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CONDOS—A Model and Computer Code to Estimate Population and Individual Radiation Doses to Man from the Distribution, Use, and Disposal of Consumer Products that Contain Radioactive Materials

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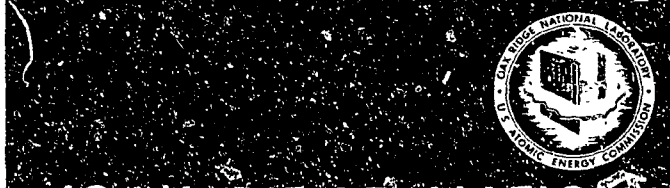
Environmental Sciences Division Publication No. 638



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CONDOS--A MODEL AND COMPUTER CODE TO ESTIMATE POPULATION AND INDIVIDUAL RADIATION DOSES TO MAN FROM THE DISTRIBUTION, USE, AND DISPOSAL OF CONSUMER PRODUCTS THAT CONTAIN RADIOACTIVE MATERIALS

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F. R. O'Donnell, O. W. Burke, F. H. Clark, and L. R. McKay

ABSTRACT

A model and computer code (CONDOS) are described that estimate radiation doses to man from distribution, use, and disposal of a variety of consumer products that contain radioactive materials. CONDOS utilizes a generalized format in which the life span of a consumer product is divided into five main stages (distribution, transport, use, disposal, and emergencies) that require descriptions of the activities by which man may be exposed to the product (events) during each stage. These descriptions identify homogeneous groups of exposed persons and, thus, facilitate the selection of individuals who represent the exposed groups. The radiation doses associated with one year of product use to the total body and to selected reference organs and tissues of representative individuals can be estimated for each mode of exposure that is applicable to each event. Summation of the doses to representative individuals yields group and total population doses. An example of the use of CONDOS is given; the radiation doses associated with a hypothetical product are estimated for assumed conditions of exposure.

1. INTRODUCTION

A variety of consumer products containing radioactive materials are available to, or are being developed for use by, the general public.[1] These consumer products include a diversity of items, such as timepieces containing tritium or promethium-147, incandescent gas mantles containing thorium, and certain types of glazed ceramic tableware containing uranium. The distribution, use, and disposal of such products can present situations (events) in which man may receive radiation doses. Estimates of the dose equivalents[a] that might be received by individuals, groups of individuals, and the entire population are required for evaluation of the radiological impacts associated with the consumer products.

A model and computer code (CONDOS) are being developed to provide a methodology for systematically estimating the radiation doses to man from such a diversity of consumer products. The model divides the life span of a consumer product into five main stages and provides a guide for description of the events. These descriptions identify homogeneous groups of exposed persons and, thus, facilitate the selection of individuals who represent the exposed population groups. The radiation doses associated with one year of product use to the total body and to the skin of the representative individuals can be estimated for each mode of exposure that is applicable to each event. Summation of the doses to representative individuals yields estimates of group and total population doses.

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[a]Dose equivalent (rem) = absorbed dose (rad) X modifying factors. For the sake of convenience, "dose" is often interchanged with "dose equivalent" in this report.

A total dose has two components. One component results from radionuclides[b] outside the body (external exposure), and the other component results from nuclides deposited in the body (internal exposure).[c] External exposure is considered, according to the relevant exposure modes, in Section 3.1, and internal exposure is considered, according to the relevant modes of nuclide deposition, in Section 3.2.

The generalized model and the product information and mathematical techniques required to program the model are presented in Sections 2 and 3. A description of the FORTRAN -IV program CONDOS is presented in Section 4. The present version of the program provides estimates of the radiation doses, to the total body (from all radiations) and to the hands (from beta particles), associated with one year of distribution, use, and disposal of a consumer product containing natural uranium or thorium. The capability to provide dose estimates to other selected body organs and tissues will be provided in a future version of the program. Additional nuclides will be added to the data file so that a greater variety of products can be investigated.

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[b]For the sake of convenience, "radionuclide" is shortened to "nuclide" in this report.

[c]"Dose commitment" is frequently used to represent the total internal dose that will be received over a specified time period after intake of radioactive material (e.g., a 50-year dose commitment is the internal dose that will be delivered during the first 50 years after intake). This concept is used in this report. All internal doses are the 50-year dose commitments from intake of the radioactive material during the year being considered. Total doses to individuals and populations are the sums of the appropriate annual external doses and the appropriate 50-year dose commitments.

2. THE MODEL

The estimation of radiation doses to man from a consumer product requires (1) a description of the product; (2) a description of the life span of the product; (3) the identification and description of events, i.e., actions or acts by which man may be exposed to radiation from the product; (4) a determination of the conditions and modes of exposure relevant to each event; (5) a definition of all persons who may be exposed to radiation from the product; (6) the estimation of doses that may be received by each person exposed; and (7) an estimation of the total population dose attributable to the product.

The CONDOS model provides a guide for the implementation of items (1) through (5) and provides a mechanism for the achievement of (6) and (7). This model is described in the following sections.

2.1 Product Description

A description of the consumer product to be assessed, although not a part of the model per se, is required by the model. Such a description provides the basic information to be used in the estimation of doses and in the selection of parts of the product life span model that are applicable to the specific consumer product. The following information is required:

1. names and quantities of the nuclides in the radioactive material which is in or on the product;

2. chemical and physical characteristics of the radioactive material, especially those that may be significant in the determination of release rates for the material, e.g., leach rate, vapor pressure, etc.;

3. density and thickness of the radioactive material;

4. density and thickness of the matrix (including the radioactive material) in which the radioactive material is incorporated;

5. density and thickness of any protective materials that may cover the radioactive material;

6. geometry of the product or of collections of the product, e.g., a shipping package;

7. identification of possible uses of the product;

8. identification of the means of transport, distribution, repair, and disposal of the product; and

9. identification of accident or misuse conditions to which the product might be subjected.

2.2 Model of Product Life Span and Conditions of Exposure

The model of the life span of a consumer product is outlined in Fig. 1, and the components that should be considered in completing the outline are listed in Table 1. The life span of a product is divided into five main "stages"--distribution, transport, use, disposal, and emergency or misuse situations. Although both distribution and transport are part of the physical transfer of the product from manufacturer to user, Table 1 shows that transport describes shipments of the product and distribution describes the presence of the product in distribution facilities such as warehouses.

Each stage is divided into a set of "substages" that delineate the general types of activities by which man could be exposed to the product.

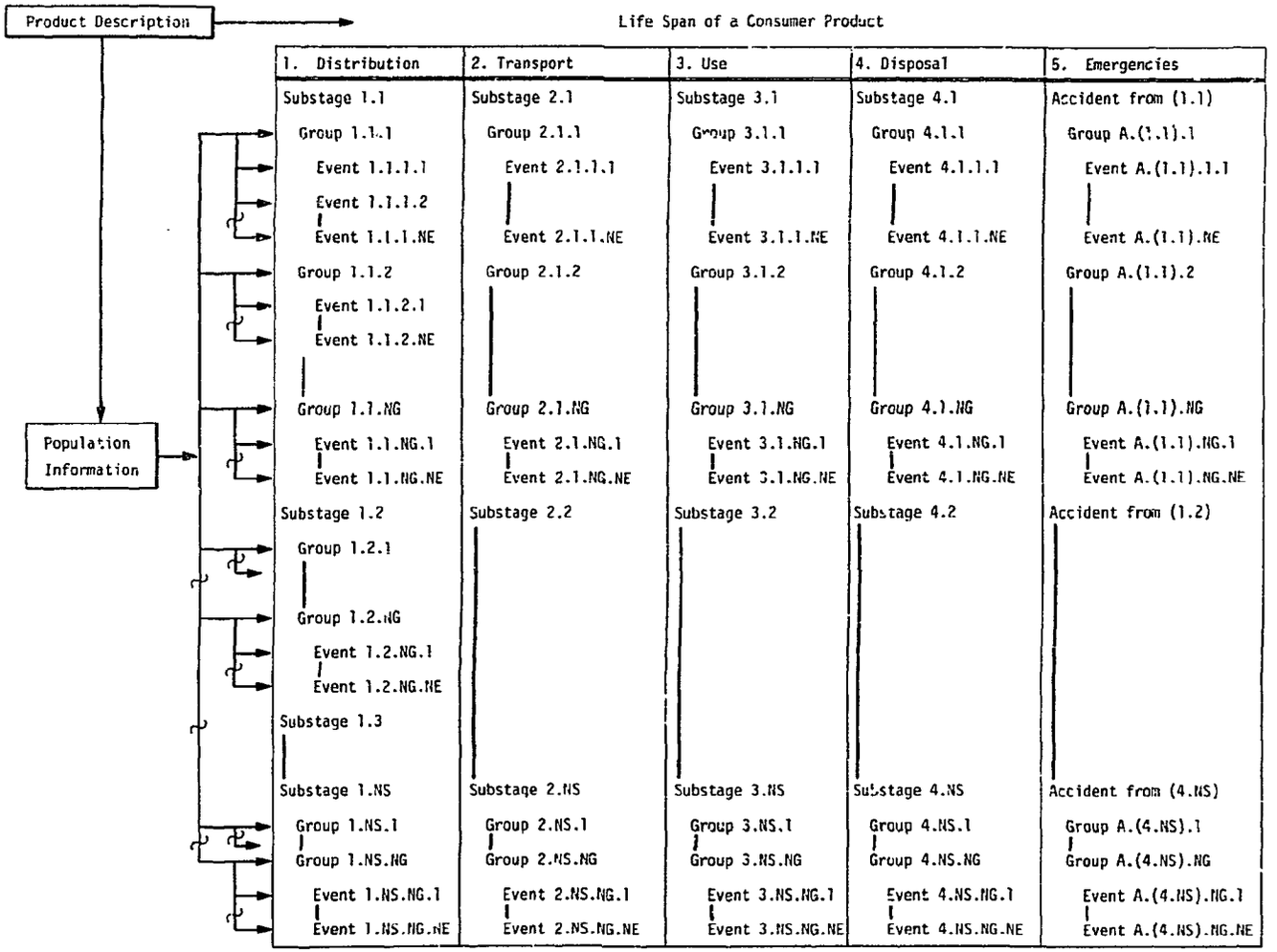

Figure 1. Outline of model of the life span of a consumer product.

Table 1. List of components to be considered in modeling the life span of a consumer product

Stages	Substages	Groups	Events (same for all groups)
Distribution	Factory	Sorters, packers, inspectors, handlers other workers, visitors, neighbors, passersby, any others	Each normal group activity, each accident or misuse
	Wholesale	See factory groups	
	Retail	Receivers, stock clerks, sales people, cashiers, other workers, examining customers, other customers, neighbors, passersby, others	
	Representative	Representatives, customers, customers' neighbors, people along representatives' routes, others	
Transport	Truck-long haul	Loaders, drivers, helpers, service personnel, people at truck stops, people along routes, passing motorists, others	
	Truck-short haul	See truck-long haul	
	Truck-local delivery	See truck-long haul	
	Rail	Loaders, train crewmen, passengers, other rail workers, people in stations, people along railways, others	
	Air	Loaders, flight crew, passengers, other workers, people at airports, people along flight routes (accidents only), others	
	Bus	Drivers, passengers, depot workers, depot visitors, service personnel, people at bus stops, people along routes, passing motorists, others	

Table 1. List of components to be considered in modeling the life span of a consumer product (continued)

Stages	Substages	Groups	Events (same for all groups)
	Water	Loaders, crew, passengers, other dock workers, passing boats, people along waterways, people at docks, others	Each normal group activity, each accident or misuse
	Mail	Handlers, sorters, carriers, other postal workers, post office visitors, other substages for long distance mail, people along delivery routes	
Use	Use No. 1 Use No. 2 Etc.	Specify user groups whose methods of use are significantly different (e.g., use no. 1, 2,..., frequent users, occasional users, etc.), people present during use, passersby, neighbors to users, others - similar for all uses	
	Maintenance	Maintenance-men, other workers, visitors, neighbors, others	
	Repair	Repairmen, other workers, visitors, neighbors, others	
Disposal	Collection	Collectors, drivers, unloaders, people along collection routes, passersby, others	
	Incineration	Facility operators, nearby residents, distant residents, people who frequent the area of the facility, passersby, others	
	Open-pit burning	See incineration	
	Conical burning	See incineration	
	Maceration	See incineration	

Table 1. List of components to be considered in modeling the life span of a consumer product (continued)

Stages	Substages	Groups	Events (same for all groups)
	Compaction	See incineration	Each normal group activity, each accident or misuse
	Sanitary landfill	See incineration	
	Dump	See incineration	
	Other methods	See incineration	
Emergencies	List each accident or misuse considered in the preceeding groups	Firemen, policemen, medical teams, other emergency workers, nearby residents, passersby, other people involved in accident or misuse, spectators, others	

These activities are made more specific by subdivision into "groups" of functionally related activities.

Population information is supplied to the model at this point by determination of the number of persons engaged in the activities of each group and exposed to the product as a result of those activities. These persons are called group members.

The group activities are further divided into a set of actions during which group members may be exposed to the product--the "events". An event description contains the parameters required to solve the dose equations and defines an individual typical of the group exposed. This individual may be an average group member (one who represents the entire group), the maximally exposed member, or any other group member. The radiation doses estimated for each event are doses that the selected individual may receive from that event. Since the event descriptions prescribe the parameters to be used in the solutions of the dose equations, the correspondence of the events described with reality and how well they are described determine how well the estimated doses reflect actual doses.

The description of an event must include the following parameters, unless certain computer program options (Section 4.5) are selected:

1. the probability that a member of the group will be involved in the event,

2. the time periods during which the individual will experience each mode of exposure,

3. the amount of radioactive material in the product.

4. the number of point sources chosen to represent the source,

5. the Cartesian coordinates of each point source and of the receptor,

6. the attenuation (shielding) factor for the composite of all materials between each point source and the receptor,

7. the amount of radioactive material ingested,

8. the concentration of radioactive material in air,

9. the effective radius of the room in which the material is airborne,

10. the rate of leakage of material from the product to the room or the total amount of material that has leaked into the room,

11. the air turnover rate for the room, and

12. the volume of the room.

Some of the substages and groups listed in Table 1 may not be required to model the life span of a particular consumer product. The modeler is responsible for choosing the substages, groups, and events that are appropriate to the description of the life span and for deleting those that are not appropriate.

All event descriptions must be supplied by the user of this version of CONDOS. The inclusion of a set of standard events which the user may select is being considered for a future version. Descriptions of the normal activities of the members of each group may require specification of more than one event because some of the activities may present very different conditions of exposure. Similarly, more than one accident or misuse event may be required.

2.3 Methodology for Estimation of Radiation Doses to Man

The methodology used in CONDOS for the estimation of potential radiation doses to man from a consumer product containing radioactive

material consists of three parts: information assembly, life span model construction, and dose estimation. This section shows how the three parts are combined to form the methodology. Figure 2 illustrates the flow of operations used in the methodology.

Product information (Section 2.1) and population information (the number of persons potentially exposed to the product and their behavioral patterns in exposure situations) are gathered and sorted. This information is used to construct the life span model for the consumer product.

The model is constructed, as shown in Figure 2, by division of each of the five stages (1. - 5.) into an appropriate set of substages, e.g., stage "3. Use" is divided into substages 3.1,...,3.X,...,3.NS. Each substage is then divided into a set of groups, e.g., substage 3.X is divided into groups 3.X.1,...,3.X.Y,...,3.X.NG. The number of persons (NM) in each group[a] is determined at this point. The various activities by which the members of each group may be exposed to the product (the events) are identified next for each group, e.g., group 3.X.Y is involved in events 3.X.Y.1,...,3.X.Y.Z,...,3.X.Y.NE.

The model is completed by selection of an individual from the group who partakes in one event, description of the event, and repetition of the selection and description process for every event identified for every group. The individual selected determines how the event should be described and, thus, determines the conditions of exposure that will

---

[a]NM may be taken as the total number of group members (e.g., all countermen who work in diners) or may be restricted to the number of group members potentially exposed to the product (e.g., all countermen who work in diners that use the product). Selection of the restricted number is preferred.

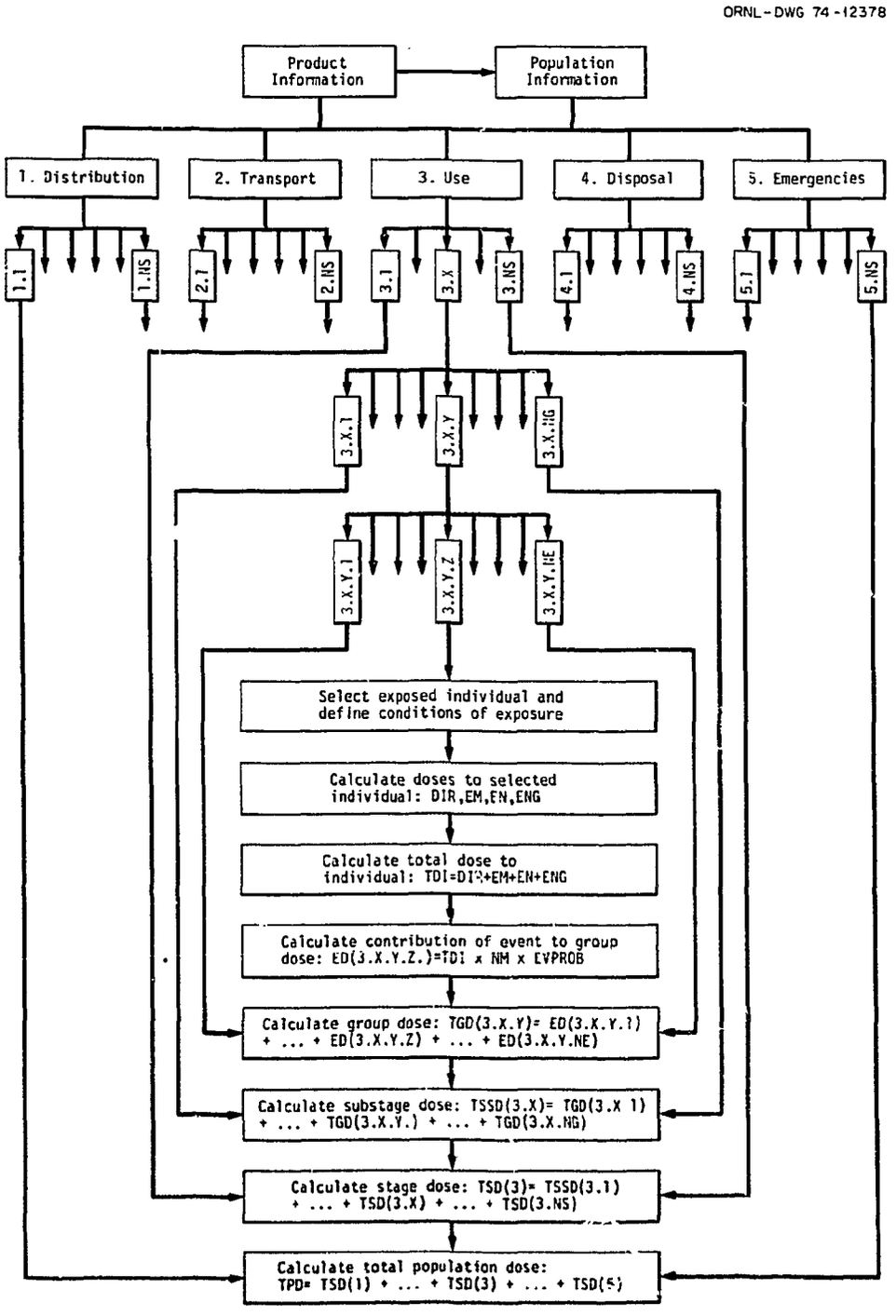

Figure 2. Flow diagram of the methodology for estimation of radiation doses to man from a consumer product containing radioactive material.

be used to quantify the parameters required to solve the dose equations. If an average individual (one who represents the entire group) is selected, average conditions of exposure are chosen in the event description. If the maximally exposed individual is selected, conditions of maximum exposure are selected. The selection of individuals should be consistent for all events and for all groups, i.e., only average individuals should be selected, or only maximally exposed individuals should be selected.

Each event description is input to the computer code (Section 4). The conditions of exposure for each event, e.g., event 3.X.Y.Z in Figure 2, are used to calculate potential radiation doses to the total body (Section 3) of each selected individual by four exposure pathways: direct exposure to gamma rays (DIR) emitted from the radioactive material in or on the product, immersion in air contaminated with radioactive material (EM) released from the product, and ingestion (ENG) and inhalation (EN) of released material. The total dose to the individual (TDI) is the sum of the doses delivered via the four exposure pathways. Each TDI contributes to the collective dose received by all group members (the group dose, TGD). The contribution of each TDI is called an event dose, e.g., ED(3.X.Y.Z), and is quantified by weighting TDI by NM and by the joint probability (EVPROB)[a] that a group member will partake in the event and that the event will occur. An ED is calculated for each event.

---

[a] If an average individual participates in a common event (one that will occur every time the group is exposed to the product), EVPROB = 1. If the maximally exposed individual is involved, EVPROB = 1/NM. For other individuals $1 \geq \text{EVPROB} \geq 1/\text{NM}$. If the event is not a common one, its probability of occurrence will be <1, e.g., = P. In this case, for the individuals noted above, EVPROB = P, P/NM, or in general, $P \geq \text{EVPROB} \geq P/\text{NM}$, respectively.

Population doses, the sum of the total body doses to each member of a population group, are estimated for each group, substage, stage, and the entire population as follows. Group doses are the sum of the appropriate event doses, e.g., $TGD(3.X.Y.) = \sum_{Z=1}^{NE} ED(3.X.Y.Z)$. A TGD is calculated for all the groups that form a substage, e.g., 3.X.1,..., 3.X.NG, and the substage dose is estimated by summation of the pertinent group doses, e.g., $TSSD(3.X) = \sum_{Y=1}^{NG} TGD(3.X.Y)$. A TSSD is estimated for all substages delineated in the model. The potential collective dose to all persons involved in a stage of the product life span is obtained by summation of the appropriate substage doses, e.g., $TSD(3) = \sum_{X=1}^{NS} TSSD(3.X)$. A similar sequence of calculations is made to obtain the remaining TSDs, and the total population dose associated with one year of product availability is estimated by $TPD = \sum_{S=1}^{5} TSD(S)$.

CONDOS also provides an estimate of the radiation dose to the skin from contact with a product containing radioactive material that emits beta particles. The present version of the computer code estimates this beta dose only for a single event, and provides the estimated dose for a specified period of contact (Section 3.1.3). The computer code is listed in Appendix D.

2.4 Discussion

CONDOS provides a methodology for estimating potential radiation doses to man from consumer products containing radioactive materials. These doses can, in principle, be estimated fairly accurately. That is,

the dose equations (Section 3) will calculate the doses fairly accurately if the input data from the "real-world" descriptions of the product and its life span are accurate. Thus, the accuracy of the dose estimates is limited essentially by the accuracy of the "real-world" descriptions.

A product can be well defined, but such a definition will frequently be unavailable. A manufacturer may be unable to supply the type of information needed (He might not have it). For example, a product might be described as tableware coated with a ceramic glaze containing 14 wt% uranium. The desired description would specify the numbers, sizes, and shapes of the various forms of tableware, the composition, and thickness of the glaze, and the identities and quantities of the nuclides present. In addition, several manufacturers of the product could exist, and each might manufacture a product with a design that is different from the designs of all other manufacturers.

The life span of a product cannot be defined precisely. Each of the infinitely large number of possible events that can occur during distribution, use, and disposal of a product cannot be considered individually. An average, or typical, event that represents many closely related events must be constructed, if the modeler is not to be overwhelmed by voluminous amounts of data. Such a construction must introduce uncertainties in the data. For example, a person might spend 8 hr/day between 1 and 100 m from a source with various absorbers between the person and the source. An accurate description, which might require 100 events, would specify the time, distance, and absorber for each different event. Construction of the average event might describe an exposure of 8 hr/day at 50 m with an average shielding factor to account

for the absorbing material. If the relative movements of products and individuals and the interposition of several, mostly uncharacterized, absorbers during these movements are considered, the complexity of life span definition becomes apparent.

Because of the uncertainties and variations possible in product definition and life-span modeling, some input parameters used to solve the dose equations could be in error by as much as a factor of 10. Careful selection of the parameters could reduce the errors appreciably.

The expected errors in input data were considered in and have influenced the models of the dose equations. Some of the calculations and nuclear data files were simplified by procedures that might introduce a combined error of less than $\pm$ 10% into the dose estimates. This error is small compared with expected input data errors. The sources of the errors are discussed in other sections of this report.

Another important factor is that the present version of CONDOS is designed primarily to estimate doses from products containing natural uranium or thorium. Therefore, the dose equation models and computer program logic are designed to accommodate heavy-element decay chains, not individual nuclides. However, this does not restrict the utility of CONDOS, because only minor modifications in certain program functions are required to add such a capability.

3. MATHEMATICAL MODELS OF THE DOSE CALCULATIONS

The potential doses from a consumer product to representative individuals and population groups that are considered by CONDOS are discussed in Section 2.3. The mathematical equations and their models,

as they appear in the computer code, are presented here. Appendix D is a listing of the computer code.

3.1 External Exposure

The modes of external exposure considered in CONDOS are direct irradiation, immersion in a contaminated cloud, and contact with a beta-particle-emitting surface.

3.1.1 Dose from direct irradiation

The direct radiation dose, in an absorbing medium, from gama photons emitted from a consumer product represented by an array of point sources is computed by the equation:[2]

$$DE = \frac{f \cdot (MF)}{4\Pi} \sum_{k=1}^{NP} \sum_{i=1}^{NG} E_{ik}\, C_{ik}\, B_{ik} \left(\frac{S_{ik}}{r_k^2}\right) \exp\left(-\mu_{ik}\, r_k\right)$$

where

DE = dose equivalent rate (rem/hr),

i = photon index,

k = source index,

NG = number of photons emitted by k th source,

NP = number of point sources,

f = dose conversion factor (rad/r),

MF = modifying factor (rem/rad),

E_{ik} = energy (MeV/photon) of i th photon emitted by k th source,

C_{ik} = exposure rate-energy flux ratio ($r\text{-}hr^{-1}/MeV\text{-}cm^{-2}\text{-}sec^{-1}$) for photon energy E_{ik},

B_{ik} = dose build-up factor (dimensionless) for i th photon from k th source in the chosen absorbing medium, a function of E_{ik} and $\mu_{ik}r_k$,

S_{ik} = emission rate (photons/sec) of the i th photon from the k th point source,

μ_{ik} = linear attenuation coefficient (cm^{-1}) for i th photon from k th source in chosen absorbing medium,

r_k = distance (cm) from k th source to receptor.

A typical consumer product will contain several nuclides that are part of a decay chain. Therefore, a simple counting of photons of various energies becomes complicated. A general method for counting photons is adopted in CONDOS. The gamma ray energy spectrum is divided into 25 energy intervals (see Appendix A) and the photons emitted by each nuclide are placed in the appropriate energy interval. In addition, all energy-dependent quantities are defined in terms of these energy intervals and those that are stored as data variables in the code are listed in Appendix A.

Since the source term for a consumer product will probably be given as the number of grams of radioactive material contained, a method for relating the amount of each nuclide present in the material is provided. Since only natural uranium and thorium are of present interest, the factors necessary to convert from grams of material to photons of a specific energy/sec are provided in the code as data variables. These variables are also listed in Appendix A.

The model of the dose equation for direct irradiation is:

$$DIR = 79.6*TDIR* \sum_{I=1}^{NGINT} ENRGY(I)*CONVR(I)* \sum_{J=1}^{NN} ACT(J)*FGM(I,J)* \sum_{K=1}^{NP} S(K)*ATN(I,K)*AATN(K)*R(K)^{-2} \quad (1)$$

where

DIR = direct dose equivalent rate (mrem/year),

I = energy interval index,

J = nuclide index,

K = source index,

NGINT = number of photon energy intervals,

NN = number of nuclides in the product,

NP = number of point sources,

79.6 = dimensional conversion factor (1000 mrem-rem^{-1}/4π),

TDIR = duration (hr/year) of exposure,

IEL = radioactive material index (1 → thorium; 2 → uranium),

ENRGY(I) = average energy (MeV/photon) of a photon in the I th energy interval,

CONVR(I) = exposure rate-energy flux ratio for I th energy photons, (r-hr^{-1}/MeV-cm^{-2}-sec^{-1})

ACT(J) = YI(J)*RA(J)*CH(J)*AVO*DEC(IEL)/3600

= disintegration rate (dps/g) of J th nuclide per gram of IEL th material,

YI(J) = abundance (g/g) of the mother nuclide of the decay chain containing the J th nuclide in the material,

RA(J) = ratio (dps/dps) of the disintegration rate of the J th nuclide to that of its mother,

CH(J) = $\frac{\lambda m/Mm}{DEC(IEL)}$, ratio (mole-g^{-1} hr^{-1}/mole-g^{-1}-hr^{-1}) relating the disintegration rate per gram of the mother nuclide (m)[a] of the decay chain containing the J th nuclide to that of the primary nuclide (p),[b]

λ_x = decay constant (hr^{-1}) for the x th nuclide,

M_x = molecular weight (g/mole) of the x th nuclide,

DEC(IEL) = λ_p/M_p, constant (mole/g-hr) for the IEL th material that is proportional to the disintegration rate[a] of one gram of the primary nuclide[b],

AVO = Avogadro's number (6.023 x 10^{23} atoms/mole),

3600 = dimensional conversion factor (sec/hr),

FGM(I,J) = number of photons (photon/dis) with energy in the I th interval emitted per disintegration of the J th nuclide,

S(k) = amount (g) of the IEL th material in or on the k th source,

---

[a] AVO * λ_x/M_x = disintegration rate per gram (dis/hr-g) of the x th nuclide.

[b] The primary nuclides are chosen to be U-238 in natural uranium and Th-232 in natural thorium.

$ATN(I,K)^C$ = shielding factor (dimensionless) for k th source and photons in I th energy group,

$AATN(K)^C$ = shielding factor (dimensionless) for k th source--taken the same for all photon energies,

$R(K) = ([X(K) - XO]^2 + [Y(K) - YO]^2 + [Z(K) - ZO]^2)^{1/2}$

= distance (cm) between the k th source and the receptor,

X(K),Y(K),Z(K) = coordinates (cm) of the k th source

XO,YO,ZO = coordinates (cm) of the receptor.

Use of this equation requires that, for any exposure situation, the source be described as a single point source or as a distribution of such sources. The distance R(K) between each source and the receptor must be specified. This may be done in three ways:

(1) set the receptor at the origin (XO=YO=ZO=0) and specify the desired distance as X(K); set Y(K)=Z(K)=0, or

(2) set the receptor at the origin and specify each point source coordinate, or

(3) specify the coordinates of the receptor and each point source.

Because the information required to calculate explicit attenuation factors will probably be unavailable, only the option to specify gross shielding factors is included. These factors may be energy independent [$0 \leq AATN(K) \leq 1$] or dependent [$0 \leq ATN(I,K) \leq 1$] and must be specified for each point source. The latter option will facilitate the eventual incorporation

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[C] For a given point source (K), either AATN(K) or ATN(I,K) must be set equal to 1 (see Section 4.6), i.e., one variable is not used in the calculation. If AATN(K) is used, its value is an input variable. If ATN(I,K) is used, it must be evaluated for each of the 25 values of I.

of the capability to deal directly with volume source distributions, the most general case. The option to calculate explicit attenuation factors can be added, if found to be necessary.

The dose conversion factor (rad/r) and modifying factor (rem/rad) were set equal to unity and not stated explicitly in the model equation. These approximations should not introduce significant errors into the results unless the dose to bone is of importance.[2] The backscatter correction was also set to unity; a procedure which could lead to small underestimates of the direct dose in some exposure situations of interest.

3.1.2 Dose from immersion in contaminated air

The dose equivalent rate (EM) from photons emitted from radioactive material suspended in air is calculated by the equation:

$$EM = (3.74E4*8760)^{-1} *CONC*TIMM*F(ABS)* \sum_{J=1}^{NN} ACT(J)*CIMM(J) \qquad (2)$$

where

EM = immersion dose equivalent rate (mrem/year),

J, NN and ACT(J) are defined in Eq. (1):

(3.74E4*8760) = dimensions conversion factor (dps/μCi)*(hr/year),

CONC = concentration (g/cm^3) of radioactive material in air,

TIMM = duration (hr/year) of immersion in contaminated air,

F(ABS) = correction factor (dimensionless) to compute dose in a medium of finite extent relative to that in an infinite medium,

CIMM(J) = dose conversion factor ($mrem\text{-}year^{-1}/\mu Ci\text{-}cm^{-3}$) for immersion in air contaminated with the J th nuclide.

The source term CONC may be expressed by one of three methods (see Section 4.2.2): (1) as a specified concentration of radioactive material containing the J th nuclides, (2) as a calculated steady-state concentration from a specified leakage rate of radioactive material into a finite air space (e.g., a room) that has a specified air exchange rate, or (3) as a calculated concentration from a specified amount of material which has leaked into a specified volume (a room) with poor ventilation (or no air exchange).

The correction factor, F(ABS), can be quite important if the air volume is defined by a closed room. F(ABS) is provided by a FUNCTION subroutine and requires input for the effective radius of the room (see Section 4.2.1).

The EXREM III[3] computer code which calculates the dose rate in an infinite volume of contaminated air was used to provide the dose conversion factor for each nuclide. Each nuclide that contributes significantly to the dose from 20-year-old natural uranium and thorium (see Appendix A) was processed. These factors, CIMM(J), are stored as data variables in the program and are listed in Appendix A.

3.1.3 Dose to skin from contact with a beta-particle source

The beta dose to the skin can be important if a product containing beta-emitting nuclides is handled. The beta dose equation is derived from the well-known Loevinger point-source dose-rate formula.[4,5] Details of the derivation are in Appendix B. Dose-rate equations (B.4) and (B.5) are represented by:

$$DBETA = PMEG*TBETA*(SOB/ROB)*AVO*DEC(IEL)* \sum_{I=1}^{NBINT} EA(I)*THETA(EO(I))*$$

$$BCOR(STH,HTH,EO(I),IAR)*BCON(I)* \sum_{J=1}^{NN} FBT(I,J)*CC(J) \qquad (3)$$

where

DBETA = beta dose equivalent (rem) for TBETA hours of contact,

TBETA = duration (hr) of contact,

PMEG = dimensional conversion factor (1/2 x 1.6E-8 g-rad/MeV),

SOB = concentration (g/cm^3) of radioactive material in the matrix material,

ROB = density (g/cm^3) of the matrix material plus the radioactive material imbedded in it,

AVO, DEC(IEL), J, and NN were defined in equation (1),

I = beta-particle energy group index (dimensionless),

NBINT = number (dimensionless) of beta-particle energy groups,

EA(I) = mean energy (MeV/beta) of a distribution of beta particles whose maximum energy falls within the I th energy group,

THETA(EO(I))= θ^{-1}, see Appendix B,

EO(I) = maximum energy (MeV/beta) assigned to a distribution of beta particles whose actual maximum energy lies within the boundaries of the I th energy group,

BCOR(STH,HTH,EO(I),IAR) = { } in equation (B.4) if IAR = 1, or in equation (B.5) if IAR = 2, see Appendix B,

BCON(I) = dose conversion factor (rem/rad),

STH = absorbing layer thickness (mg/cm^2), see Appendix B,

HTH = beta source thickness (mg/cm^2), see Appendix B,

FBT(I,J) = number of beta particles with energies in the I th group emitted per disintegration of the J th nuclide (beta/dis),

CC(J) = YI(J)*RA(J)*CH(J), all of which are defined in equation (1).

The solution of equation (3) is expressed in the output table as the absorbed dose (rad) from TBETA hours of contact with the product. This form of expression disregards the dose conversion factor BCON(I), which has been set equal to unity for all I in the computer code, thus allowing DBETA to be expressed as an absorbed dose rather than as a dose equivalent.

The user must supply SOB, ROB, STH, HTH, and TBETA. If more convenient, the weight fraction [g(IEL)/g(matrix)] of the radioactive material in the matrix may be substituted for SOB and ROB set equal to unity.

3.2 Internal Exposure

The modes of internal exposure considered in CONDOS are ingestion and inhalation of a radioactive material. All types of radiations are considered to contribute to the dose.

3.2.1 Dose from ingestion

The 50-year dose commitment to the total body of an individual who ingests radioactive material during the year being considered is given approximately by:

$$ENG = (AMT/37)* \sum_{J=1}^{NN} ACT(J)*CING(J) \qquad (4)$$

where

ENG = 50-year dose commitment (mrem/year) to the total body from ingestion during the year being considered,

J, ACT(J), and NN are defined in equation (1),

AMT = amount (g/year) of radioactive material ingested,

37 = dimensional conversion factor (3.7E4 dps/μCi)/(1000 mrem/rem),

CING(J) = 50-year dose-conversion factor (rem/μCi) to the total body from ingestion.

The INREM[6] computer code which calculates internal dose commitments from intake of radioactive materials was used to determine the values of CING(J). The CING(J) for 50-year, total-body dose commitments from ingestion of 1 μCi of the nuclides of interest, are stored as data variables in the program and are listed in Appendix A. The user must supply only AMT to obtain ENG. The dose commitments to other organs can be calculated by equation (4) if the appropriate dose-conversion factors [CING(J)] are used.

3.2.2 Dose from inhalation

The 50-year dose commitment to the total body of an individual who inhales radioactive material during the year being considered is given approximately by:

$$EN = CONC*TINH*(BR/37)*\sum_{J=1}^{NN} ACT(J)*CINH(J) \qquad (5)$$

where

EN = 50-year dose commitment (mrem/year) to the total body from inhalation during the year being considered,

J, ACT(J), and NN are defined in equation (1),

CONC = concentration (g/cm^3) of radioactive material in air, see sections 3.1.2 and 4.2,

TINH = time (hr/year) spent breathing contaminated air,

BR = breathing rate (0.833E+6 cm^3/hr) of average person,

37 = dimensional conversion factor (3.7E4 dps/μCi)/(1000 mrem/rem),

CINH(J) = 50-year dose-conversion factor (rem/μCi) to the total body from inhalation.

The INREM[6] code was used also to obtain the values of CINH(J). The values for 50-year, total-body dose commitments from inhalation of 1 μCi of the nuclides of interest are stored as data variables and listed in Appendix A.

The user must provide TINH and the means to compute CONC as discussed in section 4.2. Equation 5 can calculate dose commitments to other body organs, if the appropriate dose-conversion factors are used.

4. THE COMPUTER CODE

Two versions of the CONDOS computer code exist. Both versions are written in FORTRAN IV; one for use in the batch mode on the IBM 360 75/91 computer and one for use in the time-shared mode on the DEC PDP-10 computer. The only differences between the two versions are in the small number of details that make them compatible with the respective computers.

4.1 The Computer Solution

The computer code solves equations (1), (2), (4), and (5) and provides the logic required to read-in the input parameters supplied

by the event descriptions given in the model, to implement the calculational sequence prescribed by the methodology, and to output the results of the calculations in tabular form. This subsection describes what the code does; the remaining subsections show how it is done.

Doses to the total body of selected individuals are calculated both for external exposure pathways (direct irradiation and immersion) and for internal exposure pathways (ingestion and inhalation). The doses from external exposure are annual dose equivalents (mrem/year -- interpreted as the dose from one year of product availability), but those from internal exposure are the integrated dose equivalents that will be received during the first 50 years after intake of the radioactive material (50-year dose commitments). The internal doses are expressed also in mrem/year and are to be interpreted in the same context as the external doses, i.e., as doses from one year of product availability.

The computer code lists the potential doses to each individual considered in the model according to exposure pathway. The doses to each individual are summed and the resultant total individual doses are also listed in the output table. Appendix C contains a sample output table.

Potential doses to population groups involved in the life span of the product are computed by summation of the total individual doses, according to the sequence prescribed by the methodology (Section 2.3). These population doses (group dose, substage dose, stage dose, and total population dose) are listed also in the output table. These doses are expressed in man-rem/year and are interpreted as the collective dose from one year of product availability to all individuals in the group being considered.

The code also solves equation (3) and provides a statement of the beta dose to the skin (rads) for a specified period of contact with the product.

4.2 Auxiliary Calculations

4.2.1 Finite volume correction factor

The exposure rate, neglecting scattering, at the origin (center) of a spherical volume of contaminated air is

$$ER = \int_0^R \frac{F_1 S_V \exp(-\mu r)}{4\pi r^2} 4\pi r^2 \, dr,$$

where

ER = exposure rate (r/hr),

F_1 = dimensional conversion factor ($r\text{-}hr^{-1}/photon\text{-}sec^{-1}\text{-}cm^{-2}$),

S_V = source strength ($photons/sec\text{-}cm^3$) per unit volume

R = radius (cm) of volume,

μ = linear absorption coefficient (cm^{-1}).

The solution is, $ER = (F_1 S_V/\mu)\,[1-\exp(-\mu R)]$. For an infinite volume,

$$ER = F_1 S_V/\mu.$$

Therefore, the ratio of the dose rate from a volume of radius R to that from an infinite volume is

$$F(ABS) = 1 - \exp(-\mu R).$$

This correction factor was used in equation (2) and is calculated by the FUNCTION F(ABS) subroutine. Since μ is dependent on the photon

energy, a characteristic value of μ is provided by the code for each nuclide. The subroutines TERP1 and TERP2 provide the energy-dependent values of μ.

4.2.2 Concentration of radioactive material in air

The variable CONC, the concentration of radioactive material in air, which is used in equations (2) and (5), can be specified in one of three ways. The index ICON selects the method for specification of CONC.

1. ICON = 1. The user supplies the air concentration in g/cm^3.

2. ICON = 2. This option calculates the equilibrium air concentration in a ventilated room with an air exchange rate, VRATE (cm^3/hr), and inleakage of radioactive material, SRATE (g/hr). If the room has a volume V (cm^3), the time-dependent concentration of material in the room is

$$\frac{d\ CONC}{dt} = \frac{SRATE}{V} - \frac{VRATE}{V} * CONC \quad .$$

At equilibrium, $\frac{dCONC}{dt} = 0$,

and CONC = SRATE/VRATE .

SRATE AND VRATE must be specified by the user, if this option is chosen.

3. ICON = 3. The air concentration in an unventilated room is computed. In this case, CONC = TLEAK/V,

where

TLEAK = the total amount (g) of material leaked into the room,

V = volume (cm^3) of the room.

4.2.3 Geometric conversions

The dose from a plane source may be calculated as follows. Let G(r) be the point source kernel for an isotropic point source of unit strength that is imbedded in an infinite homogeneous medium. If a disk of radius RD (Fig. 3) and source strength SD per unit area is imbedded in such a medium and is represented by an array of point sources, the dose rate at point P, normal to the center of the disk, is

$$DR(P) = \int_0^{RD} G(r)\ (2\pi\ SD\ \rho\ d\rho) = 2\pi\ SD \int_x^{(x^2 + RD^2)^{1/2}} r\ G(r)\ dr, \text{ since}$$

$$r^2 = x^2 + \rho^2.$$

If the plane is of infinite extent,

$$DR(P) = 2\pi\ SD \int_x^{\infty} r\ G(r)\ dr\ .$$

Replacement of a distributed volume source by an approximately equivalent surface source is sometimes desirable. This can be accomplished by the approximation

$$SS = SV*T\ ,$$

where

SS = equivalent surface source,

SV = volume source,

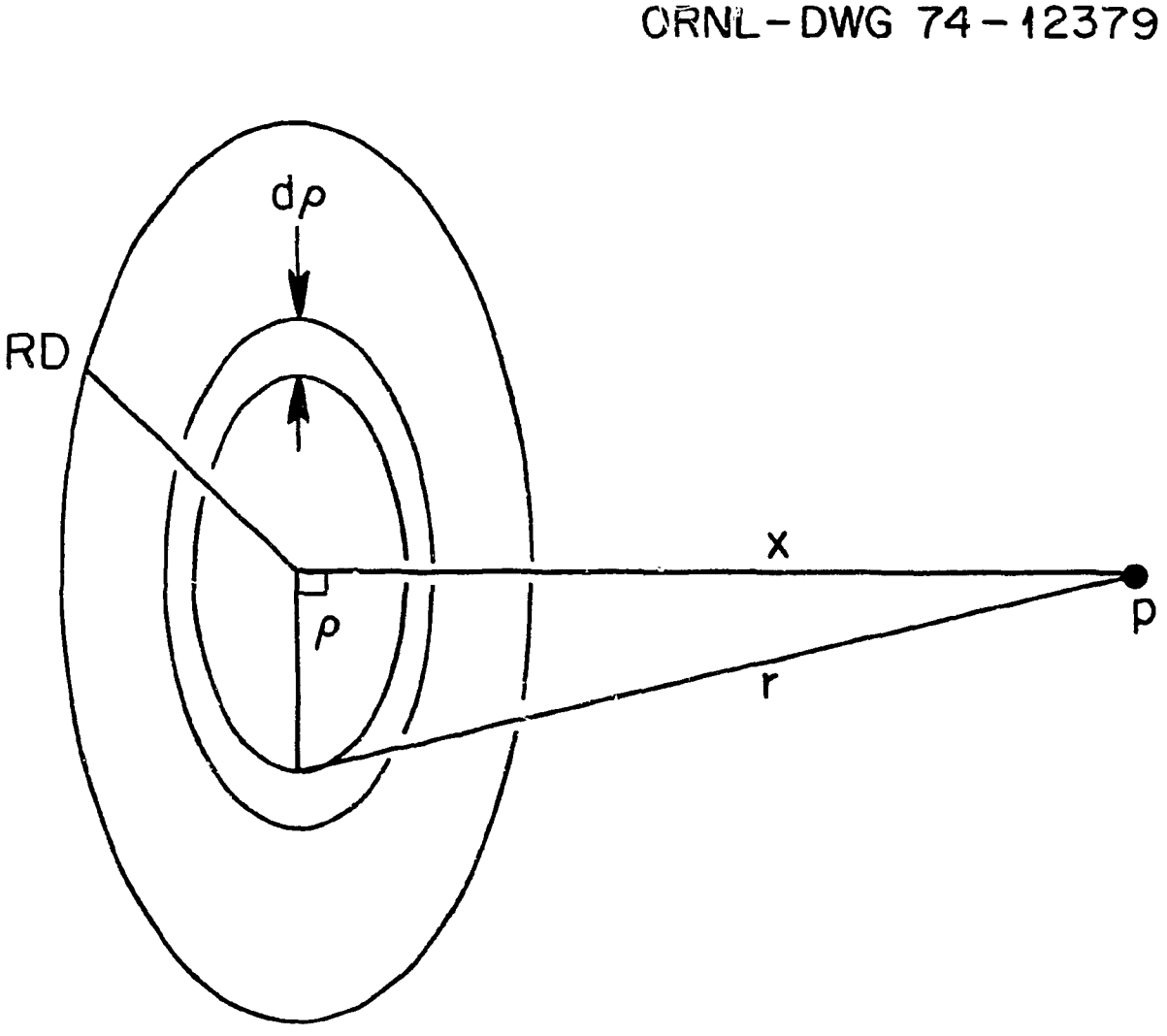

Figure 3. Coordinate system for conversion from point to disk sources.

$$T = \begin{cases} \text{thickness of volume source if } T < 1/\mu \ , \\ 1/\mu \text{ otherwise,} \end{cases}$$

$1/\mu$ = mean free path (cm) of the radiation in the absorbing medium.

4.3 Logical Flow of the Code

The main program controls the flow of operations performed by the computer code (Fig. 4). In addition, it reads in the data contained in the bulk storage area. Appendix D contains a complete program listing.

After initialization of the variables, the program calls subroutine INPUT to read, place in disk storage, and write out the input data. Subroutine PREFAS is then used to compute the beta hand dose. The format of the output table is generated by use of subroutine OUTPUT.

The remaining dose calculations are performed by subroutine CALC after the appropriate input variables are read from the disk storage area. CALC provides the doses to representative individuals and to the total group. These doses are recorded in the output table by subroutine OUTPUT.

The dose calculations are repeated and printed out for each event in which each group, substage, and stage is involved. Group, substage, and stage population doses are summed to provide, respectively, the substage, stage, and total population doses. These doses are printed in the output table. Finally, the beta hand dose is printed out.

4.4 Description of Subroutines

Several calculations are performed by subroutines. The main program calls directly on subroutines INPUT, PREFAS, OUTPUT, and CALC.

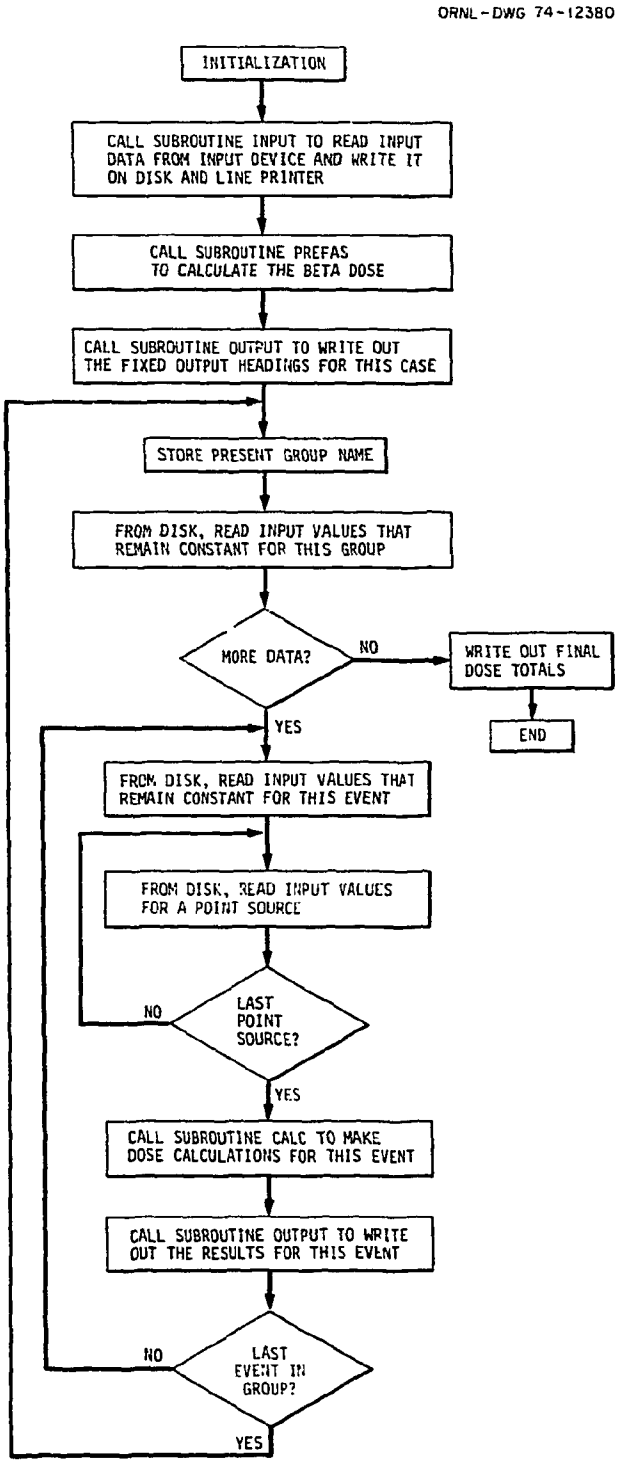

Figure 4. Logical flow diagram of the main program.

Subroutine PREFAS uses the function subroutines FC(EO), FNU(EO), BCOR(IR,EO, S,H). and THETA(EO). Subroutine CALC uses the function subroutine F(ABS) which itself calls subroutines TERP1 or TERP2.

Subroutine INPUT reads the input data from the input device, stores it on a bulk storage device (e.g., disk), and causes it to be written by an output device. Figure 5 shows the logical flow of INPUT.

Subroutine PREFAS provides the solution to equation (3), the beta dose to the hands from contact. In addition, some of the variables used in the other dose calculations are computed. These include AVO, GAMCO, CC(J), and FBET(J) = FGM(I,J)*CC(J)*ENRGY(J)*CONVR(I), all of which are defined in equation (1). The logical flow of PREFAS is given in Fig. 6.

Function subroutines FC(EO) and FNU(EO) supplies the values of c and ν, respectively, for use in specifying the form of the Loevinger function used in equation (3) and in solving that equation.

Function subroutine THETA(EO) specifies the values of THETA to be used in the solution of equation (3).

Function subroutine BCOR(IR, EO, S, H) computes the values of the Loevinger function for equation (3). Solutions to both cases specified by equations (B.4) and (B.5) are available.

Subroutine OUTPUT writes out the descriptive information supplied for the problem and generates the format of the output table. The doses computed by subroutine CALC are printed in the output table and a running summation is kept of their contributions to the total group, substage, stage, and population doses. These sums are printed in the table after each group, substage, stage, and all stages have been considered. Figure 7 shows the logical flow of OUTPUT.

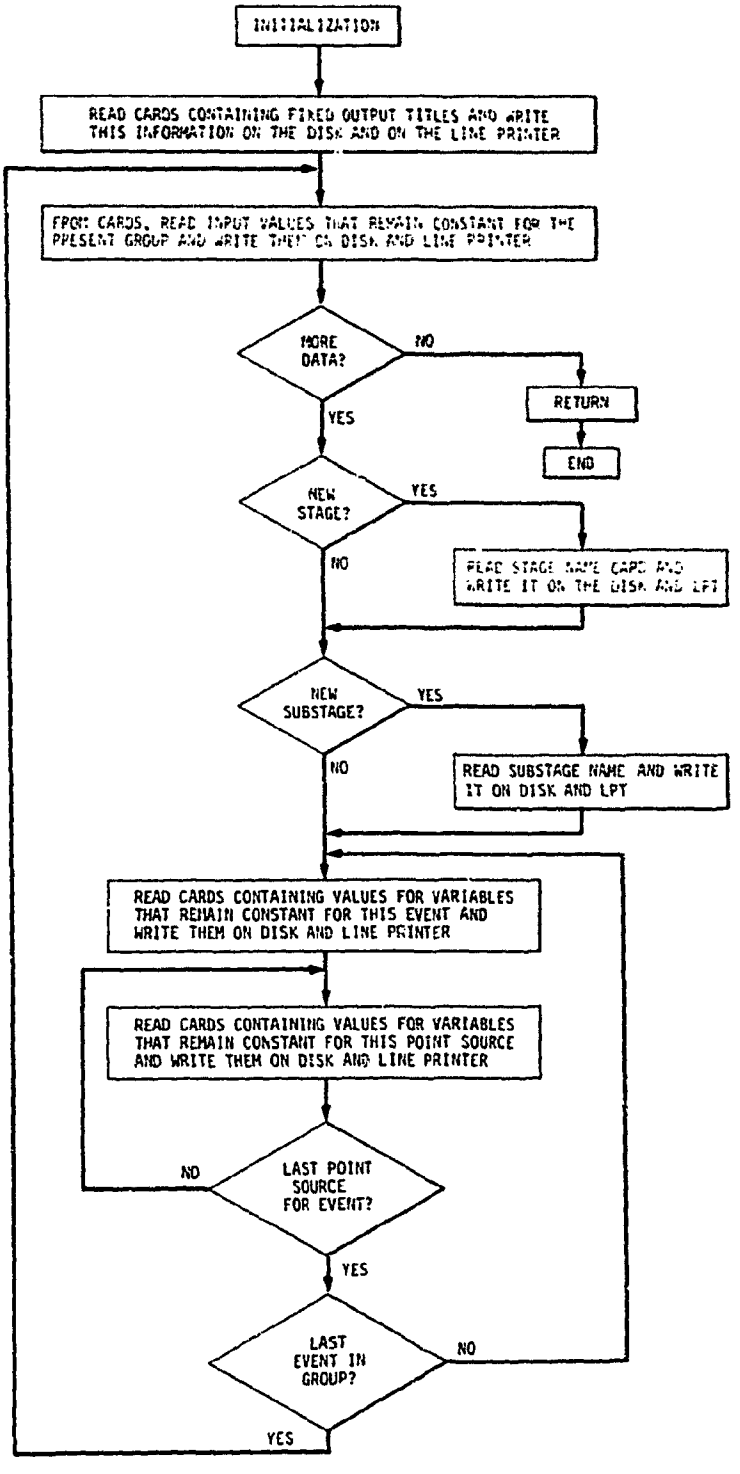

Figure 5. Logical flow diagram of subroutine INPUT.

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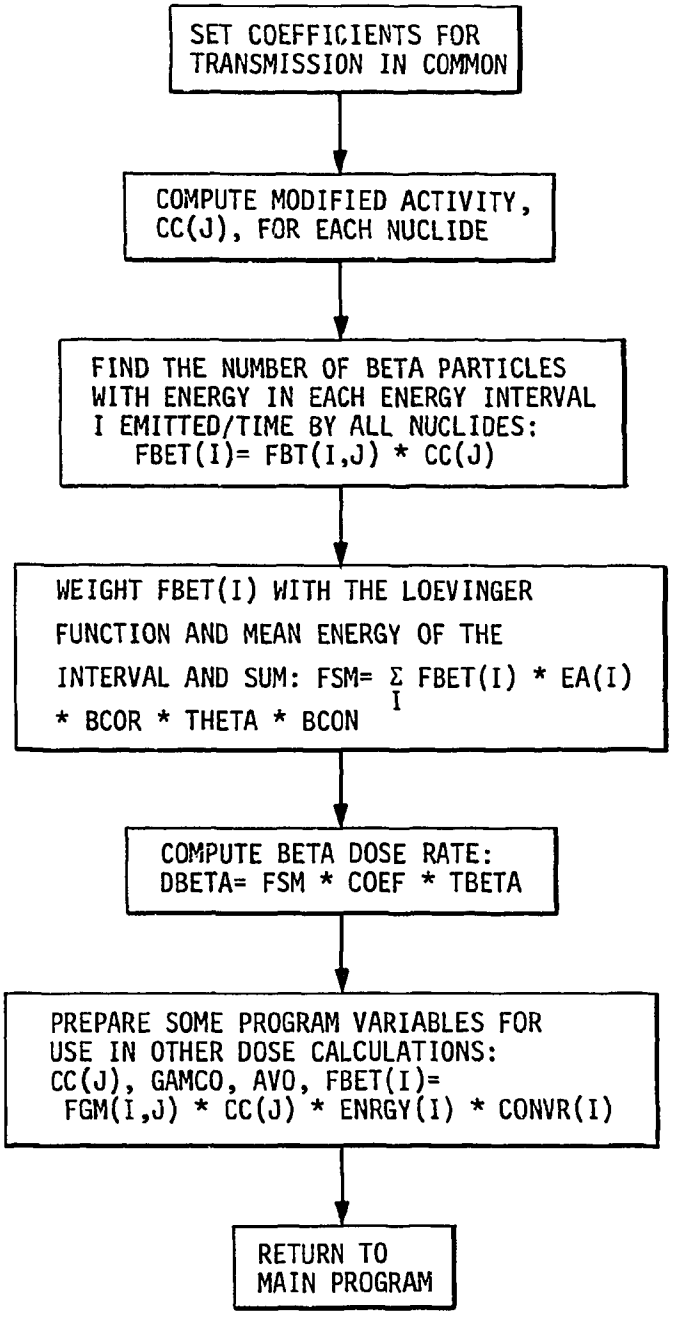

Figure 6. Logical flow of subroutine PREFAS.

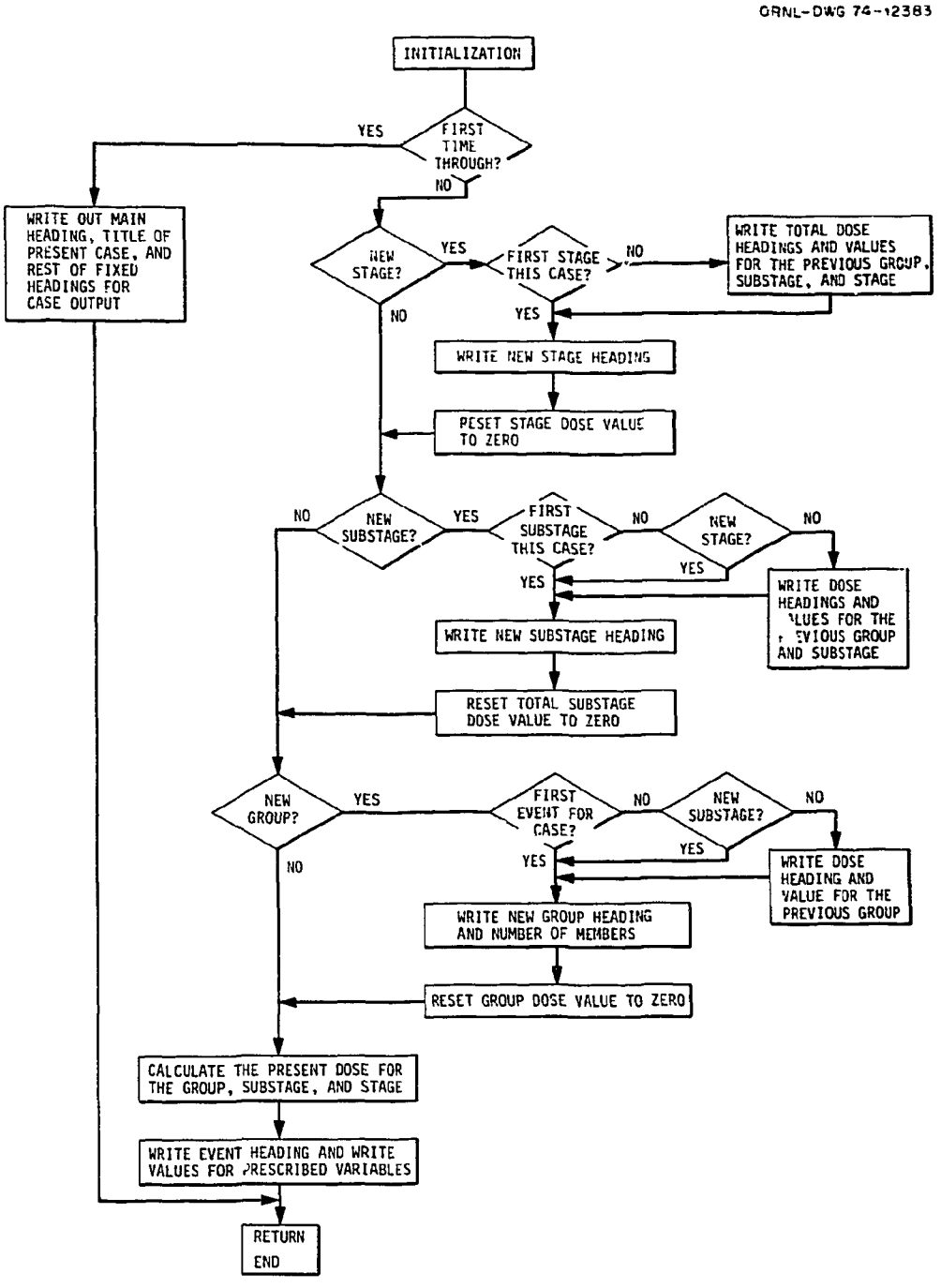

Figure 7. Logical flow of subroutine OUTPUT.

Subroutine CALC solves equations (1), (2), (4), and (5) for every event that is specified in the life span model of a consumer product. Summation of these doses for each event provides the representative individual's total dose. Multiplication by the number of group members and the probability that a member will be involved in the event provides the contribution of that event to the total dose associated with the group. Summation of these contributions yields the total group dose. Figure 8 gives the logic of subroutine CALC.

Function subroutine F(ABS) follows the logic given by Fig. 9. It calculates the finite volume correction factor given in section 4.2.1.

Subroutines TERP1 and TERP2 provide the linear absorption coefficient, μ, discussed in section 4.2.1 and used in calculating F(ABS). Both select the appropriate value for μ from stored data tables. TERP1 is used if the photon energies occur in equal increments; TERP2, if they do not. The logical flow of the subroutines are given in Figs. 10 and 11, respectively.

4.5 Definition of Program Variables

The FORTRAN variables used in CONDOS are defined in this section. These variables are listed in alphabetical order in three groups: the input variables, the more important internal variables, and the output variables. The subscript I denotes the I th energy group for photons or beta particles; the subscript J denotes the J th radionuclide; the subscript K denotes the K th point source; and the subscript IEL denotes natural thorium (IEL = 1) or natural uranium (IEL = 2). Variables marked A are obtained from the data base; variables marked B are problem input.

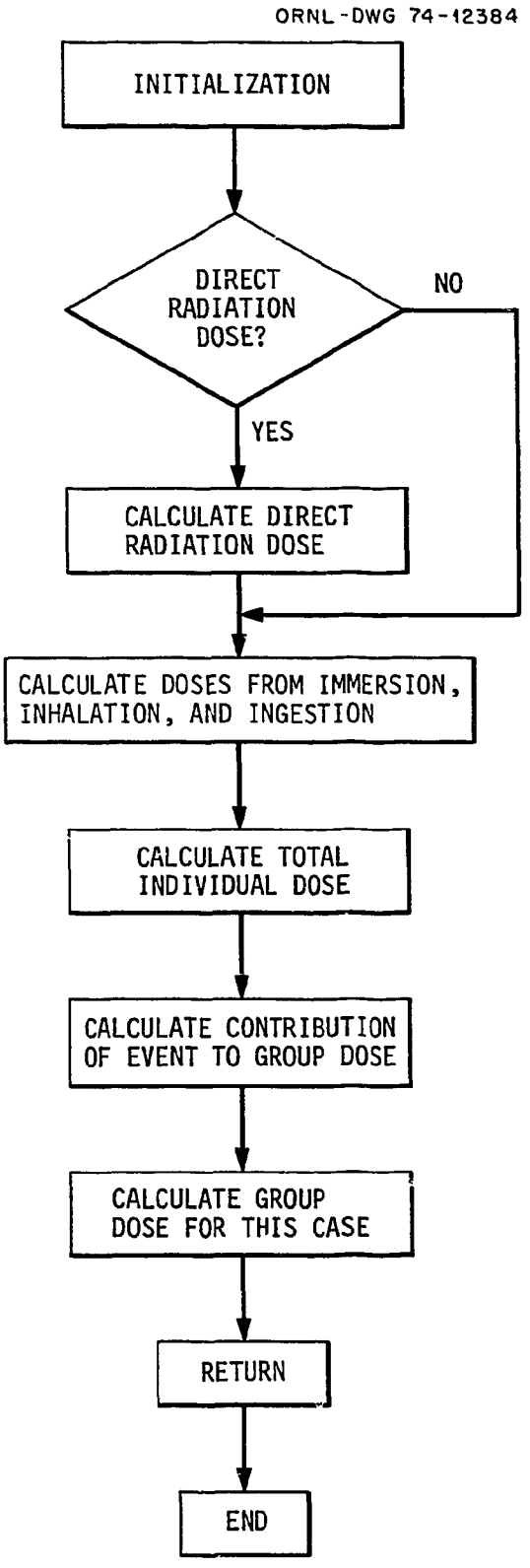

Figure 8. Logical flow of subroutine CALC.

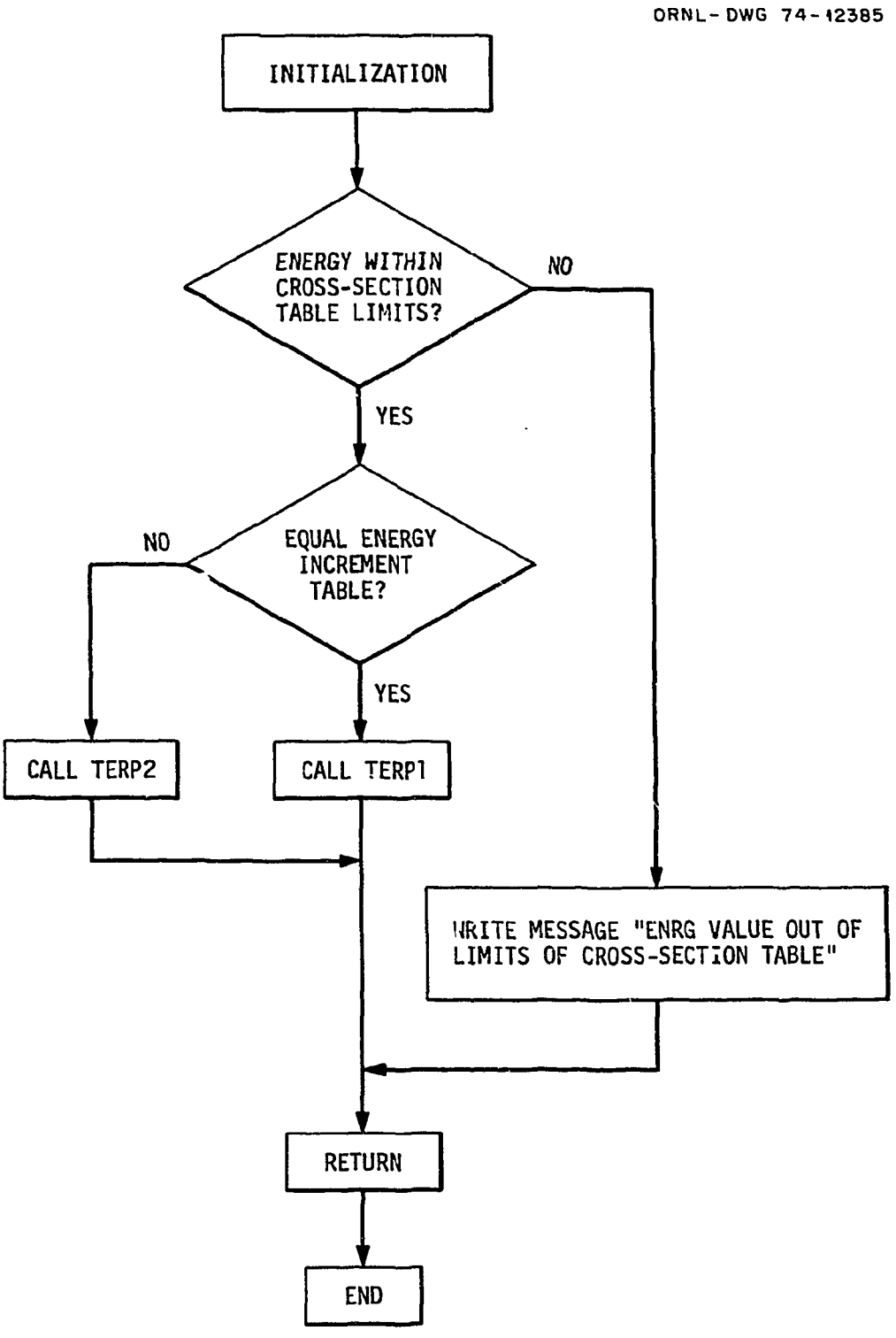

Figure 9. Logical flow of function subroutine F(ABS).

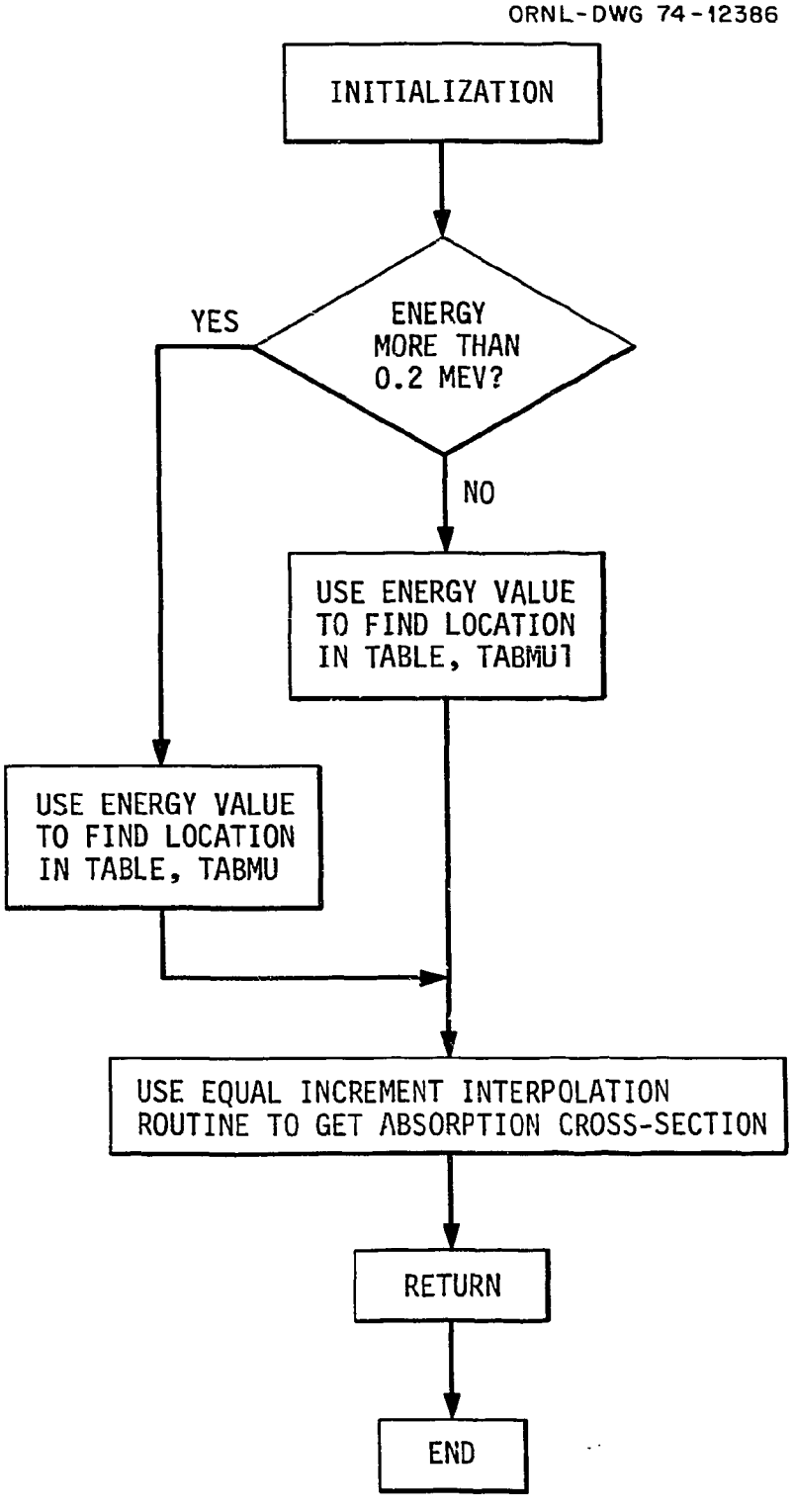

Figure 10. Logical flow of subroutine TERP1.

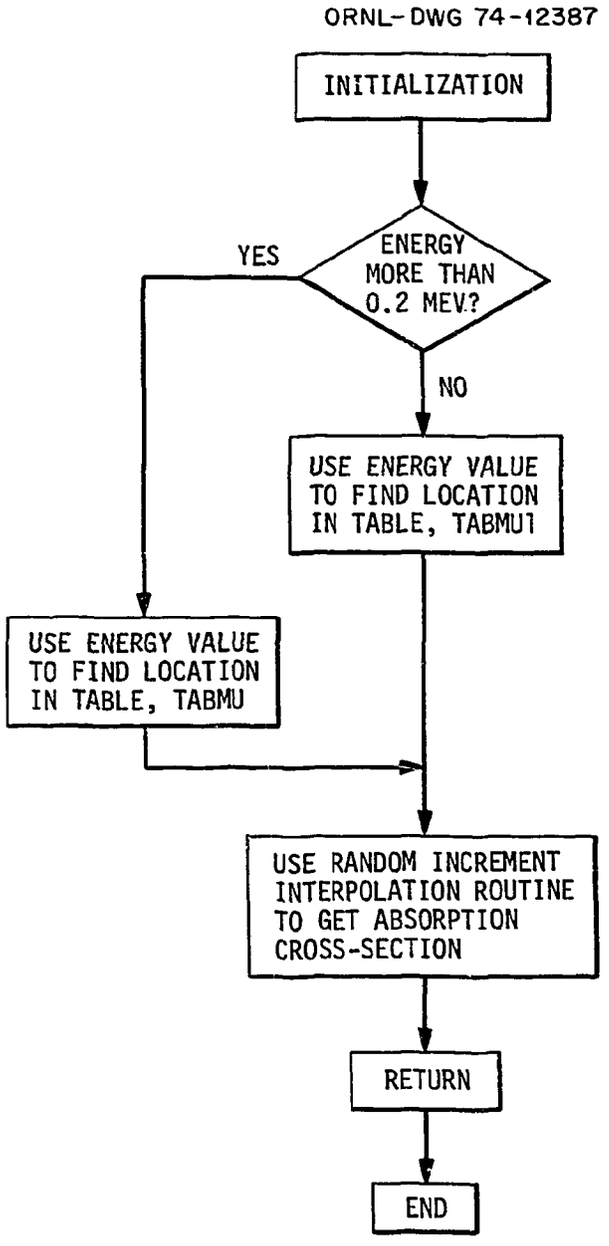

Figure 11. Logical flow of subroutine TERP2.

Input variables

B	AMT	Amount (g/year) of radioactive material ingested
B	AATN(K)	Energy-independent photon attenuation coefficient (dimensionless); see section 3
B	ATN(I,K)	Energy-dependent photon attenuation coefficient (dimensionless); see section 3
A	AVO	Avogadro's number (0.6023E24 atoms/mole)
A	BCON(I)	Dose-conversion factor (rem/rad) for beta particles
A	BR	Average breathing rate (0.833E6 cm^3/hr of an adult
A	CH(J)	Ratio (dimensionless) relating the disintegration rate per gram of the mother nuclide of the decay chain containing the J th nuclide to that of the primary nuclide; see section 3.1.1
A	CIMM(J)	Dose-conversion (mrem-$year^{-1}$/μCi-cm^{-3}) for immersion; see section 3.1.2
A	CING(J)	Dose-conversion factor (rem/μCi) for ingestion; see section 3.2.1
A	CINH(J)	Dose-conversion factor (rem/μCi) for inhalation see section 3.2.2
B	CONC	Concentration (g/cm^3) of radioactive material in air; see sections 4.2.2 and 3.1.2
A	CONVR(I)	Exposure rate energy flux ratio (r-hr^{-1}/MeV-cm^{-2}-sec^{-1}) for direct irradiation by photons; see section 3.1.1
A	DEC(IEL)	Constant (mole/g-hr) for the IEL th radioactive material that is proportional to the disintegration rate of one gram of the primary nuclide, see section 3.1.1

A	DENRG	Energy increment (MeV) between data points in TABMU; see TERP subroutines
A	DENRG1	Energy increment (MeV) between data points in TABMU1; see TERP subroutines
A	EA(I)	Mean beta particle energy (MeV/beta) in the I th energy group; see section 3.1.3
A	ENRG(J)	Photon energy (MeV) representative of photons emitted by a nuclide; see TERP subroutines
A	ENRGH	Maximum photon energy (MeV) considered in TABMU
A	ENRGH1	Maximum photon energy (MeV) considered in TABMU1
A	ENRGL	Minimum photon energy (MeV) considered in TABMU
A	ENRGL1	Minimum photon energy (MeV) considered in TABMU1
A	ENRGY(I)	Energy of the average photon (MeV/photon) in the I th energy group
A	EO(I)	Maximum beta particle energy (MeV/beta) in the I th energy group; see section 3.1.3
B	EVPROB	The joint probability (dimensionless) that a group member will be involved in a particular event and that the event will occur, see section 2.3
A	FBT(I,J)	Number of beta particles with energies in the I th group emitted per disintegration of the J th nuclide (beta/dis); see section 3.1.3
A	FGM(I,J)	Number of photons with energy in the I th group emitted per disintegration of the J th nuclide (photon/dis); see section 3.1.1
B	GROUP	Name (alphanumeric) of stage being considered; see sections 2.2 and 4.6

B	HTH	Thickness (mg/cm^2) of beta particle emitting source
B	ICON	Flag variable (dimensionless) for selection of the method for calculating CONC; see section 4.2.2
B	IGP	Stage identification index (dimensionless)
A	INCR	Index variable (dimensionless) for selection of TERP1 or TERP2 in subroutine F(ABS)
B	ISP	Substage identification index (dimensionless)
B	ITN	Index variable (dimensionless) for execution of option to select ATN(I,K) or AATN(K)
B	IVENT	Name (alphanumeric) of event being considered; see sections 2.2 and 4.6
A	JHI(IEL)	Index (dimensionless) corresponding to J for specification of the last of a sequence of nuclides in the material
A	JLO(IEL)	Index (dimensionless) for specification of the first nuclide in a sequence of nuclides in the material
A	NBINT	Number (dimensionless) of beta particle energy groups
A	NGINT	Number (dimensionless) of photon energy groups
B	NM	Number of group members (persons); see section 2.2
B	NOEV	Number (dimensionless) of events to be considered for the group being studied; see section 2.2
B	NP	Number (dimensionless) of point sources used to represent the product
B	R	Effective diameter (cm) of contaminated air space
A	RA(J)	Ratio (dimensionless) of the disintegration rate of the J th daughter nuclide to that of the mother of its chain

B	ROB	Density (g/cm^3) of matrix material which contains beta-emitting nuclides and a binder; see section 3.1.3
B	S(K)	Amount (g) of radioactive material in or on K th source
B	SOB	Concentration (g/cm^3) of beta-emitting material in matrix material
B	SRATE	Rate (g/sec) of radioactive material leakage from the product
B	SSGRP	Name (alphanumeric) of group being considered; see sections 2.2 and 4.6
B	STH	Thickness (mg/cm^2) of absorbing layer between beta-particle-emitting source and dose point, see section 3.1.3
B	SUBGRP	Name (alphanumeric) of the substage being considered; see sections 2.2 and 4.6
A	TABMU	Table of energy-dependent linear absorption coefficients (cm^{-1}) for photons of energy greater than 0.2 MeV
A	TABMU1	Table of energy-dependent linear absorption coefficients (cm^{-1}) for photons of energy less than 0.2 MeV
B	TBETA	Duration (hr) of direct contact between skin and beta particle-emitting source
B	TDIR	Duration (hr/year) of exposure to photons emitted from an external source
B	TIMM	Duration (hr/year) of immersion in a volume of air contaminated with photon-emitting nuclides
B	TINH	Duration (hr/year) of inhalation of contaminated air

B	TITLE1	Two lines of descriptive information, each up to 80 characters in length (alphanumeric); see section 4.6
B	TITLE2	
B	TLEAK	Total amount (g) of radioactive material leaked into a volume of contaminated air
B	V	Volume (cm^3) of contaminated air
B	VRATE	Air exchange rate (cm^3/sec) for a volume (room) of contaminated air
B	X(K),Y(K), Z(K)	Coordinates (cm) of a photon-emitting point source
B	XO,YO,ZO	Coordinates (cm) of receptor
A	YI(J)	Abundance (g of mother/g of material) of the mother nuclide of the decay chain containing the J th daughter nuclide per gram of the radioactive material

Internal program variables

BCOR	Value of the Loevinger function (dimensionless); see section 3.1.3
CC(J)	Modified yield term = YI(J)*RA(J)*CH(J); see section 3.1.3
F(ABS)	Finite volume correction factor (dimensionless); see section 4.2.1
FC	The value of c in the Loevinger function (dimensionless); see section 3.1.3
FNU	The value of ν, the apparent absorption coefficient (cm^2/mg) in the Loevinger function; see section 3.1.3
GAMCO	Dimensional factor = AVO*DEC(IEL)/3600

IFIRST	Index variable used to determine if subroutine OUTPUT is being called for the first time in the evaluation of the product (dimensionless)
IGS	Stage identification index (dimensionless)
IRITE	Flag variable (dimensionless) to prevent output of a nonexistent total group dose prior to entering the first group name in the output table
ISP	Current substage identification index (dimensionless)
ISS	Previous substage identification index (dimensionless)
ISSP	Current group identification index (dimensionless)
ISSS	Previous group identification index (dimensionless)
ITAB	Index variable (dimensionless) designating location of value being used in TABMU
JLOC	Location variable (dimensionless) used in reading in data
PMEG	Dimensional conversion factor (1.6E-8 rad-g/MeV X 1/2)
STORGP	Name (alphanumeric) of the stage considered prior to the current one
STORSG	Name (alphanumeric) of the substage considered prior to the current one
STORSS	Name (alphanumeric) of the group considered prior to the current one
TERP1, TERP2	Interpolation subroutines for obtaining photon linear absorption coefficients; see section 4.4
THETA	Subroutine to evaluate THETA[EO(I)] in equation (3).
XMU	Photon linear absorption coefficient (cm^{-1}) in air given by TERP1 or TERP2

Output variables

DBETA	Beta dose rate from direct contact (rad/hr); see equation (3)
DIR	Dose equivalent rate associated with one year of product availability (mrem/year) for direct irradiation from an external photon source; see equation (1)
EM	Dose equivalent rate associated with one year of product availability (mrem/year) for immersion in air contaminated with photon-emitting nuclides; see equation (2)
EN	50-year dose commitment associated with one year of product availability (mrem/year) from inhalation of radioactive material; see equation (5)
ENG	50-year dose commitment associated with one year of product availability (mrem/year) from ingestion of radioactive material; see equation (4)
GPDOS	Contribution of an event dose equivalent rate to its group population dose rate (man-rem/year) = TOT*EVPROB*NM
GPMDOS	Substage population dose equivalent rate (man-rem/year)
GTDOS	Total population dose equivalent rate (man-rem/year)
STGDOS	Stage population dose equivalent rate (man-rem/year)
TGPDOS	Group population dose equivalent rate (man-rem/year)
TOT	Total individual (event) dose equivalent rate associated with one year of product availability (mrem/year) = DIR + EM + EN + ENG

4.6 Description of Input

A description of the card input for CONDOS is presented in this section. This description and use of Fig. 12 will allow the user to take full advantage of the flexibility inherent in a computer code with a generalized format. Each rectangular box in Fig. 12 represents a data card.

The first four cards describe the problem and provide data for the beta dose calculation. The information contained in these cards need not be reentered.

The identification number (IEL) of the radioactive material is given first. CONDOS will treat only natural thorium (IEL=1) and natural uranium (IEL=2) at this time. Other materials can be considered if appropriate changes are made to the data base; that is, values must be supplied for each YI(J), RA(J), CH(J), CINH(J), CING(J), CIMM(J), ENRG(J), FBT(I,J), PGM(I,J), DEC(IEL), JHI(IEL), and JLO(IEL).

The second card contains the input data required for the calculation of DBETA; namely, SOB, ROB, STH, HTH, and TBETA. Cards 3 and 4 contain a brief description of the problem under study (TITLE1 and TITLE2). Both cards may contain up to 80 alphanumeric characters.

Point 1 is the first decision point; "is this the end of the input data?" If no more data are supplied, a blank card is inserted and data input is terminated. If more data are to be supplied, the stage index number (IGP=1,2,3,4,5) and the corresponding substage index number (ISP=1,2,...) are specified. The number of events (NOEV) that describe the group to be considered, the number of affected persons in the group (NM) and the name of the group (SSGRP) are also contained on this card.

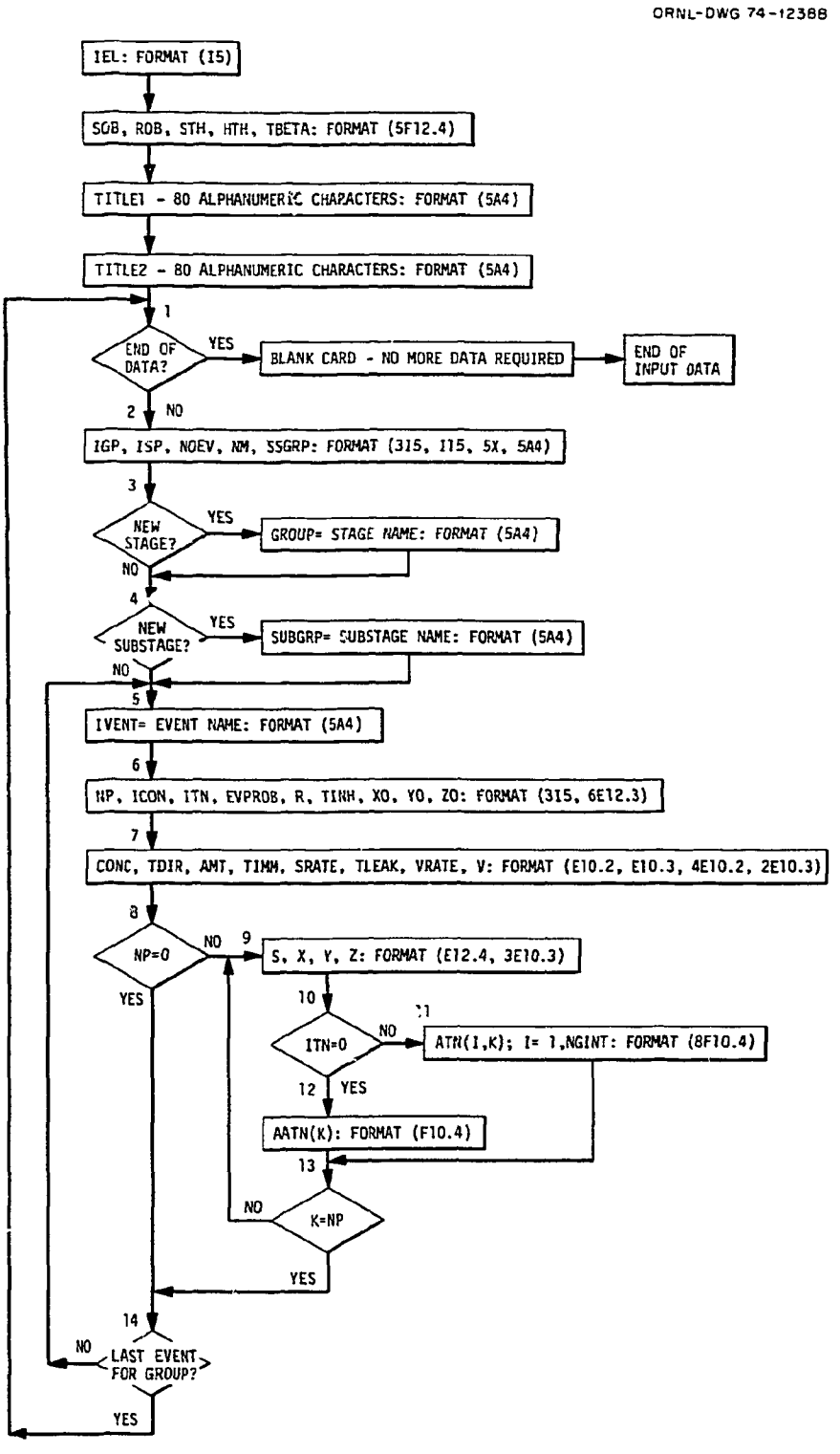

Figure 12. Logical flow of input data card sequencing.

At point 3, the decision is reached as to whether or not a new stage is to be considered. If a new stage is to be considered, a card containing GROUP is entered. If not, no card is provided. Point 4 is a decision about substages which is similar to that for stages. If a new substage, enter SUBGRP; if not, omit card and go to point 5.

The name of the event (IVENT) to be considered next is supplied. The remaining cards provide the input information required for the dose calculations. Event specific data are provided by the next two cards: (1) NP=0,1,... K, ICON=1,2,3 (see section 4.2.2), ITN=0,1 (see point 10), EVPROB (a number between 0 and 1), R, TINH, XO, YO, and ZO; (2) CONC (if ICON=1), TDIR, AMT, TIMM, SRATE (if ICON=2), TLEAK (if ICON=3), VRATE (if ICON=2), and V (if ICON=3).

If there are no external point sources (NP=0), point 8 in the flow sheet shows that the direct irradiation dose calculation is bypassed and point 14 is considered next. If NP >0, points 9 through 13 are considered for each source. Therefore, NP sets of these cards must be provided. S(K), X(K), Y(K), and Z(K) are provided.[a] If ITN=0, AATN(K) must be provided, or, if ITN=1, ATN(I,K)--for each photon energy interval and point source--must be provided. Both AATN(K) and ATN(I,K) have values between 0 and 1.

When all point sources have been provided for, point 14 is considered. If the event just considered is not the last one in the group, decision point 5 is reconsidered and points 5 through 14 repeated for each event that describes the group. If the event just considered is

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[a]Three methods for coordinate specification are given in section 3.1.1. If any coordinate is to be set equal to zero, no data entry need be made -- a blank space will be interpreted as 0.

the last one for a group, decision point 1 is reconsidered. This last cycle of data card input is repeated until the data necessary to describe each event, group, substage, and stage have been supplied.

4.7 Description of Output

Subroutine OUTPUT generates a table of dose equivalent rates to representative individuals according to exposure mode and event. Doses from each mode are summed to provide the individual's total doses, and these are weighted to indicate the contribution from each event to the group population dose. Group, substage, stage, and total population dose equivalent rates to the total body are listed after all contributions to them have been listed individually.

The beta hand dose is listed separately and the problem description given by the user (TITLE1 and TITLE2) precedes the output table.

An output table from a sample problem is shown in Appendix C.

5. SUMMARY AND FUTURE DEVELOPMENTS

A methodology is described for estimation of potential radiation doses to man from the distribution, use, and disposal of consumer products that contain radioactive material. The methodology consists of two components: a model and a computer code. The model provides a format for identifying the parameters required to solve the dose equations, i.e., the conditions of exposure to the product. The computer code provides the solutions to the dose equations and lists the solutions in tabular form.

The format provided by the model divides the life span of a consumer product into five broad categories called stages. These stages

include distribution, transport, use, disposal, and emergencies. Since a stage can encompass a variety of population groups and activities of man, subdivision of the stages is required before attempting to estimate the radiation doses associated with them. This is accomplished by division of each stage into a series of substages, each of which may encompass several groups of persons such that all group members interact with the product in quite similar circumstances. The events during which group members may be exposed to the product are then identified and an individual from the group selected to take part in the event. The conditions of exposure for the selected individual are defined. These conditions are the parameters that are used in the solutions of the dose equations.

The present version of the CONDOS computer code provides solutions to standard dose equivalent rate equations and has a generalized format that allows a variable number of events, groups, substages, and stages to be considered. The doses potentially associated with one year of product availability to the total body of the selected individuals are computed according to the relevant pathways of exposure. Direct irradiation, immersion in contaminated air, ingestion, and inhalation pathways are considered. Summation of the doses to individuals over the proper population groups provides estimates of the population doses that will accrue to each group, substage, and stage population identified in the model. A beta skin dose is estimated also, for a specified duration of contact with the product by an individual.

The present version of the CONDOS computer code provides dose estimates to the total body from consumer products that contain either

natural uranium or natural thorium. The capability to estimate doses to other selected organs or tissues would increase the utility of the program, because the total body is not the critical organ for internal deposition of many radionuclides, including those of uranium and thorium. This capability will be incorporated in the next version of the computer code.

Many consumer products contain other radioactive materials, such as Pm-147 and H-3. The provision of a larger radionuclide data file would enable a larger variety of consumer products to be investigated. This is being done and should be available soon.

Incorporation of a standard event file would ease greatly the burden of data input that is placed on the user of the present version of CONDOS. Such an event file could not be prepared at the present time, but, as product evaluations are made, the information needed to construct such a file should accumulate. When data sufficient to make incorporation of such a file has accumulated, incorporation will be considered.

A point source representation is used in the estimation of the doses from direct irradiation. Many exposure situations can arise in which such a representation may not be as desirable as a line, surface, or volume source representation. Consideration will be given to providing the user with options for source representation.

CONDOS will be used to provide estimates of the radiation doses to man from consumer products that contain byproduct or source materials.[1] This work is in progress and will be reported periodically.

6. ACKNOWLEDGMENTS

The model and computer code reported in this work was developed from a basic plan provided by Dr. A. N. Tse of the Product Standards Branch, Directorate of Regulatory Standards, U.S. Atomic Energy Commission. In addition, Dr. Tse has provided valuable suggestions throughout the development of the methodology.

The assistance of the ORNL Information Center for Internal Exposure in providing unpublished radionuclide data and the valuable comments of Dr. P. S. Rohwer of the Environmental Sciences Division are also gratefully acknowledged.

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1. Code of Federal Regulations, Title 10--Atomic Energy, Chapter I, Parts 20, 30-36, 40, and 70.

2. K. Z. Morgan and J. E. Turner, eds., Principles of Radiation Protection, John Wiley and Sons, Inc., New York, 1967.

3. D. K. Trubey and S. V. Kaye, The EXREM III Computer Code for Estimating External Radiation Doses to Populations from Environmental Releases, ORNL-TM-4322, Oak Ridge National Laboratory, Oak Ridge, Tennessee (December 1973).

4. J. J. Fitzgerald, G. L. Brownell, and F. J. Mahoney, Mathematical Theory of Radiation Dosimetry, Gordon and Breach, New York, 1967

5. J. A. B. Gibson and J. U. Ahmed, Measurement of Short-Range Radiations, Technical Reports Series No. 150, International Atomic Energy Agency, Vienna, 1973.

6. W. D. Turner, S. V. Kaye, and P. S. Rohwer, EXREM and INREM Computer Codes for Estimating Radiation Doses to Populations from Construction of a Sea-Level Canal with Nuclear Explosives, K-1752, Computing Technology Center and Oak Ridge National Laboratory, Oak Ridge, Tennessee (September 1968).

APPENDIX A

DATA BASE (JULY 1974)

The data base made available with the code in July 1974 includes the 17 nuclides that contribute about 99% of the dose from natural uranium and thorium which have been purified and aged for 20 years. Table A.1 lists the data variables related to individual radionuclides; the nuclides are also identified by name and index number J. The YI(J) are the natural abundance of the mother nuclides for each decay chain. The CH(J) are essentially the relative specific activities of the mothers to the principal nuclide in the uranium or thorium decay chains. The RA(J) are the relative disintegration rates of each nuclide in a decay chain to that of its mother. The RA(J) are time dependent terms in that they are determined at a specified time after purification of the radioactive material. These values were computed from the equations given in: I. Kaplan, Nuclear Physics, Addison-Wesley, Reading, Massachusetts, 1955.

The dose conversion factors CIMM(J), CINH(J), and CING(J) were supplied by the EXREM III[3] and INREM[6] computer codes, as noted in section 3.

All radionuclide data in the data base were assembled from:

1. C. M. Lederer, J. M. Hollander, and I. Perlman, Table of Isotopes, sixth edition, John Wiley and Sons, New York, 1968.

2. Unpublished data of the Information Center for Internal Exposure, Oak Ridge National Laboratory.

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Table A.2 lists the values of FGM(I,J), the photon energy and yield per disintegration of each nuclide. Table A.3 lists the corresponding quantities for beta emission, FBT(I,J).

Table A.4 lists the data variables related to photon and beta particle energy. The energy interval index I is specified according to the range of energies included in each interval and the average photon [ENRGY(I)] and beta particle [EO(I)] energy in that range. The mean beta particle energy, EA(I), corresponding to EO(I) was obtained from M. F. James, B. G. Steel, and J. S. Story, Average Electron Energy in Beta Decay, AERE-M 640, Atomic Energy Research Establishment, Harwell, England, 1960. The exposure rate-energy flux ratios, CONVR(I), were obtained from H. Goldstein, Fundamental Aspects of Reactor Shielding, Addison-Wesley, Reading, Massachusetts, 1959.

Table A.1 Data variables related to individual radionuclides.

Radionuclide Index J	Identification	YI(J)	RA(J)	CH(J)	CIMM(J) $\frac{mrem/hr}{\mu Ci/cm^3}$	CINH(J) rem/μCi	CING(J) rem/μCi	ENRG(J) MeV
1[a,b]	Th-232	1.0	1.00	1.00	1.18E+3	1.84E+2	7.36E-2	0.015
2	Ra-228	1.0	0.874	1.00	3.21E+4	2.22E+1	1.66E+1	0.100
3	Ac-228	1.0	0.874	1.00	7.52E+5	1.57E-2	6.26E-6	1.000
4	Th-228	1.0	0.824	1.00	3.58E+3	4.16E+1	1.66E-2	0.015
5	Ra-224	1.0	0.824	1.00	1.02E+4	2.70E-1	2.02E-1	0.200
6	Rn-220	1.0	0.824	1.00	0.0	0.0	0.0	0.500
7	Po-216	1.0	0.824	1.00	0.0	3.46E-8	7.42E-9	0.100
8	Pb-212	1.0	0.824	1.00	1.48E+5	1.10E-2	3.02E-3	0.200
9	Bi-212	1.0	0.824	1.00	1.11E+5	9.49E-4	3.65E-5	0.800
10	Tl-208	1.0	0.297	1.00	3.42E+6	2.11E-6	1.98E-6	0.700
11	Po-212	1.0	0.527	1.00	0.0	8.97E-14	1.92E-14	0.100
12[a,b]	U-238	0.993	1.00	1.00	1.20E+3	1.17	4.50E-2	0.015
13	Th-234	0.993	1.00	1.00	7.57E+3	5.74E-3	2.30E-6	0.090
14	Pa-234m	0.993	1.00	1.00	2.81E+2	8.06E-5	3.23E-8	0.700
15[a]	U-234	6.0E-5	1.00	1.87E+4	1.55E+3	1.33	5.13E-2	0.015
16[a]	U-235	7.1E-3	1.00	6.48	1.56E+5	1.20	4.82E-2	0.200
17	Th-231	7.1E-3	1.00	6.48	2.97E+4	5.04E-5	2.02E-8	0.015

[a]Mother nuclide of the decay chain of nuclides which follow it.

[b]Principal nuclide in radioactive material.

Table A.2 Photon yields per disintegration of each radionuclide (J) per energy interval (I).

FGM(I,J)

I,J=	1	2	3	4	5	6	7
	Th-232	Ra-228	Ac-228	Th-228	Ra-224	Rn-220	Po-216
1	0.0361			0.0442	0.00189		
2	0.0338		0.306	0.0414	0.00201		
3	0.00455		0.0199	0.00557			
4							
5							
6							
7	0.00191		0.00501				
8							
9				0.0129	0.00325		
10			0.0584	0.00058	0.00076		
11			0.0740	0.00014	0.00024		
12			0.0193	0.00298			
13			0.0563	0.00307	0.0401		
14			0.247				
15			0.0245				
16			0.0353			0.00067	
17							
18							
19			0.0784				
20			0.225				
21			0.197				
22			0.105				
23							
24							
25							

Table A.2. Photon yields per disintegration of each radionuclide (J) per energy interval (I) (continued).

	FGM(I,J)						
I,J=	8	9	10	11	12	13	14
	Pb-212	Bi-212	Tl-208	Po-212	U-238	Th-234	Pa-234m
1	0.0660	0.0701	0.0124				
2	0.0702	0.00503	0.0132		0.0719	0.0413	0.000513
3					0.00468	0.00269	0.00034
4							
5		0.00897	0.0030				0.00001
6					0.00059		
7						0.00962	
8	0.0896	0.00136	0.0464				
9	0.162	0.00218	0.0106				
10	0.0748	0.00056	0.00305			0.0663	0.00115
11	0.00636				0.00028		0.00312
12							
13	0.462		0.00462				
14	0.0284	0.00439	0.0768				0.00047
15	0.00017	0.00015					
16		0.00395	0.234				
17			0.852				
18		0.0710					0.00354
19		0.00958					0.00384
20		0.00388	0.117				
21		0.00777	0.00598				
22		0.0208					
23							
24			0.998				
25							

Table A.2. Photon yields per disintegration of each radionuclide (J) per energy interval (I) (continued).

FGM(I,J)

I,J=	15	16	17
	U-234	U-235	Th-231
1			
2	0.0874	0.349	0.720
3	0.00569	0.227	0.137
4		0.00156	0.121
5		0.00506	0.0005
6	0.00161		
7			0.00454
8			0.0024
9			0.0864
10		0.0849	0.0129
11	0.0058	0.0488	0.0306
12		0.151	0.00331
13		0.584	0.0004
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			

Table A.3 Beta particle yields per disintegration of each radionuclide (J) per energy interval (I).

FBT(I,J)

I,J=	1	2	3	4	5	6	7
	Th-232	Ra-228	Ac-228	Th-228	Ra-224	Rn-220	Po-216
1		1.00					
2							
3							
4							
5			0.105				
6			0.055				
7							
8							
9							
10			0.113				
11			0.065				
12			0.330				
13							
14							
15							
16							
17							
18			0.200				
19							
20							
21			0.130				
22							
23							
24							
25							

Table A.3 Beta particle yields per disintegration of each radionuclide (J) per energy interval (I) (continued).

FBT(I,J)

I,J=	8	9	10	11	12	13	14
	Pb-212	Bi-212	Tl-208	Po-212	U-238	Th-234	Pa-234m
1						0.190	
2	0.050					0.810	
3	0.810						
4							
5		0.008					
6	0.140	0.021					
7		0.013					
8							
9		0.001					
10			0.038				
11							
12							
13			0.250				0.0074
14							
15			0.210				0.0072
16		0.050					
17							
18			0.500				
19							
20							
21							
22							
23		0.547					0.985
24							
25							

Table A.3 Beta particle yields per disintegration of each radionuclide (J) per energy interval (I) (continued).

	FBT(I,J)		
I,J=	15	16	17
	U-234	U-235	Th-231
1			0.014
2			0.277
3			0.709
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			

Table A.4 Data variables related to photon and beta particle energy

Energy group index I	Photon energy interval MeV	ENRGY(I) MeV	CONVR(I) $\frac{r/hr}{MeV/cm^2\text{-}sec}$	Beta energy interval MeV	EO(I) MeV	EA(I) MeV
1	0-0.012	0.01	2.901E-4	0-0.15	0.1	0.026
2	0.013-0.018	0.015	8.183E-5	0.16-0.25	0.2	0.054
3	0.019-0.025	0.02	3.302E-5	0.26-0.35	0.3	0.084
4	0.026-0.035	0.03	0.955E-5	0.36-0.45	0.4	0.116
5	0.036-0.045	0.04	0.424E-5	0.46-0.55	0.5	0.149
6	0.046-0.055	0.05	0.259E-5	0.56-0.65	0.6	0.183
7	0.056-0.065	0.06	0.198E-5	0.66-0.75	0.7	0.217
8	0.066-0.075	0.07	0.169E-5	0.76-0.85	0.8	0.253
9	0.076-0.085	0.08	0.163E-5	0.86-0.95	0.9	0.289
10	0.086-0.095	0.09	0.154E-5	0.96-1.05	1.0	0.326
11	0.096-0.12	0.10	0.160E-5	1.06-1.15	1.1	0.363
12	0.13-0.18	0.15	0.173E-5	1.16-1.25	1.2	0.401
13	0.19-0.25	0.20	0.185E-5	1.26-1.35	1.3	0.442
14	0.26-0.35	0.30	0.199E-5	1.36-1.45	1.4	0.481
15	0.36-0.45	0.40	0.204E-5	1.46-1.55	1.5	0.522
16	0.46-0.55	0.50	0.204E-5	1.56-1.65	1.6	0.563
17	0.56-0.65	0.60	0.204E-5	1.66-1.75	1.7	0.605
18	0.66-0.75	0.70	0.202E-5	1.76-1.85	1.8	0.647
19	0.76-0.85	0.80	0.199E-5	1.86-1.95	1.9	0.688
20	0.86-0.95	0.90	0.196E-5	1.96-2.05	2.0	0.731
21	0.96-1.2	1.00	0.192E-5	2.06-2.15	2.1	0.774
22	1.3-1.7	1.50	0.177E-5	2.16-2.25	2.2	0.818
23	1.8-2.5	2.0	0.164E-5	2.26-2.35	2.3	0.862
24	2.6-3.5	3.0	0.145E-5	2.36-2.45	2.4	0.906
25	3.6-4.5	4.0	0.133E-5	2.46-2.55	2.5	0.950

APPENDIX B

DERIVATION OF THE MODEL EQUATION FOR CALCULATING THE BETA DOSE RATE

The model equation used in CONDOS, Equation (3), is derived from the well-known Loevinger point-source dose-rate formula.[4,5] Details of the derivation of Equation (3) are provided in this Appendix. The Loevinger formula is of the form

$$L(x) = K\,(\nu x)^{-2}\,[cA_1(x) + A_2(x)]$$

where $L(x)$ = beta dose rate (unspecified units, depending on K) at distance x in an absorbing medium from a point source of unit strength,

K = normalization constant (to be dimensioned below),

ν = apparent absorption coefficient (cm^2/g);

$$= 18.6\,(E_0 - 0.036)^{-1.37},$$

E_0 = maximum beta particle energy (MeV beta),

x = distance (g/cm^2) travelled by the beta particle in the absorbing medium,

c = parameter (dimensionless);

$$= \begin{cases} 2.0, & \text{if } 0.17 \le E_0 \le 0.5, \\ 1.5, & \text{if } 0.50 < E_0 \le 1.5, \\ 1.0, & \text{if } 1.50 < E_0 \le 3.0, \end{cases}$$

$$A_1(x) = \begin{cases} 0, & \text{if } x \ge c/\nu, \\ 1 - (\nu x/c)\exp(1 - \nu x/c), & \text{if } x < c/\nu, \end{cases}$$

$$A_2(x) = \nu x \exp(1 - \nu x).$$

The values of c and ν given above are for tissue, e.g., the skin. In the formulation of the model equation, $E_0 = 0$ was set as the lower limit for c = 2; $E_0 = \infty$ was set as the upper limit for c = 1. Since only a few beta particles with energies below 0.1 MeV or above 3 MeV are emitted by nuclides in the natural uranium and thorium decay chains, this formulation will introduce a negligible error in practice.

The transformation function, in mass units (g/cm^2), for conversion from a point kernel to an infinite plane kernel is

$$P(z) = \frac{2\pi}{\rho^2} \int_z^\infty x\, L(x)\, dx, \text{ where } \rho = \text{density of the absorbing medium } (g/cm^3).$$

When transformed by this expression, the Loevinger formula becomes

$$P(z) = \frac{2\pi K}{\rho^2 \nu^2} \left\{ c \left[1 - \ln \frac{\nu z}{c} - \exp\left(1 - \frac{\nu z}{c}\right)\right] + \exp(1 - \nu z) \right\},$$

where $[\quad] = 0$, if $z > c/\nu$.

The transformation, in mass units, from an infinite plane to a corresponding slab of volume sources for a receptor a distance s (g/cm^2) from a slab of thickness h (g/cm^2) is

$$D(s,h) = \rho^{-1} \int_s^{s+h} P(z)\, dz,$$

$$D(s,h) = \frac{2\pi K}{\rho^3 \nu^2} \left\{ c \int_s^{s+h} \left[1 - \ln \frac{\nu z}{c} - \exp\left(1 - \frac{\nu z}{c}\right)\right] dz + \int_s^{s+h} \exp(1 - \nu z) dz \right\}, \quad (B.1)$$

where $[\quad] = 0$, if $s + h > c/\nu$.

CONDOS estimates beta doses only to the skin from contact with a consumer product. Therefore, equation (B.1) is solved for two cases: (1) when the beta particle range (c/ν) is greater than or equal to the receptor distance (s) and less than or equal to the combined receptor distance and source thickness ($s + h$), and (2) when c/ν is greater than $s + h$. The solutions are:

Case 1: $s + h \geq c/\nu \geq s$;

$$D(s,h) = \frac{2\pi K}{\rho^3 \nu^2} \left\{ c \int_s^{c/\nu} [1 - \ln \frac{\nu z}{c} - \exp(1 - \frac{\nu z}{c})] \, dz + \int_s^{s+h} \exp(1 - \nu z) \, dz \right\} ,$$

$$D(s,h) = \frac{2\pi K}{\rho^3 \nu^3} \left\{ c^2 \ [B_1] + [C_1] \right\} , \tag{B.2}$$

where $[B_1] = 3 - \frac{\nu s}{c} (2 + \ln \frac{c}{\nu s}) - \exp(1 - \frac{\nu s}{c})$,

$$[C_1] = \exp(1 - \nu s) \, [1 - \exp(-\nu h)].$$

Case 2: $s + h < c/\nu$;

$$D(s,h) = \frac{2\pi K}{\rho^3 \nu^2} \left\{ c \int_s^{s+h} [1 - \ln \frac{\nu z}{c} - \exp(1 - \frac{\nu z}{c})] \, dz + \int_s^{s+h} \exp(1 - \nu z) \, dz \right\} ,$$

$$D(s,h) = \frac{2\pi K}{\rho^3 \nu^3} \left\{ c^2 \, [B_2] + [C_1] \right\}, \tag{B.3}$$

where $[B_2] = \frac{\nu(s+h)}{c}\left[2 + \ln \frac{c}{\nu(s+h)}\right] - \frac{\nu s}{c}\left[2 + \ln \frac{c}{\nu s}\right]$

$$-\exp\left(1 - \frac{\nu s}{c}\right)\left[1 - \exp\left(-\frac{\nu h}{c}\right)\right].$$

The normalization constant K can be evaluated from the following considerations:

(1) The total energy deposited in a unit mass by beta particles, neglecting bremsstrahlung conversion losses, for a homogeneous distribution of sources in an infinite medium is simply the total beta energy emitted per unit mass. Therefore, the dose rate is

$$D_\infty = 1.60E\text{-}8\ (S/\rho)\ \bar{E}\ ,$$

where D_∞ = dose rate (rad/hr),

1.60E-8 = dimensional conversion factor (1.60E-6 erg/MeV) (0.01g-rad/erg),

S/ρ = source strength (beta-hr^{-1}/g),

$\bar{E}$ = average beta particle energy (MeV/beta).

(2) The dose rate from an infinite distribution of sources is twice the dose rate from a semi-infinite distribution, i.e., $D_\infty = 2D(o,\infty)$. Because $D(o,\infty)$ gives the dose rate at the surface of an infinite half space source, $D(o,\infty)$ can be evaluated by solving equation (B.1) with $s = o$ and $s + h = \infty$. This solution is

$$D(o,\infty) = \frac{2\pi K}{\rho^3 \nu^3}\left[3c^2 - e(c^2-1)\right].$$

From the above considerations,

$$1.60E\text{-}8\ (S/\rho)\ \bar{E} = \frac{4\pi\ K}{\rho^3 \nu^3}\ \Theta, \text{ where } \Theta = 3c^2 - e(c^2-1).$$

$$\text{Therefore,} \quad K = \frac{1.60E\text{-}8\ (S/\rho)\ \bar{E}\ \rho^3 \nu^3}{4\pi\ \Theta}\ .$$

Substitution of the above value for K into equations(B.2) and (B.3) yields:

$$\text{Case 1: } D\ (s,h) = 0.80E\text{-}8\ (S/\rho)\ \bar{E}\ \Theta^{-1} \left\{ c^2\ [B_1] + [C_1] \right\} \text{(rad/hr)}; \quad \text{(B.4)}$$

$$\text{Case 2: } D\ (s,h) = 0.80E\text{-}8\ (S/\rho)\ \bar{E}\ \Theta^{-1} \left\{ c^2\ [B_2] + [C_1] \right\} \text{(rad/hr)}. \quad \text{(B.5)}$$

Equations (B.4) and (B.5) are used in the CONDOS computer code. They are modeled for a source that emits beta particles of several energies. The source is represented in a manner consistent with section 3.1.1. The model equation is listed in section 3.1.3 as equation (3), and can be related to equations (B.4) and (B.5) by the following substitutions:

0.80E-8 = PMEG;

$S/\rho = \left(\frac{SOB}{ROB}\right)$ *AVO*DEC(IEL)*FBT(I,J)*CC(J);

$\bar{E}$ = EA(I);

Θ^{-1} = THETA(EO(I));

{ } = BCOR(STH,HTH,EO(I),IAR), where IAR = 1 solves equation (B.4) and IAR = 2 solves equation (B.5);

s = STH; and

h = HTH.

Equation (3) contains also the correction factors that allow the user to express STH and HTH in commonly used units, i.e., mg/cm^2.

APPENDIX C

SAMPLE PROBLEM

The use of CONDOS is demonstrated by estimating the radiation doses to man from a hypothetical consumer product: earthen tableware designed for use in homes and commercial eating establishments. The tableware is assumed to be coated with a glaze containing 20 wt% natural uranium which has aged 20 years since purification. Since the density of the glaze is assumed to be 4.2 g/cm^3, the concentration of uranium in the glaze is 0.84 g/cm^3. The average piece of tableware is assumed to have a surface area of 750 cm^2 and to contain 100 g of uranium.

Shipments of the tableware are assumed to be restricted to long-haul and local-delivery truck. Warehouses and retail stores are the only distribution facilities assumed to contain the tableware. A single emergency situation is considered, i.e., a truck accident involving a cargo fire. Broken pieces of tableware are discarded in trash cans and disposed of in sanitary landfills.

Table C.1 lists and indexes the parts of the consumer product life span model (see section 2.2) selected for this example. Note that only a few of the possible parts were chosen. The names, as listed in the table, of the stages, substages, groups, and events are the alphanumeric input variables.

The input variables required to describe each event are listed in Table C.2. The first three lines of the table are the input data required by the first four input cards (see section 4.6). Even specific data are then tabulated. Details of the formulation of this data will not be discussed, because the problem is hypothetical and no attempt was made

Table C.1. Life span model for hypothetical tableware

1. Distribution
   1.1 Warehouse
      1.1.1 Handlers
         1.1.1.1 handling
         1.1.1.2 storage
      1.1.2 Nearby residents
         1.1.2.1 at home
      1.1.3 Passersby
         1.1.3.1 passing by
   1.2 Retail stores
      1.2.1 Clerks
         1.2.1.1 display
         1.2.1.2 storage
      1.2.2 Shoppers
         1.2.2.1 at display
         1.2.2.2 in store
      1.2.3 Nearby clerks
         1.2.3.1 at work
      1.2.4 Passersby
         1.2.4.1 normal

2. Transport
   2.1 Truck - long haul
      2.1.1 Drivers - helpers
         2.1.1.1 driving
         2.1.1.2 stops - rest
         2.1.1.3 accident - cargo fire
      2.1.2 Persons at stops
         2.1.2.1 normal activities
      2.1.3 Persons along route
         2.1.3.1 normal activities
      2.1.4 Motorists
         2.1.4.1 passing trucks
   2.2 Truck - local delivery
      2.2.1 Deliverymen
         2.2.1.1 normal activities
      2.2.2 Persons along route
         2.2.2.1 normal activities

3. Use
   3.1 Domestic use
      3.1.1 Frequent users
         3.1.1.1 eating
         3.1.1.2 storage
      3.1.2 Occasional users
         3.1.2.1 eating
         3.1.2.2 storage
      3.1.3 Guests
         3.1.3.1 eating
      3.1.4 Neighbors
         3.1.4.1 at home
   3.2 Commercial use
      3.2.1 Dishwashers
         3.2.1.1 at work
      3.2.2 Servers - waiters
         3.2.2.1 at work
      3.2.3 Patrons
         3.2.3.1 dining out
      3.2.4 Passersby
         3.2.4.1 normal activities

4. Disposal
   4.1 Landfill
      4.1.1 Collectors
         4.1.1.1 at work
      4.1.2 Passersby
         4.1.2.1 passing cans
      4.1.3 Fill workers
         4.1.3.1 at work
      4.1.4 Area users
         4.1.4.1 normal activities

5. Emergencies
   5.1 Transport accident
      5.1.1 Firemen
         5.1.1.1 fighting fire
      5.1.2 Policemen
         5.1.2.1 crowd control
      5.1.3 Medical team
         5.1.3.1 first aid

Table C.2. List of input variables that describe the events in the life span of the hypothetical tableware[a]

IEL=2; SOB=0.84; ROB=4.2; STH=40; HTH=666; TBETA=1
TITLE1: SAMPLE PROBLEM FOR CONDOS - HYPOTHETICAL EARTHENWARE COATED WITH CERAMIC GLAZE
TITLE2: CONTAINING 100 G OF 20-YEAR OLD NATURAL URANIUM - HYPOTHETICAL PARAMETERS.

Index	IGP	ISP	NOEV	NM	NP	ICON	ITN	EVPROB	R	TINH	XO	YO	ZO	CONC	TDIR	AMT	TIMM	SRATE	TLEAK	VRATE	V	S(K)	X(K)	Y(K)	Z(K)	AATN(K)
1.1.1.1	1	1	2	1200	1	1	0	1.0							0.1							2,000	30.5			1.
1.1.1.2	-	-	-	-	1	1	0	1.0							40							2,000	305			1.
1.1.2.1	1	1	1	1200	1	1	0	1.0							70							2,000	18,000			0.9
1.1.3.1	1	1	1	100000	1	1	0	1.0							0.02							2,000	9,000			0.9
1.2.1.1	1	2	2	500	1	1	0	1.0							120							500	150			0.9
1.2.1.2	-	-	-	-	1	1	0	1.0							480							200	700			0.9
1.2.2.1	1	2	2	1000000	1	1	0	1.0							0.05							500	150			1.
1.2.2.2	-	-	-	-	1	1	0	1.0							0.5							200	1,500			0.85
1.2.3.1	1	2	1	2000	1	1	0	1.0							1920							400	18,000			0.5
1.2.4.1	1	2	1	999000000	1	1	0	1.0							0.02							400	18,000			0.5
2.1.1.1	2	1	3	510	1	1	0	1.0							28							4,000	650			0.8
2.1.1.2	-	-	-	-	1	1	0	1.0							8							4,000	9,000			0.6
2.1.1.3	-	-	-	-	0	1	0	3.5E-3	1000	0.08				1.2E-10	0		0.08									
2.1.2.1	2	1	1	5100	1	1	0	1.0							1							4,000	9,000			0.6
2.1.3.1	2	1	1	35700000	1	1	0	1.0							0.02							4,000	15,250			0.3
2.1.4.1	2	1	1	35700	1	1	0	1.0							0.02							4,000	3,050			0.6
2.2.1.1	2	2	1	200	1	1	0	1.0							2							200	650			0.8
2.2.2.1	2	2	1	1000000	1	1	0	1.0							0.02							200	9,000			0.7
3.1.1.1	3	1	2	2000	4	1	0	1.0							700	5E-3						500	30.5			0.9
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	500	152.5			0.9
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	500	76.3	76.3		0.9
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	500	76.3	76.3		0.9
3.1.1.2	-	-	-	-	1	1	0	1.0							2920							400	1,525			0.8
3.1.2.1	3	1	2	2000	4	1	0	1.0							100	1E-3						500	30.5			0.9
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	500	152.5			0.9
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	500	76.3	76.3		0.9
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	500	76.3	76.3		0.9
3.1.2.2	-	-	-	-	1	1	0	1.0							2920							400	1,525			0.8
3.1.3.1	3	1	1	40000	4	1	0	1.0							1	1E-5						500	30.5			0.9
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	500	152.5			0.9
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	500	76.3	76.3		0.9
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	500	76.3	76.3		0.9
3.1.4.1	3	1	1	8000	1	1	0	1.0							2920							400	4,575			0.8
3.2.1.1	3	2	1	500	1	2	0	1.0	95	2000					2000		2000	1E-9		1.2E6	3.6E6	375	90.0			1.
3.2.2.1	3	2	1	1000	1	2	0	1.0	95	250					1000		250	1E-9		1.2E6	3.6E6	500	152.5			1.
3.2.3.1	3	2	1	7500000	1	1	0	1.0							4	1E-4						500	61.0			0.9
3.2.2.4	3	2	1	99900000	1	1	0	1.0							0.02							1,000	18,000			0.5
4.1.1.1	4	1	1	30	1	1	0	1.0							1							100	90.0			0.7
4.1.2.1	4	1	1	100000	1	1	0	1.0							0.02							100	150.0			0.7
4.1.3.1	4	1	1	40	1	1	0	1.0							1							500	9,000			0.5
4.1.4.1	4	1	1	1000000	1	1	0	1.0							8							500	30,000			0.5
5.1.1.1	5	1	1	5	1	1	0	1.0	1000	1				1.2E-10	1							50,000	3,050			0.7
5.1.2.1	5	1	1	2	1	1	0	1.0	1000	1				1.2E-10	1							50,000	7,100			0.7
5.1.3.1	5	1	1	3	1	1	0	1.0	1000	0.25				1.2E-10	0.25							50,000	7,100			0.7

[a]Dashes (-) indicate variables and input cards that may not be filled-in. All blank variables are set equal to zero.

to verify the realism of the parameters used in the event descriptions. Reference to sections 4.5 and 4.6 will allow the interested reader to dimension the variables. Note that the formats of the data as listed in the table are not necessarily those required by the computer code.

Almost all events describe the conditions for direct photon irradiation from a single point source. The receptor was set at the origin for all cases, and the source to receptor distance defined by a single coordinate, X(K), for most events. Multiple point sources requiring more than one coordinate are described for events 3.1.1.1, 3.1.2.1, and 3.1.3.1. The option to specify an AATN(K), which may be regarded as a shielding factor, is selected for all direct irradiation events. If the ATN(I,K) option had been selected, 25 values of that variable would have been required for each direct irradiation event for which the option was used.

Immersion in a cloud of contaminated air is considered in events 2.1.1.3 (ICON = 1; CONC specified), 3.2.1.1, and 3.2 2.1 (ICON = 2; CONC = SRATE/VRATE). Ingestion of the radioactive material is considered only for users of the tableware--events 3.1.1.1, 3.1.2.1, 3.1.3.1, and 3.2.3.1. Inhalation is considered for truckers (2.1.1.3) and emergency workers (5.1.1.1, 5.1.2.1, and 5.1.3.1) in a truck-cargo fire situation by specifying the concentration of radioactive material in air. Inhalation by dishwashers (3.2.1.1) and servers - waiters (3.2.2.1) makes use of the calculated value of CONC.

Table C.3 is the computer output of the radiation doses to man for the conditions assumed for the distribution, transport, use, disposal, and emergency care of the hypothetical consumer product. The most affected population groups and individuals can be determined easily, as

can the contributions to the total dose by each exposure pathway considered in the hypothetical example. The beta skin dose from one hour of contact is listed at the end of the table.

Table C.3. Computer output for sample problem--hypothetical tableware

POPULATION RADIATION DOSE FROM THE DISTRIBUTION, USE, AND DISPOSAL

OF CONSUMER PRODUCTS CONTAINING RADIOACTIVE MATERIALS

SAMPLE PROBLEM FOR CONDOS - HYPOTHETICAL EARTHEN TABLEWARE COATED WITH CERAMIC GLAZE CONTAINING 100 G OF 20-YEAR OLD NATURAL URANIUM - HYPOTHETICAL PARAMETERS.

	DOSE PER INDIVIDUAL INVOLVED (MREM/YR)					POPULATION DOSE		
	EXTERNAL		INTERNAL		TOTAL			
	DIRECT	IMMERSION	INHALATION	INGESTION		PROBABILITY	GROUP DOSE (MAN-REM/YR)	TOTAL DOSE (MAN-REM/YR)
DISTRIBUTION								
WAREHOUSE								
HANDLERS (1.200E 03 MEMBERS)								
HANDLING	7.99E-02	0.0	0.0	0.0	7.99E-02	1.00E 00	9.58E-02	
STORAGE	3.19E-01	0.0	0.0	0.0	3.19E-01	1.00E 00	3.83E-01	
TOTAL DOSE --- HANDLERS								4.79E-01
NEARBY RESIDENTS (1.200E 03 MEMBERS)								
AT HOME	1.44E-04	0.0	0.0	0.0	1.44E-04	1.00E 00	1.73E-04	
TOTAL DOSE --- NEARBY RESIDENTS								1.73E-04
PASSERSBY (1.000E 05 MEMBERS)								
PASSING BY	1.65E-07	0.0	0.0	0.0	1.65E-07	1.00E 00	1.65E-05	
TOTAL DOSE --- PASSERSBY								1.65E-05
TOTAL DOSE --- WAREHOUSE								4.79E-01
RETAIL STORES								
CLERKS (5.000E 02 MEMBERS)								
DISPLAY	8.91E-01	0.0	0.0	0.0	8.91E-01	1.00E 00	4.46E-01	
STORAGE	6.55E-02	0.0	0.0	0.0	6.55E-02	1.00E 00	3.27E-02	
TOTAL DOSE --- CLERKS								4.78E-01
SHOPPERS (1.000E 06 MEMBERS)								
AT DISPLAY	4.13E-04	0.0	0.0	0.0	4.13E-04	1.00E 00	4.13E-01	
IN STORE	1.40E-05	0.0	0.0	0.0	1.40E-05	1.00E 00	1.40E-02	
TOTAL DOSE --- SHOPPERS								4.27E-01
NEARBY CLERKS (2.000E 03 MEMBERS)								

AT WORK	4.40E-04	0.0	0.0	0.0	4.40E-04	1.00E 00	8.80E-04	
TOTAL DOSE --- NEARBY CITERS								8.80E-04
PASSERSBY (9.990E 08 MEMBERS)								
NORMAL	4.59E-09	0.0	0.0	0.0	4.59E-09	1.00E 00	4.58E-03	
TOTAL DOSE --- PASSERSBY								4.58E-03
TOTAL DOSE --- RETAIL STORES								9.11E-01
TOTAL DOSE --- DISTRIBUTION								1.39E 00

TRANSPORT

TRUCK - LONG HAUL

DRIVERS - HELPERS (5.100E 02 MEMBERS)								
DRIVING	7.88E-02	0.0	0.0	0.0	7.88E-02	1.00E 00	4.02E-02	
STOPS - REST	8.80E-05	0.0	0.0	0.0	8.80E-05	1.00E 00	4.49E-05	
ACCIDENT-CARGO FIRE	0.0	7.05E-12	7.25E-03	0.0	7.25E-03	3.50E-03	1.29E-05	
TOTAL DOSE --- DRIVERS - HELPERS								4.02E-02
PERSONS AT STOPS (5.100E 03 MEMBERS)								
NORMAL ACTIVITIES	1.10E-05	0.0	0.0	0.0	1.10E-05	1.00E 00	5.61E-05	
TOTAL DOSE --- PERSONS AT STOPS								5.61E-05
PERSONS ALONG ROUTE (3.570E 07 MEMBERS)								
NORMAL ACTIVITIES	3.83E-08	0.0	0.0	0.0	3.83E-08	1.00E 00	1.37E-03	
TOTAL DOSE --- PERSONS ALONG ROUTE								1.37E-03
MOTORISTS (3.570E 04 MEMBERS)								
PASSING TRUCKS	1.92E-06	0.0	0.0	0.0	1.92E-06	1.00E 00	6.84E-05	
TOTAL DOSE --- MOTORISTS								6.84E-05
TOTAL DOSE --- TRUCK - LONG HAUL								4.17E-02

TRUCK-LOCAL DELIVERY

DELIVERYMEN (2.000E 02 MEMBERS)								
NORMAL ACTIVITIES	2.81E-04	0.0	0.0	0.0	2.81E-04	1.00E 00	5.63E-05	
TOTAL DOSE --- DELIVERYMEN								5.63E-05
PERSONS ALONG ROUTE (1.000E 06 MEMBERS)								
NORMAL ACTIVITIES	1.28E-08	0.0	0.0	0.0	1.28E-08	1.00E 00	1.28E-05	
TOTAL DOSE --- PERSONS ALONG ROUTE								1.28E-05

TOTAL DOSE --- TRUCK-LOCAL DELIVERY								6.91E-05
TOTAL DOSE --- TRANSPORT								4.18E-02
USE								
DOMESTIC USE								
FREQUENT USERS (2.000E 03 MEMBERS)								
EATING	1.51E 02	0.0	0.0	1.74E-01	1.51E 02	1.00E 00	3.02E 02	
STORAGE	1.49E-01	0.0	0.0	0.0	1.49E-01	1.00E 00	2.98E-01	
TOTAL DOSE --- FREQUENT USERS								3.02E 02
OCCASIONAL USERS (2.000E 03 MEMBERS)								
EATING	2.16E 01	0.0	0.0	3.49E-02	2.16E 01	1.00E 00	4.32E 01	
STORAGE	1.49E-01	0.0	0.0	0.0	1.49E-01	1.00E 00	2.98E-01	
TOTAL DOSE --- OCCASIONAL USERS								4.35E 01
GUESTS (4.000E 04 MEMBERS)								
EATING	2.16E-01	0.0	0.0	3.49E-04	2.16E-01	1.00E 00	8.64E 00	
TOTAL DOSE --- GUESTS								8.64E 00
NEIGHBORS (8.000E 03 MEMBERS)								
AT HOME	1.66E-02	0.0	0.0	0.0	1.66E-02	1.00E 00	1.33E-01	
TOTAL DOSE --- NEIGHBORS								1.33E-01
TOTAL DOSE --- DOMESTIC USE								3.55E 02
COMMERCIAL USE								
DISHWASHERS (5.000E 02 MEMBERS)								
AT WORK	3.44E 01	1.13E-12	1.26E-03	0.0	3.44E 01	1.00E 00	1.72E 01	
TOTAL DOSE --- DISHWASHERS								1.72E 01
SERVERS - WAITERS (1.000E 03 MEMBERS)								
AT WORK	7.93E 00	1.42E-13	1.57E-04	0.0	7.93E 00	1.00E 00	7.93E 00	
TOTAL DOSE --- SERVERS - WAITERS								7.93E 00
PATRONS (7.500E 06 MEMBERS)								
DINING OUT	1.80E-01	0.0	0.0	3.49E-03	1.83E-01	1.00E 00	1.37E 03	
TOTAL DOSE --- PATRONS								1.37E 03
PASSERSBY (9.990E 07 MEMBERS)								
NORMAL ACTIVITIES	1.15E-03	0.0	0.0	0.0	1.15E-08	1.00E 00	1.15E-03	

TOTAL DOSE --- PASSERSBY								1.15E-03
TOTAL DOSE --- COMMERCIAL USE								1.40E 03
TOTAL DOSE --- USE								1.75E 03
DISPOSAL								
LANDFILL								
COLLECTORS								
(3.000E 01 MEMBERS)								
AT WORK	3.21E-03	0.0	0.0	0.0	3.21E-03	1.00E 00	9.63E-05	
TOTAL DOSE --- COLLECTORS								9.63E-05
PASSERSBY								
(1.000E 05 MEMBERS)								
PASSING CARS	2.31E-05	0.0	0.0	0.0	2.31E-05	1.00E 00	2.31E-03	
TOTAL DOSE --- PASSERSBY								2.31E-03
FILL WORKERS								
(4.000E 01 MEMBERS)								
AT WORK	1.15E-06	0.0	0.0	0.0	1.15E-06	1.00E 00	4.59E-08	
TOTAL DOSE --- FILL WORKERS								4.59E-08
AREA USERS								
(1.000E 06 MEMBERS)								
NORMAL ACTIVITIES	8.25E-07	0.0	0.0	0.0	8.25E-07	1.00E 00	8.25E-04	
TOTAL DOSE --- AREA USERS								8.25E-04
TOTAL DOSE --- LANDFILL								3.23E-03
TOTAL DOSE --- DISPOSAL								3.23E-03
EMERGENCIES								
TRANSPORT ACCIDENT								
FIREMEN								
(5.000E 00 MEMBERS)								
FIREFIGHTING	1.40E-03	8.81E-11	9.07E-02	0.0	9.21E-02	1.00E 00	4.60E-04	
TOTAL DOSE --- FIREMEN								4.60E-04
POLICEMEN								
(2.000E 00 MEMBERS)								
CROWD CONTROL	2.98E-04	8.81E-11	9.07E-02	0.0	9.09E-02	1.00E 00	1.82E-04	
TOTAL DOSE --- POLICEMEN								1.82E-04
MEDICAL TEAM								
(3.000E 00 MEMBERS)								
FIRST AID	6.45E-05	2.20E-11	2.27E-02	0.0	2.27E-02	1.00E 00	6.82E-05	
TOTAL DOSE --- MEDICAL TEAM								6.82E-05

TOTAL DOSE --- TRANSPORT ACCIDENT	7.10E-04
TOTAL DOSE --- EMERGENCIES	7.10E-04
GRAND TOTAL DOSE	1.75E 03

FOR SKIN CONTACT OF 1.0 HOURS THE BETA DOSE IS 5.09E-02 RADS.

APPENDIX D

LISTING OF THE CONDOS COMPUTER CODE

```
C     THE NAME OF THIS PROGRAM IS CONDOS.
        BLOCK DATA
        COMMON/ALPH/TITLE1(20),TITLE2(20),GROUP(5),SUBGRP(5),SSGRP(5),IVEN
      1T(5),STORSS(5),STORSG(5),STORGP(5)
        COMMON/INTG/IR,IW,ID,IFIRST,IGP,ISP,INCR,IH,NM,NP,IGS,ISS,ISSP,
      1ICON,ITN,IRITE,IDT,LPT,LI,JLOC(2),IEL,NOEV
      A,NBINT,NGINT,JLO(2),JHI(2)
        COMMON/REALX/DIR,EM,EN,ENG,TOT,EVPFOB,GPDOS,TGPDOS,TABX(100),TABMU
      1(50),ENRG(17),ENRGL,ENRGH,DENRG,GPMDOS,STODOS,GTDOS,XO,YO,ZO,TDIR
      2,CONC,SRATE,VRATE,TLEAK,V,X(10),Y(10),Z(10),S(10),ATN(10,25),TIM
      %M,ENRGY(25),EA(25),EO(25),CONVR(25),YI(17),TABMU1(20)
      3,CINM(17),CINH(17),AMT,CING(17),F,XMU,ENRGL1,ENRGH1,DENRG1,TINH
      4,AATN(10),TABX1(100),CC(17),CH(17),FA(17),
      6FBET(25),FBT(25,17),FGM(25,17)
      5,GAMCO,SOB,ROB,DEC(2),STH,HTH,TBETA,DBETA
        DATA RA/1.,2*.8736,.8239,5*.8236,.2965,.5271,6*1./
        DATA CH/14*1.,1.869E4,2*6.476/,YI/11*1.,3*.9928,.00006,2*.0071/
        DATA CINH/184.,22.15,.01565,41.6,.2697,0.,3.463E-8,.01095,
      $9.49E-4,2.11E-6,6.968E-14,1.17,.00574,8.062E-5,1.33,1.20,5.041E-5/
        DATA CING/.0739,16.62,6.261E-6,.01664,.2023,0.,7.47E-9,.003072,
      %3.65E-5,1.978E-6,1.922E-14,.0450,2.296E-6,3.225E-6,.0513,
      &.0482,2.017E-8/
        DATA CINM/1.18E3,3.21E4,7.52E5,3.58E3,1.02E4,0.,0.,1.48E5,
      &1.11E5,3.42E6,0.,1.2E3,7.57E3,281.,1.55E3,1.56E5,2.97E4/
        DATA ENRGY/.01,.015,.02,.03,.04,.05,.06,.07,.08,.09,.1,.15,.2,.3,
      &.4,.5,.6,.7,.8,.9,1.,1.5,2.,3.,4./
        DATA CONVR/29.0107E-5,8.1833E-5,3.302E-5,.955E-5,.424E-5,.259E-5,
      &.198E-5,.1686E-5,.1625E-5,.1544E-5,.1596E-5,.1728E-5,.1854E-5,
      &.1986E-5,.2037E-5,.2043E-5,.2037E-5,.2016E-5,.1991E-5,.1956E-5,
      &.1923E-5,.1758E-5,.1636E-5,.1453E-5,.1333E-5/
        DATA EO/.1,.2,.3,.4,.5,.6,.7,.8,.9,1.,1.1,1.2,1.3,1.4,1.5,1.6,
      &1.7,1.8,1.9,2.,2.1,2.2,2.3,2.4,2.5/
        DATA EA/.026,.054,.084,.116,.149,.183,.217,.253,.289,.326,.363,
      &.401,.442,.481,.522,.563,.605,.647,.688,.731,.774,.818,.862,
      &.906,.95/
        DATA FBT/25*0.,1.,28*0.,.105,.055,3*0.,.113,.065,.33,5*0.,.2,2*0.
      &,.13,105*0.,.05,.81,2*0.,.14,23*0.,.008,.021,.013,0.,.001,6*0.,
      &.05,6*0.,.547,11*0.,.038,2*0.,.25,0.,.21,2*0.,.5,57*0.,.19,.81,
      &35*0.,.0074,0.,.0072,7*0.,.9854,52*0.,.014,.277,.709,22*0./
        DATA FGM/.03608,.0338,.00455,3*0.,.00191,44*0.,.306,.0199,3*0.,.0
      &0501,2*0.,.0584,.07396,.0193,.0563,.2473,.0245,.0353,2*0.,.0784,
      &.225,.1969,.105,3*0.,.04419,.0414,.00557,5*0.,.01292,.00058,.0001
      &4,.00298,.00307,12*0.,.00189,.00201,6*0.,.00325,.00076,.00024,0.,
      &.04008,27*0.,.00067,34*0.,.06602,.07019,5*0.,.0896,.16173,.0748,
      &.00636,0.,.46153,.02847,.00017,10*0.,.07008,.00503,2*0.,.00897,
      &2*0.,.00136,.00218,.00056,3*0.,.00439,.00015,.00395,0.,.07102,.00
      &956,.00383,.00777,.02081,3*0.,.01243,.01322,2*0.,.003,2*0.,.04637,
      &.0106,.00305,2*0.,.00462,.07682,0.,.23358,.85157,2*0.,.11651,.005
      &98,2*0.,.99789,27*0.,.07188,.00468,2*0.,.00059,4*0.,.00028,15*0.,
      &.04131,.00269,3*0.,.00962,2*0.,.06628,16*0.,.00513,.00034,0.,
      &.00001,4*0.,.00115,.00312,2*0.,.00047,3*0.,.00354,.00384,7*0.,
      &.08736,.00569,2*0.,.00161,4*0.,.00058,15*0.,.34911,.0266,.00156,
      &.00506,4*0.,.08487,.04878,.15126,.58399,13*0.,.71977,.13712,
      &.12135,.0005,0.,.00454,.0024,.08636,.0129,.03058,.00331,
      &.0004,12*0./
        DATA DEC/.243E-16,.739E-16/,JLO/1,12/,JHI/11,17/,
      &NBINT/25/,NGINT/25/
        DATA ENRO/.015,.1,1.,.015,.2,.5,.1,.2,.8,.7,.1,.015,.09,.7,.015,
      &.2,.015/
        DATA TABMU/   2.252E-02,   2.671E-02,   2.877E-02,   2.957E-02,
      12.975E-02,   2.963E-02,   2.930E-02,   2.893E-02,   2.846E-02,   2
      2.801E-02,   2.744E-02,   2.699E-02,   2.647E-02,   2.606E-02,   2.
      3564E-02,   2.525E-02,   2.482E-02,   2.448E-02,   2.410E-02,   2.3
      480E-02,   2.349E-02,   2.312E-02,   2.285E-02,   2.259E-02,   2.22
      57E-02,   2.204E-02,   2.181E-02,   2.159E-02,   2.132E-02,   2.112
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     6E-02,   2.093E-02,   2.075E-02,   2.053E-02,   2.037E-02,   2.020E
     7-02,   2.004E-02,   1.985E-02,   1.970E-02,   1.955E-02,   1.941E-
     802,   1.928E-02,   1.916E-02,   1.698E-02,   1.686E-02,   1.875E-0
     92,   1.863E-02,   1.852E-02,   1.842E-02,   1.831E-02,   1.816E-02
     %/
      DATA TABMU1/   4.560E 00,   4.964E-01,   1.412E-01,   6.290E-02,
     A 3.860E-02,   2.920E-02,   2.570E-02,   2.364E-02,   2.320E-02,
     B2.312E-02,   2.328E-02,   2.358E-02,   2.400E-02,   2.444E-02,   2
     C.495E-02,   2.527E-02,   2.561E-02,   2.598E-02,   2.636E-02,   2.
     D674E-02/
      DATA ENRGL/0.10/, ENRGH/5.0/, DENRG/0.10/, INCR/0/,ID1/1/
     5,IW/6/,LPT/6/,IR/5/,ID/1/,ENRGL1/.01/,ENRGH1/.2/,DENRG1/.01/
      DATA JLOC/1,2/
      END
      COMMON/ALPH/TITLE1(20),TITLE2(20),GROUP(5),SUBGRP(5),SSGRP(5),IVEN
     1T(5),STORSS(5),STORSG(5),STORGP(5)
      COMMON/INTG/IR,IW,ID,IFIRST,IGP,ISP,INCR,IH,NM,NP,IGS,ISS,ISSP,
     1ICON,ITN,IRITE,ID1,LPT,L1,JLOC(2),IEL,NOEV
     A,NBINT,NGINT,JLO(2),JHI(2)
      COMMON/REALX/DIR,EM,EN,ENG,TOT,EVPROB,GPDOS,TGPDOS,TABX(100),TABMU
     1(50),ENRG(17),ENRGL,ENRGH,DENRG,GPMDOS,STGDOS,GTDOS,XO,YO,ZO,TDIR
     2,CONC,SRATE,VRATE,TLEAK,V,X(10),Y(10),Z(10),S(10),ATN(10,25),TIM
     %M,ENRGY(25),EA(25),EO(25),CONVR(25),YI(17),TABMU1(20)
     3,CIMM(17),CINH(17),AMT,CING(17),R,XMU,ENRGL1,ENRGH1,DENRG1,TINH
     4,AATN(10),TABX1(100),CC(17),CH(17),RA(17),
     6FBET(25),FBT(25,17),FGM(25,17)
     5,GAMCO,SOB,ROB,DEC(2),STH,HTH,TBETA,DBETA
      IFIRST=0
      GTDOS=0
      CALL INPUT
C      CALL IFILE(ID,'INPU')
      READ(ID,103) IEL
      READ(ID,104) SOB,ROB,STH,HTH,TBETA
  104 FORMAT(5F12.4)
      CALL PREFAS
      READ(ID,102) (TITLE1(I1),I1=1,20)
  102 FORMAT(20A4)
      READ(ID,102) (TITLE2(I2),I2=1,20)
      CALL OUTPUT
      IRITE=0
  103 FORMAT(I5)
   68 DO 71 LS=1,5
   71 STORSS(LS)=SSGRP(LS)
      READ(ID,100) IGP,ISP,NOEV,NM,(SSGRP(LG),LG=1,5)
  100 FORMAT(3I5,I15,5X,5A4)
      IF(IGP) 51,52,51
   51 IF(IGS-IGP) 54,53,54
   54 DO 72 LS=1,5
   72 STORGP(LS)=GROUP(LS)
      READ(ID,105) (GROUP(LG),LG=1,5)
  105 FORMAT(5A4)
   53 IF(ISS-ISP) 57,56,57
   56 IF(IGS-IGP) 57,59,57
   57 DO 73 LS=1,5
   73 STORSG(LS)=SUBGRP(LS)
      READ(ID,105) (SUBGRP(LG),LG=1,5)
   59 DO 61 I=1,NOEV
      READ(ID,105) (IVENT(LV),LV=1,5)
      READ(ID,110) NP,ICON,ITN,EVPROB,R,TINH,XO,YO,ZO
  110 FORMAT(3I5,E12.2,F10.4,F7.2,3F12.6)
      READ(ID,115) CONC,TDIR,AMT,TIMM,SRATE,TLEAK,VRATE,V
  115 FORMAT(E10.2,E10.3,4E10.2,2E10.3)
      IF(NP) 58,62,58
   58 DO 62 J=1,NP
      READ(ID,120) S(J),X(J),Y(J),Z(J)
```

```
  120 FORMAT(E12.4,3F10.4)
      IF(ITN) 66,63,66
   63 DO 64 L=1,NGINT
   64 ATN(J,L)=1.
      READ(ID,150) AATN(J)
  150 FORMAT(F10.4)
      GO TO 62
   66 READ(ID,125) (ATN(J,L),L=1,NGINT)
  125 FORMAT(8F10.4)
      AATN(J)=1.
   62 CONTINUE
      IRITE=IRITE+1
      CALL CALC
      CALL OUTPUT
   61 CONTINUE
      ISSP=ISSP+1
      GO TO 68
   52 WRITE(IW,130) (STORSS(L),L=1,5),TGPDOS
  130 FORMAT(1HO,10X,'TOTAL DOSE --- ',5A4,73X,1PE12.3)
      WRITE(IW,135) (SUBGRP(L),L=1,5),GPMDOS
  135 FORMAT(1HO,20X,'TOTAL DOSE --- ',5A4,63X,1PE12.3)
      WRITE(IW,140) (GROUP(L),L=1,5),STGDOS
  140 FORMAT(1HO,30X,'TOTAL DOSE --- ',5A4,53X,1PE12.3/)
      WRITE(IW,145) GTDOS
  145 FORMAT(1HO,40X,'GRAND TOTAL DOSE',62X,1PE12.3)
      WRITE(IW,90)TBETA,DBETA
   90 FORMAT(1H1,'FOR SKIN CONTACT OF ',F9.1,' HOURS
     & THE BETA DOSE IS',E14.7,' RADS.'/)
      REWIND 1
C      CALL RELEAS(ID)
      STOP
      END
      SUBROUTINE CALC
      COMMON/ALPH/TITLE1(20),TITLE2(20),GROUP(5),SUBGRP(5),SSGRP(5),IVEN
     1T(5),STORSS(5),STORSG(5),STORGP(5)
      COMMON/INTG/IR,IW,ID,IFIRST,IGP,ISP,INCR,IH,NM,NP,IGS,ISS,ISSP,
     1ICON,ITN,IRITE,ID1,LPT,LI,JLOC(2),IEL,NOEV
     A,NBINT,NGINT,JLO(2),JHI(2)
      COMMON/REALX/DIR,EM,EN,ENG,TOT,EVPROB,GPDOS,TGPDOS,TABX(100),TABMU
     1(50),ENRG(17),ENRGL,ENRGH,DENRG,GPMDOS,STGDOS,GTDOS,XO,YO,ZC,TDIR
     2,CONC,SRATE,VRATE,TLEAK,V,X(10),Y(10),Z(10),S(10),ATN(10,25),TIM
     %M,ENRGY(25),EA(25),EO(25),CONVR(25),YI(17),TABMU1(20)
     3,CIMN(17),CINH(17),AMT,CING(17),R,XMU,ENRGL1,ENRGH1,DENRG1,TINH
     4,AATN(10),TABX1(100),CC(17),CH(17),FA(17),
     6FBET(25),FBT(25,17),FGM(25,17)
     5,GAMCO,SOB,ROB,DEC(2),STH,HTH,TBETA,DBETA
      JLO1=JLO(IEL)
      JHI1=JHI(IEL)
      DIR=0
      IF(NP) 3,4,3
    3 SUMD=0
      DO 1 LA=1,NP
      SGM=0
      DO 2 LG=1,NGINT
    2 SGM=SGM+FBET(LG)*ATN(LA,LG)
    1 SUMD=SUMD+S(LA)*GAMCO*SGM*AATN(LA)/((XO-X(LA))**2
     *+(YO-Y(LA))**2+(ZC-Z(LA))**2)
      DIR=SUMD*TDIR*79.6
    4 CONTINUE
C  COMPUTE THE DOSE DUE TO IMMERSION(EM).
      GO TO (8,9,11), ICON
    9 CONC=SRATE/VRATE
      GO TO 8
   11 CONC=TLEAK/V
    8 EM=0
```

```
      EN=0
      ENG=0
      DO 7 L1=JLO1,JHI1
      EM=EM+CC(L1)*CIMM(L1)*F(ABS)
      EN=EN+CINH(L1)*CC(L1)
    7 ENG=ENG+CING(L1)*CC(L1)
      EM=EM*CONC*TIMM*GAMCO/(3.7E4*8766.)
      EN=EN*CONC*TINH*.833E 09*GAMCO/3.7E4
      ENG=ENG*AMT*GAMCO/37.
      TOT=DIR+EM+EN+ENG
      GPDOS=TOT*EVPROB*NM/1000.
      GTDOS=GTDOS+GPDOS
      RETURN
      END
      FUNCTION F(ABS)
      COMMON/ALPH/TITLE1(20),TITLE2(20),GROUP(5),SUBGRP(5),SSGRP(5),IVEN
     1T(5),STORSS(5),STORSG(5),STORGP(5)
      COMMON/INTG/IR,IW,ID,IFIRST,IGP,ISP,INCR,IH,NM,NP,IGS,ISS,ISSP,
     1ICON,ITN,IRITE,ID1,LPT,L1,JLOC(2),IEL,NOEV
     A,NBINT,NGINT,JLO(2),JHI(2)
      COMMON/REALX/DIR,EM,EN,ENG,TOT,EVPROB,GPDOS,TGPDOS,TABX(100),TABMU
     1(50),ENRG(17),ENRGL,ENRGH,DENRG,GPMDOS,STGDOS,GTDOS,XO,YO,ZO,TDIR
     2,CONC,SRATE,VRATE,TLEAK,V,X(10),Y(10),Z(10),S(10),ATN(10,25),TIM
     %M,ENRGY(25),EA(25),EO(25),CONVR(25),YI(17),TABMU1(20)
     3,CIMM(17),CINH(17),AMT,CING(17),R,XMU,ENRGL1,ENRGH1,DENRG1,TINH
     4,AATN(10),TABX1(100),CC(17),CH(17),RA(17),
     6FBET(25),FBT(25,17),FGM(25,17)
     5,GAMCO,SOB,ROB,DEC(2),STH,HTH,TBETA,DBETA
      IF(ENRG(L1).LT.0.01.OR.ENRG(L1).GT.5.) GO TO 4
      IF(INCR) 2,1,2
    1 CALL TERP1
      GO TO 3
    2 CALL TERP2
    3 F=1.-EXP(-XMU*R)
      GO TO 5
    4 WRITE(IW,200)
  200 FORMAT(1HO,5X,'ENRG VALUE OUT OF LIMITS OF CROSS-SECTION TABLE')
    5 RETURN
      END
      SUBROUTINE TERP1
      COMMON/ALPH/TITLE1(20),TITLE2(20),GROUP(5),SUBGRP(5),SSGRP(5),IVEN
     1T(5),STORSS(5),STORSG(5),STORGP(5)
      COMMON/INTG/IR,IW,ID,IFIRST,IGP,ISP,INCR,IH,NM,NP,IGS,ISS,ISSP,
     1ICON,ITN,IRITE,ID1,LPT,L1,JLOC(2),IEL,NOEV
     A,NBINT,NGINT,JLO(2),JHI(2)
      COMMON/REALX/DIR,EM,EN,ENG,TOT,EVPROB,GPDOS,TGPDOS,TABX(100),TABMU
     1(50),ENRG(17),ENRGL,ENRGH,DENRG,GPMDOS,STGDOS,GTDOS,XO,YO,ZO,TDIR
     2,CONC,SRATE,VRATE,TLEAK,V,X(10),Y(10),Z(10),S(10),ATN(10,25),TIM
     %M,ENRGY(25),EA(25),EO(25),CONVR(25),YI(17),TABMU1(20)
     3,CIMM(17),CINH(17),AMT,CING(17),R,XMU,ENRGL1,ENRGH1,DENRG1,TINH
     4,AATN(10),TABX1(100),CC(17),CH(17),RA(17),
     6FBET(25),FBT(25,17),FGM(25,17)
     5,GAMCO,SOB,ROB,DEC(2),STH,HTH,TBETA,DBETA
C   ENRG=GAMMA RAY ENERGY IN MEV.
C   ENRGL=LOWEST ENERGY VALUE IN TABLE,TABMU.
C   DENRG=ENERGY INCREMENT BETWEEN POINTS IN TABMU.
      IF(ENRG(L1).GT.ENRGL) GO TO 13
      TABLOC=(ENRG(L1)-ENRGL1)/DENRG1
      GO TO 14
   13 TABLOC=(ENRG(L1)-ENRGL)/DENRG
   14 ITAB=IFIX(TABLOC)+1
      FR=TABLOC+1.-ITAB
      IF(ENRG(L1).GT.ENRGL) GO TO 16
      XMU=(TABMU1(ITAB+1)-TABMU1(ITAB))*FR+TABMU1(ITAB)
      GO TO 17
```

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16  XMU=(TABMU(ITAB+1)-TABMU(ITAB))*FR+TABMU(ITAB)
17  RETURN
    END
    SUBROUTINE TERP2
    COMMON/ALPH/TITLE1(20),TITLE2(20),GROUP(5),SUBGRP(5),SSGRP(5),IVEN
   1T(5),STORSS(5),STORSG(5),STORGP(5)
    COMMON/INTG/IR,IW,ID,IFIRST,IGP,ISP,INCR,IH,NM,NP,IGS,ISS,ISSP,
   1ICON,ITN,IRITE,ID1,LPT,L1,JLOC(2),IEL,NOEV
   A,NBINT,NGINT,JLO(2),JHI(2)
    COMMON/REALX/DIR,EM,EN,ENG,TOT,EVPROB,GPDOS,TGPDOS,TABX(100),TABMU
   1(50),ENRG(17),ENRGL,ENRGH,DENRG,GPMDOS,STGDOS,GTDOS,XO,YO,ZO,TDIR
   2,CONC,SRATE,VRATE,TLEAK,V,X(10),Y(10),Z(10),S(10),ATN(10,25),TIM
   %M,ENRGY(25),EA(25),EO(25),CONVR(25),YI(17),TABMU1(20)
   3,CIMM(17),CINH(17),AMT,CING(17),F,XMU,ENRGL1,ENRGH1,DENRG1,TINH
   4,AATN(10),TABX1(100),CC(17),CH(17),FA(17),
   6FBET(25),FBT(25,17),FGM(25,17)
   5,GAMCO,SOB,BOB,DEC(2),STH,HTH,TBETA,DBETA
    LO=0
    IF(ENRG(L1).GT.ENRGL) GO TO 1
 4  LO=LO+1
    IF(TABX1(LO)-ENRG(L1))  4,5,6
 5  XMU=TABMU1(LO)
    GO TO 7
 6  FR=(TABX1(LO)-ENRG(L1))/(TABX1(LO)-TABX1(LO-1))
    XMU=TABMU1(LO)-FR*(TABMU1(LO)-TABMU1(LO-1))
    GO TO 7
 1  LO=LO+1
    IF(TABX(LO)-ENRG(L1))  1,2,3
 2  XMU=TABMU(LO)
    GO TO 7
 3  FR=(TABX(LO)-ENRG(L1))/(TABX(LO)-TABX(LO-1))
    XMU=TABMU(LO)-FR*(TABMU(LO)-TABMU(LO-1))
 7  RETURN
    END
    SUBROUTINE OUTPUT
    COMMON/ALPH/TITLE1(20),TITLE2(20),GROUP(5),SUBGRP(5),SSGRP(5),IVEN
   1T(5),STORSS(5),STORSG(5),STORGP(5)
    COMMON/INTG/IR,IW,ID,IFIRST,IGP,ISP,INCR,IH,NM,NP,IGS,ISS,ISSP,
   1ICON,ITN,IRITE,ID1,LPT,L1,JLOC(2),IEL,NOEV
   A,NBINT,NGINT,JLO(2),JHI(2)
    COMMON/REALX/DIR,EM,EN,ENG,TOT,EVPROB,GPDOS,TGPDOS,TABX(100),TABMU
   1(50),ENRG(17),ENRGL,ENRGH,DENRG,GPMDOS,STGDOS,GTDOS,XO,YO,ZO,TDIR
   2,CONC,SRATE,VRATE,TLEAK,V,X(10),Y(10),Z(10),S(10),ATN(10,25),TIM
   %M,ENRGY(25),EA(25),EO(25),CONVR(25),YI(17),TABMU1(20)
   3,CIMM(17),CINH(17),AMT,CING(17),F,XMU,ENRGL1,ENRGH1,DENRG1,TINH
   4,AATN(10),TABX1(100),CC(17),CH(17),FA(17),
   6FBET(25),FBT(25,17),FGM(25,17)
   5,GAMCO,SOB,BOB,DEC(2),STH,HTH,TBETA,DBETA
    IF(IFIRST) 2,1,2
 1  WRITE(IW,900)
900 FORMAT(1H1,34X,'POPULATION RADIATION DOSE FROM THE DISTRIBUTION,US
   1E,AND DISPOSAL'/1HO,39X,'OF CONSUMER PRODUCTS CONTAINING RADIOACTI
   2VE MATERIALS'//)
    WRITE(IW,905)(TITLE1(I1),I1=1,20)
905 FORMAT(1H ,25X,20A4)
    WRITE(IW,906) (TITLE2(I2),I2=1,20)
906 FORMAT(1H ,(25X,20A4)//)
    WRITE(IW,910)
910 FORMAT(46X,'DOSE PER INDIVIDUAL INVOLVED(MREM/YR)',18X,'POPULATION
   1 DOSE')
    WRITE(IW,911)
911 FORMAT(1H ,31X,'|-----------------------------------------|',1X,
   '-------|',1X,'|-----------------------------------------|')
    WRITE(IW,915)
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```
915 FORMAT(38X,'EXTERNAL',16X,'INTERNAL',11X,'TOTAL')
    WRITE(IW,917)
917 FORMAT(1H ,31X,'|--------------------||----------------------||---
   1-------|')
    WRITE(IW,920)
920 FORMAT(33X,'DIRECT',5X,'IMMERSION',2X,'INHALATION',3X,'INGESTION',
   115X,'PROBABILITY',7X,'GROUP',9X,'TOTAL')
    WRITE(IW,919)
919 FORMAT(110X,'DOSE',10X,'DOSE'/1H ,105X,'(MAN-REM/YR)',2X,'(MAN-REM
   1/YR)')
    IFIRST=1
    IGS=-1
    ISS=-1
    ISSS=-1
    GO TO 50
  2 CONTINUE
    IF(IGS-IGP) 4,3,4
  4 IF(IGP-1) 11,5,11
 11 WRITE(IW,600) (STORSS(L),L=1,5),TGPDOS
600 FORMAT(1HO,10X,'TOTAL DOSE --- ',5A4,73X,1PE12.3)
    WRITE(IW,605) (STORSG(L),L=1,5),GPMDOS
605 FORMAT(1HO,20X,'TOTAL DOSE --- ',5A4,63X,1PE12.3)
    WRITE(IW,610) (STORGP(L),L=1,5),STGDOS
610 FORMAT(1HO,30X,'TOTAL DOSE --- ',5A4,53X,1PE12.3)
  5 WRITE(IW,925) (GROUP(L),L=1,5)
925 FORMAT(1H ,(5A4)/)
    STGDOS=0
  3 IF(ISS-ISP) 7,6,7
  6 IF(IGS-IGP) 7,55,7
  7 IF(ISP-1) 13,12,13
 13 IF(IGS-IGP) 12,19,12
 19 WRITE(IW,600) (STORSS(L),L=1,5),TGPDOS
    WRITE(IW,605) (STORSG(L),L=1,5),GPMDOS
 12 WRITE(IW,930) (SUBGRP(L),L=1,5)
930 FORMAT(1H ,2X,(5A4)/)
    GPMDOS=0
 55 IF(ISSS-ISSP) 9,8,9
  9 IF(IRITE-1) 15,14,15
 15 IF(ISS-ISP) 14,25,14
 25 IF(IGS-IGP) 14,26,14
 26 WRITE(IW,600) (STORSS(L),L=1,5),TGPDOS
 14 WRITE(IW,935) (SSGRP(L),L=1,5)
935 FORMAT(1H ,4X,5A4)
    XM=NM
    WRITE(IW,936) XM
936 FORMAT(1H ,5X,'(',1PE10.3,1X,'MEMBERS)'/)
    ISSS=ISSP
    IGS=IGP
    ISS=ISP
    TGPDOS=0
  8 TGPDOS=TGPDOS+GPDOS
    GPMDOS=GPMDOS+GPDOS
    STGDOS=STGDOS+GPDOS
    WRITE(IW,940) (IVENT(L),L=1,5),DIR,EM,EN,ENG,TOT,EVPROB,GPDOS
940 FORMAT(1H ,6X,5A4,1PE12.2,2X,1P4E12.2,1PE14.2,1PE13.2)
 50 RETURN
    END
    SUBROUTINE INPUT
    COMMON/ALPH/TITLE1(20),TITLE2(20),GROUP(5),SUBGRP(5),SSGRP(5),IVEN
   1T(5),STORSS(5),STORSG(5),STORGP(5)
    COMMON/INTG/IR,IW,ID,IFIRST,IGP,ISP,INCR,IH,NM,NP,IGS,ISS,ISSP,
   1ICON,ITN,IRITE,ID1,LPT,L1,JLOC(2),IEL,NCEV
   A,NBINT,NGINT,JLO(2),JHI(2)
    COMMON/REALX/DIR,EM,EN,ENG,TOT,EVPROB,GPDOS,TGPDOS,TABX(100),TABMU
   1(50),ENRG(17),ENRGL,ENRGH,DENRG,GPMDOS,STGDOS,GTDOS,XO,YO,ZO,TDIR
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     2,CONC,SRATE,VRATE,TLEAK,V,X(10),Y(10),Z(10),S(10),ATN(10,25),TIM
     3M,ENRGY(25),EA(25),EC(25),CONVR(25),YI(17),TABMU1(20)
     3,CINH(17),CINH(17),AMT,CING(17),F,XMU,ENRGL1,ENRGH1,DENRG1,TINH
     4,AATN(10),TABX1(100),CC(17),CH(17),FA(17),
     6FBET(25),FBT(25,17),FGM(25,17)
     5,GAMCO,SOB,FOB,DEC(2),STH,HTH,TBETA,DBETA
C      CALL IFILE(IR,'INPU')
       IGS=-1
       ISS=-1
       READ(IR,403) IEL
  403 FORMAT(I5)
       WRITE(ID1,403) IEL
       WRITE(LPT,404) IEL
  404 FORMAT(1H ,I5)
       READ(IR,406) SOB,FOB,STH,HTH,TBETA
  406 FORMAT(5F12.4)
       WRITE(ID1,406) SOB,FOB,STH,HTH,TBETA
       WRITE(LPT,407) SOB,FOB,STH,HTH,TBETA
  407 FORMAT(1H ,5F12.4)
       READ(IR,400) (TITLE1(L1),L1=1,20)
       WRITE(ID1,400) (TITLE1(L1),L1=1,20)
       WRITE(LPT,401) (TITLE1(L1),L1=1,20)
  400 FORMAT(20A4)
  401 FORMAT(1H ,20A4)
       READ(IR,400) (TITLE2(L2),L2=1,20)
       WRITE(ID1,400) (TITLE2(L2),L2=1,20)
       WRITE(LPT,401) (TITLE2(L2),L2=1,20)
   68 READ(IR,100) IGP,ISP,NOEV,NM,(SSGRP(LG),LG=1,5)
  100 FORMAT(3I5,I15,5X,5A4)
       WRITE(ID1,100) IGP,ISP,NOEV,NM,(SSGRP(LG),LG=1,5)
       WRITE(LPT,101) IGP,ISP,NOEV,NM,(SSGRP(LG),LG=1,5)
  101 FORMAT(1H ,3I5,I15,5X,5A4)
       IF(IGP) 51,52,51
   51 IF(ICS-IGP) 54,53,54
   54 READ(IR,105) (GROUP(LG),LG=1,5)
  105 FORMAT(5A4)
       WRITE(ID1,105) (GROUP(LG),LG=1,5)
       WRITE(LPT,106)(GROUP(LG),LG=1,5)
  106 FORMAT(1H ,5A4)
   53 IF(ISS-ISP) 57,56,57
   56 IF(ICS-IGP) 57,59,57
   57 READ(IR,105) (SUBGRP(LG),LG=1,5)
       WRITE(ID1,105) (SUBGRP(LG),LG=1,5)
       WRITE(LPT,106)(SUBGRP(LG),LG=1,5)
       ICS=IGP
       ISS=ISP
   59 DO 61 L=1,NOEV
       READ(IR,105) (IVENT(LV),LV=1,5)
       WRITE(ID1,105) (IVENT(LV),LV=1,5)
       WRITE(LPT,106) (IVENT(LV),LV=1,5)
       READ(IR,110) NP,ICON,ITN,EVPROB,F,TINH,XO,YO,ZO
  110 FORMAT(3I5,E12.2,F10.4,F7.2,3F12.6)
       WRITE(ID1,110) NP,ICON,ITN,EVPROB,F,TINH,XO,YO,ZO
       WRITE(LPT,111) NP,ICON,ITN,EVPROB,F,TINH,XO,YO,ZO
  111 FORMAT(1H ,3I5,6E12.3)
       READ(IR,115) CONC,TDIR,AMT,TIMM,SRATE,TLEAK,VRATE,V
  115 FORMAT(E10.2,E10.3,4E10.2,2E10.3)
       WRITE(ID1,115) CONC,TDIR,AMT,TIMM,SRATE,TLEAK,VRATE,V
       WRITE(LPT,116) CONC,TDIR,AMT,TIMM,SRATE,TLEAK,VRATE,V
  116 FORMAT(1H ,E10.2,E10.3,4E10.2,2E10.3)
       IF(NP) 58,62,58
   58 DO 62 J=1,NP
       READ(IR,120) S(J),X(J),Y(J),Z(J)
  120 FORMAT(E12.4,3F10.4)
       WRITE(ID1,120) S(J),X(J),Y(J),Z(J)
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      WRITE(LPT,121) S(J),X(J),Y(J),Z(J)
  121 FORMAT(1H ,E12.4,3E12.3)
      IF(ITN) 66,63,66
   66 READ(IR,125) (ATN(J,L),L=1,NGINT)
  125 FORMAT(8F10.4)
      WRITE(ID1,125) (ATN(J,L),L=1,NGINT)
      WRITE(LPT,126) (ATN(J,L),L=1,NGINT)
  126 FORMAT(1H ,8F10.4)
      GO TO 62
   63 READ(IR,130) AATN(J)
  130 FORMAT(F10.4)
      WRITE(ID1,130) AATN(J)
      WRITE(LPT,131) AATN(J)
  131 FORMAT(1H ,F10.4)
   62 CONTINUE
   61 CONTINUE
      GO TO 68
   52 REWIND 1
C    52 CALL RELEAS(IR)
      RETURN
      END
      SUBROUTINE PREFAS
      COMMON/ALPH/TITLE1(20),TITLE2(20),GROUP(5),SUBGRP(5),SSGRP(5),IVEN
     1T(5),STORSS(5),STORSG(5),STORGP(5)
      COMMON/INTG/IR,IW,ID,IFIRST,IGP,ISP,INCR,IH,NM,NP,IGS,ISS,ISSP,
     1ICON,ITN,IRITE,ID1,LPT,L1,JLOC(2),IEL,NOEV
     A,NBINT,NGINT,JLO(2),JHI(2)
      COMMON/REALX/DIR,EM,EN,ENG,TOT,EVPROB,GPDOS,TGPDOS,TAEX(100),TABMU
     1(50),ENRG(17),ENRGL,ENRGH,DENRG,GPMDOS,STGDOS,GTDOS,XO,YO,ZC,TDIR
     2,CONC,SRATE,VRATE,TLEAK,V,X(10),Y(10),Z(10),S(10),ATN(10,25),TIM
     %M,ENRGY(25),EA(25),EO(25),CONVR(25),YI(17),TABMU1(20)
     3,CIMM(17),CINH(17),AMT,CING(17),F,XMU,ENRGL1,ENRGH1,DENRG1,TINH
     4,AATN(10),TABX1(100),CC(17),CH(17),FA(17),
     6FBET(25),FET(25,17),FGM(25,17)
     5,GAMCO,SOB,ROB,DEC(2),STH,HTH,TBETA,DBETA
      DIMENSION BCON(25)
      JLO1=JLO(IEL)
      JHI1=JHI(IEL)
      DO 60 L=1,NBINT
   60 BCON(L)=1.
      PMEG=.5*1.6E-8
      AVO=.6023E24
      COEF=PMEG*AVO*DEC(IEL)*SOB/ROB
      COGAM=AVO*DEC(IEL)
      GAMCO=COGAM/3600.
      DO 1 L=JLO1,JHI1
    1 CC(L)=YI(L)*RA(L)*CH(L)
      FSM=0.
      DO 2 L=1,NBINT
      FBET(L)=0.

      DO 3 LA=JLO1,JHI1
    3 FBET(L)=FBET(L)+FET(L,LA)*CC(LA)
      IF(STH+HTH-FC(EO(L))/FNU(EO(L))) 4,4,5
    4 IAR=2
      GO TO 6
    5 IAR=1
    6 FBET(L)=FBET(L)*EA(L)*BCOR(IAR,EO(L),STH,HTH)
     &*THETA(EO(L))*BCON(L)
    2 FSM=FSM+FBET(L)
      DBETA=FSM*COEF*TBETA
      DO 7 L=1,NGINT
      FBET(L)=0.
      DO 8 LA=JLO1,JHI1
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 8 FBET(L)=FBET(L)+FGM(L,LA)*CC(LA)
   FBET(L)=FBET(L)*ENRGY(L)*CONVF(L)
 7 CONTINUE
   RETURN
   END
   FUNCTION BCOR(IR,EO,S,H)
   B1=FNU(EO)
   B2=FC(EO)
   B3=B1*S
   B4=B3/B2
   B5=B1*H
   E1=EXP(1.-B3)
   IF(B5-60.) 10,11,11
11 B5A=60.
   GO TO 12
10 B5A=B5
12 CONTINUE
   E2=1.-EXP(-B5A)
   E3=B2*B2
   E4=2.-ALOG(B4)
   E5=EXP(1.-B4)
   IF(IR-1)1,1,2
 1 BCOR=E1*E2+E3*(3.-B4*E4-E5)
   GO TO 50
 2 B6=B1*(S+H)/B2
   E6=2.-ALOG(B6)
   B7=B5/B2
   IF(B7-60.) 20,21,21
21 B7A=60.
   GO TO 22
20 B7A=B7
22 CONTINUE
   E7=1.-EXP(-B7A)
   BCOR=E1*E2+E3*(B6*E6-B4*E4-E5*E7)
50 RETURN
   END
   FUNCTION THETA(EO)
   THETA=1./(EXP(1.)+FC(EO)**2*(3.-EXP(1.)))
   RETURN
   END
   FUNCTION FC(EO)
   IF(.5-EO)2,1,1
 1 FC=2.
   GO TO 50
 2 IF(1.5-EO)4,3,3
 3 FC=1.5
   GO TO 50
 4 FC=1.
50 RETURN
   END
   FUNCTION FNU(EO)
   EX=-1.37
   FNU=18.6E-3*(EO-.036)**EX
    RETURN
   END
```