TR-1797-3

USER'S MANUAL FOR BIOSPHERE AND DOSE SIMULATION PROGRAM

(BIODOSE)

4 January 1980

Prepared for:

THE UNIVERSITY OF CALIFORNIA
Lawrence Livermore Laboratory
Livermore, California

Under Subcontract No. 4250209

Prepared by:

John J. Duffy
Gary P. Bogar

Approved by:

John Bartlett
Gary W. Good

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

THE ANALYTIC SCIENCES CORPORATION
Six Jacob Way
Reading, Massachusetts 01867

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

CAUTION OF THIS DOCUMENT IS UNLIMITED

PREFACE

This user's manual documents the BICaccu-
mulation and DOSE prediction (BIODOSE) computer
program developed for Lawrence Livermore Laboratory.
The authors wish to acknowledge the contributions to
the development of the BIODOSE model and program of
Charles Koplik, Stephen Hodgkin, Gary Good, and
Kathryn Baribeau of TASC.

TABLE OF CONTENTS

	<u>Page No.</u>
PREFACE	ii
List of Figures	v
List of Tables	v
 1. INTRODUCTION	 1-1
1.1 Purpose	1-1
1.2 Model Description	1-1
1.2.1 Radionuclide Concentrations in Compartments	1-4
1.2.2 Potential Hazard Calculations	1-13
1.2.3 Model Assumptions	1-26
 2. PROGRAM DESCRIPTION	 2-1
2.1 Introduction	2-1
2.2 Main Program BIODOSE	2-1
2.3 Subroutine INPUT - Data Input Controller	2-3
2.3.1 Subroutine INVRD - Nuclide Inventory File Input	 2-4
2.3.2 Subroutine INIT - Non-Standard Dose Factor Initialization	 2-4
2.3.3 Subroutine NUCOUT - Nuclide Data Input Summary	 2-5
2.4 Subroutine COMPUT - Computation Controller	2-5
2.4.1 Subroutine USERAT - Compartment Usage Rate Computation	 2-6
2.4.2 Subroutine CALC - Potential Hazard Rate Computation	 2-6
2.4.3 Subroutine CONCNT - Quasi-Steady-State Computation	 2-6
2.4.4 Subroutine EQUAL - Steady-State Computation	 2-7
2.4.5 Subroutine SETUP - Compartment Flow Rates Computation	 2-7
2.4.6 Subroutine TIMVAR - Time-Varying Computation	 2-7
2.4.7 Subroutine EIGRF - Eigenvalues and Eigenvector Computation	 2-8
2.4.8 Subroutine DOSE - Potential Hazards Summation	 2-9
2.4.9 Subroutine PRNT - Potential Hazards Report Printer	 2-10

TABLE OF CONTENTS (Continued)

	<u>Page No.</u>
2.5 Utility Subroutines	2-10
2.6 Block Data BLKGEN - General Parameters Initialization	2-11
2.7 Block Data BLKINV - Nuclide Inventory Initialization	2-11
2.8 Block Data BLKNUC - Nuclide Parameters Initialization	2-11
3. PROGRAM USAGE	3-1
3.1 Introduction	3-1
3.2 Program Inputs	3-1
3.3 Program Outputs	3-12
APPENDIX A PROGRAM INSTALLATION	A-1
APPENDIX B SUBPROGRAM CROSS-REFERENCE AND COMMON BLOCK CROSS-REFERENCE	B-1
REFERENCES	R-1

LIST OF FIGURES

<u>Figure No.</u>		<u>Page No.</u>
1.2-1	BIODOSE Water and Food Pathways Model: River, Estuary and Ocean System	1-2
2.2-1	BIODOSE Block Diagram	2-2

LIST OF TABLES

<u>Table No.</u>		
1.2-1	Dose Categories and Subcategories	1-15
1.2-2	Organ Code List	1-17
1.2-3	Compartment Codes	1-18
2.3-1	Namelist and Labeled Common Blocks	2-3
3.2-1	BIODOSE Input Data Summary, System Parameters (Namelist/SYSLST/)	3-2
3.2-2	BIODOSE Input Data Summary, Animal Parameters (Namelist/ANLST/)	3-3
3.2-3	BIODOSE Input Data Summary, Soil Parameters (Namelist/SOILST/)	3-4
3.2-4	BIODOSE Input Data Summary, Usage Parameter (Namelist/ULST/)	3-5
3.2-5	BIODOSE Input Data Summary, Vegetable Parameters (Namelist/VEGLST/)	3-8
3.2-6	BIODOSE Input Data Summary, Water Parameters (Namelist/WLST/)	3-9
3.2-7	Nuclide Parameters (Namelist/NUCLST/)	3-10
3.2-8	Inventory Input (Namelist/INVLST/)	3-10

1. INTRODUCTION

1.1 PURPOSE

This user's manual describes the BIOsphere Transport and DOSE program (BIODOSE) prepared for, and delivered to, Lawrence Livermore Laboratory (LLL) by The Analytic Sciences Corporation (TASC). BIODOSE simulates the transport of radionuclides in surface water systems and the resulting concentration of nuclides in the food chain. It includes the prediction of human dosage risks for individuals and for populations resulting from release of radionuclides into surface water or well water. The BIODOSE program was designed for easy use, including standard defaults and a flexible input scheme.

1.2 MODEL DESCRIPTION

The BIODOSE model predicts doses to humans from releases of radionuclides to the surface environment. It simulates soil and water bodies as perfectly mixed compartments with many dose pathways to man including aquatic food, crops, animal products, drinking water and ground exposure. Figure 1.2-1 schematically depicts the model. Air pathways were not considered. The model is described in detail in Appendix G of Ref. 1. Key model assumptions and equations solved in the model are given here in a form consistent with the computations as performed in the computer program.

The time frame of the model simulations is currently set at five million years. The basic conditions and parameters

Figure 1.2-1 BIODOSE Water and Food Pathways Model:
River, Estuary and Ocean System

(such as physical flow rates between compartments and food usage rates) are assumed to be unchanged during this time period. Lack of information about future conditions makes this assumption reasonable. However, different hypothesized scenarios can be modeled and tested with the program.

Conceptually, the model solves two basic types of equations: one describing the concentration of radionuclides in surface water compartments resulting from releases into them, and the other relating human organ doses to these compartment concentrations via various pathways. These equations are:

$$V \frac{dC_r}{dt} = -\lambda_r V C_r + A_r C_r + Q_r + \sum_s \lambda_s V C_s \quad (1.2-1)$$

$$D_{r\ell u} = C_{r\ell} U_\ell DF_{r\ell u} \quad (1.2-2)$$

where

C_r is a vector of dimension n whose components are the concentrations of nuclide r in the n compartments (Ci/m^3)

λ_r is the radioactive decay constant for nuclide r (yr^{-1}). Note that λ_s does not enter into the equation for nuclide r because concentrations are given in curies

A_r is the matrix of volumetric flow rates with the off-diagonal elements a_{ij} representing transfer from compartment j to compartment i and the diagonal elements a_{ii} being the flow rates out of compartment i (m^3/yr)

Q_r is the vector of inputs to the compartments (Ci/yr)

V is a diagonal matrix whose elements are the compartment volumes (m^3)

s is a subscript labeling those nuclides which decay into nuclide r

$D_{r\ell u}$ is the dose rate to organ u from nuclide r from compartment ℓ (rem)

$C_{r\ell}$ is the concentration of nuclide r in compartment ℓ (Ci/m^3)

U_ℓ is the usage rate associated with compartment ℓ (m^3)

$DF_{r\ell u}$ is the radiation dose factor for nuclide r in compartment ℓ for organ u (rem per Ci)

A normalized input of radionuclides is used in the model: the waste resulting from one megawatt-electric-year of power production per year. Thus, the model predictions are expressed as potential hazards. To obtain dose predictions, account must be taken of the predicted inputs to the water system. The manner in which the inputs can be taken into account is discussed in Section 1.2.1, along with the compartment concentration calculations. The potential hazard calculations are discussed in Section 1.2.2.

1.2.1 Radionuclide Concentrations in Compartments

Equation 1.2-1 can be simplified by expressing the concentrations as ratios to the total inventory of that nuclide, viz.,

$$\underline{c}_r = \underline{C}_r / I_r \quad (1.2-3)$$

where I_r is the total amount (C_i) of nuclide r from the waste in existence anywhere at a given time. The differential equation for I_r can be written as

$$\frac{dI_r}{dt} = -\lambda_r I_r + \sum_s \lambda_r I_s \quad (1.2-4)$$

Combining the above equations yields

$$V \frac{dc_r}{dt} = A_r \underline{c}_r + \frac{Q_r}{I_r} + \sum_s \lambda_r \frac{I_s V}{I_r} (\underline{c}_s - \underline{c}_r) \quad (1.2-5)$$

It is assumed that $\underline{c}_r(0) = \underline{c}_s(0) = 0$; that is, nuclide r and its parents are not present in the compartments at time zero. By the uniqueness theorem for differential equations, $\underline{c}_r = \underline{c}_s$ if the compartment flow matrix is the same for both nuclide r

and nuclide s . Therefore if $A_r = A_s$ for any s (which is assumed in all the cases which follow),

$$\frac{dc_r}{dt} = V^{-1} A_r c_r + V^{-1} q_r \quad (1.2-6)$$

where $q_r = \frac{Q_r}{I_r}$. The compartment equations are thus simplified by expressing the radionuclide concentrations as proportions of total inventory and thereby avoiding analysis of decay chains.

The user should be aware that the compartment flow matrices (A_r) are not identical for every nuclide in a decay chain in the default values of A_r in BIODOSE. The distribution coefficients for the sediment compartments, the retardation factors for the topsoil, and the crop removal rates are included in the compartment flow matrix A_r (see Eq. 1.2-8 below) and vary for each nuclide in the default version of BIODOSE. The effect of this deviation from the underlying assumption of the compartment concentration model is believed to be relatively minor with the default BIODOSE parameters. However, the user should beware of changing distribution coefficients or retardation factors of nuclides in the same decay chain to widely varying values without further analysis of the effects on potential hazard predictions.

The BIODOSE model has parameter values set to simulate a large river in the Northwestern United States. However, the parameter values can be relatively easily changed for other water body systems (Ref. 1). Seven compartments are included: river water, river sediment, topsoil, estuary water, estuary sediment, plume water, and ocean water. The radionuclide concentration vector for the Northwestern river is:

$$\underline{c}_r = [c_{rw} \ c_{rt} \ c_{rs} \ c_{re} \ c_{rse} \ c_{rp} \ c_{ro}]^T \quad (1.2-7)$$

and T denotes transpose and the subscripts w, t, s, e, se, p, and o represent river water, topsoil, river sediment, estuary water, estuary sediment, plume water and ocean water, respectively. The differential equations used in the model to describe the radionuclide concentrations in each of the compartments are the following:

$$\begin{aligned} V_w \frac{d c_{rw}}{dt} = & - \left[F + I + \frac{DA_s}{d} + K_{rs} A_s v_w \right] c_{rw} + q_r \\ & + \left(\frac{I+R-E}{B_{rt} \theta} \right) c_{rt} + \left(\frac{DA_s}{K_{rs} d} \right) c_{rs} \end{aligned}$$

$$\begin{aligned} V_s \frac{d c_{rs}}{dt} = & - \left[\frac{DA_s}{d K_{rs}} + A_s v_w + I R_s \right] c_{rs} + (S_t A_t) c_{rt} \\ & + \left[\frac{DA_s}{d} + K_{rs} A_s v_w \right] c_{rw} \end{aligned}$$

$$\begin{aligned} V_t \frac{d c_{rt}}{dt} = & - \left[\frac{I+R-E}{B_{rt} \theta} + M_r + S_t A_t \right] c_{rt} + I c_{rw} \\ & + I R_s c_{rs} \end{aligned}$$

$$\begin{aligned} V_e \frac{d c_{re}}{dt} = & - \left[\frac{V_e}{T_e} + \frac{DA_e}{d} + K_{rse} A_e v_e \right] c_{re} + F c_{rw} \\ & + \left(\frac{DA_e}{K_{rse} d} \right) c_{rse} \end{aligned}$$

$$V_{se} \frac{d c_{rse}}{dt} = - \left[\frac{DA_e}{K_{rse} d} + A_e v_e \right] c_{rse} + \left[\frac{DA_e}{d} + K_{rse} A_e v_e \right] c_{re}$$

$$V_p \frac{d c_{rp}}{dt} = - (10F) c_{rp} + \frac{V_e}{T_e} c_{re}$$

$$V_o \frac{d c_{ro}}{dt} = - \left[\left(1 - \frac{A_p}{A_o} \right) \frac{V_o}{T_o} \right] c_{ro} + \left[10 F - \frac{V_p}{T_o} \right] c_{rp}$$

If these equations are put in the matrix form of Eq. 1.2-6, the transfer coefficient matrix, $V^{-1}A_r$, becomes:

$$V^{-1}A_r = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 & 0 & 0 & 0 \\ I/V_t & a_{22} & a_{23} & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 & 0 & 0 \\ F/V_e & 0 & 0 & a_{44} & a_{45} & 0 & 0 \\ 0 & 0 & 0 & a_{54} & a_{55} & 0 & 0 \\ 0 & 0 & 0 & a_{64} & 0 & a_{66} & 0 \\ 0 & 0 & 0 & 0 & 0 & a_{76} & a_{77} \end{bmatrix} \quad (1.2-8)$$

where

$$a_{11} = - \left[F + I + \frac{DA_s}{d} + K_{rs} A_s v_w \right] / V_w$$

$$a_{12} = (I + R - E) / (\theta B_{rt} V_w)$$

$$a_{13} = \frac{DA_s}{d K_{rs} V_w}$$

$$a_{22} = - [(1 + R - E)/B_{rt} \theta + M_r + A_t S_t]/V_t$$

$$a_{23} = IR_s/V_t$$

$$a_{31} = \left[\frac{DA_s}{d} + K_{rs} A_s v_w \right] / V_s$$

$$a_{32} = A_t S_t / V_s$$

$$a_{33} = - \left[\frac{DA_s}{dK_{rs}} + A_s v_w + IR_s \right] / V_s$$

$$a_{44} = - \left[\frac{V_e}{T_e} + \frac{DA_e}{d} + K_{rse} A_e v_e \right] / V_e$$

$$a_{45} = \frac{DA_e}{dK_{rse} V_e}$$

$$a_{54} = \left[\frac{DA_e}{d} + K_{rse} A_e v_e \right] / V_{se}$$

$$a_{55} = - \left[\frac{DA_e}{K_{rse} d} + A_e v_e \right] / V_{se}$$

$$a_{64} = V_e / (T_e V_p)$$

$$a_{66} = - (10F) / V_p$$

$$a_{76} = [10F - V_p / T_o] / V_o$$

$$a_{77} = - [(1 - A_p / A_o) / T_o]$$

and

$$V^{-1}q_r = [q_r/V_w \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]^T$$

where

V_ℓ is the effective volume of compartment ℓ
[VOL(ℓ)]

A_ℓ is the surface area of compartment ℓ

$K_{r\ell}$ is the distribution coefficient of compartment ℓ , which is the ratio of the volumetric concentration in the dry sediment to that in the water [FKS,FKE]

T_ℓ is the flushing time of compartment ℓ
[TE,TO]

q_r is the input of nuclide r from the aquifer connecting the repository to the water body
[VIN(r)]

v_ℓ is the net rate of sedimentation from compartment ℓ [SRATE,SERATE]

F is the net outflow rate of the river (or lake) [FLOW]

I is the average yearly rate at which water is withdrawn from the river (or lake) for irrigation [WRATE]

D is the average diffusion coefficient [DC]

d is the average diffusion depth [DD]

R is the average yearly rainfall on the topsoil [RA]

E is the average yearly evapotranspiration from the topsoil [ET]

M_r is the effective average yearly removal rate of nuclide r from the topsoil that is taken up by plants [REMOVL(r)]

S_t is the erosion rate of topsoil [ERATE]

θ is the volumetric water content of topsoil
[THETA]

B_{rt} is the retardation factor for topsoil,
i.e., $(1 + K_{rt}/\theta)$, where the parameters
are defined above [1/FKT]

The names in brackets are the labels used in the program code
if different from the algebraic symbol used here.

Three different methods of solution of the set of
compartment equations (1.2-6) are available in the simulation
model: quasi-steady-state with the topsoil radionuclide build-
up over a relatively short time period, steady-state, and time-
varying for all the compartments with continuous topsoil nu-
clide buildup. The three solution options are described below.

Quasi-Steady-State-Solution - The quasi-steady-state
solution takes into account the effect of nuclide buildup in
the topsoil. In this solution, the topsoil concentration is
treated as time-varying, while the concentrations in the re-
mainder of the compartments are considered to be in the equi-
librium state. The topsoil buildup time can be long compared
with changes in the input. In this simulation model it is
assumed that irrigation takes place every year to a maximum
limit (currently set at one thousand years). For times later
than that maximum limit, it is assumed that irrigation took
place only over the preceding time period equal to the maximum
limit (one thousand years). The limited irrigation period is
intended to simulate the limited period during which the hypo-
thetical nuclear waste is expected to be released into the
river (Ref. 1). This limitation of irrigation allows expected
doses to be estimated by simply multiplying the BIODOSE poten-
tial hazard outputs by the predicted nuclear waste input to
the river (in units of MWe-yr/yr).

The quasi-steady state solution to the compartment equations is the following:

$$c_{rt} = \frac{b}{a} (\exp(at_b) - 1) \quad (1.2-9)$$

where

$$a = \left\{ - \left(\frac{I+R-E}{B_{rt} \theta} + M_r + A_t S_t \right) + \frac{1}{K_2} S_t A_t I R_s \right. \\ \left. + \frac{\left[\frac{I+R-E}{B_{rt} \theta} + \frac{DA_s S_t A_t}{K_{rs} d K_2} \right]}{\left[K_1 - \frac{DA_s}{K_{rs} d K_2} \left(K_{rs} A_s v_w + \frac{DA_s}{d} \right) \right]} \left[I + \frac{I R_s}{K_2} \frac{DA_s}{d} + K_{rs} A_s v_w \right] \right\} \div V_t$$

$$b = \left\{ \frac{I + \frac{I R_s}{K_2} \left(\frac{DA_s}{d} + K_{rs} A_s v_w \right)}{K_1 - \frac{DA_s}{K_{rs} d K_2} \left(K_{rs} A_s v_w + \frac{DA_s}{d} \right)} \right\} \frac{q_r}{V_t}$$

$$K_1 = F + I + \frac{DA_s}{d} + K_{rs} A_s v_w$$

$$K_2 = \frac{DA_s}{K_{rs} d} + A_s v_w + I R_s$$

$$c_{rw} = \frac{q_r + \left(\frac{I+R-E}{B_{rt} \theta} + \frac{DA_s S_t A_t}{K_{rs} d K_2} \right) c_{rt}}{K_1 - \frac{DA_s}{K_{rs} d K_2} \left(K_{rs} A_s v_w + \frac{DA_s}{d} \right)} \quad (1.2-10)$$

$$c_{rs} = \frac{1}{K_2} \left\{ A_t S_t c_{rt} + \left(\frac{DA_s}{d} + K_{rs} A_s V_w \right) c_{rw} \right\} \quad (1.2-11)$$

$$c_{re} = (F T_e / V_e) c_{rw} \quad (1.2-12)$$

$$c_{rp} = [(V_e / (T_e 10F))] c_{re} \quad (1.2-13)$$

$$c_{ro} = \frac{(V_e T_o / T_e) c_{re} - V_p c_{rp}}{V_o [1 - A_p / A_o]} \quad (1.2-14)$$

$$c_{rse} = K_{rse} c_{re} \quad (1.2-15)$$

$$t_b = \begin{cases} t/T & \text{if } t < T_m \\ T_m & \text{if } t > T_m \end{cases}$$

where T (TRVLS) is an interval factor between irrigations, and T_m (TMAX) is the maximum limit of irrigation time.

The quasi-steady-state solution for a well system is the following:

$$\begin{aligned} c_{rw} &= q_r \\ c_{rt} &= (1 c_{rw} / V_t) [1 - \exp(-L_r t_b)] / L_r \end{aligned}$$

where

$$L_r = \frac{I+R-E}{K_{rt} V_t} + \frac{M_r}{V_t} + \frac{A_t S_t}{V_t}$$

Steady-State Solutions - The dynamics of the assumed water body systems are reasonably fast relative to input changes

except for the topsoil and sediment compartments. That is, for all the water body compartments, the time to reach a steady-state concentration is short compared with the time period over which past studies (Ref. 1) indicate that changes take place in the waste input to the compartment system. The sediment compartments contribute a minor amount to overall hazard. Consequently, a steady-state, or equilibrium, solution to those compartment equations is appropriate for simulations of those systems in which the topsoil compartment is not significant. The steady-state solution to Eq. 1.2-6 is:

$$C_r = -A_r^{-1} q_r \quad (1.2-16)$$

To obtain predicted doses, the potential hazard predictions resulting from this solution method can be simply multiplied by the expected waste input into the river.

Time-Varying Solution - With this solution, the radio-nuclide concentrations in all the compartments are assumed to vary in time in response to input changes. This solution method provides a more realistic simulation compared to the other methods. It may result in a less conservative prediction of potential hazard. It, like the steady-state method, is flexible in the sense of ease in changing the compartment transfer rate terms (in $V^{-1}A$ of Eq. 1.2-8). The quasi-steady-state solution requires that a closed-form solution to the compartment concentration equations (Eq. 1.2-6) be rederived after changes are made in the transfer rate terms (other than just changing the numerical values of existing parameters). The method is less flexible than the steady-state method in the sense that the radioactive input function (release rate from the repository into the biosphere) should be put into the compartment solution equations (see below) before the hazard is computed. With the steady-state or the quasi-steady-state

solution the predicted input and the potential hazard can be computed separately and then simply multiplied together. The simulation presently has an annual input of the waste resulting from one MWe-yr of power production.

The time-varying solution to the compartment equation (Eq. 1.2-8) with zero initial conditions is the following:

$$\underline{c}_r(t) = \exp(V^{-1}A_r t) \int_0^t \exp(-V^{-1}A_r \tau) V^{-1} \underline{q}_r d\tau \quad (1.2-17)$$

Since the nuclide input $\underline{q}_r$ is treated as a piecewise constant function and the nuclide amounts are evaluated at discrete time points for computational purposes, Eq. 1.2-17 may be discretized:

$$\begin{aligned} \underline{c}_r(t_N) = & \sum_{i=1}^N \left\{ \exp[V^{-1}A_r(t_N - t_{i-1})] \right. \\ & \left. - \exp[V^{-1}A_r(t_N - t_i)] \right\} (V^{-1}A_r)^{-1} V^{-1} \underline{q}_r(t_i) \end{aligned} \quad (1.2-18)$$

where t_i is the i^{th} time point, ($\underline{q}_r(t_i)$ is constant between t_{i-1} and t_i), and N is the index of the time at which $\underline{c}_r$ is to be evaluated.

Due to computational difficulties in the exponentiation of $V^{-1}A_r \Delta t$ for large values of Δt , an appropriate coordinate transformation of $\underline{c}_r$ is utilized to diagonalize the transformed $V^{-1}A_r$ matrix. Specifically, let

$$\underline{c}_r = P_r \underline{y}_r \quad (1.2-19)$$

where P_r is the matrix whose columns are eigenvectors of the matrix $(V^{-1}A_r)$. Substitution of Eq. 1.2-19 into Eq. 1.2-6 yields:

$$\frac{dy_r}{dt} = D_r y_r + P_r^{-1} V^{-1} q_r \quad (1.2-20)$$

where $D_r = P_r^{-1} V^{-1} A_r P_r$, which is a diagonal matrix of eigenvalues corresponding to the eigenvectors of P_r if all the eigenvalues are distinct. This condition would normally hold for all cases to be studied. Nevertheless, a warning message is printed if nondistinct eigenvalues are detected in the computer program. Equation 1.2-20 represents a set of n decoupled scalar differential equations instead of a system of n coupled differential equations as in Eq. 1.2-6.

The solution to Eq. 1.2-20 (analogous to Eq. 1.2-18) becomes:

$$y_r^j(t_N) = \sum_{i=1}^N \exp[\lambda_j(t_N - t_{i-1})] - \exp[\lambda_j(t_N - t_i)] \frac{1}{\lambda_j} \left[P_r^{-1} V^{-1} q_r(t_i) \right]_j \quad (1.2-21)$$

where y_r^j is the j^{th} element of the vector y_r and λ_j is the corresponding eigenvalue and the notation $[x]_j$ denotes the j^{th} element of vector x . The original vector of nuclide concentrations, $c_r(t_N)$, can then be calculated via Eq. 1.2-19.

For a seven compartment system, to prevent numerical difficulties associated with having too large a range of eigenvalues of the $(V^{-1}A_r)$ matrix, the system is decoupled and two sets of equations are solved sequentially. The $(V^{-1}A_r)$ matrix in Eq. 1.2-8 has a structure which readily lends itself to decoupling. The equations for the first three compartments can be solved independently of the last four compartment equations.

Then, the system of equations for the last four compartments can be solved with the input to the estuary compartment being ($F_{c_{rw}}$). The mathematical structure of each of the two subsystems is thus identical.

For any of the solution methods, once the concentration c_r relative to the total inventory I_r are obtained, concentrations in Ci/m^3 result from the following computation:

$$C_r = c_r I_r$$

1.2.2 Potential Hazard Calculations

The concentrations calculated for the five media: sediment, river, estuary, ocean and topsoil, are used with a simple ecosystem model to give radionuclide dose rates to man. Potential hazards are assumed to be received by ingestion and external exposure. The ingestion pathways considered are drinking water, aquatic foods, irrigated crops and farm animals. The external exposure pathways considered are shoreline, boating, swimming and topsoil.

For individual potential hazard predictions, each adult is assumed to drink all his water and eat all his aquatic food from the river or lake system into which radioactive material was released. Furthermore, each adult's diet is assumed to be composed solely of food products that were either directly or indirectly contaminated by the river or lake water. In addition, all water-related recreation time is assumed to be spent somewhere within the river, estuary and ocean system. These assumptions ensure that no important pathway for exposure is overlooked for each nuclide in the system.

The basic dose equation can be expressed as:

$$D_{r\ell ua} = G_{r\ell ua} C_{r\ell} \quad (1.2-22)$$

where

$D_{r\ell ua}$ is the potential hazard to organ u from nuclide r from compartment ℓ and exposure category a

$C_{r\ell}$ is the concentration of nuclide r in compartment ℓ

$G_{r\ell ua}$ is the dose rate per compartment ℓ concentration of nuclide r to organ u via category a.

Doses are calculated for the whole body and seven organs of interest: gastrointestinal and lower large intestine, thyroid, bone, liver, lung, kidney and skin. The means of exposure includes immersion and surface irradiation as well as ingestion. A whole-body dose equivalent can also be calculated which combines the dose to all organs by using dose equivalent factors (Ref 2). These factors weight each organ dose according to cancer risk. This equivalent dose may provide a more meaningful and compact way of presenting the hazard from radioactive waste.

The dose rates per concentration, $G_{r\ell ua}$, in Eq. 1.2-22 are decomposed in the model into exposure categories and subcategories, which are listed in Table 1.2-1. The dose rates per concentration (G) are functions of usage rates and dose factors. Let $U_{r\ell ab}$ be the usage rate in compartment ℓ of category a and subcategory b, and define D_{rau} as the dose factor for nuclide r from category a to organ u.

TABLE 1.2-1
DOSE CATEGORIES AND SUBCATEGORIES

CATEGORY		SUBCATEGORY	
CODE(a)	NAME	CODE(b)	NAME
1	Exposure to plane surfaces		
2	Immersion in water		
3	Ingestion of aquatic food	1	Fish
		2	Mollusk
		3	Crustacean
4	Ingestion of crops	1	Leafy vegetables
		2	Other above ground vegetables
		3	Potatoes
		4	Other root vegetables
		5	Berries
		6	Melons
		7	Orchard fruit
		8	Wheat
		9	Other grains
		10	Grass
5	Ingestion of drinking water		
6	Ingestion of animal products	1	Eggs
		2	Milk
		3	Beef
		4	Pork
		5	Poultry

The dose factor is computed as follows:

$$D_{\text{rau}} = 18.7 \frac{f_w \epsilon}{m} \frac{\lambda_{\text{ur}} t_1 + \exp(-\lambda_{\text{ur}} t_2) - \exp(-\lambda_{\text{ur}} [t_2 - t_1])}{\lambda_{\text{ur}}^2}$$

(1.2-23)

where

D_{rau} is the dose factor for nuclide r , organ u , and category a (the units are mrem/Ci/yr for ingestion categories 3, 4, 5 and 6, mrem/hr/hr per pCi/l for immersion category 2, and mrem/hr/yr per pCi/m² for exposure category 1) [DF50(r, i, u), where $i=1,2,3$ for ingestion, exposure, and immersion, respectively]

f_w is the fraction of the ingested nuclide reaching the organ via category a

m is the mass of the organ in grams

ϵ is the effective energy of the nuclide in the organ under consideration (MeV/disintegration) $\times$ (rem/rad)

λ_{ur} equals $(0.693/T_B + 0.693/T_R)$

T_B is the biological half-life for the nuclide in the organ (yr) [BHL(r, u)]

T_R is the radioactive half-life for the nuclide (yr) [TR(r)]

t_1 is the time over which exposure occurs (yr) [IT1]

t_2 is the time over which dose is calculated (yr) [IT2]

and 18.7 is the factor which converts $\frac{\text{MeV rem}}{\text{dis rad gm}}$ to $\frac{\text{mrem}}{\text{yr}} \frac{1}{\text{pCi}}$

The above parameters values were taken from Ref. 3 and personal communication from Soldat*. In the model the default values of t_1 and t_2 are fifty years. The dose factors are inputs to the program and are modified if t_1 and t_2 are not equal to

*J. Soldat, Battelle Pacific Northwest Laboratory.

fifty years. If the time over which the dose is calculated remains at fifty years, the individual potential hazards are expressed in units of fifty-year doses in rem per unit input.

Individual Potential Hazards - The individual usage rates (U_{lab}) are inputs to the program and are in units of liters/yr, kg/yr, or hr/yr, depending on the category and sub-category. There are two sets of usage rates: for an individual with an average diet and one with a maximum diet.

The dose rates per concentration are computed according to the equations below. Tables 1.2-2 and 1.2-3 list the organ codes and compartment codes for reference.

$$G_{r\ell u\ell} = 10^9 D_{r\ell u} U_{\ell\ell\ell} (SD) W_{\ell}, \quad 5 \leq \ell \leq 7 \quad (1.2-24)$$

TABLE 1.2-2
ORGAN CODE LIST

CODE(u)	ORGAN NAME
1.	Whole body equivalent
2.	Whole body
3.	Gastrointestinal and lower large intestine (GI-LLI)
4.	Thyroid
5.	Bone
6.	Liver
7.	Lung
8.	Kidney
9.	Skin

TABLE 1.2-3
COMPARTMENT CODES

CODE(l)	COMPARTMENT NAME
1.	River (or lake) water
2.	Estuary water
3.	Plume water
4.	Ocean water
5.	Topsoil
6.	River (or lake) sediment
7.	Estuary sediment

where

10^9 converts $\frac{\text{mrem}}{\text{pCi}}$ to $\frac{\text{rem}}{\text{Ci}}$

U_{l11} is exposure usage in units of hr/yr
[$U_{511} = 8760$, $U_{611} = \text{SHORE}$]

SD is the effective soil or shoreline depth (m)

W_2 is the shielding factor for the topsoil
(Ref. 4) and a shoreline - width factor
for the sediment compartments (from Ref. 5).

$$G_{r2u2} = 10^6 D_{r2u} U_{l21}, 1 \leq l \leq 4 \quad (1.2-25)$$

where

U_{l21} is swimming usage in hr/yr [$U_{l21} = \text{SWIM}$
*SWIMT(l), where SWIMT(l) is the fraction
of swimming time per compartment]

and 10^6 converts $\frac{\text{mrem}}{\text{pCi/l}}$ to $\frac{\text{rem}}{\text{Ci/m}^3}$

$$G_{r2u3} = 10^6 D_{r3u} \sum_{b=1}^3 U_{23b} B_{r2b}, \quad 1 \leq \ell \leq 4 \quad (1.2-26)$$

where

U_{23b} is usage of aquatic subcategory b in kg/yr [$U_{23b} = FC(b) \cdot F(b, \ell)$ where F is the fraction of food consumed from each compartment]

B_{r2b} is a bioaccumulation factor (PCi/kg biota per PCi/ ℓ of water) for fresh water for $\ell=1$ [$B(r, 2, b)$] and for salt water for $\ell=2, 3, 4$ [$B(r, 1, b)$]

and 10^6 converts $\frac{\text{mrem}}{\text{PCi}/\ell}$ to $\frac{\text{rem}}{\text{Ci}/\text{m}^3}$

$$G_{r1u4} = 10^6 D_{r3u} \sum_{b=1}^9 \frac{U_{24b} IR_b R T_b (1 - e^{-\lambda_E t_b})}{Y_b \lambda_E} \quad (1.2-27)$$

where

IR_b is the irrigation rate ($\ell/\text{m}^2 \cdot \text{day}$) for crop b during the growing season [$VIR(b)$]

R is the fraction of deposited activity retained on crop [R]

T_b is the fraction of the deposited activity which remains in the edible portion of the plant [$TV(b)$]

λ_E is the weathering removal constant (day^{-1}) [REMOVE]

t_b is the time of above-ground exposure of crops to contamination during the growing season (days) [TEXP(b)]

Y_b is the plant yield (kg/m^2)

10^6 converts $\frac{\text{mrem}}{\text{PCi}/\ell}$ to $\frac{\text{rem}}{\text{Ci}/\text{m}^3}$

and U_{14b} is the usage of crop b in kg/yr $[VC(b)]$.

$$G_{r5u4} = 10^9 D_{r3u} \sum_{b=1}^9 \frac{U_{54b} B_r}{D_T} \quad (1.2-28)$$

where

B_r is the plant concentration factor, in Ci/kg wet weight of plant per Ci/kg dry weight of soil $[BV(r)]$

D_T is the bulk density of soil, in kg/m^3 , dry weight $[DT]$

and 10^9 converts $\frac{mrem}{pCi}$ to $\frac{rem}{Ci}$

[Note that $U_{14b} = U_{54b}$.]

$$G_{r1u5} = 10^6 D_{r3u} U_{151} TREAT_r \quad (1.2-29)$$

where

$TREAT_r$ is the fraction of nuclide r remaining in drinking water after treatment

U_{151} is the usage rate of drinking water for humans $[WC]$

and 10^6 converts $\frac{mrem}{pCi/\ell}$ to $\frac{rem}{pCi/m^3}$

$$G_{r1u6} = 10^6 D_{r3u} \left\{ \left(\sum_{b=1}^5 U_{16b} S_{rb} Q_{Fb} \right) \frac{IR_{10} RT_{10} (1 - e^{-\lambda E t_{10}})}{Y_{10} \lambda_E} + \sum_{b=1}^5 U_{16b} S_{rb} Q_{Wb} \right\} \quad (1.2-30)$$

where

IR_{10} , T_{10} , t_{10} , Y_{10} , and R are parameters defined in Eq. 6.2-27 for the grass crop which it is

conservatively assumed makes up the total diet for animals

S_{rb} is the transfer coefficient of nuclide r from daily intake of animal to edible portion of animal product, in days/l for milk and days/kg for other animal products $[SA(r,b)]$

QF_b is the consumption rate of contaminated feed (grass) by an animal in kg/day $[QF(b)]$

QW_b is the consumption rate of water by an animal in l/day $[QW(b)]$

10^6 is the conversion factor to obtain $\frac{\text{rem}}{\text{Ci/m}^3}$

and U_{16b} is the usage rate of animal product b $[AC(b)]$

$$G_{r5u6} = 10^9 D_{r3u} \left(\sum_{b=1}^5 U_{56b} S_{rb} QF_b \right) \frac{B_r}{D_T} \quad (1.2-31)$$

where the parameters have been defined above and $U_{16b} = U_{56b}$. [Note that two usage rates exist in the program: one for the individual with an average diet and one for the individual with a maximum diet. The two different sets of values are clearly labeled in the "input summary" listing of the program output, shown in Table 3.2-4.]

Individual Potential Hazard from Wells - The calculations of dose factors per concentrations for a well water system are identical to the above except that only compartment 1 (well water) and compartment 5 (topsoil) are considered. It is assumed that the well water is used for irrigation of topsoil and for drinking water. Also, immersion and ingestion of aquatic food are not considered. It is assumed that the input is the nuclide concentration in the well water or that a unit well flow rate exists (one m^3/yr) or that the output is divided

by the well flow rate.* The potential hazard to individuals from nuclide r to organ u at time t is computed as follows:

$$P_{ru}(t) = \sum_a \sum_l D_{r2ua}(t)$$

Population Potential Hazard - The population potential hazards per year are predicted in a manner similar to that for the individual hazards except that the usage factors (U) are computed on a population basis rather than an individual basis. The individual rates (U_{lab}) used in Eqs. 1.2-24 through 1.2-31 are replaced with the following expressions for population usage:

$$U_{l11} = USER_l A_l, \quad l = 6, 7 \quad (1.2-32)$$

where

$USER_l$ is the number of hours spent in compartment l per year per square meter of compartment l [$USER(l)$] and A_l is the area of compartment l

$$U_{511} = USER_5 P A_5$$

where

P is the population density on the topsoil
(number/m²) [POPDEN]

$$U_{l21} = USER_l A_l, \quad 1 \leq l \leq 4 \quad (1.2-33)$$

$$U_{l3b} = H_{bl}, \quad 1 \leq l \leq 4 \quad (1.2-34)$$

* If BIODOSE is to be used with the WASTE program, the input should be Ci/yr from one MWe-yr/yr, as the WASTE output units are Ci/MWe-yr/yr/m³ and BIODOSE units are rem per Ci/MWe-yr/m³ for a fifty-year dose.

where

$H_{b\ell}$ is the fish harvest in kg/yr from compartment ℓ of type subcategory b [HARVST(b, ℓ)]

$$p_{\ell 4b}^U \approx \frac{10^3 U_{\ell 4b} f_v I}{\left(\sum_{b=1}^9 \frac{U_{\ell 4b} IR_b t_b}{Y_b} \right)} \quad (1.2-35)$$

where

$U_{\ell 4b}$ is the average individual usage rate of crop b in kg/yr [VC(ℓ, b)]

f_v is the fraction of the irrigation rate that is used for irrigating crops for human consumption [FVEG]

F is the river (or well) flow rate in m^3 /yr [FLOW]

IR_r , t_b , and Y_b are defined in Eq. 1.2-27

1000 converts m^3 to liters

and the denominator term represents the number of kilograms of crop produced per liter of irrigation water

$$p_{151}^U \approx 10^3 f_d F \quad (1.2-36)$$

where

f_d is the fraction of river (or well) flow rate used by humans for drinking water [FDRINK]

$$p_{\ell 6b}^U = \frac{10^3 f_b I Y_{10} R_b}{IR_{10} t_{10} QF_b}, \quad \ell=1,5 \quad (1.2-37)$$

where

f_b is the fraction of irrigation rate that is used for irrigating crops for consumption by animals for producing product b [FIR(b,c), where c=1 for river and c=2 for well]

R_b is the production rate of product b in kg (or l for milk) per animal per day [RATE(b)]

Y_{10} , IR_{10} , t_{10} are yield parameters for animal feed (grass)

and 1000 converts m^3 to liters.

It is assumed for internal model consistency that the sum of the total of the fractions of irrigation water used for crops for humans and animals must equal one; i.e.,

$$[f_v + \sum_{b=1}^9 f_b] = 1.0$$

Also, the equation for G_{rlu6} for the population hazard per compartment concentration is changed from Eq. 1.2-30 to the following:

$$G_{rlu6} = 10^6 D_{r3u} \left\{ \left(\sum_{b=1}^5 p_{16b} S_{rb} Q_{fb} \right) \frac{IR_{10} RT_{10} (1 - e^{-\lambda_E t_{10}})}{Y_{10} \lambda_E} + \left(\sum_{b=1}^5 g_b F R_b S_{rb} \right) \right\} \quad (1.2-38)$$

where

q_f is the fraction of river (or well) water flow used as drinking water for animal product b [FDR(b,c), where c=1 and c=2 for well].

From the above expressions it is evident that, except for topsoil exposure, the population potential hazard predictions are independent of population density assumptions. For calculations of population doses far into the future it is very difficult to make realistic population estimates. However, the total potential hazard from some pathways will be essentially independent of the size of the neighboring population. The aquatic food pathway depends on the net fish harvest and the vegetable and animal pathways primarily depend on the yearly irrigation rate. The population potential hazard from these pathways will be independent of how these products are distributed. That is, the population potential hazard is the same if a small number of individuals in the population consume all the contaminated products or if many individuals each consume only a small part of the contaminated products.

The total crop uptake (used in the compartment concentration calculations) is computed according to the following equation:

$$M_r = 10^3 I \left[\sum_{b=1}^5 \frac{S_{rb} B_r f_b Y_{10} R_b}{D_T IR_{10} t_{10}} + \frac{\sum_{b=1}^9 B_r U_{54b} f_v}{D_T \sum_{b=1}^9 \frac{U_{54b} IR_b t_b}{Y_b}} \right]$$

where

M_r is the total crop uptake of water removed from the topsoil in m^3/yr and all the other parameters have been defined previously.

Potential hazards to populations are expressed in terms of annual doses rather than fifty-year doses. The population is assumed to have approximately a uniform distribution of ages. As radionuclide releases are approximately constant for time periods on the order of fifty years, a population will at any time contain equal numbers of individuals who have been exposed for each number of years from one to fifty. The dose in one year to fifty individuals, each of whom has been exposed for a different number of years, is equal to the dose over fifty years to one individual. Since the $D_{r\ell ua}$ represent accumulated fifty-year doses, a division of fifty (or t_2 if different from fifty) is necessary in the case of population potential hazards to obtain an annual dose. For releases to surface water systems, the potential hazard to the population is therefore given by

$$P_{re}(t) = \frac{1}{t_2} \sum_a \sum_{\ell} D_{r\ell ua}(t)$$

Population Potential Hazard from Wells - The potential hazard predictions from the well water system are the same as for the river or lake system except that only the well water compartment (1) and topsoil compartment (5) are considered. In addition, immersion and ingestion of aquatic food are not considered. Also, the parameters f_v , f_b , g , I and F are replaced with values appropriate for well systems.

In the case of population doses from wells, a somewhat different formula is used for the potential hazard:

$$P_{ru}(t) = \frac{1}{t_2 Q_w} \sum_a \sum_{\ell} D_{r\ell ua}(t)$$

where Q_w is the well water flow rate (m^3/yr) (WRATE(2)). This division by Q_w makes the potential hazard independent of well

water withdrawal rate and makes the output compatible with the NUTRAN programs WASTE and WPLOT so that they can be run with values of Q_w different from the value used in BIODOSE (Ref. 7).

Potential Hazards Pathway Categorization - The potential hazards for either individuals or population can be grouped according to several different criteria: individual nuclide, body organ, water system compartment, exposure category, and the three nuclide categories based on retardation factors in aquifer media. The potential hazards may be grouped according to any of the above criteria or most combinations, as explained in Section 3.3.

Short-Lived Daughters - Certain daughter nuclides considered in BIODOSE have half-lives which are sufficiently short that essentially all of their potential hazard can be attributed to the parent decaying in the biosphere subsequent to input to surface waters. In BIODOSE the potential hazards of some short-lived daughters are added to those of their parents unless the parameter NODAUT is set equal to FALSE. These are listed in Table 1.2-4. The nuclide Cm^{242} is included in the list because after about one hundred years it is essentially in secular equilibrium with Am^{242m} .

1.2.3 Model Assumptions

Several key assumptions of the model, which should be noted in interpreting the simulation results, are summarized here for convenience:

- Water and soil bodies are modeled as perfectly-mixed compartments with first-order transfer rates
- Radionuclide doses are linear functions of concentration

TABLE 1.2-4
SHORT-LIVED DAUGHTERS WHOSE POTENTIAL HAZARDS
ARE ADDED TO THOSE OF PARENTS FOR PRINTOUT

DAUGHTER	PARENT	HALF-LIFE (DAYS)
Y^{90}	Sr^{90}	2.7
Sb^{126}	Sn^{126}	12.4
Cm^{242}	Am^{242m}	160
Np^{239}	Am^{243}	2.4
Ac^{225}	Ra^{225}	10.0

- The annual rate at which radionuclides enter the water body is normalized to be the waste from one MWe-yr of power production
- The potential population hazard predictions are expressed as doses per year to the population from a fifty-year exposure per unit of waste entering the water system in units of man-rem
- The potential individual hazard predictions are expressed as fifty-year doses to individuals eating an average or maximum diet of food, all of which is from contaminated areas, per unit of waste entering the water system per year, in units of rem
- To convert potential hazards to doses, the rate at which waste enters the water system must be taken into account.

2. PROGRAM DESCRIPTION

2.1 INTRODUCTION

The BIDOSE program is written in ANSI FORTRAN with the NAMELIST option and four-dimensional arrays. It consists of 26 subprograms: 3 BLOCK DATA units, 19 computational routines, and 4 utility routines. It was designed top-down, with highest levels performing sequencing functions. Computations are performed at lower levels. Since the modules communicate large amounts of data, labeled COMMONs were used to avoid unwieldy subroutine calls. The actual code is highly structured to enhance understanding and ease of maintenance with comments, mnemonic labels and indentation.

Section 2.2 of this chapter describes the main program. Sections 2.3 through 2.9 describe data input (INPUT), computation control (COMPUT), report output (OUTPUT), general parameters initialization (BLKGEN), nuclide inventory initialization (BLKINV), and nuclide parameters initialization, respectively.

2.2 MAIN PROGRAM BIDOSE

The main program, BIDOSE, performs the highest level sequencing. It calls the input routine (INPUT), the main computational routine (COMPUT), and output routine (OUTPUT). The overall program structure is shown in Fig. 2.2-1.

IT 43767a

Figure 2.2-1 BIODOSE Block Diagram

2.3 SUBROUTINE INPUT - DATA INPUT CONTROLLER

The subroutine INPUT controls data input, variable initialization, and echoing of the input data. INPUT uses eight NAMELISTs. The NAMELISTs and their associated defaults are discussed in Section 3.2. Each NAMELIST label corresponds to the labeled common with the same initial letters. Each NAMELIST accepts inputs for variables in the corresponding labeled common. For example, the NAMELIST SYSLST contains variables that are contained in the labeled common SYSPAR. (See Table 2.3-1.)

TABLE 2.3-1
NAMELIST AND LABELED COMMON BLOCKS

NAMELIST	LABELLED COMMON	DESCRIPTION
SYSLST	SYSPAR	System control parameters
ANLST	ANPAR	Animal product parameters
SOILST	SOIPAR	Soil parameters
ULST	UPAR	Usage parameters
VEGLST	VEGPAR	Vegetable pr duct parameters
WLST	WPAR	Water parameters
NUCLST	NUCPAR	Nuclide physical parameters
INVLST	INVPAR	Nuclide inventory parameters

There are two forms on initialization in the program. Default values for all input variables are assigned at run time initialization by the BLOCK DATA subprograms: BLKGEN, BLKINV, and BLKNUC. These values can then be overwritten in the NAMELIST input. Dynamic initialization of variables is accomplished in the subroutine INIT, called by INPUT.

File input is controlled by logical variables in the SYSLST NAMELIST. If INVBIT is set to .TRUE. in the input, the subroutine INVRD is called to read the nuclide inventory file. If NUCBIT is set to .TRUE. the subroutine NUCRD is called to read the nuclide specific parameter file. The files are read before the NAMELISTS are read. Thus, a file may be read, and then its values overwritten by using the appropriate NAMELIST input. INVBIT and NUCBIT are defaulted to .TRUE..

The input data is echoed, or summarized. The first seven reports are generated by INPUT for every run. They contain the non-nuclide parameters read by the NAMELISTS: SYSLST, ANLST, SOILST, ULST, VEGLST, and WLST. INPUT calls the subroutine NUCOUT to print summaries of the nuclide parameters specified for the current run by the logical array INCLUD.

2.3.1 Subroutine INVRD - Nuclide Inventory File Input

The subroutine INVRD reads the nuclide inventory data from the appropriate file on the logical device specified by the variable IOFILE. First, two parameters are tested against current values as a guard against using the wrong file. Next the inventory sampling times are read. Finally, the inventory values at each time for each nuclide are read. If no files are specified, the default values set in the Block Data BLKINV are used.

2.3.2 Subroutine INIT - Non-Standard Dose Factor Initialization

The subroutine INIT initializes variables that depend on input data. It transfers the requested number (NTIME) of simulated time points and their associated nuclide inventory values into work arrays. Then variables involving vegetable and water rates are initialized.

The dose factors (DF50) are modified if both the exposure time (IT1) and the calculation time (IT2) are not 50. The exposure response time is the length of time an individual or population is exposed to nuclide radioactivity; the calculation time is the length of time over which the effects of exposure are calculated.

2.3.3 Subroutine NUCOUT - Nuclide Data Input Summary

Subroutine NUCOUT prints input data summaries of the nuclide parameters requested in the current run by the logical array INCLUD. A nuclide is included in the run if the corresponding flag in the logical array INCLUD is .TRUE.. The default initialization for all elements in the INCLUD array is .TRUE.. For each included nuclide, NUCOUT prints its chemical symbol and inventory sequence number, its fifty year dose factors, various physical and ecological parameters, and a table of inventory parameters.

2.3.4 Subroutine NUCRD - Nuclide Parameter File Input

The subroutine NUCRD reads the nuclide specific parameters (DF50, B, FKT, BV, SA, TR, BHL, NCAT, FKS, FKSE, TREAT, and NAME) from the file associated with logical unit number 10. If the subroutine NUCRD is not called (when NUCBIT is equal to .FALSE.), the default nuclide parameters in BLKNUC are used. Note that NNUC must equal 36 if the default parameters and inventory are used.

2.4 SUBROUTINE COMPUT - COMPUTATION CONTROLLER

The subroutine COMPUT sequences the computation routines. It calls USERAT to calculate usage rates and CALC to calculate potential hazard rates per dose factor. Concentrations in the water system compartments are calculated by one

of three methods, depending on the value of the system variable ICTYP. If ICTYP is 1, CONCNT calculates the concentrations by a pre-defined quasi-steady-state solution to the differential equation for concentrations (Eq. 1.2-6). If ICTYP is 2, EQUAL calculates steady-state concentrations by solving the equation $\underline{c} = -A^{-1}\underline{q}$, where $\underline{c}$ is the concentration array, A is the transfer matrix, and $\underline{q}$ is the input array. If ICTYP is 3, the subroutine TIMVAR is called to calculate the time-varying solution.

2.4.1 Subroutine USERAT - Compartment Usage Rate Computation

The subroutine USERAT calculates usage rates (the matrix U) in each compartment in units per year (e.g., kg/yr, μ /yr, hr/yr). Average individual, maximum individual, or population usage rates are calculated depending on the system variable LDSIG being 1, 2, or 3, respectively.

2.4.2 Subroutine CALC - Potential Hazard Rate Computation

The subroutine CALC computes the potential hazard rates for each nuclide in each organ from each compartment and category of the pathway excluding the dose factors (DF50). Several general terms are calculated, and the number of water compartments (NWC) in the system are determined. The potential hazard rates per dose factors for each included nuclide are calculated as functions of the usage rates (U). These rates are stored in the BIO arrays in the labeled common BIOPAR. The rate of removal of nuclides is calculated for the individual cases or the population case.

2.4.3 Subroutine CONCNT - Quasi-Steady-State Computation

The subroutine CONCNT is one of three alternatives for calculating concentration (in Curies per meter³) for each

nuclide in each compartment. CONCNT solves the concentration equations using a pre-defined method (Section 1.2-1). First, constants are initialized, and the concentration matrix (CON) is initialized to zero by a call to ZERO. For each included nuclide, each included compartment and for each time step (loop index J) the concentration is calculated. The system switch TMAX is used to determine the maximum time interval over which water is withdrawn for irrigation.

2.4.4 Subroutine EQUAL - Steady-State Computation

The subroutine EQUAL is an alternative method of calculating the nuclide concentrations. It solves the equation $\underline{c} = -A^{-1}\underline{q}$ for a steady-state system (Eq. 1.2-16). The arrays are initialized to zero, and the included compartments are determined in the array IC. The routine SETUP is called to compute the transfer rates into and out of each compartment. The inverse of A is calculated by the utility routine MFG. The concentration matrix $\underline{c}$ (CON in the program) is $(-A^{-1}\underline{q})$, calculated by the utility MULT.

2.4.5 Subroutine SETUP - Compartment Flow Rates Computation

The subroutine SETUP calculates the flow rate into and out of each compartment, that is, it sets up the transfer matrix A (FLOWIN in the program). The system variable IC indicates which compartments are included in the current run, and thus controls the dimension of the transfer matrix. For example, if only compartments 1, 5, and 6 are to be included in a simulation, SETUP selects the appropriate 3x3 transfer matrix A_r for each nuclide r.

2.4.6 Subroutine TIMVAR - Time-Varying Computation

The subroutine TIMVAR implements the time-varying solution of the compartment model (Section 1.2-1). First, the transfer matrix (FLOWIN) is set by a call to SETUP. Then for each nuclide the time-varying solution is calculated. The appropriate transfer matrix is transposed. The IMSL subroutine ELGRF is called to calculate the eigenvalues (EVALS) and the eigenvectors (EVECS). The inverse of the eigenvectors is calculated. Then for each time, the factors Q (inventory of nuclide in the water system, Q) and U (fraction of total inventory input to the water system, q) are initialized (see Eq. 1.2-6). The results are stored in sequential order in a temporary matrix (TMPCON) and then transferred to the concentrations matrix (CON) via the appropriate subscript transformation corresponding to the original compartment code numbers (Table 1.2-3).

To prevent numerical difficulties, if seven compartments are simulated, TIMVAR should be called twice to solve the compartment concentrations in two stages through the use of the parameter IC(ℓ) (see Section 1.2-1). If IC(ℓ) = 0, compartment ℓ concentrations are set to zero. If IC(ℓ) = 1, then compartment ℓ concentrations are solved on the first pass. If IC(ℓ) = 2, then compartment ℓ concentrations are computed on the second pass. Normally for the seven compartment codes listed in Table 1.2-3, IC should be set equal to [1,2,2,2,1,1,2] for $\ell = 1$ to 7, respectively. In any case, if two passes are used, the first compartment on the first pass should be the river compartment (code 1) and on the second pass the estuary compartment (code 2) should be called first by setting IC(2) = 2.

2.4.7 Subroutine EIGRF - Eigenvalues and Eigenvector Computation

The subroutine EIGRF is a product of International Mathematical and Statistical Libraries, Inc. (IMSL), Houston, Texas. It is available in the IMSL Library 1 (Ref. 6). EIGRF computes eigenvalues and eigenvectors of a real matrix. The eigenvectors are not normalized in this routine.

2.4.8 Subroutine LINV2F - Matrix Inversion

The subroutine LINV2F is also from the IMSL Library 1 (Ref. 6). LINV2F inverts a real matrix.

2.4.9 Subroutine DOSE - Potential Hazards Summation

The subroutine DOSE calculates the requested aggregations of the final potential hazards and calls PRNT to output the results. Because of the number of nuclides, compartments, and categories, the number of final potential hazards is overwhelming. Thus, these final potential hazards may be summed across a dimension, or dimensions for output. The facility is controlled by the system variables SUMS.

DOSE first initializes the work array to zero. Then for each included nuclide and each time point, intermediate potential hazards are obtained by multiplying the potential hazard per dose factor by the compartment concentrations (Curies per meter³). Then for each organ category, compartment and/or nuclide, the potential hazard is calculated by multiplying the intermediate potential hazard by the dose factor (DF50), and a running sum is maintained. The results are printed by the routine PRNT.

2.4.10 Subroutine PRNT - Potential Hazards Report Printer

The subroutine PRNT prints the final potential hazard reports in table format. It utilizes a non-exclusive case structure that prints all the tables satisfying a given criterion on the control variable ICODE. Several arrays are set up with the appropriate characters to provide the titles for the reports.

2.4.11 Subroutine PLTDOS - Potential Hazard Plotter

The subroutine PLTDOS provides graphic displays of potential hazard as a function of time. PLTDOS utilizes subroutines from the DISSPLA package (Ref. 8). Linkage to the DISSPLA routines must be provided if PLTDOS is to be used. PLTDOS is called if the parameter PLOT is set to .TRUE.. The three-digit code number which appears on the graph for convenience in identifying some key parameters of the simulation is the following:

$$100*(IOFILE-1) + 10*(ISYSTEM-1 + IDSIG-1) + (IPORG-1)$$

The parameter IPORG is an input parameter indicating the organ code number to be plotted and has a default value of 1 (whole body equivalent).

2.5 UTILITY SUBROUTINES

There are four support subroutines in program BIOPOSE that perform general purpose functions. These routines are called from numerous other subprograms and are not described in the previous program description sections. The implementation and usage of each of these routines is straightforward.

The calling sequence, array and dimensions and purpose of each is summarized below:

```
MFG (A,UL,ULI,AI,IPER,N,IERR)
A(N,N); UL(N,N); ULI(N,N); AI(N,N); IPER(N)
AI is computed as the inverse matrix of A.
MULT(A,B,C,N,L,M)
A(N,L); B(L,M); C(N,M)
C is computed as the matrix product A*B.
```

```
TRNP(A,B,N,M)
A(N,M); B(M,N)
B is computed as the matrix transpose of A.
```

```
ZERO(A,NTOT)
A(NTOT)
A is set to the zero matrix. NTOT is the
product of the dimensions of the matrix A.
```

2.6 BLOCK DATA BLKGEN - GENERAL PARAMETERS INITIALIZATION

The block data BLKGEN contains the default values for non-nuclide-specific parameters, that is, for those variables in the labeled COMMONS ANPAR, SYSPAR, SOIPAR, UPAR, VEGPAR and WPAR. All variables are initialized (see Tables 3.2-1 through 3.2-8).

2.7 BLOCK DATA BLKINV - NUCLIDE INVENTORY INITIALIZATION

The block data BLKINV contains the default values for the nuclide inventories, that is, those variables in the labeled common INVPAR. Subscripting in the DATA statements is avoided by array equivalences and FORTRAN-style subscript usage.

2.8 BLOCK DATA BLKNUC - NUCLIDE PARAMETERS INITIALIZATION

The block data BLKNUC contains the default values for the nuclide physical parameters, that is, the variables in the labeled common NUCPAR. Subscripting in the DATA statement is avoided by array equivalences and FORTRAN-style subscript usage.

3. PROGRAM USAGE

3.1 INTRODUCTION

The BLODOSE program was designed for the user. Ease of input is achieved through the NAMELIST option with default values assigned for every input variable. Thus the only values required in the input stream are those that differ from the defaults. The inputs are summarized, or echoed, in clear tabular reports.

Since all input variables have default values, the program can be run with null NAMELISTS. The NAMELIST insert sequence for this default run and the output generated are shown in the attachment to this report. The input and output structures are explained in detail in the following sections.

3.2 PROGRAM INPUTS

The input structure is simple: it consists of 8 NAMELIST input statements. Each NAMELIST refers to a different class of inputs (see Table 2.3-1) and references variables in an associated labeled COMMON. If the default values for a given NAMELIST are satisfactory, then only a null NAMELIST is required in the input. If changes to values are desired, the appropriate value is entered with the associated variable name. This procedure is explained in detail below. A complete list of the NAMELIST variables and their defaults is given in Tables 3.2-1 through 3.2-8. These inputs are summarized by the INPUT routine.

TABLE 3.2-1
BIODOSE INPUT DATA SUMMARY, SYSTEM PARAMETERS
(NAMELIST/SYSLST/)

SYSTEM PARAMETERS VALUE	MNEMONIC	DESCRIPTION
#	DEBUD	PRINT DEBUD INFORMATION
#	PLDT	PLDT POTENTIAL HAZARDS
53	MNUC	NUMBER OF NUCLIDES
3	JMXX	NUMBER OF NUCLIDE TYPES
1	IDP FILE	NUCLIDES WITHIN A TYPE HAVE IDENTICAL RETARDATION COEFFICIENTS
1	IDSIG	UNIT NUMBER FOR ALTERNATE INVENTORY FILE
1	INVB1T	1, 2, OR 3 FOR AVERAGE, MAXIMUM, OR POPULATION POTENTIAL HAZARDS
1	ISV2TH	CONTROL INPUT OF ALTERNATE INVENTORY FILE
1	ICTYP	1 OR 2 FOR RIVER OR WELL
50	IC1	1, 2 OR 3 FOR QUASI-STEADY OR STEADY STATE OR TIME-VARYING SOLUTIONS
7	NDDAUT	TIME DURING WHICH INDIVIDUAL IS EXPOSED TO RADIATION (YEARS)
50	JTS	CONTROL TO ADD POTENTIAL HAZARDS OF SHORT-LIVED DAUGHTERS
7	NCONPS	TO THOSE OF THEIR PARENTS IN PRINTOUT ONLY, IF TRUE
29	NTIME	TIME OVER WHICH DOSE COMMITMENT IS CALCULATED (YEARS)
50	NINVT	NUMBER OF COMPARTMENTS
1	NCSBT	NUMBER OF TIME POINTS SELECTED FROM INVENTORY FILE
7	IDISA	NUMBER OF INVENTORY FILE TIMES
1		CONTROL INPUT FOR ALTERNATE NUCLIDE PARAMETER FILE
1		CONTROL FOR DISK OUTPUT TYPE
1		NO OUTPUT FILE (TO BE READ BY WASTE PROGRAM)
1		1 FILE BY NUCLIDE TYPE
1		2 FILE BY TYPE AND NUCLIDE
0	INVTYP	DISK OUTPUT UNIT NUMBER (20=INVTYP)
2	NDRG	NUMBER OF ORGANS
2	IECHO	CONTROL LENGTH OF INPUT ECHO SUMMARY:
		0 NO ECHO
		1 SYSTEM PARAMETERS ONLY
		2 SYSTEM & COMPARTMENT PARAMETERS
		OTHER SYSTEM, COMPARTMENT, & NUCLIDE PARAMETERS
#	SUMS(1)	SELECT TYPES OF OUTPUT
#	SUMS(2)	DOSES BY NUCLIDE TYPE, COMPARTMENT, TIME, ORGAN AND CATEGORY
#	SUMS(3)	DOSES BY NUCLIDE, COMPARTMENT, TIME AND ORGAN
#	SUMS(4)	DOSES BY NUCLIDE, TIME, ORGAN AND CATEGORY
#	SUMS(5)	DOSES BY NUCLIDE, TIME AND ORGAN
#	SUMS(6)	DOSES BY NUCLIDE TYPE, COMPARTMENT, TIME AND ORGAN
#	SUMS(7)	DOSES BY NUCLIDE TYPE, TIME, ORGAN AND CATEGORY
1		DOSES BY NUCLIDE TYPE, TIME AND ORGAN
1		PARTITION NUMBER FOR COMPARTMENT (0, 1, OR 2)
1		0 DENOTES WHICH COMPARTMENTS ARE TO BE INCLUDED
2		IN SECOND PASS THROUGH TIMEVARY SOLUTION SUBROUTINE)
2	IC(1)	RIVER WATER
2	IC(2)	ESTUARY WATER
2	IC(3)	PLUME WATER
1	IC(4)	OCEAN WATER
1	IC(5)	TOPSOIL
2	IC(6)	RIVER SEDIMENT
2	IC(7)	ESTUARY SEDIMENT
0	IC(8)	OCEAN SHORELINE
7	INCLUD(1)	SIGNALS INCLUSION OF NUCLIDE IN THE CALCULATIONS
T	INCLUD(2)	AM243
T	INCLUD(3)	AM241
T	INCLUD(4)	PU240
T	INCLUD(5)	PU239
T	INCLUD(6)	PU238
T	INCLUD(7)	NP237
T	INCLUD(8)	U235
T	INCLUD(9)	U233
T	INCLUD(10)	U234
T	INCLUD(11)	RA231
T	INCLUD(12)	TM232
T	INCLUD(13)	TM230
T	INCLUD(14)	TM229
T	INCLUD(15)	AC227
T	INCLUD(16)	RA229
T	INCLUD(17)	RA228
T	INCLUD(18)	PO210
T	INCLUD(19)	PA210
T	INCLUD(20)	EU154
T	INCLUD(21)	SM137
T	INCLUD(22)	CS137
T	INCLUD(23)	CS136
T	INCLUD(24)	I129
T	INCLUD(25)	SM126
T	INCLUD(26)	PO137
T	INCLUD(27)	TC99
T	INCLUD(28)	MB93M
T	INCLUD(29)	Z895
T	INCLUD(30)	SR90
T	INCLUD(31)	SR90
T	INCLUD(32)	N189
T	INCLUD(33)	C14
T	INCLUD(34)	NP239
T	INCLUD(35)	AC225
T	INCLUD(36)	RA225
T	INCLUD(37)	RA223
T	INCLUD(38)	SB128
T	INCLUD(39)	Y90
T	INCLUD(40)	C244
T	INCLUD(41)	C242
T	INCLUD(42)	PU241
T	INCLUD(43)	PU147
T	INCLUD(44)	CS144
T	INCLUD(45)	CS136
T	INCLUD(46)	RU108
T	INCLUD(47)	MB99
T	INCLUD(48)	Z895
T	INCLUD(49)	Y91
T	INCLUD(50)	JR99
T	INCLUD(51)	AM242M
T	INCLUD(52)	PU242
T	INCLUD(53)	U236

TABLE 3.2-2
BIODOSE INPUT DATA SUMMARY, ANIMAL PARAMETERS
(NAMELIST/ANLST/)

ANIMAL PARAMETERS VALUE	MNEMONIC	DESCRIPTION
1.20000E-01	QF(1)	FEED CONSUMPTION PER ANIMAL (WET WEIGHT) IN KG/DAY
5.50000E+01	QF(2)	EGGS
6.80000E+01	QF(3)	MILK
4.20000E+00	QF(4)	BEEF
1.20000E-01	QF(5)	PORK
		POULTRY
3.00000E-01	QW(1)	WATER CONSUMPTION PER ANIMAL IN L/DAY
6.00000E+01	QW(2)	EGGS
5.00000E+01	QW(3)	MILK
1.00000E+01	QW(4)	BEEF
3.00000E-01	QW(5)	PORK
		POULTRY
0.0	FIR(1,1)	FRACTION OF IRRIGATION WATER FLOW USED FOR IRRIGATING CROPS FOR ANIMAL USE
7.50000E-02	FIR(2,1)	EGGS
6.75000E-01	FIR(3,1)	MILK
0.0	FIR(4,1)	BEEF
0.0	FIR(5,1)	PORK
		POULTRY
0.0	FIR(1,2)	FRACTION OF WELL WATER FLOW USED FOR IRRIGATING CROPS FOR ANIMAL USE
7.50000E-02	FIR(2,2)	EGGS
6.75000E-01	FIR(3,2)	MILK
0.0	FIR(4,2)	BEEF
0.0	FIR(5,2)	PORK
		POULTRY
0.0	FDR(1,1)	FRACTION OF RIVER WATER FLOW USED BY ANIMALS FOR DRINKING
7.00000E-03	FDR(2,1)	EGGS
5.50000E-04	FDR(3,1)	MILK
0.0	FDR(4,1)	BEEF
0.0	FDR(5,1)	PORK
		POULTRY
0.0	FDR(1,2)	FRACTION OF WELL WATER FLOW USED BY ANIMALS FOR DRINKING
1.20000E-03	FDR(2,2)	EGGS
1.20000E-02	FDR(3,2)	MILK
0.0	FDR(4,2)	BEEF
0.0	FDR(5,2)	PORK
		POULTRY
0.0	RATE(1)	PRODUCTION RATE PER ANIMAL IN KG/DAY FOR BEEF AND L/DAY FOR MILK
1.50000E+01	RATE(2)	EGGS
4.00000E-01	RATE(3)	MILK
0.0	RATE(4)	BEEF
0.0	RATE(5)	PORK
		POULTRY

TABLE 3.2-3
 BIODSE INPUT DATA SUMMARY, SOIL PARAMETERS
 (NAMELIST/SOILST/)

SOIL PARAMETERS VALUE	MNEMONIC	DESCRIPTION
1.60000E+03	UT	TOPSOIL DENSITY IN KG/M**3
4.95000E-02	REMOVE	WEATHERING REMOVAL CONSTANT IN 1/DAY
2.50000E-02	SD	EFFECTIVE DEPTH OF SHORELINE SEDIMENT IN M
1.00000E+00	TRVLS	NUMBER TO DIVIDE TIMES SINCE REPOSITORY DECOMMISSIONING TO GIVE IRRIGATION TIMES
1.00000E+03	THAX	MAXIMUM TIME FOR CONTINUOUS IRRIGATION OF TOPSOIL
6.10000E-05	ERATE	EROSION RATE OF TOP SOIL IN M/YR
4.00000E-02	DC	DIFFUSION COEFFICIENT FOR SEDIMENT IN M**2/YR
1.00000E-03	SRATE	SEDIMENTATION RATE OF RIVER IN M/YR
1.00000E-01	DD	DIFFUSION DEPTH OF SEDIMENT IN M
1.00000E-01	SERATE	SEDIMENTATION RATE OF ESTUARY IN M/YR
0.0	RS	RATIO OF SUSPENDED SEDIMENT TO IRRIGATION WATER
4.70000E+08	RA	RAINFALL IN M**3/YR
4.70000E+08	ET	EVAPOTRANSPIRATION IN M**3/YR

TABLE 3.2-4
BIODOSE INPUT DATA SUMMARY, USAGE PARAMETER
(NAMELIST/ULST)

USAGE PARAMETERS VALUE	MMEMONIC	DESCRIPTION
VEGETABLE PRODUCTS CONSUMED PER YEAR IN KG		
5.00000E+00	VC(1.1)	AVERAGE LEAFY VEGETABLES
3.20000E+01	VC(2.1)	MAXIMUM LEAFY VEGETABLES
5.00000E+00	VC(1.2)	AVERAGE OTHER ABOVE GROUND VEGETABLES
3.20000E+01	VC(2.2)	MAXIMUM OTHER ABOVE GROUND VEGETABLES
4.40000E+01	VC(1.3)	AVERAGE POTATOES
1.31000E+02	VC(2.3)	MAXIMUM POTATOES
2.80000E+01	VC(1.4)	AVERAGE OTHER ROOT VEG.
8.60000E+01	VC(2.4)	MAXIMUM OTHER ROOT VEG.
5.00000E+00	VC(1.5)	AVERAGE BERRIES
1.00000E+01	VC(2.5)	MAXIMUM BERRIES
7.00000E+00	VC(1.6)	AVERAGE MELONS
1.40000E+01	VC(2.6)	MAXIMUM MELONS
4.30000E+01	VC(1.7)	AVERAGE ORCHARD FRUIT
9.00000E+01	VC(2.7)	MAXIMUM ORCHARD FRUIT
5.00000E+01	VC(1.8)	AVERAGE WHEAT
1.13000E+02	VC(2.8)	MAXIMUM WHEAT
4.00000E+00	VC(1.9)	AVERAGE OTHER GRAINS
1.20000E+01	VC(2.9)	MAXIMUM OTHER GRAINS
ANIMAL PRODUCTS CONSUMED PER YEAR IN KG		
4.87000E+02	AC(1.1)	AVERAGE EGGS (NUMBER PER YR)
7.30000E+02	AC(2.1)	MAXIMUM EGGS (NUMBER PER YR)
1.10000E+02	AC(1.2)	AVERAGE MILK (LITERS PER YR)
3.10000E+02	AC(2.2)	MAXIMUM MILK (LITERS PER YR)
3.90000E+01	AC(1.3)	AVERAGE BEEF
4.50000E+01	AC(2.3)	MAXIMUM BEEF
3.90000E+01	AC(1.4)	AVERAGE POULTRY
4.50000E+01	AC(2.4)	MAXIMUM POULTRY
1.70000E+01	AC(1.5)	AVERAGE PORK
2.00000E+01	AC(2.5)	MAXIMUM PORK
FISH PRODUCTS CONSUMED PER YEAR IN KG		
5.90000E+00	FC(1.1)	AVERAGE FISH
2.10000E+01	FC(2.1)	MAXIMUM FISH
3.00000E+01	FC(1.2)	AVERAGE MOLLUSK
2.50000E+00	FC(2.2)	MAXIMUM MOLLUSK
5.00000E+01	FC(1.3)	AVERAGE CRUSTACEANS
2.50000E+00	FC(2.3)	MAXIMUM CRUSTACEANS
AQUATIC FOOD HARVEST IN EDIBLE KG		
5.80000E+04	HARVST(1.1)	RIVER FISH
0.0	HARVST(2.1)	RIVER CRUSTACEANS
4.50000E+03	HARVST(3.1)	RIVER MOLLUSKS
3.80000E+06	HARVST(1.2)	ESTUARY FISH
3.00000E+06	HARVST(2.2)	ESTUARY CRUSTACEANS
7.70000E+05	HARVST(3.2)	ESTUARY MOLLUSKS
0.0	HARVST(1.3)	PLUME FISH
0.0	HARVST(2.3)	PLUME CRUSTACEANS
0.0	HARVST(3.3)	PLUME MOLLUSKS
9.10000E+07	HARVST(1.4)	OCEAN FISH
0.0	HARVST(2.4)	OCEAN CRUSTACEANS
0.0	HARVST(3.4)	OCEAN MOLLUSKS
WATER CONSUMED PER YEAR IN L		
0.37000E+03	WC(1)	AVERAGE
0.73000E+03	WC(2)	MAXIMUM
SHORE USAGE PER YEAR IN HOURS		
8.30000E+00	SHORE(1)	AVERAGE
1.20000E+01	SHORE(2)	MAXIMUM
SWIM AND BOAT USAGE PER YEAR IN HOURS		
5.00000E+00	SWIM(1)	AVERAGE
2.00000E+02	SWIM(2)	MAXIMUM

TABLE 3.2-4

BIODOSE INPUT DATA SUMMARY, USAGE PARAMETERS
(NAMELIST/ULST) (Continued)

THE ANALYTIC SCIENCES CORPORATION

USAGE PARAMETERS - CONTINUED VALUE		DESCRIPTION
FRACTION OF A GIVEN FOOD TYPE COMING FROM EACH PATHWAY		
1.00000E-01	F(1,1)	RIVER FISH
0.0	F(2,1)	RIVER CRUSTACEANS
0.0	F(3,1)	RIVER MOLLUSKS
4.00000E-01	F(1,2)	ESTUARY FISH
1.00000E+00	F(2,2)	ESTUARY CRUSTACEANS
1.00000E+00	F(3,2)	ESTUARY MOLLUSKS
1.25000E-01	F(1,3)	PLUME FISH
0.0	F(2,3)	PLUME CRUSTACEANS
0.0	F(3,3)	PLUME MOLLUSKS
3.75000E-01	F(2,4)	OCEAN FISH
0.0	F(1,4)	OCEAN CRUSTACEANS
0.0	F(3,4)	OCEAN MOLLUSKS
SHIELDING OR GEOMETRY FACTOR FOR EACH COMPARTMENT		
0.0	W(1)	RIVER WATER
0.0	W(2)	ESTUARY WATER
0.0	W(3)	PLUME WATER
0.0	W(4)	OCEAN WATER
3.30000E-01	W(5)	TOPSOIL
2.00000E-01	W(6)	RIVER SEDIMENT
1.00000E+00	W(7)	ESTUARY SEDIMENT
5.00000E-01	W(8)	OCEAN SHORELINE
AREA OF EACH COMPARTMENT IN M**2		
2.00000E+09	A(1)	RIVER WATER
1.40000E+08	A(2)	ESTUARY WATER
1.25000E+10	A(3)	PLUME WATER
1.50000E+11	A(4)	OCEAN WATER
4.80000E+09	A(5)	TOPSOIL
2.00000E+09	A(6)	RIVER SEDIMENT
1.40000E+08	A(7)	ESTUARY SEDIMENT
4.00000E+05	A(8)	OCEAN SHORELINE
VOLUME OF EACH COMPARTMENT IN M**3		
1.20000E+09	VOL(1)	RIVER WATER
2.60000E+09	VOL(2)	ESTUARY WATER
2.50000E+11	VOL(3)	PLUME WATER
6.00000E+12	VOL(4)	OCEAN WATER
7.20000E+08	VOL(5)	TOPSOIL
6.10000E+08	VOL(6)	RIVER SEDIMENT
4.30000E+07	VOL(7)	ESTUARY SEDIMENT
1.00000E+00	VOL(8)	OCEAN SHORELINE
AVERAGE POPULATION USE OF EACH COMPARTMENT IN HR/M**2/YR EXCEPT TOPSOIL IS IN HR/YR		
1.30000E-02	USER(1)	RIVER WATER
0.0	USER(2)	ESTUARY WATER
0.0	USER(3)	PLUME WATER
0.0	USER(4)	OCEAN WATER
8.76000E+03	USER(5)	TOPSOIL
2.25000E-02	USER(6)	RIVER SEDIMENT
0.0	USER(7)	ESTUARY SEDIMENT
0.0	USER(8)	OCEAN SHORELINE
5.00000E-05	POPDEN	POPULATION DENSITY IN PEOPLE/M**2
FRACTION OF SWIMMING TIME		
1.00000E+00	SWINT(1)	RIVER
0.0	SWINT(2)	ESTUARY
0.0	SWINT(3)	PLUME
0.0	SWINT(4)	OCEAN
3.00000E-01	THETA	AVERAGE VOLUMETRIC WATER CONTENT OF TOPSOIL

TABLE 3.2-5
BIODOSE INPUT DATA SUMMARY, VEGETABLE PARAMETERS
(NAMELIST/VEGLST/)

VEGETABLE PARAMETERS VALUE	MEMORIC	DESCRIPTION
5.00000E+00	VIR(1)	CROP IRRIGATION RATE IN L/M**2/DAY
5.00000E+00	VIR(2)	LEAFY VEGETABLES
5.00000E+00	VIR(3)	OTHER ABOVE GROUND VEGETABLES
5.00000E+00	VIR(4)	OTHER ROOT VEGETABLES
5.00000E+00	VIR(5)	BERRIES
5.00000E+00	VIR(6)	MELONS
5.00000E+00	VIR(7)	WICKETED FRUIT
5.00000E+00	VIR(8)	WHEAT
5.00000E+00	VIR(9)	OTHER GRAINS
5.00000E+00	VIR(10)	GRASS
1.50000E+00	Y(1)	CROP YIELD IN KG/M**2 (WET WEIGHT)
7.00000E-01	Y(2)	LEAFY VEGETABLES
5.00000E+00	Y(3)	OTHER ABOVE GROUND VEGETABLES
5.00000E+00	Y(4)	OTHER ROOT VEGETABLES
2.70000E+00	Y(5)	BERRIES
8.00000E-01	Y(6)	MELONS
7.00000E-01	Y(7)	WICKETED FRUIT
7.20000E-01	Y(8)	WHEAT
1.50000E+00	Y(9)	OTHER GRAINS
1.30000E+00	Y(10)	GRASS
9.00000E+01	TEXP(1)	TIME OF EXPOSURE TO RADIATION DURING GROWING SEASON IN DAYS
6.00000E+01	TEXP(2)	LEAFY VEGETABLES
9.00000E+01	TEXP(3)	OTHER ABOVE GROUND VEGETABLES
9.00000E+01	TEXP(4)	OTHER ROOT VEGETABLES
6.00000E+01	TEXP(5)	BERRIES
9.00000E+01	TEXP(6)	MELONS
9.00000E+01	TEXP(7)	WICKETED FRUIT
9.00000E+01	TEXP(8)	WHEAT
3.00000E+01	TEXP(9)	OTHER GRAINS
3.00000E+01	TEXP(10)	GRASS
1.00000E+00	TV(1)	FRACTION OF DEPOSITED ACTIVITY ON EDIBLE PORTIONS OF VEGETABLES
1.00000E-01	TV(2)	LEAFY VEGETABLES
1.00000E-01	TV(3)	OTHER ABOVE GROUND VEGETABLES
1.00000E-01	TV(4)	OTHER ROOT VEGETABLES
1.00000E-01	TV(5)	BERRIES
1.00000E-01	TV(6)	MELONS
1.00000E-01	TV(7)	WICKETED FRUIT
1.00000E-01	TV(8)	WHEAT
1.00000E-01	TV(9)	OTHER GRAINS
1.00000E-01	TV(10)	GRASS
2.50000E-01	R	FRACTION OF DEPOSITED ACTIVITY RETAINED ON CROPS

TABLE 3.2-6
 BIODOSE INPUT DATA SUMMARY, WATER PARAMETERS
 (NAMELIST/WLIST/)

WATER PARAMETERS VALUE	MNEMONIC	DESCRIPTION
1.15200E+11	FLOW(1)	RIVER FLOW RATE IN M**3/YR (NET OUTFLOW RATE)
2.00000E+05	FLOW(2)	WELL FLOW RATE IN M**3/YR (GROSS OUTFLOW RATE)
6.64930E-03	TE	FLUSHING TIME OF ESTUARY IN YEARS
3.33000E-01	TO	FLUSHING TIME OF OCEAN IN YEARS
4.80000E+09	WRATE(1)	RATE AT WHICH WATER IS WITHDRAWN FROM RIVER FOR IRRIGATION IN M**3/YR
1.70000E+05	WRATE(2)	RATE AT WHICH WATER IS WITHDRAWN FROM WELL FOR IRRIGATION IN M**3/YR
2.50000E-01	FVEG(1)	FRACTION OF IRRIGATION RATE USED FOR IRRIGATING CROPS FOR HUMAN USE
2.50000E-01	FVEG(2)	FRACTION OF TOTAL WELL WITHDRAWAL USED FOR IRRIGATING CROPS FOR HUMAN USE
3.70000E-05	FDRINK(1)	FRACTION OF TOTAL RIVER FLOW USED BY POPULATION FOR DRINKING
1.40000E-04	FDRINK(2)	FRACTION OF TOTAL WELL WITHDRAWAL USED BY POPULATION FOR DRINKING

TABLE 3.2-7
NUCLIDE PARAMETERS (NAMELIST/NUCLST/)

MNEMONIC	DESCRIPTION*
DF50	Dose commitment factors for chronic exposure over 50 years
B	Water accumulation factors
FKT	Soil retention factor
BV	Plant concentration factor
SA	Transfer coefficients for animal products
TR	Atomic half life
BHL	Effective half life in seven organs
NCAT	Nuclide category number
FKS	River sediment concentration factor
FKSE	Estuary sediment concentration factor
TREAT	Fraction of nuclide remaining in water after treatment
NAME	Chemical name of nuclide

*Default values and units are displayed in output listings (available upon request).

TABLE 3.2-8
INVENTORY INPUT (NAMELIST/INVLST/)

MNEMONIC	DESCRIPTION*	UNITS
TIMEIN	Nuclide inventory time	Years
VIN	Nuclide inventory value	Ci/Mwe-yr per year

*Default values are displayed in output listings (available upon request).

There are only a relatively few general rules which govern the specification of values for input parameters through a NAMELIST. Let STATUS represent a general NAMELIST name. Then, the first card in the input deck must contain a blank in the first column, &STATUS starting in the second column, and a blank in column 9. The specification of individual data items then begins in column 10 of the first data card and continues on succeeding cards if necessary. A data item for an unsubscripted variable is of the form $v=c$ where v is the program mnemonic and c is a constant (e.g., NTRIAL=10 and END=10.0). Data items for subscripted variables are of the form $a=d_1, \dots, d_j$ or the form $a(n)=d_1, \dots, d_m$ where a is the array name, n is an integer constant, and the d_i are simple constants or repeated constants of the form k^*c where i is the repetition factor. With the unsubscripted array name, the total number of constants must equal the number of elements in the array (e.g., GL=5.0, 5.0, 15.0). With the subscripted array name, the total number of constants need not equal, but may not exceed, the number of array elements needed to fill the array starting with $a(n)$ (e.g., ALAMB(1)=2.0 and PDIAG(8)=1.E7, 2.5E5). All data items must be separated by commas, and any desired number of blanks may be inserted between data items.

The end of a NAMELIST record is indicated by a &END after the last data item. The &END may appear directly after the last constant in the data item or may be separated by one or more blanks. For convenience in adding data items to a given NAMELIST, a comma may always be inserted after the last data item and the &END for the end of the NAMELIST may be placed on the next card.

Three other important points regarding NAMELIST input data should be made. First, there are no restrictions on the order in which the data items are arranged within the list.

Second, the first column of every data card, not just the first card, must be left blank; all other 79 columns may be used. Third, the name of every NAMELIST to be read must appear in the input deck, even if no data items are specified for some NAMELIST.

The inventory file, to be read by the subroutine INVRD, should be associated with the value of IOFILE. The variables are listed in the order of the file in Table 3.2-9. The format of the data should be compatible with a FORTRAN unformatted READ statement.

TABLE 3.2-9
INVENTORY INPUT FILE VARIABLES

LNUC [*]
LXTIME [*]
TITLE(18) [†]
TIMEIN(MXTIME)
VIN(MXTIME,LNUC)

* LNUC is the number of nuclides (must equal NNUC)
LXTIME is the number of time points (must equal MXTIME)

† This title which identifies the inventory type is printed on the second line of every page of output.

The nuclide-specific parameter file to be read by the subroutine NUCRD should be on logical device number 10. The format should be compatible with FORTRAN unformatted READ statement. The variables are listed in order in Table 3.2-10.

TABLE 3.2-10
NUCLIDE-SPECIFIC PARAMETER FILE VARIABLES

DF50(NNUC,3,9)
B(NNUC,2,3)
FRT(NNUC)
BV(NNUC)
SA(NNUC,5)
TR(NNUC)
BHL(NNUC,7)
NCAT(NNUC)
FKS(NNUC)
FKSE(NNUC)
TREAT(NNUC,2)
NAME(NNUC,2)

3.3 PROGRAM OUTPUTS

There are two types of printed outputs. The input data summary is described in Section 3.2. The final results are printed in a series of tables which show the potential hazards (in rem/MWe or man-rem/MWe-yr for the individual or population, respectively) to each body organ over time. These tables are printed selectively, depending on the value of the control array SUMS. (The array SUMS is described in Table 3.2-1.)

Each report is headed by a title that describes the type of run (average individual, maximum individual, or population) and the category of nuclides in the table. The next

line contains the inventory title, the third line identifies the path category, and the fourth line identifies the compartment. The potential hazards are printed in a table with the time axis running down the page and the organ running across the page. These are the potential hazards received by the target organ at the time stated. The 'BODY EQUIVALENT' category shows the average, weighted by cancer risks.

APPENDIX A
SUBPROGRAM CROSS-REFERENCE AND
COMMON BLOCK CROSS-REFERENCE

TABLE A-1
 SUBPROGRAM CROSS REFERENCES
 Calling Subprogram*

	MAIN	COMPUT	CONCNT	DOSE	EQUAL	INPUT	OUTPUT	TIMVAR
CALC		X						
COMPUT	X	X						
CONCNT		X						
DOSE							X	
EQUAL		X						
EIGRF								X
INIT						X		
INPUT	X					X		
INVRD						X		
LINV2F								X
MFG					X			
MULT								X
NUCOUNT						X		
NUCRD						X		
OUTPUT	X							
PLTDOS				X				
PRNT				X				
SETUP					X			X
TIMVAR		X						
TRNP								X
USERAT		X						
ZERO			X	X	X			X

*Subprograms not calling other subprograms are not listed.

TABLE A-2
COMMON BLOCK CROSS REFERENCES

Common Block

	ANPAR	BIOPAR	COMPAR	INVPAR	NUCPAR	SOIPAR	SYSPAR	UPAR	VEGPAR	WPAR
BLKGEN	X					X	X	X	X	X
BLKINV				X						
BLKNUC					X					
CALC	X	X			X	X	X	X	X	X
COMPUT					X		X			
CONCNT				X	X	X	X	X		X
DOSE		X		X	X		X			
EQUAL			X	X	X		X			
INIT					X		X			
INPUT	X			X	X	X	X	X	X	X
INVRD				X			X			
NUCOUT				X	X		X			
NUCRD					X					
OUTPUT							X			
PLTDOS				X			X			
PRNT				X	X		X			
SETUP			X		X	X	X	X		X
TIMVAR			X	X	X	X	X	X		X
USERAT	X						X	X	X	X

REFERENCES

1. Berman, L.E., et al., "Analysis of Some Nuclear Waste Management Options," The Analytic Sciences Corporation, Report No. TR-1103-1-1, Lawrence Livermore Laboratory Report No. UCRL-13917, October 1978.
2. Strom, P.O., and Watson, E.C., "Calculated Doses from Inhaled Transuranium Radionuclides and Potential Risk Equivalence to Whole-Body Radiation," Transuranium Nuclides in the Environment, IAEA, Vienna, 1976, pp. 603-626.
3. Burkholder, H.C., et al., "Incentives for Partitioning High-Level Waste," Battelle Pacific Northwest Laboratories, BNWL-1927, November 1975.
4. "Reactor Safety Study: An Assessment of Accident Risk in U.S. Commercial Nuclear Power Plants. Appendix VI. Calculation of Reactor Accident Consequences," U.S. Nuclear Regulatory Commission, WASH-1400, October 1975.
5. "Calculation of Annual Dose to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I," U.S. Nuclear Regulatory Commission, Office of Standards Development, Regulatory Guide 1.109, March 1976.
6. "IMSL Library 1 Reference Manual, Volume 1," Edition 6, International Mathematical and Statistical Libraries, Inc., Houston, Texas, IMSL LIB1-0006, July 1977.
7. Ross, B.I., Koplik, C.M., Giuffre, M.S., Hodgins, S.P., and Duffy, J.J., "NUTRAN: A Computer Model of Long-Term Hazards from Waste Repositories," The Analytic Sciences Corporation, Report No. TR-1797-7, December 1979.
8. Integrated Software Systems Corporation, "DISSPLA User's Manual," Version 7.5, December 1978.