT UNIT
IF (T .EQ. 0.CG1) WRITE(17,2001)NAMNUC(1),KASE,NAMMOD(MODE),TO
IF (NOBONE) GC TO 175
WRITE(17,2000) T,(NAMSCU(ISOU),ISOU=1,3)
DO 160 ISPEC=1,NSPEC
  WRITE(17,2010) NAMNUC(ISPEC),(AW(ISPEC,ISOU),ISOU=1,13)
160  CONTINUE

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WRITE(17,2015) (NAMSOU(ISCU),ISCU=4,NSOU2)
NS11=NSOU+11
DO 170 ISPEC=1,NSPEC
  WRITE(17,2010)NAMNUC(ISPEC),(AW(ISPEC,ISCU),ISOU=14,NS11),
  $ YEXCRW(ISPEC)
170 CONTINUE
GO TO 177
175 WRITE(17,2100) T,(NAMSOU(ISOU),ISOU=1,NSOU2)
NSOU7=NSOU+7
DO 176 ISPEC=1,NSPEC
  WRITE(17,2010)NAMNUC(ISPEC),(AW(ISPEC,ISOU),ISOU=1,NSOU7),
  $ YEXCRW(ISPEC)
176 CONTINUE
177 CONTINUE
C
C OUTPUT COMMITTED DOSE AT TIME T TO AUXILIARY OUTPUT UNIT
IF (T.EQ. 0.C01)WRITE(18,2020)NAMNUC(1),KASE,NAMMOD(MODE),TO
LAST=13
IF (NTRG.LT. 13) LAST=NTRG
WRITE(18,2030) T
WRITE(18,2040) (NAMTRG(ITRG),ITRG=1,LAST)
WRITE(18,2050) (DCSE(1,ITRG),ITRG=1,LAST)
IF (NLET.EQ. 2) WRITE(18,2060) (DOSE(2,ITRG),ITRG=1,LAST)
IF (LAST.EQ. NTRG) GO TO 135
WRITE(18,2040) (NAMTRG(ITRG),ITRG=14,NTRG)
WRITE(18,2050) (DCSE(1,ITRG),ITRG=14,NTRG)
IF (NLET.EQ. 2) WRITE(18,2060) (DOSE(2,ITRG),ITRG=14,NTRG)
135 CONTINUE
C
2001 FORMAT('1',A8,2X,'CASE',I2,' (',A8,')', BEGINNING ',
$ 'AGE=',I4/'',130('-''))
2000 FORMAT('0ACCUMULATED ACTIVITIES (MICROCURIE-DAYS) AT ',1PE10.3,
$ ' DAYS:'/'0 NUCLIDE',
$ T14,'LUNGS',T23,'ST CNT',T32,'SI CNT',T41,'ULI CNT',T50,
$ 'LLI CNT',T59,'BLOOD C SURF T SURF ',2(A8,1X),
$ 'RED MAR YEL MAR ',A8)
2100 FORMAT('0ACCUMULATED ACTIVITIES (MICROCURIE-DAYS) AT ',1PE10.3,
$ ' DAYS:'/'0 NUCLIDE',T14,'LUNGS',T23,'ST CNT',T32,'SI CNT',
$ T41,'ULI CNT',T50,'LLI CNT',T59,'BLOOD ',7(A8,1X))
2010 FORMAT(' ',A8,1P13E9.2)
2015 FORMAT('0',T14,13(A8,1X))
2020 FORMAT(' ',A8,2X,'CASE',I2,' (',A8,')', BEGINNING ',
$ 'AGE=',I4/'',130('-''))
2030 FORMAT('/' COMMITTED DOSE (RAD) AT ',1PE10.3,' DAYS:')
2040 FORMAT('/' ',T11,13(A8,1X))
2050 FORMAT(' LOW-LET ',1P13E9.2)
2060 FORMAT(' HIGH-LET ',1P13E9.2)
C
RETURN
END
C

```

SUBROUTINE OUTPLT

C
C
C TABULATE RESULTS OF DOSE RATE CALCULATIONS.
C

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INTEGER OUT,SCL,TC
REAL LMGIA,LMABA,NAMCLS(4),CLASS(12)
DOUBLE PRECISION NAMLET(2),NAMNUC,NAMSOU,NAMTRG,NAME,BLANK,
$ NMSACT(12),NAMTCT
COMMON /NUMBR/ NSPEC,NSOU,NTRG,NLET
COMMON /NAMES/ NAMNUC(12),NAMSOU(10),NAMTRG(24)
COMMON /GI/ LMGIA(4,7),LMABA(12,4,7),GIFRAC(12,4,7)
COMMON /AGE/ MPHYS(7),MAGE(7),NAGEP,NAGEM
COMMON /STEPS/ NTIMES
COMMON /NOUGHT/ YSO,YNP0,Y1TB0,YP0,YBLUD0,YCRG0(10)
COMMON /CASE/ KASE
COMMON /SOLUB/ MOCE,SOL(12)
COMMON /TIME/ T0,TEND
COMMON /ACTVTY/ ACT(12,150,20),AWIGL(12,16),AW(12,20)
COMMON /DOSES/ DOSRAT(2,150,24),DOSTIM(150),DCSE(2,24)
DATA BLANK/8H /
DATA NAMLET/8HLOW-LET ,8HHIGH-LET/
DATA NAMCLS/4H D ,4H W ,4H Y ,4H * /
DATA NMSACT/8HLUNGS ,8HST CNT ,8HSI CNT ,8HULI CNT,
$ 8HLLI CNT ,8HBLOOD ,8HCOR SUR ,8HTRA SUR ,8HCOR VOL ,
$ 8HTRA VOL ,8HRED MAR ,8HYEL MAR /
DATA NAMTOT/8HTOTAL /
DATA OUT/6/

```

```

C      WRITE(OUT,200C)
C
C PRINT INITIAL CONCITIONS FOR THIS CASE..
WRITE(OUT,201C) YEO,YNPO,Y1TBO,YPO,YBLUDO,(NAMSOU(I),YORGO(I),
$ I=1,NSOU)
WRITE(OUT,207C) TC
DO 10 ISPEC=1,NSPEC
  ICLS=SOL(ISPEC)
  CLASS(ISPEC)=NAMCLS(ICLS)
10 CONTINUE
  IF (MODE .EQ. 1) WRITE(OUT,2080)(NAMNLC(ISPEC),CLASS(ISPEC),
$ ISPEC=1,NSPEC)
C
C PRINT TABLE OF GI ABSORPTION FRACTIONS..
WRITE(OUT,209C)
DO 30 ISPEC=1,NSPEC
  DO 20 IAGE=1,NAGEM
    NAME=NAMNLC(ISPEC)
    IF (IAGE .NE. 1) NAME=BLANK
    WRITE(OUT,210C) NAME,MAGE(IAGE),(CIFRAC(ISPEC,IAGE,IAGE),
$ ISEG=1,4)
  20 CONTINUE
  30 CONTINUE
C
C PRINT MATRIX OF DCSE RATES..
DO 40 ILET=1,NLET
  WRITE(OUT,2110) NAMLET(ILET)
  IFIRST=1
  LAST=NTIMES
  IF (NTIMES .GT. 11) LAST=11
  CALL DOSTAB(ILET,IFIRST,LAST)
  IF (LAST .EQ. NTIMES) GC TO 40
  IFIRST=12
  LAST=NTIMES
  IF (NTIMES .GT. 22) LAST=22
  CALL DOSTAB(ILET,IFIRST,LAST)
  IF (LAST .EQ. NTIMES) GC TO 40
  IFIRST=23
  LAST=NTIMES
  IF (NTIMES .GT. 33) LAST=33
  CALL DOSTAB(ILET,IFIRST,LAST)
  IF (LAST .EQ. NTIMES) GC TO 40
  IFIRST=34
  LAST=NTIMES
  IF (NTIMES .GT. 44) LAST=44
  CALL DOSTAB(ILET,IFIRST,LAST)
  IF (LAST .EQ. NTIMES) GC TO 40
  IFIRST=45
  LAST=NTIMES
  IF (NTIMES .GT. 55) LAST=55
  CALL DOSTAB(ILET,IFIRST,LAST)
  IF (LAST .EQ. NTIMES) GC TO 40
  IFIRST=56
  LAST=NTIMES
  IF (NTIMES .GT. 66) LAST=66
  CALL DOSTAB(ILET,IFIRST,LAST)
  IF (LAST .EQ. NTIMES) GC TO 40
  IFIRST=67
  LAST=NTIMES
  IF (NTIMES .GT. 77) LAST=77
  CALL DOSTAB(ILET,IFIRST,LAST)
  IF (LAST .EQ. NTIMES) GC TO 40
  IFIRST=78
  LAST=NTIMES
  IF (NTIMES .GT. 88) LAST=88
  CALL DOSTAB(ILET,IFIRST,LAST)
  IF (LAST .EQ. NTIMES) GC TO 40
  IFIRST=89
  LAST=NTIMES
  IF (NTIMES .GT. 99) LAST=99
  CALL DOSTAB(ILET,IFIRST,LAST)
  IF (LAST .EQ. NTIMES) GC TO 40
  IFIRST=100
  LAST=NTIMES
  IF (NTIMES .GT. 110) LAST=110
  CALL DOSTAB(ILET,IFIRST,LAST)
  IF (LAST .EQ. NTIMES) GC TO 40
  IFIRST=111
  LAST=NTIMES
  IF (NTIMES .GT. 121) LAST=121

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CALL DOSTAB(ILET,IFIRST,LAST)
IF (LAST .EQ. NTIMES) GC TO 40
IFIRST=122
LAST=NTIMES
IF (NTIMES .GT. 132) LAST=132
CALL DOSTAB(ILET,IFIRST,LAST)
IF (LAST .EQ. NTIMES) GC TO 40
IFIRST=133
LAST=NTIMES
IF (NTIMES .GT. 143) LAST=143
CALL DOSTAB(ILET,IFIRST,LAST)
IF (LAST .EQ. NTIMES) GC TO 40
IFIRST=144
LAST=NTIMES
IF (NTIMES .GT. 154) LAST=154
CALL DOSTAB(ILET,IFIRST,LAST)
40 CONTINUE
C
C PRINT TABLE OF COMMITTED DOSE TO ALL TARGET ORGANS..
WRITE(OUT,2120) DOSTIM(NTIMES)
DO 50 ITRG=1,NTRG
WRITE(OUT,2130) NAMTRG(ITRG),(DOSE(ILET,ITRG),ILET=1,NLET)
50 CONTINUE
C
C OUTPUT DOSE RATES TO DISK FILE FOR LATER REFERENCE..
WRITE(27,3000)NAMNUC(1),MCDE,SOL(1),GIFRAC(1,2,7),T0,NTRG,NLET,
$ NTIMES,(DOSTIM(ITIM),ITIM=1,NTIMES)
DO 70 ITRG=1,NTRG
DO 60 ILET=1,NLET
WRITE(27,3010)NAMTRG(ITRG),ILET,(DCSRAT(ILET,ITIME,ITRG),
$ ITIME=1,NTIMES)
60 CONTINUE
70 CONTINUE
C
C OUTPUT ACTIVITIES TO DISK FILE FOR LATER REFERENCE..
NS11=NSOU+11
WRITE(25,3000)NAMNUC(1),MCDE,SOL(1),GIFRAC(1,2,7),T0,NS11,NSPEC,
$ NTIMES,(DOSTIM(ITIM),ITIM=1,NTIMES)
DO 100 ISPEC=1,NSPEC
DO 80 ISOU=1,12
WRITE(25,3020) NMSACT(ISCU),(ACT(ISPEC,ITIME,ISOU),ITIME=1,
$ NTIMES)
80 CONTINUE
DO 90 ISOU=3,NSOU
WRITE(25,3020) NAMSOU(ISCU),(ACT(ISPEC,ITIME,ISOU+10),ITIME=1,
$ NTIMES)
90 CONTINUE
WRITE(25,3020) NAMTOT,(ACT(ISPEC,ITIME,NSOU+11),ITIME=1,NTIMES)
100 CONTINUE
C
2000 FORMAT(//'0EXPOSURE CASE: '// ,14(' - '))
2010 FORMAT('0INITIAL ACTIVITY IN BODY ORGANS (UCI):',
$ T50,'STOMACH',T60,1PG9.2/' ,T50,'N-P',T60,1PG9.2/
$ ' ,T50,'T-B',T60,1PG9.2/' ,T50,'PULMONARY',T60,1PG9.2/
$ ' ,T50,'BLCOD',T60,1PG9.2/(' ,T50,A8,T60,1PG9.2))
2070 FORMAT(' BEGINNING AGE = ',I4,' DAYS')
2080 FORMAT('/'0NUCLIDE',T15,'SOLUBILITY CLASS'//(' ,A8,T22,A4))
2090 FORMAT('0',T34,'GI UPTAKE FRACTIONS'/' ,T26,37(' - '))/' NUCLIDE',
$ T18,'AGE',T26,'STOMACH',T38,'S INT',T46,'U L INT',T56,'L L INT')
2100 FORMAT(' ,A8,T17,I4,T25,1P4G10.2)
2110 FORMAT(//'0',A8,' DOSE RATES (RAD/DAY) : '// ,30(' - '))
2120 FORMAT(///'0CCMITTED DGSE AT ',1PG9.2,' DAYS: '// ,33(' - ')/
$ '0TARGET',T14,'LOW LET',T26,'HIGH LET')
2130 FORMAT(' ,A8,T13,1PE9.2,T25,1PE9.2)
3000 FORMAT(A8,2I4,4X,E10.3,4I4/(1P8E10.4))
3010 FORMAT(A8,I4,EX,1F6E10.4/(1P8E10.4))
3020 FORMAT(A8,2X,1P7E10.4/(1P8E10.4))
3025 FORMAT(8E10.4)
RETURN
END

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CONVOL

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CONVOL..
CONVOLUTION ROUTINE FOR COMPUTING DOSE RATES AT ANY TIME FOR AN
INDIVIDUAL OF A SPECIFIED BEGINNING AGE, BASED UPON SPECIFIED INTAKE
RATES AND AGE-DEPENDENT DOSE RATE ESTIMATES FROM AGEDDS.
-----
      REAL GRID(141),S(141),BAGE(7),INTIME(20),
      ENRATE(20),INTAKE(141),DOSRAT(2,7,141,21),DU(2,21,141),
      SUM(2,21),SAGE(20),SCALE(20),SCALE(141),AVGRAT(141),RAFIN(10),
      TIMIN(10),NAMCLS(4)
      INTEGER SOL
      DOUBLE PRECISION NAMNUC,NAMTRG(21),NAMMOD(3)
      DATA NAMMOD/RHHALATION,RHGESTION,RHJECTION /
      DATA NAMCLS/4H D ,4H W ,4H Y ,4H * /
C READ DOSE RATES FROM AGEDDS DISK FILE..
      TYPE 2040
      ACCEPT 3050,INDAT
      CALL IFILE(27,INDAT)
      DO 30 IRAGE=1,7
      READ(27,3000)NAMNUC,MODE,SOL,GIFRAC,NBAGE,NTRG,NLET,
      NTIMES,(GRID(IT),IT=1,NTIMES)
      BAGE(IRAGE)=FLOAT(NBAGE)
      DO 20 ITRG=1,NTRG
      DO 10 ILET=1,NLET
      READ(27,3100)NAMTRG(ITRG),IDUM,(DOSRAT(ILET,IRAGE,ITIME,
      ITRG),ITIME=1,NTIMES)
      IF (ILET.NE.IDUM) TYPE 2600
      10 CONTINUE
      20 CONTINUE
      30 CONTINUE
C READ INTAKE RATES( 0.0 AND 31026. POINTS MUST BE INCLUDED)..
      TYPE 2201
      ACCEPT 3200,NRATES
      TYPE 2301,NRATES
      ACCEPT 3300,(INTIME(IT),ENRATE(IT),IT=1,NRATES)
C READ SCALE FACTORS (0.0 AND 31026. POINTS MUST BE INCLUDED)..
      TYPE 2202
      ACCEPT 3200,NSCALE
      TYPE 2303,NSCALE
      ACCEPT 3300,(SAGE(ISCALE),SCALE(ISCALE),ISCALE=1,NSCALE)
C READ AGE AT BEGINNING OF EXPOSURE AND ENDING TIME T..
      40 TYPE 2304
      ACCEPT 3300,B,T
C DEFINE GRID POINTS BETWEEN B AND B+T.
      KOUNT=0
      DO 50 J=1,NTIMES
      S(J)=B+T-GRID(J)
      KOUNT=KOUNT+1
      IF (GRID(J).GE.T) GO TO 60
      50 CONTINUE
      60 CONTINUE
C COMPUTE SCALE FACTOR FOR EACH GRID POINT S(I)..
      DO 90 K=1,KOUNT
      DO 70 L=2,NSCALE
      IF (SAGE(L).GT.S(K)) GO TO 80
      70 CONTINUE
      80 CONTINUE
      X1=SAGE(L-1)
      X2=SAGE(L)
      Y1=SCALE(L-1)
      Y2=SCALE(L)
      SCALE(K)=((X2-S(K))*Y1+(S(K)-X1)*Y2)/(X2-X1)
      90 CONTINUE

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C COMPUTE INTAKE (ENTAKE(K)) AT EACH GRID POINT S(K)..
DO 120 K=1,KOUNT
  DO 100 L=2,NRATES
    IF (INTIME(L)+AINT(B) .GT. S(K)) GO TO 110
  100 CONTINUE
  110 CONTINUE
    X1=INTIME(L-1)+AINT(B)
    X2=INTIME(L)+AINT(B)
    Y1=ENRATE(L-1)
    Y2=ENRATE(L)
    ENTAKE(K)=((X2-S(K))*Y1+(S(K)-X1)*Y2)/(X2-X1)
  120 CONTINUE
C COMPUTE AVERAGE INTAKE RATE BETWEEN S(K) AND S(K+1)..
DO 125 K=2,KOUNT
  AVGRAT(K)=0.0
  IKOUNT=1
  RATIN(IKOUNT)=ENTAKE(K)
  TIMIN(IKOUNT)=S(K)
  DO 124 L=1,NRATES
    IF (INTIME(L)+B .LE. S(K) .OR. INTIME(L)+B .GE. S(K-1))
  $   GO TO 124
    IKOUNT=IKOUNT+1
    RATIN(IKOUNT)=ENRATE(L)
    TIMIN(IKOUNT)=INTIME(L)+B
    AVGRAT(K)=AVGRAT(K) + (TIMIN(IKOUNT)-TIMIN(IKOUNT-1))*
  $   (RATIN(IKOUNT-1)+RATIN(IKOUNT))/2.0
  124 CONTINUE
  $ AVGRAT(K)=(AVGRAT(K) + (S(K-1)-TIMIN(IKOUNT))*(ENTAKE(K-1)+
  $   RATIN(IKOUNT))/2.0) * (SKALE(K)+SKALE(K-1))/2.0 /
  $   (S(K-1)-S(K))
  125 CONTINUE
C OUTPUT INTERMEDIATE ARRAYS.
TYPE 2400,NAMNOC,NAMMOD(MODE),GIFRAC
IF (MODE .EQ. 1) TYPE 2450,NAMCLS(SOL)
TYPE 2700,(INTIME(IT),ENRATE(IT),IT=1,NRATES)
TYPE 2200,(SAGE(ISCALE),SCALE(ISCALE),ISCALE=1,NSCALE)
C INITIALIZE SUM(ILET,ITRG) TO ZERO.
DO 140 ILET=1,NLET
  DO 130 ITRG=1,NTRG
    SUM(ILET,ITRG)=0.0
  130 CONTINUE
  140 CONTINUE
C COMPUTE DOSE RATES AT TIME T, SUM(ILET,ITRG)..
DO 230 J=1,KOUNT
C FIND CONSECUTIVE BEGINNING AGES BRACKETING S(J) FOR EACH J.
DO 150 IAGE=2,7
  IF (BAGE(IAGE) .GT. S(J)) GO TO 160
  150 CONTINUE
  BAGE1=BAGE(IAGE)
  BAGE2=BAGE(IAGE)
  IBAGE1=7
  IBAGE2=7
  GO TO 170
  160 BAGE1=BAGE(IAGE-1)
  BAGE2=BAGE(IAGE)
  IBAGE1=IAGE-1
  IBAGE2=IAGE
  170 CONTINUE
  DO 220 ILET=1,NLET
    DO 210 ITRG=1,NTRG
      IF (BAGE1 .EQ. 7300,) GO TO 180
      DU(ILET,ITRG,J)=((S(J)-BAGE1)*
  $   DOSRAT(ILET,IBAGE2,J,ITRG)+(BAGE2-S(J))*
  $   DOSRAT(ILET,IBAGE1,J,ITRG))/(BAGE2-BAGE1)
      GO TO 190
      180 DU(ILET,ITRG,J)=DOSRAT(ILET,7,J,ITRG)
      190 CONTINUE
      IF (J .EQ. 1) GO TO 210
      SUM(ILET,ITRG)=SUM(ILET,ITRG)
  $   +(DU(ILET,ITRG,J)*AVGRAT(J))*(S(J-1)-S(J))
    210 CONTINUE
  220 CONTINUE
  230 CONTINUE

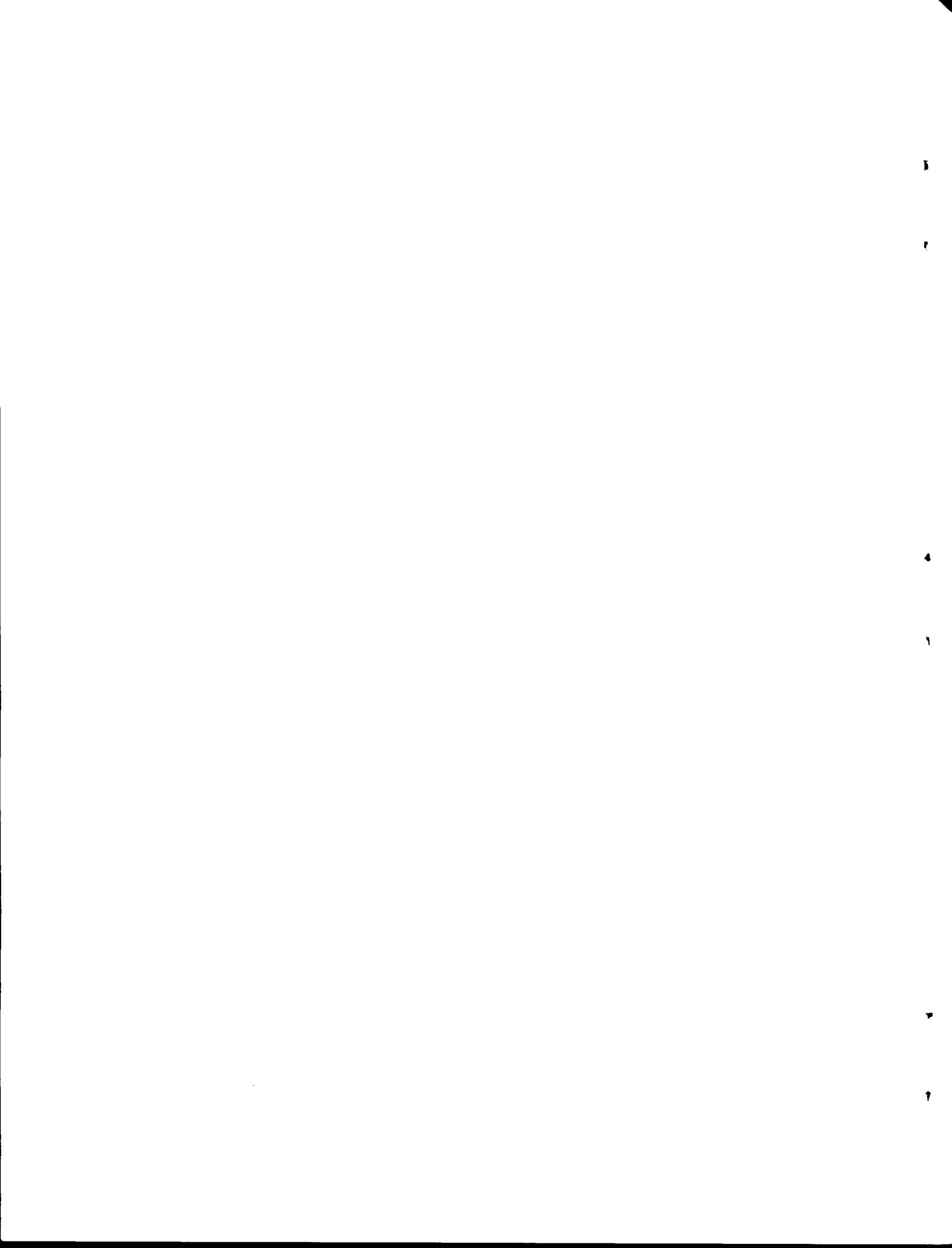
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      IF (NLET, EQ, 2)
      $ TYPE 2500, I, B, (NAMTRG(ITRG), (SUM(ILET, ITRG), ILET=1, NLET),
      $ ITRG=1, NTRG)
      IF (NLET, EQ, 1)
      $ TYPE 2501, I, B, (NAMTRG(ITRG), SUM(1, ITRG), ITRG=1, NTRG)
      GO TO 40
99 STOP

C. FORMATS.
2040 FORMAT(' CONVOL: CONVOLUTION OF AGEDOS DOSE ESTIMATES'//',',50('-')/
$ // ' ENTER NAME OF INPUT FILE CONTAINING DOSE RATES (A5)')//
2200 FORMAT(/'0',T4,'AGE (DAYS)',T25,'SCALE FACTOR'/'(',F10.3,T20,
$ F10.3))
2201 FORMAT(/' ENTER NUMBER OF STEPS FOR INTAKE RATE FUNCTION ',
$ '(INTEGER)'// ' TO TERMINATE A STEP INTAKE, INSERT AN INTAKE ',
$ 'RATE OF ZERO 0.001 DAYS'// ' AFTER INTAKE, IS TO CEASE, ',
$ ' FOLLOWED BY AN INTAKE RATE OF ZERO AT 31026 DAYS.'//
$ '(POINTS 0 AND 31026 MUST BE INCLUDED.)')//
2301 FORMAT(/' ENTER THE ',T2,' PAIRS OF ',
$ 'LEFT ENDPOINTS AND INTAKE RATES'// '(2F, ONE PAIR PER LINE)')//
2202 FORMAT(/' ENTER NUMBER OF STEPS IN SCALE FUNCTION (INTEGER)'//
$ ' TO AVOID SCALING, INSERT SCALE FACTORS OF 1.0 AT 0.0 AND AT ',
$ ' 31026 DAYS.'// '(POINTS 0 AND 31026 MUST BE INCLUDED.)')//
2303 FORMAT(/' ENTER THE ',T2,' PAIRS OF LEFT ENDPOINTS ',
$ 'AND SCALE FACTORS'// '(2F, ONE PAIR PER LINE)')//
2304 FORMAT(/' ENTER BEGINNING AGE B AND TIME OF INTEGRATION T (2F)'//)
2400 FORMAT(/'////' RADIONUCLIDE :',A8/' ',23('-')//
$ ' EXPOSURE MODE : IN',A8//' GI UPTAKE FRACTION = ',1PE9.2//)
2450 FORMAT(' TGLW CLEARANCE CLASS =',A4//)
2500 FORMAT(/' DOSES COMPUTED AT ',F7.0,' DAYS AFTER BEGINNING AGE ('
$ F5.0,' DAYS):'//' TARGET ORGAN',T15,' LOW LET',T30,' HIGH LET'//
$ (' ',A8,T15,1PE9.2,T30,1PE9.2))
2501 FORMAT(/' DOSES COMPUTED AT ',F7.0,' DAYS AFTER BEGINNING AGE ('
$ F5.0,' DAYS):'//' TARGET ORGAN',T15,' LOW LET'//
$ (' ',A8,T15,1PE9.2))
2600 FORMAT(' ERROR IN DOSE DATA FILE: ILET DOES NOT AGREE'//)
2700 FORMAT(' INTAKE TIME (DAYS) INTAKE RATE (PER DAY)'//
$ (' ',E10.3,T24,E10.3))
3000 FORMAT(A8,T14,4X,E10.0,4T4/(8E10.0))
3050 FORMAT(A5)
3100 FORMAT(A8,T4,8X,6E10.0/(8E10.0))
3200 FORMAT(I)
3300 FORMAT(2F)
      END

```



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