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PARAMETERS USED IN THE ENVIRONMENTAL PATHWAYS (DESCARTES) AND RADIOLOGICAL DOSE (CIDER) MODULES OF THE HANFORD ENVIRONMENTAL DOSE RECONSTRUCTION INTEGRATED CODES (HEDRIC) FOR THE AIR PATHWAY

Hanford Environmental Dose
Reconstruction Project

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PREFACE

This report is a description of work performed for the Hanford Environmental Dose Reconstruction (HEDR) Project. The HEDR Project was established to estimate radiation doses to individuals resulting from releases of radionuclides at the Hanford Site since 1944, when facilities there first began operating. An independent Technical Steering Panel directs the project, which is conducted by staff from Battelle, Pacific Northwest Laboratories, under a contract with the Centers for Disease Control.

Computer codes known as CIDER and DESCARTES have been developed to determine environmental accumulation and doses to individuals from historical airborne releases of radionuclides from Hanford facilities.

This document builds on the earlier code-development work of the project and has as its primary goal the further explication of the parameters used by the DESCARTES and CIDER codes.

SUMMARY

This letter report is a description of work performed for the Hanford Environmental Dose Reconstruction (HEDR) Project. The HEDR Project was established to estimate the radiation doses to individuals resulting from releases of radionuclides from the Hanford Site since 1944. This work is being done by staff at Battelle, Pacific Northwest Laboratories (Battelle) under a contract with the Centers for Disease Control (CDC) with technical direction provided by an independent Technical Steering Panel (TSP). This report fulfills the requirements of Milestone 0703B as described in the Fiscal Year 1992 Task Plans (Shipler 1992).

The objective of this report is to document the environmental accumulation and dose-assessment parameters that will be used to estimate the impacts of past Hanford Site airborne releases. During 1993, dose estimates made by staff at Battelle will be used by the Fred Hutchinson Cancer Research Center as part of the Hanford Thyroid Disease Study (HTDS).

This document contains information on parameters that are specific to the airborne release of the radionuclide iodine-131. Future versions of this document will include parameter information pertinent to other pathways and radionuclides. This report is being published as a controlled document. Those individuals and organizations that receive controlled copies of this report will be issued periodic updates representing the most current project interpretations of parameter definitions, numerical values, and uncertainties as they are changed.

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CONTENTS

1.0 INTRODUCTION

This report documents work performed on parameters for dose estimation conducted under the Hanford Environmental Dose Reconstruction (HEDR) Project. The HEDR Project objective is to estimate radiation doses to individuals and population groups from exposure to historical radioactive emissions from the Hanford Site since 1944.

Mathematical models and computer codes have been developed that will be used to calculate historical radiation doses. The overall HEDR computational model for computing doses from releases from the Hanford Site is called HEDRIC (Hanford Environmental Dose Reconstruction Integrated Codes). The set of interrelated and coupled computer codes currently consists of source term, atmospheric transport, environmental accumulation, and individual dose modules (STRM, RATCHET, DESCARTES, and CIDER, respectively [Ikenberry et al. 1992]).

Preliminary dose estimates were calculated in early work (termed Phase I) and reported in July 1990 (PNL 1991a, 1991b). A large set of Hanford-specific data was required to implement the computer codes. Many of the parameters used to determine these Phase I doses were documented in 1992 (Shindle et al. 1992). Since the estimation of the Phase I doses, revised environmental accumulation and dose models have been developed. The models and computer codes are documented in Integrated Codes For Estimating Environmental Accumulation and Individual Dose from Past Hanford Atmospheric Releases (Ikenberry et al. 1992). That document describes the initial implementation of the environmental accumulation model and computer code known as DESCARTES (Dynamic Estimates of Concentrations and Accumulated Radionuclides in Terrestrial Environments) and the individual dose model and computer code known as CIDER (Calculation of Individual Doses from Environmental Radionuclides). This letter report documents the parameters used as input to the DESCARTES and CIDER codes.

The HEDR computer codes have been designed to incorporate the uncertainty in the calculated doses. This process is accomplished by varying the numerical value assigned to a particular parameter from one realization to the next. The codes will be run at least 100 times; each realization will produce one possible combination of the release, transport, environmental accumulation, and dose for a specific exposure condition. A large amount of the uncertainty in the dose history arises from the variability in natural systems and from the inability to precisely characterize these systems, i.e., lack of knowledge. This stochastic dose-assessment process requires that the uncertainty in each input parameter be estimated. This report documents the range of possible individual parameter values and the probability distribution that will be used in the DESCARTES and CIDER codes.

A sensitivity analysis, which will determine the parameters and exposure pathways that contribute most to dose uncertainties, is planned for fiscal year 1993. The most important parameters will be determined on the basis of their degree of correlation with the calculated doses. This sensitivity analysis will be used to direct additional refinements in models and parameters. If the uncertainty of a parameter is found to contribute significantly to the uncertainty in the dose estimate, then ways in which the uncertainty of that parameter may be better defined or reduced will be investigated. A repeated interpretation of the scientific literature or the solicitation of expert opinion may be warranted. The parameter descriptions contained in this report would then be revised to incorporate any such new information. The sensitivity analysis is expected to show that uncertainties associated with many parameters do not contribute significantly to the uncertainties in the dose estimates. If this hypothesis is found to be true, those parameters may be assigned nominal values (i.e., made constant) and eliminated from future uncertainty analyses.

The parameters described in this report include those that will be used in DESCARTES and CIDER to estimate doses from historical releases of iodine-131 to the atmosphere. Parameters that will be required to calculate doses for other pathways and radionuclides will be included in subsequent revisions to this document. This report is, thus, a "living" document and is intended to be updated based upon additional information or new interpretations of the underlying information sources. Input from the Technical Steering Panel (TSP), Native Americans, and other sources including the public will also be used to update this document. Some distribution copies of this document will be controlled or assigned. Those individuals or organizations that hold controlled copies of this document will receive periodic updates as new parameters are added or previous parameter descriptions are revised. The document will also serve as a record of the parameter values used in future dose calculations. Upon completion of the HEDR dose calculations, this document will be finalized and issued as an uncontrolled document. All future reports presenting dose estimates will include references to the parameter descriptions and values contained in this document.

For the purposes of estimating the uncertainty in dose estimates and for performing the sensitivity analysis, only original data sources have been used. This original-source criterion eliminates some of the "data" in the scientific literature. Many sources of data are available in the scientific literature, but very few of these references contain original data. Many other references provide data compilations or data sets used in other computer models. These data sets have not been used because they do not contain original data or because they contain data that is not directly applicable to the Hanford Site or the environmental accumulation or dose models used in this study.

While this document is intended to be comprehensive, some additional data sources certainly exist and will be included to the extent necessary and possible in future versions of this controlled document. This document contains information with sufficient detail to support and justify the parameters used in the environmental accumulation and dose estimation portions of HEDRIC. Based upon the results of the structured sensitivity analysis that is to be conducted as part of the HEDR Project, more resources may be expended on those parameters that contribute to the greatest amount of uncertainty in the estimated doses.

Section 2.0 of this document discusses the equations used in the DESCARTES and CIDER codes and related databases. Section 3.0 explains the reasoning behind the choices made for the defined value ranges, the frequency of selection, and the distribution of parameters in the modeling. Section 4.0 explains the project's data quality objectives, while Section 5.0 lists references for the first four sections. (For individual parameters, the relevant references are listed at the end of each discussion.) Section 6.0 constitutes the main part of this document—the detailed discussions of individual parameters used in the DESCARTES and CIDER codes. For the reader's additional convenience, the appendix tabulates the parameters from Section 6.0.

The TSP has requested that all references to information sources include the author, date, and page number. Because much of the work on this document was conducted prior to this request, specific page numbers have not been included. All updates to this document will include page numbers for new references.

2.0 MODEL EQUATIONS AND RELATED DATABASES

The computer code DESCARTES uses several basic equations to estimate the environmental accumulation in soil, plants, and animal products. The computer code CIDER uses additional equations to estimate the dose to individuals from exposure to internal and external radiation sources. Section 2.3 lists all the equations used to estimate the amount of radioactivity accumulated in the environment around the Hanford Site from historical releases and to estimate the dose to an individual that may have resulted from exposure to these releases.

A variety of other data is required to estimate individual and population doses. These other data include the output from the atmospheric transport code, certain demographic information, human dietary data, and cattle diet data. A brief discussion of how the data will be used in the environmental accumulation and dose assessment models is included below. These four databases will be documented as part of other HEDR Project deliverables; thus, a complete data listing is not presented here.

2.1 DESCARTES AND CIDER EQUATIONS

The environmental accumulation and individual dose assessment model equations that are implemented in the DESCARTES and CIDER computer codes are listed in Section 2.3. For a complete discussion of the development of the equations, the reader is referred to Integrated Codes For Estimating Environmental Accumulation and Individual Dose from Past Hanford Atmospheric Releases (Ikenberry et al. 1992). Based on TSP and other peer reviews, some enhancements have been made to the DESCARTES and CIDER codes since the publication of that report. The equations and parameters presented here represent the current information contained in the computer codes.

A number of input variables (parameters) are required to execute the DESCARTES and CIDER computer codes. A complete list of these parameters is included in Section 2.3. Many input variables are either developed outside of the computer code or are calculated as intermediate values inside the codes. For example, χ, the integrated daily radionuclide air concentration, is calculated in the atmospheric transport code, and C_{ap}, the animal product concentration, is a calculated value in DESCARTES. The parameters that are addressed in this report are clearly indicated in the parameter listing (Section 2.3.3).

2.2 RELATED DATABASES

In addition to the parameters addressed in this report, the DESCARTES and CIDER codes require data from compiled data sets. These inputs include the output from the atmospheric transport code, data describing the production and distribution of milk and produce, data describing realistic cattle diets, and information regarding actual human diets. These data are all determined outside of the DESCARTES and CIDER codes but are essential for the estimation of doses to individuals and populations. These four databases and their use with the environmental accumulation and dose codes are described below.

Air Transport Data - The atmospheric transport code, RATCHET (Regional Atmospheric Transport Code for Hanford Emission Tracking) (Ramsdell and Burk 1992), will provide daily integrated radionuclide air concentrations and surface deposition rates. These output data will be used as input to the DESCARTES and CIDER codes. Deposition rates are used in the DESCARTES equations listed in Section 2.3. Daily average air concentrations are used in the CIDER code. The parameters used by the RATCHET code to estimate the air concentrations and deposition rates are not included in this report.

Cattle Feeding Regimes - Radionuclide concentrations in animal products (i.e., milk and meat) are estimated as the product of the ingested activity and the animal-product transfer factor. DESCARTES cattle ingestion rates are based on the concept of feeding regimes to account for the various types of feeds consumed. Beck et al. (1992) describe each of the feeding regimes being considered. A submodel, external to DESCARTES, has been developed to estimate the ingestion rates of the various types of vegetation consumed by cattle.

The model used in HEDR Phase I to generate cattle diets was found to predict unreasonable estimates of feed intake (i.e., it underestimated the ingestion rate of fresh pasture). The revised model uses a submodel to calculate representative cattle diets. These diets are stored in a database that will be accessed by DESCARTES. During a given realization of the DESCARTES computer code, this database will be accessed and a realistic daily diet will be randomly selected for each day and season. It is expected that this database will be published as part of background information on the air pathway dose calculations.

Milk and Vegetable Production and Distribution - Data about the production and distribution of milk and vegetables within the project domain are being collected by staff from Task 06 as part of the HEDR Project. This information will allow the estimation of radiation doses from ingestion of a food type grown in one part of the region and consumed in another. This information will be input to a database that will be accessed by DESCARTES. These data will be published as part of Task 06 activities.

Human Dietary Data - The HEDR Phase I model estimated the intakes of food types that were randomly selected from a possible range of values. The ranges were established by evaluation of U.S. Department of Agriculture (USDA) dietary survey data. As with the cattle diets, this methodology was found to produce consumption rates that were uncorrelated.

As part of the revised model, a daily diet will be selected in CIDER from a pre-existing database. This database will contain realistic diets for each age and demographic group that preserve the correlations between the consumption rates of all food types. This dietary database will be established using actual daily dietary information from USDA data. The dietary information contained in this database is expected to be published with the background data for the air pathway dose calculations.

2.3 EQUATIONS AND VARIABLES

To explicitly relate the parameters in this document and the DESCARTES and CIDER code equations, the code equations are listed for easy reference in this section. The equations were originally presented in Ikenberry et al. (1992).

Differences will be noted between some equations presented here and those in Ikenberry et al. (1992). Modifications were made to incorporate the best available parameter information in the scientific literature and to incorporate alternative model algorithms that were deemed more desirable.

The DESCARTES and CIDER equations are listed separately, below. After the CIDER equations, an alphabetical summary lists all the parameters used in the equations.

DESCARTES AND CIDER EQUATIONS

2.3.1 DESCARTES Equations

DES-1. Biomass rate of change over time (January 1 - June 30):

$$\frac{dB}{dt} = \frac{k_g}{2}\left[1-\cos\left(\frac{2\pi t}{365}\right)\right] B\left(\frac{B_{max}-B}{B_{max}}\right)$$

DES-2. Biomass rate of change over time with senescence (July 1 - December 31):

$$\frac{dB}{dt} = \frac{k_g}{2}\left[1-\cos\left(\frac{2\pi t}{365}\right)\right] B\left(\frac{B^*_{max}-B}{B^*_{max}}\right) - k_s\left(B-B_{min}\right)$$

DES-3. Maximum biomass adjustment for senescence:

$$B^*_{max} = \frac{k_g(B_{max})^2}{B_{max}(k_g-k_s) + k_s B_{min}}$$

DES-4. Foliar interception fraction:

$$f_v = 1 - e^{-\alpha B}$$

DES-5. Translocation rate constant:

$$\lambda_{trans} = \frac{f_{trans}\,\lambda_{weath}}{1-f_{trans}}$$

DES-6. Upper soil layer concentration rate of change:

$$\frac{dQ_{usl}}{dt} = If_s - Q_{usl}(\lambda_{perc} + \lambda_{rad} + \lambda_{splash}) + Q_{ov}\lambda_{weath} - R_{resus} + R_{senc,iv} + R_{senc,ov}$$

DES-7. Root zone concentration rate of change:

$$\frac{dQ_{rz}}{dt} = Q_{usl}\ \lambda_{perc} - Q_{rz}(\lambda_{leach} + \lambda_{rad}) - R_{root}$$

DES-8. Outer vegetation concentration rate of change:

$$\frac{dQ_{ov}}{dt} = If_v - Q_{ov}(\lambda_{weath} + \lambda_{rad} + \lambda_{trans}) + Q_{usl}\lambda_{splash} - R_{senc,ov} + R_{resus}$$

DES-9. Inner vegetation concentration rate of change:

$$\frac{dQ_{iv}}{dt} = Q_{ov}\lambda_{trans} - Q_{iv}\lambda_{rad} + R_{root} - R_{senc,iv}$$

DES-10. Deposition rate of resuspended upper soil layer material:

$$R_{resus} = \frac{Q_{usl}\ ML\ V_d}{\rho_{usl}}$$

DES-11. Rate of inner vegetation senescence (July 1 - December 31):

$$R_{senc,iv} = \frac{Q_{iv}}{B} k_s (B - B_{min})$$

DES-12. Rate of outer vegetation senescence (July 1 - December 31):

$$R_{senc,ov} = \frac{Q_{ov}}{B} k_s (B - B_{min})$$

DES-13. Rate of uptake through roots (January 1 - June 30):

$$R_{root} = Q_{rz} \frac{CR}{\rho_{rz}} \left(\frac{dB}{dt} \right)$$

DES-14. Rate of uptake through roots (July 1 - December 31):

$$R_{root} = Q_{rz} \frac{CR}{\rho_{rz}} \left[\frac{dB}{dt} + k_s \left(B - B_{min} \right) \right]$$

DES-15. Quantity-to-concentration conversion:

$$C_p = \frac{Q_p}{B}$$

$$C_{p,iv} = \frac{Q_{iv}}{B}$$

$$C_{p,ov} = \frac{Q_{ov}}{B}$$

DES-16. Quantity of nuclide consumed by an animal at location l and day t:

$$A_{cons}(t,l) = \sum_{v=1}^{V} R_{v\_a}\, C_v(h,l)\, e^{-\lambda_{rad} th_s}$$

DES-17. Animal-product concentration at location l and day t:

$$C_{ap}(t,l) = TF_{ap}\left[A_{cons}(t,l) + \frac{FS_a\, Q_{usl}(t,l)}{\rho_{usl}}\right]$$

DES-18. Undecayed concentration in a commercially available animal product:

$$C_{com,ap}(t,l) = \sum_{m=1}^{M} f_{groc}(l,m) \sum_{l=1}^{L} f_{cntr}(l,m)\, C_{ap}(t,l)$$

2.3.2 CIDER Equations

CID-1. Immersion dose:

$$D_{imm}(t,1) = \frac{DF_{imm}\ \chi(t,1)\ \left[f_{time} + \left(1 - f_{time}\right) Sh1\ R_{io}\right]}{86,400}$$

CID-2. Groundshine dose:

$$D_{grd}(t,1) = f_{time}\ A + \left(1 - f_{time}\right) Sh1\ A$$

$$\text{where } A = Q_{us1}(t,1)\ DF_{us1} + Q_{rz}(t,1)\ DF_{rz}$$

CID-3. Inhalation dose:

$$D_{inh}(t,1) = BR\ DF_{inh}\ [f_{time}\ A + \left(1 - f_{time}\right) R_{io}\ A]$$

$$\text{where } A = \frac{\chi(t,1)}{86,400} + Q_{us1}\left(\frac{ML}{\rho_{us1}}\right)$$

CID-4. Ingestion dose for foods with a single concentration compartment:

- Other vegetables and grain:

$$D_{ing}(t,1) = DF_{ing} \sum_{p=1}^{P} C_p\ (t-th_p,1)\ R_p\ f_d\ e^{-\lambda_{rad} th_p}$$

- Meat, milk, and eggs:

$$D_{ing,ap}(t,l) = DF_{ing} \sum_{ap=1}^{AP} C_{ap}(t-th_p,l)\ R_p\ e^{-\lambda_{rad} th_p}$$

CID-5. Ingestion dose from crops with inner and outer vegetation compartments:

$$D_{ing,veg2}(t,l) = DF_{ing} \sum_{p=1}^{P} [C_{p,iv}(t-th_p,l)$$

$$+ C_{p,ov}(t-th_p,l)\ L_{proc}]\ R_p\ f_d\ e^{-\lambda_{rad} th_p}$$

2.3.3 Variable Symbols and Definitions

All parameters used in the previous equations are listed alphabetically and defined below. An indication of where the parameter values can be located is indicated by the capitalized letter beginning each parameter definition. The letter symbols are defined below.

D: The parameter values, probability distribution, and technical basis are detailed within this document.

C: The parameter value is calculated by the DESCARTES or CIDER codes.

R: The parameter value is obtained from a related database of values separate from DESCARTES and CIDER.

86,400	conversion factor, s/d
α	(D) empirical foliar interception constant, m^2/kg(dry)
λ_{leach}	(D) leaching rate from root zone to deep soil, d^{-1}
λ_{perc}	(D) percolation rate from upper soil layer to root zone, d^{-1}
λ_{rad}	(D) radiological decay constant, d^{-1}
λ_{splash}	(D) rainsplash rate constant, d^{-1}

λ_{trans}	(D,C) plant translocation rate, d^{-1}
λ_{weath}	(D) weathering rate, d^{-1}
ρ_{rz}	(D) root zone soil areal density from 1 mm to 15 cm depth, kg(wet)/m^2
ρ_{usl}	(D) upper soil layer from areal density to a depth of 1 mm, kg(wet)/m^2
$\chi(t,l)$	(R) integrated daily radionuclide air concentration on day t at location l, Ci·s/m^3 per d
$A_{cons}(t,l)$	(C) animal radionuclide consumption rate on day t at location l, Ci/d
B	(C) current daily biomass, kg(dry)/m^2
B_{max}	(D) maximum potential biomass, kg(dry)/m^2
B^*_{max}	(C) maximum biomass adjustment factor, kg(dry)/m^2
B_{min}	(D) minimum (winter) biomass, kg(dry)/m^2
BR	(D) age-dependent breathing rate, m^3/d
$C_{ap}(t,l)$	(C) animal product radionuclide concentration on day t at location l, where ap = milk, beef, chicken, eggs, Ci/L (milk), or Ci/kg(wet) (others)
$C_{com,ap}(t,l)$	(R) radionuclide concentration in commercially available milk on day t at location l, Ci/kg
C_p	(C) food crop radionuclide concentration where p = leafy vegetables, other vegetables, fruit, and grain, Ci/kg(dry)
$C_{p,iv}$	(C) radionuclide concentration of the inner vegetation compartment for other vegetables, fruits, and grains, Ci/kg(dry)
$C_{p,ov}$	(C) radionuclide concentration of the outer vegetation compartment for other vegetables, fruits, and grains, Ci/kg(dry)
$C_v(h,l)$	(C) animal feed radionuclide concentration harvested on date h at location l, where v = grain, pasture, grass hay, alfalfa, and silage, Ci/kg(dry)
CR	(D) plant-to-soil concentration ratio, Ci/$kg_{vegetation}$(dry) per Ci/kg_{soil}(wet)

DF_{imm}	(D) immersion dose rate factor, $rad_{thyroid}$/d per Ci/m^3
DF_{ing}	(D) ingestion dose factor, $rad_{thyroid}/Ci$
DF_{inh}	(D) inhalation dose factor, $rad_{thyroid}/Ci_{inhaled}$
DF_{rz}	(D) dose rate factor for radionuclides in the soil root zone, rem/d per Ci/m^2
DF_{usl}	(D) dose rate factor for upper soil layer or surface activity, rem/d per Ci/m^2
$D_{grd}(t,l)$	(C) dose from groundshine on day t at location l, rem
$D_{ing}(t,l)$	(C) ingestion dose from local or commercial foods on day t at location l, $rad_{thyroid}$
$D_{inh}(t,l)$	(C) inhalation dose on day t at location l, $rad_{thyroid}$
$D_{imm}(t,l)$	(C) air-immersion dose on day t at location l, rad
$D_{ing}(t,l)$	(C) ingestion dose from food crops with a single compartment on day t at location l, $rad_{thyroid}$
$D_{ing,ap}(t,l)$	(C) ingestion dose from an animal product on day t at location l, where ap = beef, poultry, eggs, or milk, $rad_{thyroid}$
$D_{ing,veg2}(t,l)$	(C) ingestion dose from leafy vegetables and fruits on day t at location l, rad
$f_{cntr}(l,m)$	(R) fraction of milk at location l from collection center m
f_d	(D) dry-weight to wet-weight conversion factor
$f_{groc}(l,m)$	(R) fraction of milk purchased at a grocery store at location l that came from collection center m
f_s	(C) soil deposition fraction, equal to 1 - f_v, dimensionless
FS_a	(D) animal soil ingestion rate where a = chicken or cow, kg(wet)/d
f_{time}	(D) fraction of day spent outdoors, dimensionless
f_{trans}	(D) fraction of outer vegetation deposition that translocates to the inner vegetation compartment
f_v	(C) vegetation foliar interception fraction, dimensionless
I	(R) areal deposition rate (from RATCHET), $Ci/(m^2 \cdot d)$

k_g	(D) growth rate constant (d^{-1})
k_s	(D) senescence rate constant (d^{-1})
l	(D) location of interest
L_{proc}	(D) food processing loss fraction, dimensionless
ML	(D) mass loading factor for local soil in air, kg/m^3
Q_{iv}	(C) activity in the inner vegetation compartment, Ci/m^2
Q_{ov}	(C) activity in the outer vegetation compartment, Ci/m^2
Q_p	(C) activity in vegetation, where p = leafy vegetables, pasture, grass hay, alfalfa, silage, sagebrush
Q_{rz}	(C) activity in the rooting zone soil compartment, Ci/m^2
Q_{usl}	(C) activity in the upper soil layer, Ci/m^2
R_{io}	(D) ratio of indoor air to outdoor air activity, dimensionless
R_p	(R) food product consumption rate, where p is a food crop or animal product (kg[wet]/d for all foods except milk and L/d for milk)
R_{resus}	(C) rate of radionuclide redeposition on vegetation from resuspension of soil, $Ci/m^2 \cdot d$
$R_{senc,iv}$	(C) rate of radionuclide transfer from the inner vegetation compartment of plants to the soil by vegetation senescence, $Ci/m^2 \cdot d$
$R_{senc,ov}$	(C) rate of radionuclide transfer from the outer vegetation compartment of plants to the soil by vegetation senescence, $Ci/m_2 \cdot d$
R_{root}	(C) rate of radionuclide uptake through roots, $Ci/m^2 \cdot d$
R_{v_a}	(R, D) daily quantity of feed that an animal eats, where v is the feed type and a is an animal, kg(dry)/d
Shl	(D) shielding factor, dimensionless
t	(R) day of interest, Julian day (number of days since the start of the year)
TF_{ap}	(D) animal product transfer factor, where ap = milk_ind, milk_herd, beef, poultry, or eggs, d/L (milk) or d/kg (beef, poultry, eggs)

th_p — (D) holdup time from collection or harvest to consumption, where p is a food crop or animal product

th_s — (R) holdup time for stored feed crops, d

V_d — (D) local deposition velocity of resuspended soil back to soil or vegetation, m/d

3.0 PARAMETER DISTRIBUTIONS AND SELECTION STRATEGY

The HEDR Project computer codes will generate estimates of the doses that specific individuals and population groups received from exposure to radionuclides released into the environment from the Hanford Site since 1944. The values of most of the parameters in these models are not well known because of a lack of complete and detailed knowledge of the amounts of radionuclides released into the environment, the dispersion and subsequent accumulation and fate of those radionuclides in the environment, the production and distribution of food products, and the lifestyles and diets of specific individuals and groups. This section documents the process used to assess and specify the uncertainty in model parameters. This documentation is needed because the magnitude of parameter uncertainties will determine to a large extent the uncertainty of the doses estimated by the models.

The specification of parameter uncertainties is important because the HEDR Project is using computer simulation methods to quantify dose uncertainties for important exposure pathways, e.g., for doses attributable to atmospheric releases of radionuclides from Hanford-Site operations (Ikenberry et al. 1992). For the air pathway, the computer simulation method consists of repeating calculations of the dose computer model HEDRIC (Napier et al. 1992) at least 100 times to generate 100 or more estimates of dose for a specific individual. Each repetition of HEDRIC (i.e, STRM, RATCHET, DESCARTES, and CIDER) for the multiyear period is referred to as a realization. For at least each realization, a new value for each uncertain parameter in HEDRIC is randomly selected from its specified probability density function (pdf) (defined in Section 3.1), which is a function used to express the uncertainty of the parameter. Hence, parameter uncertainties have a direct impact on variability (spread or uncertainty) exhibited by the 100 estimates of dose computed by HEDRIC.

Because of the relationship between parameter uncertainties and dose uncertainties, the methods used to specify parameter pdfs must be well understood.

3.1 DEFINITIONS

Definitions of terms used in this section are listed below.

Computer Simulation Study:

A computational technique for investigating the properties and behavior of a variable by repeated random sampling from a known or assumed probability density function (pdf) representing the variable (Meyer and Booker 1991). In the context of this report, the properties and behavior of dose estimates are investigated by repeated random sampling from the assigned pdfs of the uncertain parameters in the models.

Expert:

An expert is a person who has knowledge in the subject area at the desired level of detail and who is recognized by his or her peers or those conducting the study as qualified to answer questions (Meyer and Booker 1991).

Expert Judgment:

Expert judgment is judgment by those with expertise or knowledge in the area of interest. Expert judgment is usually elicited when data are sparse or lacking (Meyer and Booker 1991).

Informal Solicitation of Expert Opinion:

Informal solicitation of expert opinion is a method wherein the analyst asks an expert to interpret the available information and quantify an assessment of the parameter and its uncertainty.

Lognormal Probability Density Function:

The lognormal pdf assigns probabilities of occurrence to the logarithms of the possible parameter values such that the pdf of those logarithms is symmetric and bell shaped. The mathematical definition of a lognormal pdf is given by Iman and Shortencarier (1984), PNL (1991c), and Gilbert (1987).

Loguniform Probability Density Function:

If a parameter (random variable) has a loguniform pdf, all values of the logarithms of the parameter between the specified minimum and maximum logarithmic values are equally likely to occur. If the parameter has a loguniform pdf, then the logarithms of the parameter have a uniform pdf. The mathematical definition of a loguniform pdf is given by Iman and Shortencarier (1984) and PNL (1991c).

Normal Probability Density Function:

A normal (Gaussian) pdf is symmetric and has the shape of a bell. The mathematical definition of a normal pdf is given by Iman and Shortencarier (1984), IAEA (1989), and by most statistics text books.

Piecewise Uniform Probability Density Function:

The piecewise uniform pdf describes the situation in which the range (maximum value minus minimum value) is divided into segments or "pieces" and a different level of equal probability is assigned to all values of the parameter within each segment. The mathematical definition of this pdf is given by the International Atomic Energy Agency (IAEA) (1989).

Probability:

Probability refers to the chance of something occurring. Probabilities are values from 0.0 to 1.0. A probability equal to 0.0 means the event never happens. A probability equal to 1.0 means the event always happens (Meyer and Booker 1991).

Probability Density Function of a Parameter (Random Variable):

The probability density function of a parameter is a real-valued function for assigning probabilities to the possible values of a model parameter (random variable).

Probability Encoding:

Probability encoding is a systematic, defensible, and expensive method for developing individual subjective probability assessments wherein the analyst trained in probability theory elicits in a proper and self-consistent manner a technical expert's assessment of the pdf of a parameter value. This pdf expresses quantitatively that expert's uncertainty in the possible values of the parameter (Roberds 1990).

Random Variable:

A random variable is a function that assigns real numbers to the set of possible outcomes of an experiment.

Range of a Model Parameter:

The range of a model parameter is the difference between the maximum and minimum possible values of the parameter.

Self-Assessment:

Self-assessment is a method wherein the analyst relies upon his/her own knowledge and experience to specify the possible values of a model parameter.

Triangular Probability Density Function:

A triangular pdf assigns probabilities of occurrence to possible parameter values such that the pdf is in the form of a triangle. The mathematical definition of a triangular pdf is given by Iman and Shortencarier (1984), IAEA (1989), and PNL (1991c).

Uniform Probability Density Function:

If a parameter (random variable) has a uniform pdf, all values of the parameter between the specified minimum and maximum values are equally likely to occur. The uniform pdf has the shape of a rectangle. The mathematical definition of a uniform pdf is given by Iman and Shortencarier (1984), IAEA (1989), and PNL (1991c).

3.2 METHODS FOR OBTAINING EXPERT OPINION

The following discussion of the primary methods for obtaining information about the uncertainty (pdf) of model parameters from experts is taken mostly word-for-word from Roberds (1990). His paper, as well as Meyer and Booker (1991), should be examined for further details and insight into the problems and challenges of eliciting and analyzing information from experts. This material is provided as a basis for understanding the strategy selected for this study as described in Section 3.3.

3.2.1 Self-Assessment

The analyst interprets the available information and then quantifies an assessment of the likely value of the parameter and its uncertainty (Good 1965, von Holstein 1970). The rationale behind the assessment should be well documented, including a description of the available information and an evaluation of that information, to enhance defensibility of such subjective probability assessments. This method is simple, but has significant limitations:

- poor quantification of uncertainty
- uncorrected biases or unspecified assumptions or both, possibly in spite of documentation
- imprecision
- lack of credibility if the analyst cannot be considered an expert in the technical field.

3.2.2 Informal Solicitation of Expert Opinion

The analyst asks an expert to interpret the available information and quantify an assessment of the likely value of a parameter and its uncertainty (Morgan et al. 1979, Bernreuter 1980). The defensibility of such assessments is increased over self-assessment techniques primarily because of the increased credibility of the expert involved. The expert's rationale for the assessment should be well documented, including a description of the information available to the expert and the expert's evaluation of that information.

Although generally an improvement over self-assessment techniques, because of its increased credibility, informal solicitation of expert opinion has similar significant limitations and increased cost and potentially poor problem definition.

3.2.3 Calibrated Assessment

Calibrated assessment is a systematic approach wherein the assessor's biases are identified and calibrated and the assessments are adjusted to correct for such biases (Winkler 1969, Agnew 1985). Two sets of assessments are required:

- the assessor's assessment (e.g., through the informal solicitation of expert opinion)
- an assessment of the assessor's biases using subjective or objective methods.

Calibrated assessment is a general improvement over self-assessment or informal solicitation of expert opinion techniques because it mitigates some of the biases. However, the method entails similar significant limitations (even after calibration). Also, there are increased costs and inherent difficulties in objectively determining calibration factors for many of the parameters of interest. These difficulties may arise because direct measurements might never be available for verification. Also, the calibration factor may not be constant in any case.

3.2.4 Probability Encoding

Probability encoding (Spetzler and von Holstein 1972, Zamora 1975, von Holstein and Matheson 1979, and Merkhofer and McNamee 1982) is the most systematic and defensible approach to developing individual subjective probability assessments, but it is also the most expensive. The analyst trained in probability theory elicits, in a proper and self-consistent manner, a technical expert's assessment of the pdf of a parameter value, which expresses that expert's uncertainty in the value in quantified terms. This is done in a formalized way in five stages:

- motivating
- structuring
- conditioning
- encoding
- verifying.

Although a general improvement over other available methods (because it mitigates most of the potential problems), some imprecision may remain, and probability encoding is relatively costly because it is labor intensive.

3.3 STRATEGY FOR SPECIFYING PARAMETER UNCERTAINTIES

The uncertainty of a parameter is expressed in two ways: the range of possible values and the frequency with which any value within that range is expected to occur. Both the range and frequency define the pdf for each parameter.

3.3.1 Estimating the Maximum Conceivable Range

The maximum conceivable range of a parameter is estimated by searching Hanford-originated and general scientific literature for relevant reports, books, and scientific papers that contain information on the parameter. This search had the following components:

- Conduct a computerized search of the radiation protection literature citation databases, such as QUEST (Schadt and Kellogg 1991).

- Review relevant reports, papers, and books that originated at Hanford or were authored by acknowledged Hanford or non-Hanford experts in the subject area of interest.
- Review, manually, recently issued scientific journals for relevant papers and information.
- Review pertinent references found in identified relevant reports, papers, and books and those recommended by experts.

After the literature review was completed, the maximum and minimum parameter values found in the literature (relevant to the release scenario at Hanford) were determined. Then either self-assessment and/or informal solicitation of expert opinion was used to evaluate whether the maximum and minimum values as obtained from the literature should be changed to reflect physical limitations on parameter values and conditions present in the HEDR study region. That is, the maximum and minimum values, as found in the literature, were in some cases changed to reduce the possibility that the "true" value of a parameter for a HEDR Project code would be larger than the (revised) maximum value or smaller than the (revised) minimum value.

3.3.2 Obtaining Subjective Information

Specifying the maximum and minimum value of the parameter applicable to the HEDR study region does not completely determine the uncertainty of the parameter. In particular, the probability that various values of the parameter between the maximum and minimum could have been the true value must be specified. That is, we must indicate the pdf of each uncertain parameter.

Specifying the pdf that best fits the available uncertainty information for a parameter's value is largely a subjective process. For some parameters, literature that investigates the pdf does exist. Subjective determination of the pdf for most parameters is necessary, however, because it is uncommon to have enough data to evaluate statistically (objectively) which pdf should be selected. Hence, once the conceivable maximum and minimum for the parameter's value were resolved, one or more of the following subjective methods were used to develop additional information about the parameter, information required for specifying the pdf:

- self-assessment

- informal solicitation of expert opinion
- probability encoding.

Self-assessment, informal solicitation of expert opinion, and information from the scientific literature were primarily relied upon to determine the most appropriate pdf. Probability encoding is the most systematic and defensible approach for developing additional (subjective) information needed to specify a particular pdf for a parameter, but it is also the most expensive. Because of this expense, HEDR Project staff used probability encoding for only a limited set of parameters.

A fourth option for identifying a parameter pdf, calibrated assessment, is also expensive and, therefore, may be difficult to use in the objective determination of calibration factors for most parameters. For these reasons calibrated assessment is not being used by the HEDR Project.

The critically important parameters, those for which probability encoding may be used, are to be determined on the basis of sensitivity analyses of DESCARTES and CIDER. The purpose of sensitivity analyses is to identify those model parameters that have the greatest impact on dose estimates. The milestone letter report 0803A (Project Sensitivity Uncertainty Analysis Plan, Shipler 1992), which is currently in preparation, will describe the sensitivity analyses plan for the HEDR Project.

Since subjective information obtained from experts is used throughout the HEDR Project, the following quote from Meyer and Booker (1991) concerning the type of inferences that can be made on the basis of expert opinion is of interest:

> "In most expert judgment applications, the experts' knowledge represents the state of the existing or available knowledge. In that sense, general inferences can be made as follows: the results from the experts' information can be used to draw conclusions about the existing or available knowledge base which may or may not represent the true state of nature. In other words, the inferences that can be made are not necessarily relevant to truth; nor are they statistically based inferences" (p. 365).

Although this quote may cause one to pause and wonder about the validity of using expert opinion to select pdfs, it is important to remember that all science is subjective to some degree. Indeed, even measurements obtained in the laboratory by a chemist have elements of subjectivity because judgments and the experience of the scientist affect the scientific protocol and procedures that he/she selects to collect and interpret the data. Meyer and Booker (1991) state that expert judgment data can provide valuable information and valid conclusions, and that expert judgment data can improve the process of making general inferences. They also stress the importance of taking care to properly design the elicitation process and the analysis of the data; hence the preference expressed above for probability encoding elicitation techniques for the crucially important model parameters.

3.3.3 Selecting a Probability Density Function

A particular pdf for each uncertain parameter is selected using information obtained from the literature search and the assessment of subjective opinions (Sections 3.2.1 and 3.2.2). The six pdfs considered for use by HEDR Project staff are displayed in Figure 3.1 and defined in Section 3.2. These six pdfs are the uniform, piecewise uniform, loguniform, triangular, normal (Gaussian), and lognormal pdfs. The mathematical definitions of these pdfs as they relate to the specified maximum and minimum values of the parameters are provided in Iman and Shortencarier (1984). Criteria for selection of each of these distributions are as follows:

- The uniform pdf, which assigns equal probability to each possible value of the parameter between the minimum and maximum values, is selected if minimal information (actual measurements or subjective opinions of experts) is available about the parameter. In other words, the uniform pdf is used as a default pdf and is used whenever it is impossible to defend the assertion that a more complex distribution is appropriate.

- The piecewise uniform pdf describes the situation where the range of the parameter (maximum value minus minimum value) can be divided into segments or "pieces" and for each segment a different level of equal probability assigned to all values of the parameter within the segment. This pdf is selected when data are sufficient to divide the range into distinct segments, but inadequate to defend unequal probabilities within segments.

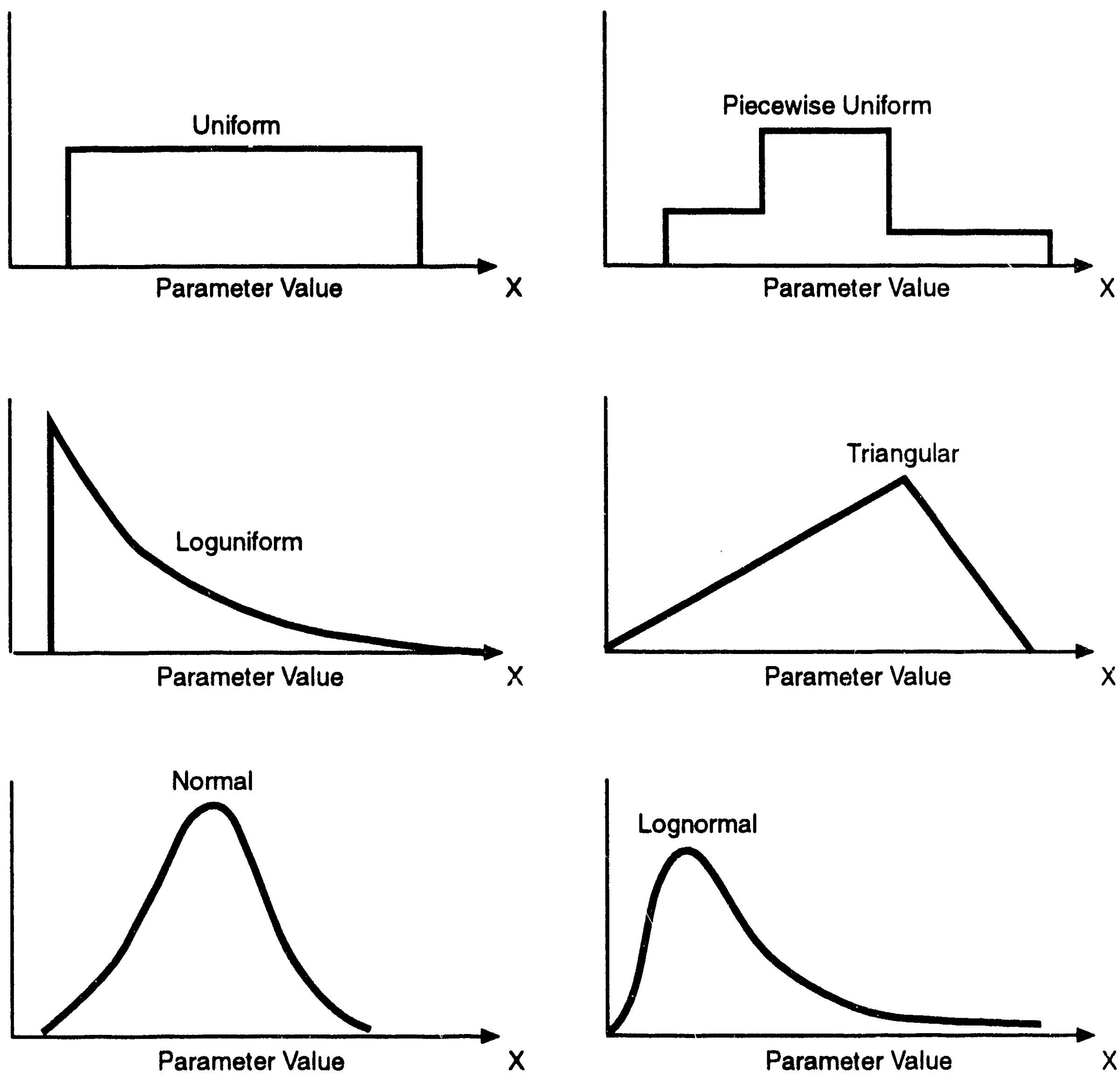

FIGURE 3.1. Potential Distribution Shapes for HEDRIC Parameters

- The loguniform pdf, which assigns equal probability of occurrence to the logarithm of each possible value of the parameter, is selected if 1) the minimum and maximum values span a distance of several orders of magnitude, 2) there is some reason to believe that a uniform distribution of the logarithms is a plausible model, and 3) insufficient information is available to defend the assertion that a more complex distribution is appropriate.

- The triangular pdf assigns probabilities of occurrence to the possible parameter values such that the pdf is in the form of a triangle. This pdf is selected if 1) the available information indicates that one value of the parameter is more likely to occur than any other single value, and 2) insufficient information is available to defend the assertion that a pdf shape more complex than a triangle is appropriate. The most likely parameter value need not be located at the center of the range. It may be located near the maximum or minimum value.

- The normal (Gaussian) pdf assigns probability of occurrence to the possible parameter values such that the pdf is symmetric and bell shaped. This distribution is used only when sufficient data, statistical analyses, or other information exists to defend the assertion that the normal distribution is a more accurate model than a symmetric triangular distribution.

- The lognormal pdf assigns probabilities of occurrence to the logarithms of the possible parameter values such that the pdf of those logarithms is symmetric and bell shaped. The lognormal pdf is used only when sufficient data, statistical analyses, or other information exist to defend the assertion that the normal distribution of the logarithms is a more accurate model than a symmetric triangular distribution of the logarithms.

Along with specifying the pdf of each model parameter, it is necessary to specify the relationships and dependencies among parameters. These relationships are modeled by HEDR Project staff as correlation coefficients or mathematical functions. These correlations and functions are determined on the basis of information obtained from literature searches and the elicitation of expert opinion. However, it is frequently the case that very little quantitative information about correlations or functional relationships is available from the literature. In that case, self-assessment and informal solicitation of expert opinion are relied upon to subjectively derive the needed relationships. Probability encoding may be used for the most critical relationships if sensitivity analyses indicate that the added expense is justified.

Changes in these specifications are made as necessary to reflect the best combined judgement of all reviewers.

3.4 PARAMETER SELECTION FREQUENCY

In addition to selecting a pdf for each model parameter, as discussed in Section 3.3, it was also necessary to decide how often parameter pdfs should change over time and space. For example, for each of the 100 realizations of HEDRIC, the environmental concentrations of radionuclides (i.e., those in soil, plants, and animal products) are computed at many different locations (see parameter 1) in the study area for each day of the multiyear time period of interest. The pdf specified for a given parameter may or may not be suitable for all times and locations. The selection of pdfs for the same parameter at different times and places will be made on the basis of literature reviews, self-assessment, or informal solicitation of expert opinion. In general, the pdf for a given parameter is not changed over space and time unless there is a compelling reason to do so.

Suppose the pdf of a parameter does not change over space and time. We must still decide whether to select a new random value from the pdf for each different time and location or whether to select a single value and use it for all times and locations in a realization. The answer depends on how the parameter is expected to vary in reality. For example, the ratio of the indoor air concentration relative to the outdoor air concentration (parameter R_{io}) can be expected to vary on a daily basis. Hence, although the same pdf is used for all days, a new random value from the pdf is selected each day within a realization.

The greatest time frequency indicated for use by DESCARTES and CIDER when selecting from a parameter's pdf is limited by the time step used for input parameters. For example, the atmospheric transport computer code, RATCHET, provides daily estimates of air concentrations and depositions of radionuclides (Ramsdell and Burk 1992). Hence, parameters in the environmental accumulation model, DESCARTES, and the dose model, CIDER, that use the estimated air concentrations and depositions from RATCHET will not be varied more than daily.

4.0 DATA QUALITY OBJECTIVES

Data quality objectives (DQOs) for this effort are as presented in Shipler (1992). These data quality objectives are as follows:

Accuracy - The objective is to estimate best estimates or ranges of parameter values that are consistent with available data, information, and expert opinion. The attainment of this objective will be assessed by peer reviews. The results of these reviews will be documented in project files, and changes will be made to individual parameter descriptions as required.

Precision - The objective is to develop, for each parameter, a distribution of possible values that is consistent with available information and expert opinion. The attainment of this objective will be assessed by peer reviews. The results of these reviews will be documented in project files, and changes will be made to individual parameter descriptions as required.

Completeness - The objective is to ensure that all pertinent information on each parameter has been evaluated and incorporated as appropriate. This will be done by refining and agreeing on the parameters and literature to be searched. Completeness will be verified by expert judgement and peer review. The results of these reviews will be documented in project files, and changes will be made to individual parameter descriptions as required.

Comparability - The objective is that the final set of parameter values and their uncertainties be within the range found in the literature. Direct comparisons will be used to determine comparability, which will be measured by evaluating and technically justifying the results of the comparison. These comparisons will be documented in the individual parameter descriptions.

The DQOs for this work have been met through discussions with experts and peer review. Both the experts listed as authors and those in the Acknowledgments contributed to the parameter discussions. Peer review has been conducted prior to the issuance of this report. Additional comments are expected from experts on the Technical Steering Panel, the Centers for Disease Control, and other scientists. These comments will be addressed and incorporated, as appropriate, in future issues of this document. The controlled-document format will allow for the updating of all parameter values. In addition, subsequent sensitivity and uncertainty analyses will help verify attainment of the DQOs.

5.0 REFERENCES

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6.0 PARAMETER DESCRIPTIONS

Descriptions of individual parameters used in the DESCARTES and CIDER equations are found in this section. The parameters are presented alphabetically, with Greek symbols before the Arabic. Currently, the environmental and dose parameters included are those required to estimate doses from historic airborne releases of iodine-131 only. Future versions will include parameter information for additional radionuclides.

The format of this document allows for periodic updating of individual parameter descriptions and the adding of parameters for radionuclides other than iodine-131. The descriptions included herein will be updated based upon additional information acquired by HEDR Project staff and comments from other technical experts. These descriptions will undoubtedly be changed based on the results of the sensitivity analysis. After the sensitivity analysis, those parameters that lead to the greatest amount of uncertainty in the dose estimates will receive more scrutiny and those that lead to little or no uncertainty may be set to constant values. Updates will include parameter values for radionuclides other than iodine-131.

6.1 TECHNICAL APPROACH

Only original data sources are included as references for the parameter descriptions and values. "Original" is defined as the first presentation of the parameter value(s) in the scientific literature. This original-source criterion eliminates some of the "data" in the scientific literature. Many sources of data are available in the scientific literature, and many provide data compilations, but very few of these references contain original data. Only data that are applicable to the environmental accumulation or dose models are used in this study.

While this document is intended to be comprehensive, it does not include every reference for every parameter; some additional data sources certainly exist and will be included to the extent possible in future versions of this document. Based upon the results of the structured sensitivity analysis that is to be conducted as part of the HEDR project, more resources can be expended on those parameters that contribute to the greatest amount of uncertainty in the estimated doses.

The chemical form of the radionuclide may affect its transport and accumulation in various environmental pathways. For example, much research has been done on the quantitative differences caused by the different chemical forms of iodine for atmospheric deposition (see V_d parameter, Sehmel 1980) and ingestion of iodine (see TF_{milk_ind} parameter, Bretthauer et al. 1972). Much less is known about the effects of chemical form for all other parameters. Because of this lack of information, the DESCARTES and CIDER codes assume one chemical form. Most iodine research was conducted using iodide, the most reactive form of iodine. Use of the results of iodide research will generate conservative dose estimates for those individuals with the highest exposure. For any parameter for which research has been performed using other chemical forms (i.e., non-iodide forms), the parameter's range of values reflects the quantitative differences created by the differences in chemical form.

Each parameter discussion is organized into a uniform format. Every page footer indicates the current version and the number of pages for the particular parameter description. Both the header and footer of each page indicate the symbol used for the relevant parameter; radionuclide-dependent parameters indicate the radionuclide of interest. Format subheadings are listed and described below:

Parameter: A short description of the parameter.

Dependencies: Other model parameters or conditions upon which the value of the parameter being discussed depends. These are model-specific dependencies. Use of alternative model equations or approaches may result in alternative dependencies.

Frequency of selection: The frequency at which the parameter is selected during the representative individual dose calculations. Values that are constants have no selection frequency alternatives. Therefore, "frequency of selection" does not apply to these parameters.

Reference equation(s): The DESCARTES or CIDER reference equation(s) (see Section 2.1) that use(s) the parameter.

Equation symbol: The generic form of the parameter. Parameter subscripts are those used in the DESCARTES and CIDER reference equations (see Section 2.3). The subscript of the parameter being discussed may differ. Parameter discussions address specific cases of the generic form.

Definition: A definition of the parameter as it is used in DESCARTES and CIDER.

Units: The units for the parameter values.

Values: The values used for the parameter in DESCARTES and CIDER. (Scientific notation is used throughout: e.g., 2E-7 is equivalent to $2x10^{-7}$.)

Distribution: The probability distribution of the parameter (see Section 3.3.3).

Technical basis: A summary of the following: 1) the available literature that discusses original experimental data reported for the parameter, 2) values derived by modelers, and/or 3) the methods of deriving values and distributions used by the HEDR Project. The basis for the distribution selection is also provided.

References: A list of references cited in the Technical Basis section.

PARAMETER DESCRIPTIONS

Parameter Symbol	Parameter Description	Current Version Date
α	Empirical foliar interception constant	9/92
$^{131}I\ \lambda_{leach}$	Leaching rate from root zone to deep soil	9/92
$^{131}I\ \lambda_{perc}$	Percolation rate from upper soil layer to root zone	9/92
$^{131}I\ \lambda_{rad}$	Radiological decay constant	9/92
$^{131}I\ \lambda_{splash}$	Rainsplash rate constant	9/92
λ_{trans}	Plant translocation rate	9/92
λ_{weath}	Weathering rate	9/92
ρ_{rz}	Root zone soil areal density from 1 mm to 15 cm depth	9/92
ρ_{usl}	Upper soil layer from areal density to a depth of 1 mm	9/92
B_{max}	Maximum potential biomass	9/92
B_{min}	Minimum (winter) biomass	9/92
BR	Age-dependent breathing rate	9/92
^{131}I CR	Plant-to-soil concentration ratio	9/92
$^{131}I\ DF_{imm}$	Immersion dose rate factor	9/92
$^{131}I\ DF_{ing}$	Ingestion dose factor	9/92
$^{131}I\ DF_{inh}$	Inhalation dose factor	9/92
$^{131}I\ DF_{rz}$	Dose rate factor for radionuclides in the soil root zone	9/92
$^{131}I\ DF_{usl}$	Dose rate factor for upper soil layer or surface activity	9/92
f_d	Dry-weight to wet-weight conversion factor	9/92
$FS_{chicken}$	Chicken soil-ingestion rate	9/92
FS_{cow}	Cow soil-ingestion rate	9/92
f_{time}	Fraction of day spent outdoors	9/92
$^{131}I\ f_{trans}$	Translocation fraction	9/92
k_g	Growth rate constant	9/92
k_s	Senescence rate constant	9/92
l	Location of interest	9/92

Parameter Symbol	Parameter Description	Current Version Date
$^{131}I\ L_{proc}$	Food processing loss fraction	9/92
ML	Mass loading factor for local soil in air	9/92
R_{io}	Ratio of indoor air to outdoor air activity	9/92
$R_{v\_chicken}$	Total quantity of feed consumed by a chicken	9/92
^{131}I Shl	Shielding factor	9/92
$^{131}I\ TF_{beef}$	Beef transfer factor	9/92
$^{131}I\ TF_{eggs}$	Egg transfer factor	9/92
$^{131}I\ TF_{milk\_herd}$	Accumulated milk transfer factor	9/92
$^{131}I\ TF_{milk\_ind}$	Individual cow milk transfer factor	9/92
$^{131}I\ TF_{poultry}$	Poultry transfer factor	9/92
th_p	Holdup time, from collection or harvest to consumption, where p is a food crop or animal product	9/92
V_d	Local deposition velocity of resuspended soil back to soil or vegetation	9/92

Parameter: Foliar interception **Reference equation:** DES-4

Dependencies: none **Equation symbol:** α

Frequency of selection: realization

Definition: The empirically derived interception constant for foliage.

Units: m^2/kg(dry)

Value(s): minimum: 1.0
maximum: 4.0

Distribution: uniform

Technical basis: Chamberlain (1970) originally investigated the relationship between interception fraction and plant biomass and suggested the exponential equation shown in Equation DES-4. The Chamberlain data resolved the α value by analysis of the relationship between areal biomass and experimentally derived interception fractions.

The α values Chamberlain reported, from experiments using iodine vapor to droplet-sized particles, range from 2.3 to 3.3. These values represent data from grassland interception-fraction experiments. The author cautioned against use of these values for other vegetative types, particularly xerophytic types.

Pinder et al. (1989) evaluated the α value for corn and estimated a value of 3.6. This value is larger than, but similar to, the Chamberlain values. Pinder et al. also evaluated the use of the grass and corn α value for other plant types. They concluded that linear models are as accurate as the exponential model, such as that used in DESCARTES, when other plant types are considered.

Miller (1979) evaluated the literature values of α published up to 1979. The values summarized range from 1.0 to 4.0. Miller concluded that a lognormal distribution described this parameter. The indicated transformed median for pasture was 0.61 with a geometric standard deviation (gsd) of 0.44. For silage, the median was 0.14 with a gsd of 0.27.

Little information is available for food crop types consumed by humans. Therefore, the α values derived for grasses and corn will be used across all food types. The range identified by Miller, 1 to 4, is representative of all values in the literature. Because of lack of information about the α values of food crops consumed by humans, a more conservative uniform distribution, rather than lognormal as suggested by Miller (1979), will be used as the distribution for this parameter.

References:

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Miller, C. 1979. "The Interception Fraction." In: A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides. F. O. Hoffman and C. F. Baes, III, eds. NUREG/CR-1004, pp. 31-42. October 1979. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Pinder, III, J. E., K. W. McLeod, and D. C. Adriano. 1989. "The Accuracy of Some Simple Models for Predicting Particulate Interception and Retention in Agricultural Systems." Health Physics 56:441-450.

Parameter: Soil leaching rate

Reference equation: DES-7

Dependencies: radionuclide

Equation symbol: λ_{leach}

Frequency of selection: realization

Definition: The rate at which radionuclide leaches from the soil rooting zone into deeper soil layers.

Units: d^{-1}

Value(s): minimum: 4E-6
maximum: 5E-3

Distribution: uniform

Technical basis: A fraction of the activity that deposits on the soil surface is expected to move downward from the upper soil layer to the soil rooting zone to the deep soil layers. The portion of the activity that leaches to the deep soil layer is assumed to be unavailable for entry into the food crop pathway. Experiments evaluating the movement of iodine in a local sandy loam soil demonstrated its mobility throughout a wetted area. Iodine is unlike some other relatively immobile elements (e.g., zinc and phosphorous) that remain near their point of introduction into the soil (Price 1965).

The rate at which the activity enters the deep soil layer is represented by the rate constant λ_{leach}. The general equation used to derive the leaching-rate constant is a modification of an equation presented by Baes and Sharp (1981). The equation was modified to exclude evapotranspiration. The original form of the Baes and Sharp equation is presented below:

$$\lambda_{leach} = \frac{P + I + E}{d\left(1 + \frac{\rho K_d}{\theta}\right)}$$

where P = precipitation rate (cm/yr)

I = irrigation rate (cm/yr)

E = evapotranspiration rate (cm/yr)

d = depth to deep soil layer (15 cm)

ρ = soil bulk density ([wet]g/cm^3)

θ = soil volumetric water content (mL/cm^3)

K_d = soil-water distribution coefficient (mL/g).

The numerator in the above equation describes the net annual water balance in the root zone. This water balance is controlled by farmers' irrigation in the arid Columbia Basin during the growing season. It was assumed that the farmers over-irrigate by 10%. The total volume of surplus irrigation water (i.e., the over-irrigated volume) was assumed to enter the deep soil layer.

The average irrigation rates for the eight Washington counties surrounding the Hanford Site are listed below (USDA 1974).

County	Average Irrigation Rate (ft/yr)	(cm/yr)
Adams	2.0	61.0
Benton	2.7	82.3
Franklin	2.5	76.2
Grant	2.7	82.3
Kittitas	3.2	97.5
Klickitat	2.3	70.1
Walla Walla	2.2	67.1
Yakima	2.5	76.2

Assuming an over-irrigation rate of 10%, the volume of surplus irrigation water applied in the listed counties ranges from 6.1 to 9.8 cm/yr

(0.05 to 0.08 cm/d for a 120-d growing season). These levels of over-irrigation would not be expected to move far from the 15-cm root zone modeled in DESCARTES.

The range of the leaching rate was determined by changing the variables in the above equation as follows:

K_d = 0 to 5 (Sheppard and Thibault 1990)
ρ = 1.25 to 1.55 (SCS 1992)
θ = 0.05 to 0.2 (SCS 1982)
daily I = 0.05 to 0.08.

The minimum and maximum values derived for the leaching-rate constant represent halftimes of approximately 4.5 months to 470 years. These halftimes are longer than expected, considering the mobility of iodine. These values may not be accurate for the early growing season. However, organic matter strongly adsorbs iodine (Coughtrey et al. 1983). As roots grow over the growing season, the iodine will be more strongly bound in the root zone. Iodine-131 contamination actually in or modeled in the root-zone soil early in the growing season will have decayed away long before crop harvest.

A uniform distribution was selected for the leaching rate parameter to reflect changes in the irrigation rate, the soil's volumetric water content, and the soil's bulk density resulting from root growth over the growing season. These variables would be expected to vary daily over the growing season as a result of changes in evapotranspiration rates and plant growth.

Leaching-rate constants summarized by Coughtrey (1985) range from 2.1E-7 to 5.7E-2 per day, with a best estimate of 3.2E-4 per day. This best estimate lies within the range derived above for the HEDR study region.

References:

Baes, C. F., and R. D. Sharp. 1981. Predicting Radionuclide Leaching from Root Zone Soil from Assessment Applications. CONF-81601, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Coughtrey, P. J., D. Jackson, and M. C. Thorne. 1983. Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems. Volume 3. A. A. Balkema, Rotterdam, Boston.

Coughtrey, P. J., D. Jackson, and M. C. Thorne. 1985. Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems. Volume 6. A. A. Balkema, Rotterdam, Boston.

Price, K. R. 1965. "Uptake of Iodine-131 from the Soil as Related to Root Distribution and Phenology in Sagebrush Vegetation." Ph.D. Thesis, Washington State University, Pullman, Washington.

Sheppard, M. I., and D. H. Thibault. 1990. "Default Soil Solid/Liquid Partition Coefficients, K_ds for Four Major Soil Types: A Compendium." Health Physics 59:471-482.

U.S. Department of Agriculture (USDA). 1974. 1974 Census of Agriculture, Washington State and County Data. Volume I, Part 47, Washington, D.C.

U.S. Soil Conservation Service (SCS). 1992. Soil Conservation Service Soil Interpretation Records for Franklin County; see ρ_{rz} for complete listing.

U.S. Soil Conservation Service (SCS). 1982. "Stevens County Soil Survey." Soil Conservation Service, Washington, D.C.

Parameter: Percolation rate

Dependencies: radionuclide

Frequency of selection: realization

Reference equations: DES-6
DES-7

Equation symbol: λ_{perc}

Definition: The rate at which the upper soil layer activity percolates to the soil root zone.

Units: d^{-1}

Value(s): minimum: 0.14
maximum: 8.2

Distribution: uniform

Technical basis: Some of the surface-deposited iodine will move from the upper to the soil rooting zone and lower soil layers. The percolation rate describes the rate at which the soil moves from the upper soil layer to the root zone. The leaching-rate (see λ_{leach}) describes the rate at which the activity moves from the root zone to the deep soil layer. The percolation rate constant is inversely proportional to the residence halftime of the element in the upper soil layer.

The percolation-rate constant was derived by the use of an equation presented by Baes and Sharp (1981). The Baes and Sharp equation is presented below.

$$\lambda_{leach} = \frac{P + I + E}{d\left(1 + \frac{\rho K_d}{\theta}\right)}$$

where P = precipitation rate (cm/yr)

I = irrigation rate (cm/yr)

E = evapotranspiration rate (cm/yr)

d = depth to deep soil layer (15 cm)

ρ = soil bulk density ([wet]g/cm^3)

θ = soil volumetric water content (ml/cm^3)

K_d = soil-water distribution coefficient (ml/g).

The values used to estimate the minimum and maximum percolation rates are listed below. These values are similar to those described in the evaluation of λ_{leach}, except that the full volume of irrigation water is used for I.

K_d = 0 to 5 (Sheppard and Thibault 1990)
ρ = 1.2 to 1.4 (SCS 1992)
θ = 0.2, and
daily I = 0.51 to 0.82.

Research by Barth and Veater (1964) investigated the residence time of iodine-131 fallout in the top half-inch of undisturbed farm soil in an arid Nevada environment. They found the residence time to be equivalent to the radiological half-life of the isotope. This finding indicates a lack of notable vertical movement (relative to the iodine-131 halftime) in an arid environment.

Because of a lack of information, the uniform distribution was assumed.

References:

Baes, C. F., and R. D. Sharp. 1981. Predicting Radionuclide Leaching from Root Zone Soil from Assessment Applications. CONF-81601, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Barth, D. S., and J. G. Veater. 1964. Dairy Farm Radioiodine Study Following the Pike Event. TID-21764, Public Health Service, Southwestern Radiological Health Laboratory, Las Vegas, Nevada.

Sheppard, M. I., and D. H. Thibault. 1990. "Default Soil Solid/Liquid Partition Coefficients, K_ds for Four Major Soil Types: A Compendium." Health Physics 59:471-482.

U.S. Soil Conservation Service (SCS). 1992. Soil Conservation Service Soil Interpretation Records for Franklin County; see ρ_{rz} parameter discussion for complete listing.

Parameter: Radiological decay constant

Dependencies: radionuclide

Frequency of selection: N/A

Reference equations: DES-6, DES-7, DES-8, DES-9, DES-16, CID-4, CID-5

Equation symbol: λ_{rad}

Definition: The probability that a given iodine-131 atom will disintegrate during a specified unit of time.

Units: d^{-1}

Value(s): 0.086

Distribution: none (constant)

Technical basis: The rate at which an element decays is a physical constant. This rate is independent of temperature and pressure (Pearson 1986) and is characteristic for each radionuclide. Radioactive decay occurs because the nucleus of an atom is in an excited state and must release energy in order to exist in a more stable (less excited) state. The process of radioactive decay occurs as a decreasing exponential function over time. The decay constant is determined from the decay law:

$$N = N_0\, e^{-\lambda_{rad}\, t}$$

where N = final activity after time t, disintegrations/second
N_0 = initial activity at time = 0, disintegrations/second
λ_{rad} = radiological decay constant, d^{-1}
t = time, d.

A number of scientists have confirmed the 0.086 value experimentally (e.g., Lederer and Shirley 1978).

References:

Lederer, C. M., and V. S. Shirley. 1978. Table of Isotopes. Seventh Edition. Lawrence Berkeley Laboratory, University of California. John Wiley and Sons, New York.

Pearson, J. M. 1986. Nuclear Physics: Energy and Matter. Adam Hilger, Ltd., Bristol, England.

Parameter: Rainsplash rate constant

Dependencies: none

Frequency of selection: N/A

Reference equations: DES-6
DES-8

Equation symbol: λ_{splash}

Definition: The constant that describes the rate at which ground-surface activity is splashed onto the crop surface.

Units: d^{-1}

Value(s): 0

Distribution: none (constant)

Technical basis: A portion of the activity that deposits on the ground surface will be splashed onto the plant surface during rainfall events. This contribution to the total surface activity may be found to contribute a significant fraction of the soil deposited on plant surfaces (Dreicer et al. 1984).

Rainsplash occurs, of course, during rainfall events. DESCARTES does not consider the timing of specific weather events. It was felt that efforts to include rainsplash through the use of a rate constant would not contribute significant doses from relatively short half-lived materials (relative to the length of the growing season) from the consumption of human food crops in the HEDR study region for the following reasons:

- the timing-sensitive nature of rainsplash (especially rainfall events occurring shortly before harvest)
- the small amount of rainfall during the growing season
- the rill rather than spray irrigation practiced during the late 1940s.

In addition, experimental measurements of concentration ratio and weathering half-life account for rainsplash contributions to some degree.

Because of a lack of data on rainsplash, the dependency of the rainsplash rate constant on specific rain events, and the short halflife of iodine-131, which enhances the sensitivity to the rain event, the λ_{splash} for iodine-131 will be defined as 0. The use of a rate constant may be reintroduced when the crop concentrations of longer-lived radionuclides are evaluated.

References:

Dreicer, M., T. E. Hakonson, G. C. White, and F. W. Whicker. 1984. "Rainsplash as a Mechanism for Soil Contamination of Plant Surfaces." Health Physics 46:177-187.

Parameter: Translocation rate constant

Reference equations: DES-5, DES-8, DES-9

Dependencies: vegetation type

Frequency of selection: N/A

Equation symbol: λ_{trans}

Definition: The translocation-rate constant for vegetation types with no fleshy edible portion. The rate constant models the movement of activity from the exterior to the interior, fleshy, edible portions of the crop. This rate constant is non-zero for other vegetables, fruits, and grains.

Units: d^{-1}

Value(s): leafy vegetables, alfalfa, grass hay, pasture grass, silage, sagebrush: 0

other vegetables, fruit, grain: calculated (DES-5)

Distribution: none

Technical basis: The translocation-rate constant is either calculated by Equation DES-5 or defined as 0. The calculation is performed for the other vegetables, grain, and fruit vegetation types. The translocation-rate constant is defined as 0 for leafy vegetables, alfalfa, pasture grass, silage, and sagebrush.

Translocation is used to model the movement of activity from a non-edible portion of a crop to an edible portion. The initial interception fraction is modeled to deposit the airborne activity on the foliage and other above-ground vegetative portions. The foliage is the edible portion of the vegetative types for which λ_{trans} is defined as 0. Equation DES-8 uses the λ_{trans} parameter to estimate the decrease in outer vegetative compartment activity as a result of translocation to the edible, inner vegetative portion.

References: none

Parameter: Weathering rate

Reference equations: DES-5, DES-6, DES-8

Dependency: none

Frequency of selection: realization

Equation symbol: λ_{weath}

Definition: The mathematically derived rate at which physical processes (e.g., rain, wind, mechanical action, isotopic exchange) remove radionuclides from a crop's surface.

Units: d^{-1}

Value(s): central: (ln 2)/14 = 0.0495
minimum: (ln 2)/20 = 0.0347
maximum: (ln 2)/8 = 0.0866

Distribution: triangular

Technical basis: After radionuclides are deposited on vegetation, environmental-removal processes (i.e., weathering) combine with radioactive decay to reduce the quantity of initial contamination on the vegetation (Miller and Hoffman 1983). The weathering halftime describes the amount of time it takes 50% of the deposited radionuclides to be removed by weathering processes.

The weathering-rate constant is calculated from the weathering halftime:

$$\lambda_{weath} = \frac{(\ln 2)}{T_{weath}}$$

where ln 2 = natural logarithm of 2 = 0.693 and

T_{weath} = weathering halftime, d.

Weathering halftime values are calculated from measurements of the effective halftimes of radionuclides on vegetation. The effective halftime, or residence time, of a radionuclide on vegetation is a function of both the radiologic half-life of an element and the weathering halftime. The constant radiologic half-life of a radionuclide permits the calculation of the weathering halftime as follows:

$$\frac{1}{T_{eff}} = \frac{1}{T_{rad}} + \frac{1}{T_{weath}}$$

where T_{eff} = effective halftime, d

T_{rad} = radiological half-life, d

T_{weath} = weathering halftime, d.

Weathering halftimes may vary as a result of the weather conditions, the crop under evaluation, and the chemical form of the radioisotope. Experimentally determined values of weathering halftime have been reported by a number of researchers, listed below.

Weathering halftime	Reference
15 to 24 d	Martin (1965)
7.4 to 11 d	Coughtrey et al. (1990)
9.4 to 11 d	"
8.3 to 29 d	"
4.3 to 30 d	"
1 to 11 d	"
6.2 to 17 d	"
13 d	Reinig (1961)
approx. 24 d	Soldat (1963)
4.1 to 34.6 d	Till and Meyer (1983)
6.5 and 10.2 d	Douglas et al. (1971)
5.9 to 14 d	Kohler et al. (1991)

Weathering halftime values used by other models are listed below. The most common default value used is 14 d and represents all radionuclides and plant types (Miller and Hoffman 1983).

Default values of other models	Reference
14 d	BIOMOVS (1990)
8.1 d	"
10 d	"
11.5 d	"
9.1 d	"
14 d	Schreckhise (1980)
14 d	Napier et al. (1988)
14 d	NRC (1977)
12 to 14 d	As summarized by Hoffman (1977)
14 d	Zach (1980)

Miller and Hoffman (1983) evaluated the weathering halftime of iodine particulates and gases in comparison with those of other nuclides. They found that, for growing vegetation, the values for iodine are about half the values reported for other particulate elements. As a result of their research, Miller and Hoffman (1983) reported an iodine vapor and particulate weathering halftime range of 2.8 to 16 days, and a geometric mean of 7.5 days (geometric standard deviation = 1.5). These values were based on an assumed lognormally distributed T_{weath} as indicated by Hoffman and Baes (1979).

HEDR model developers did not believe the experimental evidence was strong enough to support the assumption of a lognormally distributed weathering halftime. A triangular distribution was assumed.

References:

BIOMOVS. 1990. "Scenario B1, Atmospheric Deposition, BIOMOVS Technical Report 8," March 1990. Swedish National Institute of Radiation Protection, Stockholm, Sweden.

Coughtrey, P. J., J. A. Kirkton, and N. G. Mitchell. 1990. "Evaluation of Food Chain Transfer Data for Use in Accident Consequence Assessment." In: Proceedings of the Seminar on Methods and Codes for Assessing the Off-Site Consequences of Nuclear Accidents. Volume 1, Preprint, May 7 to 11, 1990. Athens, Greece.

Douglas, R. L., S. C. Black, and D. B. Barth. 1971. Iodine-131 Transport Through the Air-Forage-Cow-Milk System Using an Aerosol Mist, (Project Rainout). SWRHL-43r, U.S. Environmental Protection Agency, Las Vegas, Nevada.

Hoffman, F. O. 1977. "A Reassessment of the Deposition Velocity in the Prediction of the Environmental Transport of Radioiodine from Air to Milk." Health Physics 32:437-441.

Hoffman, F. O., and C. F. Baes, III, eds. 1979. A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides. NUREG/CR-1004, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Kohler, H., S.-R. Peterson, and F. O. Hoffman, eds. 1991. BIOMOVS Technical Report 13, Part 1, Scenario A4: Multiple Model Testing Using Chernobyl Fallout Data of I-131 in Forage and Milk and Cs-137 in Forage, Milk, Beef, and Grain. Swedish National Institute of Radiation Protection, Stockholm, Sweden.

Martin, W. E. 1965. "Interception and Retention of Fallout by Desert Shrubs." Health Physics 11:1341-1354.

Miller, C. W., and F. O. Hoffman. 1983. "An Examination of the Environmental Half-Time for Radionuclides Deposited on Vegetation." Health Physics 45:731-744.

Napier, B. A., D. L. Strenge, R. A. Peloquin, and J. V. Ramsdell. 1988. GENII - The Hanford Environmental Radiation Dosimetry System, Volume 1: Conceptual Representation. PNL-6584 Vol. 1, Pacific Northwest Laboratory, Richland, Washington.

Reinig, W. C. 1961. Environmental Release of Iodine-131. DPSP-61-25-7, E.I. du Pont de Nemours and Company, Savannah River Plant, Aiken, South Carolina.

Schreckhise, R. G. 1980. Simulation of the Accumulation of Radiocontaminants in Crop Plants. PNL-2636, Pacific Northwest Laboratory, Richland, Washington.

Soldat, J. K. 1963. "The Relationship between Iodine-131 Concentrations in Various Environmental Samples." Health Physics 9:1167-1171.

U.S. Nuclear Regulatory Commission (NRC). 1977. Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Revision 1. Regulatory Guide 1.109, Washington, D.C.

Till, J. E., and H. R. Meyer, eds. 1983. Radiological Assessment, A Textbook on Environmental Dose Assessment. NUREG/CR-3332, U.S. Nuclear Regulatory Commission, Washington, D.C.

Zach, R. 1980. Sensitivity Analysis of the Terrestrial Food Chain Model FOOD III. AECL-6794, Atomic Energy of Canada Limited, Whiteshell Nuclear Research Establishment, Manitoba, Canada.

Parameter: Root zone soil density **Reference equations:** DES-14

Dependencies: none **Equation symbol:** ρ_{rz}

Frequency of selection: realization

Definition: The areal bulk density of soil in the 0.1- to 15-cm depth below the soil surface.

Units: kg(wet)/m^2

Value(s): minimum: 186
maximum: 230

Distribution: uniform

Technical basis: Percolation is the rate at which radionuclides are removed from the soil root zone. The bulk density of the soil root zone is required in order to determine the percolation-rate constant, Equation DES-13. The values listed above are wet bulk-density values reported for Franklin County farmed soils. Bulk-density values are those listed in the Soil Interpretation Records of the U.S. Soil Conservation Service (SCS).

References:

U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS). "Soil Interpretation Records," soil types evaluated (IRR = irrigated; NIRR = not irrigated):

Record number	
43	Quincy Loamy Fine Sand, 0 to 15 Percent Slopes, Quincy Part - NIRR
48	Quincy Loamy Fine Sand, Loamy Substratum, 0 to 10 Percent Slopes, Quincy Part - NIRR
53	Ritzville Silt Loam, 2 to 5 Percent Slopes, Ritzville Part - NIRR
54	Ritzville Silt Loam, 5 to 10 Percent Slopes, Ritzville Part - IRR
53	Ritzville Silt Loam, 10 to 15 Percent Slopes, Ritzville Part - IRR
56	Ritzville Silt Loam, 15 to 30 Percent Slooes, Ritzville Part - IRR
61	Royal Loamy Fine Sand, 0 to 10 Percent Slopes, Royal Part - NIRR
64	Royal Loamy Fine Sand, 10 to 30 Percent Slopes, Royal Part - IRR
65	Royal-Timmerman Fine Sandy Loams, 15 to 30 Percent Slopes, Timmerman Part - NIRR
68	Sagehill Very Fine Sandy Loam, 0 to 2 Percent Slopes, Sagehill Part - IRR
69	Sagehill Very Fine Sandy Loam, 2 to 5 Percent Slopes, Sagehill Part - IRR
71	Shano Silt Loam, 0 to 2 Percent Slopes, Shano Part - IRR
72	Shano Silt Loam, 2 to 5 Percent Slopes, Shano Part - NIRR
73	Shano Silt Loam, 5 to 10 Percent Slopes, Shano Part - IRR
74	Shano Silt Loam, 10 to 15 Percent Slopes, Shano Part - NIRR
80	Taunton Very Fine Sandy Loam, 0 to 2 Percent Slopes, Taunton Part - NIRR
81	Taunton Very Fine Sandy Loam, 2 to 5 Percent Slopes, Taunton Part - NIRR

82	Timmerman Fine Sandy Loam, 0 to 2 Percent Slopes, Timmerman Part - NIRR
83	Timmerman Fine Sandy Loam, 2 to 5 Percent Slopes, Timmerman Part - IRR
84	Timmerman Fine Sandy Loam, 5 to 10 Percent Slopes, Timmerman Part - IRR
85	Warden Silt Loam, Saline 0 to 2 Percent Slopes, Warden Part - IRR
85	Warden Silt Loam, Saline, 0 to 2 Percent Slopes, Warden Part - NIRR
86	Warden Very Fine Sandy Loam, 0 to 2 Percent Slopes, Warden Part - NIRR
87	Warden Very Fine Sandy Loam, 2 to 5 Percent Slopes, Warden Part - IRR
89	Warden Very Fine Sandy Loam, 10 to 15 Percent Slopes, Warden Part - IRR
91	Schlomer Silt Loam, Loam, Moderately Deep, 2 to 5 Percent Slopes - IRR
92	Schlomer Silt Loam, Moderately Deep, 5 to 10 Percent Slopes - IRR
98	Winchester Loamy Coarse Sand, 2 to 5 Percent Slopes, Winchester Part - IRR
120	Sagemoor Very Fine Sandy Loam, 0 to 2 Percent Slopes, Sagemoor Part - IRR
121	Sagemoor Very Fine Sandy Loam, 2 to 5 Percent Slopes, Sagemoor Part - NIRR
122	Sagemoor Very Fine Sandy Loam, 5 to 10 Percent Slopes, Sagemoor Part - IRR
140	Farrell Silt Loam, 0 to 5 Percent Slopes, Farrell Part - IRR
141	Farrell Silt Loam, 5 to 10 Percent Slopes, Farrell Part - NIRR
151	Wacota Silt Loam, 2 to 5 Percent Slopes - NIRR
152	Wacota Silt Loam, 5 to 10 Percent Slopes - NIRR
520	Ritzville Silt Loam, Stratified Substratum, 2 to 5 Percent Slopes - NIRR
610	Royal Fine Sandy Loam, 0 to 2 Percent Slopes, Royal Part - NIRR
611	Royal Fine Sandy Loam, 2 to 5 Percent Slopes, Royal Part - IRR
740	Shano Silt, 15 to 30 Percent Slopes, Shano Part - NIRR
741	Shano Silt Loam, 30 to 40 Percent Slopes - NIRR

Parameter: Upper soil layer density

Dependencies: none

Frequency of selection: realization

Reference equation: DES-10
DES-17

Equation symbol: ρ_{usl}

Definition: The areal bulk density of surface soil to a depth of 1 mm.

Units: kg(wet)/m^2

Value(s): minimum: 1.10
maximum: 1.45

Distribution: uniform

Technical basis: Resuspended material originates from the surface layer of soil, called the upper soil layer in DESCARTES. The evaluation of resuspended material, Equation DES-10, requires soil bulk-density values. The U.S. Soil Conservation Service (SCS) publishes soil-interpretation records that indicate the moist bulk-density of soil in each surveyed county. These records for Franklin County indicate a bulk-density of 1.10 to 1.45 kg/m^2 for the upper 1 mm of soil. This value was determined by the evaluation of the indicated bulk-density of the upper (approximately) 5 inches of soil for 39 different soil types. The soils evaluated are the types most commonly farmed, whether irrigated or not irrigated.

References:

U.S. Department of Agriculture (USDA), Soil Conservation Service (SCS). "Soil Interpretation Record" soil types evaluated (IRR = irrigated; NIRR = not irrigated):

Record number	
43	Quincy Loamy Fine Sand, 0 to 15 Percent Slopes, Quincy Part - NIRR
48	Quincy Loamy Fine Sand, Loamy Substratum, 0 to 10 Percent Slopes, Quincy Part - NIRR
53	Ritzville Silt Loam, 2 to 5 Percent Slopes, Ritzville Part - NIRR
54	Ritzville Silt Loam, 5 to 10 Percent Slopes, Ritzville Part - IRR
53	Ritzville Silt Loam, 10 to 15 Percent Slopes, Ritzville Part - IRR
56	Ritzville Silt Loam, 15 to 30 Percent Slopes, Ritzville Part - IRR
61	Royal Loamy Fine Sand, 0 to 10 Percent Slopes, Royal Part - NIRR
64	Royal Loamy Fine Sand, 10 to 30 Percent Slopes, Royal Part - IRR
65	Royal-Timmerman Fine Sandy Loams, 15 to 30 Percent Slopes, Timmerman Part - NIRR
68	Sagehill Very Fine Sandy Loam, 0 to 2 Percent Slopes, Sagehill Part - IRR

69	Sagehill Very Fine Sandy Loam, 2 to 5 Percent Slopes, Sagehill Part - IRR
71	Shano Silt Loam, 0 to 2 Percent Slopes, Shano Part - IRR
72	Shano Silt Loam, 2 to 5 Percent Slopes, Shano Part - NIRR
73	Shano Silt Loam, 5 to 10 Percent Slopes, Shano Part - IRR
74	Shano Silt Loam, 10 to 15 Percent Slopes, Shano Part - NIRR
80	Taunton Very Fine Sandy Loam, 0 to 2 Percent Slopes, Taunton Part - NIRR
81	Taunton Very Fine Sandy Loam, 2 to 5 Percent Slopes, Taunton Part - NIRR
82	Timmerman Fine Sandy Loam, 0 to 2 Percent Slopes, Timmerman Part - NIRR
83	Timmerman Fine Sandy Loam, 2 to 5 Percent Slopes, Timmerman Part - IRR
84	Timmerman Fine Sandy Loam, 5 to 10 Percent Slopes, Timmerman Part - IRR
85	Warden Silt Loam, Saline 0 to 2 Percent Slopes, Warden Part - IRR
85	Warden Silt Loam, Saline, 0 to 2 Percent Slopes, Warden Part - NIRR
86	Warden Very Fine Sandy Loam, 0 to 2 Percent Slopes, Warden Part - NIRR
87	Warden Very Fine Sandy Loam, 2 to 5 Percent Slopes, Warden Part - IRR
89	Warden Very Fine Sandy Loam, 10 to 15 Percent Slopes, Warden Part - IRR
91	Schlomer Silt Loam, Loam, Moderately Deep, 2 to 5 Percent Slopes - IRR
92	Schlomer Silt Loam, Moderately Deep, 5 to 10 Percent Slopes - IRR
98	Winchester Loamy Coarse Sand, 2 to 5 Percent Slopes, Winchester Part - IRR
120	Sagemoor Very Fine Sandy Loam, 0 to 2 Percent Slopes, Sagemoor Part - IRR
121	Sagemoor Very Fine Sandy Loam, 2 to 5 Percent Slopes, Sagemoor Part - NIRR
122	Sagemoor Very Fine Sandy Loam, 5 to 10 Percent Slopes, Sagemoor Part - IRR
140	Farrell Silt Loam, 0 to 5 Percent Slopes, Farrell Part - IRR
141	Farrell Silt Loam, 5 to 10 Percent Slopes, Farrell Part - NIRR
151	Wacota Silt Loam, 2 to 5 Percent Slopes - NIRR
152	Wacota Silt Loam, 5 to 10 Percent Slopes - NIRR
520	Ritzville Silt Loam, Stratified Substratum, 2 to 5 Percent Slopes - NIRR
610	Royal Fine Sandy Loam, 0 to 2 Percent Slopes, Royal Part - NIRR
611	Royal Fine Sandy Loam, 2 to 5 Percent Slopes, Royal Part - IRR
740	Shano Silt, 15 to 30 Percent Slopes, Shano Part - NIRR
741	Shano Silt Loam, 30 to 40 Percent Slopes - NIRR

Parameter: Maximum potential biomass

Reference equations: DES-1, DES-3

Dependencies: vegetation type

Equation symbol: B_{max}

Frequency of selection: year

Definition: The potential maximum amount of above-ground biomass on a unit area of ground.

Units: kg(dry)/m^2

Value(s):

Vegetation Type	Central Value	Minimum	Maximum
Leafy vegetables	0.2	0.07	0.6
Other vegetables	0.5	0.17	1.2
Tree fruit	0.54	0.3	2.0
Grain	0.14	0.09	0.3
Pasture	0.3	0.1	0.7
Grass hay	0.3	0.1	0.6
Alfalfa	0.2	0.07	0.4
Silage	0.3	0.1	0.6
Sagebrush	0.01	0.008	0.052

Distribution: triangular

Technical basis: Previous HEDR Project tasks determined the central value for the B_{max} parameter, the product of Y, f_s, and f_d, as reported in Shindle et al. (1992). A distribution of values was desired for updated work. The Y (maximum wet available biomass), f_s (available monthly fraction of maximum wet biomass), and f_d (dry weight:wet weight ratio) parameters are modified in this parameter update to be represented by the B_{max} and B_{min} parameters. Phase I modeled the biomass as the multiple of Y, f_s, and f_d. In DESCARTES these parameters are replaced with equations DES-1, DES-2, DES-3, and the B and B_{max} parameters.

The maximum B_{max} values were derived from the same sources used in the derivation of the central values. Yakima Irrigation District Crop Yield Reports (CYRs) from 1944 and 1945 were evaluated (BOR 1944 and 1945). Average and maximum crop yields were listed on these documents. These values are not immediately useful, however, because yields are listed in the CYRs as fresh volume per area, rather than the required dry mass per area. To derive the values required to translate the listed B_{max} central value to an approximate maximum B_{max} value, the percentage change between the average and maximum crop yields on the CYRs was determined. By multiplying the average percent increase for a crop type by the central value of dry biomass, the maximum B_{max} was determined.

The following lists the derived average percent increase of the maximum B_{max} over the average B_{max}, as determined from the CYRs.

Vegetation Type	Average Increase	Crops Used in Derivation
Leafy vegetables	200%	Spinach, lettuce
Other vegetables	140%	Beans, onions, potatoes, green peas, carrots, grapes, watermelon, turnips, asparagus
Tree fruit	270%	Apples, peaches, plums, cherries, apricots, pears
Grains, grass hay, alfalfa, silage	100%	Barley, cereal corn, corn fodder, oats, wheat, alfalfa

The maximum pasture B_{max} was taken from the reported maximum rangeland biomass values of the Stevens County Soil Survey (USDA 1982). This value represents the maximum productivity of natural rangeland during a favorable year. The minimum pasture B_{max} value is representative of the most commonly reported productivity values for various soil types during a year with unfavorable weather conditions. The minimum pasture B_{max} value approximates the reported values for Stevens (USDA 1982) and Yakima (USDA 1985) counties.

Minimum B_{max} values were more difficult to obtain for the other vegetation types. Most of the biomass literature describes the average and maximum yield of various crops. Little information is available on minimum values.

The yields of a limited number of irrigated and not irrigated crops are listed in the USDA Soil Surveys (1982, 1985, 1988). These values reflect the crop yields in the 1980s. The listed values for wheat, corn, alfalfa, and grass hay were evaluated and are listed below. The wet-biomass-per-acre values listed in the soil surveys were converted to the dry-kg-per-m^2 units used in DESCARTES.

Crop	Irrigated	Biomass
Wheat	Yes	0.42-0.66
	No	0.09-0.27
Corn	Yes	0.42-0.59
Alfalfa	Yes	0.27-0.43

The B_{max} central and maximum value of grain falls within the range of the listed not irrigated wheat values. Therefore, the lower end of the listed not irrigated wheat biomass value will be used for the minimum B_{max} value for grain in the DESCARTES code.

At this point, we have established the minimum B_{max} values for pasture and grain. Information by which to empirically derive the minimum B_{max} values for other vegetation types is not readily available. Therefore, we decided to infer the other vegetation type's values from the pasture and grain B_{max} values. The minimum pasture value is 33% of its central value, and the minimum grain value is 64% of its central value. It was assumed that the minimum B_{max} values for the other vegetation types, except fruits, would be 33% (the more conservative of the 33% and 64% values) of their respective central values. Thirty-three percent of the fruit central value produces a minimum B_{max} that is less than the B_{min}. This problem was resolved by using 50% (the average of the 33% and 74% values) of the central value to determine B_{min}.

References:

Shindle, S. F., T. A. Ikenberry, and B. A. Napier. 1992. Parameters Used in the Environmental Pathways and Radiological Dose Modules of the Phase I Air Pathway Code. PNL-8093 HEDR, Pacific Northwest Laboratory, Richland, Washington.

U.S. Bureau of Reclamation (BOR). 1944. Crop Yield Reports for the Yakima Irrigation Project. Department of the Interior, Washington, D.C.

U.S. Bureau of Reclamation (BOR). 1945. Crop Yield Reports for the Yakima Irrigation Project. Department of the Interior, Washington, D.C.

U.S. Department of Agriculture (USDA). 1982. Soil Survey of Stevens County, Washington. Soil Conservation Service, Washington, D.C.

U.S. Department of Agriculture (USDA). 1985. Soil Survey of Yakima County, Washington. Soil Conservation Service, Washington, D.C.

U.S. Department of Agriculture (USDA). 1988. Soil Survey of Umatilla County Area, Oregon. Soil Conservation Service, Washington, D.C.

Parameter: Minimum (winter) biomass

Dependencies: vegetation type

Frequency of selection: N/A

Reference equations: DES-2, DES-3, DES-11, DES-12, DES-14

Equation symbol: B_{min}

Definition: The minimum annual above-ground biomass in the HEDR study region.

Units: kg(dry)/m^2

Value(s):

Vegetation Type	Central Value
Leafy vegetables	0.01
Other vegetables	0.01
Tree fruit	0.27
Grain	0.01
Pasture	0.04
Grass hay	0.03
Alfalfa	0.01
Silage	0.01
Sagebrush	0.01

Distribution: none

Technical basis: The B_{min} parameter is a new parameter that was developed after the preliminary Phase I HEDR code was completed. The previous work determined a discrete monthly biomass value, the product of Y, f_s, and f_d, as reported in Shindle et al. (1992). DESCARTES estimates the fraction of above-ground biomass by the use of a cosine function (see Equations DES-1, DES-2, and DES-3).

The minimum biomass values represent the living or dormant portion of the crop that exists over the year, i.e., mid-winter biomass. Most of the vegetation types do not grow year-round. A B_{min} value of zero was desired for leafy vegetables, other vegetables, alfalfa, and silage. However, the B_{min} value is used for the initial biomass value, B. Use of zero for the biomass calculations causes the cosine function never to be realized; the dB/dt functions of Equations DES-1 and DES-2 would never be non-zero. Therefore, a non-zero number sufficiently close to zero, 0.01, was chosen for annual crops.

Pasture biomass was taken from research conducted in the Hanford region (Rickard et al. 1975). The winter pasture biomass values listed in Rickard et al. range from 0.03 to 0.09. Lawn grass biomass was assumed to be equivalent to the pasture value.

The discrete values chosen for the annual crops (leafy vegetables, alfalfa, and silage) provided the grounds for the use of discrete values for the other vegetation types.

References:

Rickard, W. H., D. W. Uresk, and J. F. Cline. 1975. "Impact of Cattle Grazing on Three Perennial Grasses in South-Central Washington." Journal of Range Management 28(2):108-112.

Shindle, S. F., T. A. Ikenberry, and B. A. Napier. 1992. Parameters Used in the Environmental Pathways and Radiological Dose Modules of the Phase I Air Pathway Code. PNL-8093 HEDR, Pacific Northwest Laboratory, Richland, Washington.

Parameter: Age-dependent breathing rate **Reference equation:** CID-3

Dependencies: age **Equation symbol:** BR

Frequency of selection: daily

Definition: The age-dependent volume of air an individual breathes in a day.

Units: m^3/d

Value(s):

Age	Central Value	Minimum	Maximum
3 mo	1.62	0.5	4.9
1 yr	5.14	1.7	15.4
5 yr	8.71	2.9	26.1
10 yr	15.3	5.1	45.9
15 yr	17.7	5.9	53.9
Adult	22.0	7.3	66.0

Distribution: triangular

Technical basis: Inhalation of airborne activity is a pathway by which radioactive materials enter the body. Breathing-rate values are required to estimate the activity inhaled by an individual. Inhalation rates vary according to the activity level of an individual (e.g., sleeping, walking, running). The most commonly used values for inhalation rates are based on information in Reference Man (ICRP 1981). However, Reference Man values indicate only adult rates.

The adult central value listed above assumes 16 h of light activity and 8 h of resting. The U.S. Environmental Protection Agency (EPA) (1991) recommends an adult value similar to that listed above. EPA (1991) states that an inhalation rate of 20 m^3/d represents a reasonable upper bound for the segment of the population that spends a majority of their time at home (e.g., housewives, service and household workers, retired people). A breathing rate of 30 m^3/d was recommended by EPA (1989) for use as a reasonable upper bound breathing-rate value for the entire adult population.

The central value of the nonadult age groups, listed above, were taken from recent work by Roy and Courtay (1991). Roy and Courtay investigated age-dependent breathing parameters specifically for use in radiation dosimetry. Their values were designed to reflect realistic activity levels of different age groups.

Further evaluation of age-dependent breathing rates extensively used Table 4.5 of Anderson et al. (1985). This additional evaluation was performed to determine the distribution for the breathing-rate values. Table 4.5 of Anderson et al. (1985) listed a summary of age-dependent minute-ventilation rates from the literature for various activity levels (rest, light activity, and moderate activity). Minute-ventilation rate is defined as the average volume of air inspired by an individual in one minute. The data were translated into central, minimum, and maximum values of daily breathing rates by converting units of l/min to m^3/d. Central values were determined by assuming 8 h of rest, 8 h of light activity, and 8 h of moderate activity. Minimum values assumed 8 h of rest and 16 h of light activity. Maximum values assumed 8 h of rest and 16 h of moderate activity. Results, in m^3/d, are listed below.

Age Group	Central Value	Minimum Value	Maximum Value
Infant	1.2	0.4	3.0
6 yr	25.8	16.5	35.1
10 yr	37.3	19.9	54.6
13 yr	27.1	20.1	34.1
Adult-F	19.3	10.5	28.2
Adult-M	32.1	19.1	45.1

The central values listed in the above table approximate the Roy and Courtay values for infants and adults. The central values derived from the data of Anderson et al. (1985) for all other age groups are greater than the Roy and Courtay (1991) values. The use of the Roy and Courtay values is more sound as a result of their greater consideration of realistic activity levels.

A triangular distribution was assumed to reflect the Anderson values listed above. This distribution was bounded at 3 times and 0.3 times the central values for the maximum and minimum values, respectively. The factor of three difference was derived from the estimated differences in the minima and maxima of the data evaluation by Anderson et al. (1985).

References:

Anderson, A., N. Browne, S. Duletsky, J. Ramig, and T. Warn. 1985. Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments. EPA No. 600/8-85-010, U.S. Environmental Protection Agency, Office of Health and Environmental Assessment, Washington, D.C.

International Commission on Radiological Protection (ICRP). 1981. Report of the Task Group on Reference Man. Publication No. 23, Pergamon Press, New York.

Roy, M., and C. Courtay. 1991. "Daily Activities and Breathing Parameters for Use in Respiratory Tract Dosimetry." Radiation Protection Dosimetry 35(3):179-186.

U.S. Environmental Protection Agency (EPA). 1989. Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual. EPA/540/1-89/002, Office of Emergency and Remedial Response, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1991. Risk Assessment Guidance For Superfund, Volume I: Human Health Evaluation Manual, Supplemental Guidance, "Standard Default Exposure Factors, Interim Final." OSWER Directive 9285.6-03, Washington, D.C.

Parameter: Plant-to-soil concentration ratio

Reference equations: DES-13, DES-14

Dependencies: radionuclide

Equation symbol: CR

Frequency of selection: realization

Definition: The ratio of the radionuclide concentration in a unit mass of vegetation to the radionuclide concentration in a unit mass of growth medium.

Units: $Ci/kg_{vegetation}$(dry) per Ci/kg_{soil}(wet)

Value(s): lower: 0.01
upper: 0.25

Distribution: loguniform

Technical basis: Nutrients enter plants by two routes: roots and leaves. The concentration ratio (CR) value is intended to provide an estimate of the root intake of a radionuclide. As a result of its experimental derivation, however, it unavoidably includes contributions from rainsplash, as well as translocation and removal by weathering and mechanical action. Carbon, hydrogen, and oxygen are the only elements that are predominantly taken in through the leaves and distributed to other plant parts (Bowling 1976). All other essential elements are chiefly taken in through plant roots. Iodine is not known to be an essential plant nutrient and is not considered to be concentrated in plants by soil uptake (Menzel 1965).

Iodine-131 taken up by the roots enters the internal circulatory system of crops. The significant iodine-131 contribution resulting from foliar uptake is not known to significantly translocate from the site of deposition (see f_{trans}). Therefore, root uptake is most important for root crops and for crops with both inner and outer vegetative compartments. The iodine-131 potentially available for root uptake and distribution through the internal plant tissues is found attached to soil particles and in the soil solution.

The CR is commonly used when modeling the uptake of a radionuclide from the soil when the soil-root-vegetation uptake is at equilibrium. It is a relatively simple measurement to make experimentally, although the methodology has not been standardized. Methods used to determine the ratio of the radionuclide concentration of vegetation to that of soil include the following:

- CR measurements based on the activity in a unit mass of plant and the initial activity uniformly amended into the soil at the beginning of the experiment

- CR measurements based on the activity in a unit mass of plant and the activity input into the hydroponic system into which the plant was grown

- CR measurements based on the activity in a unit mass of plant and the average activity over the rooting zone for radionuclides deposited on the soil's surface

- CR measurements evaluated by one of the methods above, but plant radionuclide concentration may also include aerial deposition (e.g., dry deposition, rainsplash) on the above-ground portion of the plant.

The measurements made using the above methodologies produce CR values that range over two orders of magnitude (Ng et al. 1982). Caution should be used in the evaluation of these values, however, because increased uptake is to be expected from nutrient-solution experiments when compared with pot experiments, and increased uptake is often observed in pot tests in comparison with field tests (Rouston 1973).

A majority of CR experiments uniformly amend the growth medium when determining the CR value. This is dissimilar from the situation considered by the HEDR Project. The HEDR Project considers the situation in which the incoming radionuclides deposit on the soil surface and reach the rooting zone through transport after deposition.

The relatively short half-life of iodine-131 has a bearing on CR values derived from soil-surface depositions because the iodine-131 must survive long enough both to reach the rooting zone and to be taken up by the rooting system. The residence time of iodine in the top 5 cm of soil is reported to be approximately 2.4 yr (Boone et al. 1985). In addition, the apparent decay half-life of fallout iodine-131 on the soil surface has been reported as 8 days (Barth and Veater 1964), equivalent to the radiological half-life of the nuclide. As a result of these considerations, some consider root uptake from the soil to be an insignificant pathway of entry into the food chain (Russel 1966). To provide a comprehensive model, however, and to err on the side of conservatism, the consideration of root uptake is included in the HEDR code.

Experimental CR values summarized in the literature range as follows:

Values	Reference
0.01 to 0.08	Coughtrey et al. (1983)
0.003 to 1.25	Ng et al. (1982)
0.01 to 1.5	Klepper (1976)

One experiment evaluated the distribution of the iodine taken in by root uptake for bean plants grown in an iodine-131-amended hydroponic solution. In this experiment, McFarlane and Mason (1970) indicated that 96.5% of the uptake was found in the roots; 2.1% was found in the stem; 1.1% was found in the leaves; and 0.2% was found in the fruit. This experiment provides evidence that iodine is rather strongly sorbed to the plant at the point of uptake.

Default CR values used in other models included are listed in the table below.

Leafy Vegetables	Fruit	Pasture	Other crops	Reference
1.9E-2		1.0E-1	3.6E-1 cereals 5.3E-3 root crops	Grogan (1985)
3.4E-3				IUR (1989)
			2.0E-2 all	NRC (1977)
3.4E-3			5.0E-2 all	Baes et al. (1984)
8.0E-2	4.0E-2	8.0E-2	9.8E-2 potatoes 2.4E-1 grain 7.7E-2 root crops	Ashton and Sumerling (1988)
			0.02 all crops	Zach (1980)

The values listed in Coughtrey (1983) were used as the primary basis for the range of values chosen. The logarithmic scale of the uniform probability distribution was chosen to emphasize the greater frequency of values found in the lower end of the chosen range, which are summarized in Ng (1982).

References:

Ashton, J., and T. J. Sumerling. 1988. Biosphere Database for Assessments of Radioactive Waste Disposals (Edition 1). DOE/RW/88.083, ANS Report No. 595-13, Associated Nuclear Services, Epsom, U.K. for the U.K. Department of the Environment.

Baes, III, C. F., R. D. Sharp, A. L. Sjoreen, and O. W. Hermann. 1984. TERRA: A Computer Code for Simulating the Transport of Environmentally Released Radionuclides through Agriculture. ORNL-5785, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Barth, D. S., and J. G. Veater. 1964. Dairy Farm Radioiodine Study Following the Pike Event. TID-21764, Public Health Service, Southwestern Radiological Health Laboratory, Las Vegas, Nevada.

Boone, F. W., M. V. Kantelo, P. G. Mayer, and J. M. Palms. 1985. "Residence Half-Times of Iodine-129 in Undisturbed Soils Based on Measured Soil Concentration Profiles." Health Physics 48:401-413.

Bowling, D. J. F. 1976. Uptake of Ions by Plant Roots. John Wiley and Sons, New York.

Coughtrey, P. J., D. Jackson, and M. C. Thorne. 1983. Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems, A Critical Review. Vol. 3:322-372, A.A. Balkema, Rotterdam.

Grogan, H. A. 1985. Concentration Ratios for BIOPATH: Selection of the Soil-to-Plant Concentration Ratio Database. EIR-Bericht Nr. 575, Swiss Federal Institute for Reactor Research, Wurenlingen, Switzerland.

International Union of Radioecologists (IUR). 1989. "VIth Report of the Working Group Soil-to-Plant Transfer Factors." Report of the Working Group meeting in Guttannen, May 24-26, 1989, Grimselpass, Switzerland.

Klepper, B. 1976. Radioiodine Uptake by Wheat Plants with Time After Amendment to Soil. BNWL-SA-5682, Battelle, Pacific Northwest Laboratories, Richland, Washington.

McFarlane, J. C., and B. J. Mason. 1970. Plant Radioiodine Relationships, A Review. SWRHL-90r, Southwest Radiological Health Laboratory, Las Vegas, Nevada.

Menzel, R. G. 1965. "Soil-Plant Relationships of Radioactive Elements." Health Physics 11:1325-1332.

Ng, Y., C. Colsher, and S. Thompson. 1982. Soil-to-Plant Concentration Factors for Radiological Assessments. NUREG/CR-2975, U.S. Nuclear Regulatory Commission, Washington, D.C.

Rouston, R. C. 1973. A Review of Studies on Soil-Waste Relationships on the Hanford Reservation from 1944 to 1947. BNWL-1464, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Russel, R. S., ed. 1966. Radioactivity and Human Diet. Pergamon Press, New York.

U.S. Nuclear Regulatory Commission (NRC). 1977. Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I. Regulatory Guide 1.109, Revision 1, Washington, D.C.

Zach, R. 1980. Sensitivity Analysis of the Terrestrial Food Chain Model FOOD III. AECL-6794, Atomic Energy of Canada Limited, Whiteshell Nuclear Research Establishment, Manitoba, Canada.

Parameter: Immersion dose rate factor **Reference equation:** CID-1

Dependencies: radionuclide **Equation symbol:** DF_{imm}

Frequency of selection: realization

Definition: The external dose to the thyroid resulting from exposure to airborne activity.

Units: $rad_{thyroid}$/d per Ci/m^3

Value(s): minimum: 5.7E+3
maximum: 3.6E+4

Distribution: uniform

Technical basis: When an individual stands in air dispersed with radionuclides, he or she is exposed to the decay energy of those radionuclides. If iodine-131 is the radionuclide of concern, the individual will receive a dose from its decay. A semi-infinite plume is assumed to account for modifications that must be made in the conversion factor calculation as a result of the fact that an individual stands on a solid surface and, therefore, is not uniformly surrounded by the plume. This external dose conversion factor is distinct from the internal dose conversion factors (ingestion and inhalation conversion factors) because the iodine does not cycle through the individual's metabolism. Other external dose conversion factors consider the external dose from radionuclide deposition on surfaces and in the soil profile, DF_{usl} and DF_{rz}, respectively.

The immersion dose conversion factor used to calculate thyroid dose from immersion in a plume of iodine-131 that is used at U.S. Department of Energy facilities is 5.68E3 rad/d per Ci/m^3 (DOE 1988). This number estimates the thyroid dose resulting from exposure to outdoor air 100% of the time.

Kocher (1983) provides thyroid dose conversion factors for air immersion for iodine-131. The air immersion dose resulting from exposure to the

0.36 MeV photon of iodine-131 is interpolated from the values in Kocher (1983), Table 2 as 3.56E-1 Sv/yr per Bq/cm^3 (3.6E4 rem/d per Ci/m^3).

Since both the DOE and Kocher methodologies are believed to provide reasonable estimates, both values will be used. Because little information is known about the distribution of this parameter, a uniformly distributed range of values was chosen.

References:

Kocher, D. C. 1983. "Dose-Rate Conversion Factors for External Exposure to Photons and Electrons." Health Physics 45:665-686.

U.S. Department of Energy (DOE). 1988. External Dose-Rate Conversion Factors for Calculation of Dose to the Public. DOE/EH-0070, Washington, D.C.

Parameter: Ingestion dose conversion factor

Reference equations: CID-4, CID-5

Dependencies: age, sex, radionuclide

Equation symbol: DF_{ing}

Frequency of selection: realization

Definition: The age- and sex-dependent thyroid dose per unit intake via ingestion.

Units: $rad_{thyroid}/Ci_{ingested}$

Value(s):

Age	Central Value	Minimum	Maximum
3 mo	1.4E+7	1.6E+6	1.2E+8
1 yr	1.3E+7	1.5E+6	1.1E+8
5 yr	7.8E+6	9.2E+5	6.6E+7
10 yr	4.1E+6	4.8E+5	3.5E+7
15 yr	2.5E+6	2.9E+5	2.1E+7
Adult-male	1.4E+6	1.6E+5	1.2E+7
-female	1.7E+6	2.0E+5	1.4E+7

Distribution: lognormal

Technical basis: The iodine-131 in the foodstuffs being evaluated by the HEDR Project follow the same metabolic path as ingested stable iodine. The iodine is virtually completely absorbed from the gastrointestinal tract into the blood stream, regardless of its chemical form (Linder 1985). The iodine circulating in the blood may be extracted by the thyroid. The plasma iodine may concentrate 20- to 50-fold in the thyroid (Ingbar and Braverman 1986). The thyroidal iodine is used to create hormones important to metabolic regulation. Iodine is accumulated in the thyroid until a signal is sent from the brain to release more iodinated hormones into the blood stream.

The dose conversion factor is calculated by dosimetrists with consideration for the thyroid mass, the fraction of the circulating iodine removed from the bloodstream (which is dependent on the total amount circulating), and the halftime over which the iodine is stored in the thyroid (Dunning and Schwarz 1981). These factors can vary among individuals and among individuals of different ages.

The ICRP (1990) recently published age-dependent dose factors for the ingestion of iodine-131. These factors represent the internationally accepted age-dependent values and will be used in the HEDR model. Sex differences in the metabolism of iodine, primarily after puberty, are known to occur in humans. Therefore, it was desirable for the ingestion-dose conversion factor to reflect the sex difference in the adult values. Sex-specific ingestion-dose conversion factors were published in Johnson (1982).

An evaluation of the distribution of the ingestion dose conversion factors was performed by Dunning and Schwarz (1981). Their research indicated a lognormal distribution for this parameter. A geometric standard deviation of 2.0 was assumed from the data presented in Dunning and Schwarz (1981). Minimum and maximum values were calculated as the 0.1 and 99.9th percentile values, respectively.

References:

Dunning, D. E., and G. Schwarz. 1981. "Variability of Human Thyroid Characteristics and Estimates of Dose from Ingested Iodine-131." Health Physics 40:661-675.

Ingbar, S., and L. Braverman. 1986. Werner's, The Thyroid, A Fundamental and Clinical Text, Chapter 3. Fifth edition, Lippincott, Philadelphia.

International Commission on Radiological Protection (ICRP). 1990. Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 1. Publication 56, Pergamon Press, New York.

Johnson, J. R. 1982. "Fetal Thyroid Dose from Intakes of Radioiodine by the Mother." Health Physics 43:573-582.

Linder, M. 1985. Nutritional Biochemistry and Metabolism. Elsevier, New York.

Parameter: Inhalation dose conversion factor **Reference equation:** CID-3

Dependencies: age, sex, radionuclide **Equation symbol:** DF_{inh}

Frequency of selection: realization

Definition: The age- and sex-dependent thyroid dose per unit intake via inhalation.

Units: $rad_{thyroid}/Ci_{inhaled}$

Value(s):

Age	Central Value	Minimum	Maximum
3 mo	1.1E+7	1.3E+6	9.4E+7
1 yr	8.1E+6	9.5E+5	6.9E+7
5 yr	4.8E+6	5.6E+5	4.1E+7
10 yr	2.7E+6	3.2E+5	2.3E+7
15 yr	1.3E+6	1.5E+5	1.1E+7
Adult-male	1.0E+6	1.2E+5	8.5E+6
-female	1.2E+6	1.4E+5	1.0E+7

Distribution: Lognormal

Technical basis: Radiation doses may result from the uptake of the inhaled radionuclide. Inhalation dosimetry is complicated somewhat because the amount inhaled is not the same as the amount absorbed into an individual's system. Some of the activity inhaled will be exhaled and will not contribute to an internal radiation dose.

Iodine-131 inhalation intakes that deposit in the respiratory tract are believed to be cleared from the lung relatively rapidly, although experimental data are limited (Stather and Greenhalgh 1983). Lung clearance occurs by absorption into the bloodstream. Once in the bloodstream, the iodine will follow the same metabolic route as the ingested iodine that was absorbed into the bloodstream (see DF_{ing}).

The National Radiation Protection Board (NRPB) of the United Kingdom has calculated age-dependent inhalation doses for iodine-131 (Phipps et al. 1991) in accordance with the dosimetric methodology of ICRP 56 (ICRP 1990). Dose factors, based on the inhalation of 1 micrometer activity median aerodynamic diameter (AMAD) particles, were reported. These values will be used in the CIDER calculations. Sex-dependent dose conversion factor (DCF) values for adults are indicated in the literature for ingestion but not inhalation. Therefore, sex differences were determined by calculating the ratio of male to female ingestion DCF and applying that same ratio to the inhalation DCF. The literature value of DCF was assumed to represent the male.

Others (Killough et al. 1978) previously published similar values for adult thyroid inhalation dose, 1.13E6 rad/Ci.

The indicated distribution, lognormal, was chosen in accordance with the distribution of the ingestion-dose conversion factor. Dunning and Schwarz (1981) presented evidence of a lognormal distribution for iodine-131 ingestion dose factors. The only difference in the calculation of inhalation- and ingestion-dose factors is the additional consideration of the exhalation of a portion of the intake. This difference is assumed to be constant within each age category; therefore, the lognormal distribution of the ingestion dose conversion factor will be the same as the inhalation-dose conversion factor.

A geometric standard deviation of 2.0 was assumed from the data presented by Dunning and Schwarz (1981). Minimum and maximum values were calculated as the 0.1 and 99.9th percentile values, respectively.

References:

Dunning, D. E., and G. Schwarz. 1981. "Variability of Human Thyroid Characteristics and Estimates of Dose from Ingested Iodine-131." Health Physics 40:661-675.

International Commission on Radiological Protection (ICRP). 1990. Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 1. Publication 56, Pergamon Press, New York.

Killough, G. G., D. E. Dunning, S. R. Bernard, and J. C. Pleasant. 1978. Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel-Cycle Facilities. Volume 1, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Phipps, A. W., G. M. Kendall, J. W. Stather, and T. P. Fell. 1991. Committed Equivalent Doses and Committed Effective Doses from Intakes of Radionuclides. NRPB-R245, National Radiological Protection Board, Chilton, Didcot, Oxon, United Kingdom.

Stather, J. W., and J. R. Greenhalgh. 1983. The Metabolism of Iodine in Children and Adults. NRPB-R140, National Radiological Protection Board, Chilton, Didcot, Oxon, United Kingdom.

Parameter: Soil activity dose conversion factor

Reference equation: CID-2

Equation symbol: DF_{rz}

Dependencies: radionuclide

Frequency of selection: realization

Definition: The external dose to the thyroid resulting from radionuclides in the soil root zone.

Units: rem/d per Ci/m^2

Value(s): minimum: 49
maximum: 88

Distribution: uniform

Technical basis: The external dose an individual receives from an airborne release includes the dose from immersion in the semi-infinite plume (see DF_{imm}), surface deposition (see DF_{usl}), and radionuclides in the soil root zone (DF_{rz}). The 0.36 MeV iodine-131 photon is assumed to provide the great majority of the dose. The dose contribution from the 0.6 MeV beta of iodine-131 is neglected.

The external dose resulting from the accumulation of radionuclides in the soil root zone differs from that of radionuclides in the upper soil layer because some shielding of the emitted radiation by the soil will occur. Kocher (1985) reported on the external dose rates resulting from incorporation of photon-emitting radionuclides into the soil to various depths. To estimate minimum and maximum DF_{rz} values, the soil radionuclide was assumed to be exponentially distributed throughout the root zone for the minimum value and throughout the top 5 cm of the root zone for the maximum value.

Although these values are technically air-dose calculations, the maximum value listed above is expected to be lower than the DESCARTES organ-specific DF_{usl} values (see DF_{usl}) because of the soil shielding consideration for radionuclides incorporated into the root zone. In fact, the independently calculated DF_{usl} values are higher than the DF_{rz} values and, therefore, will be considered reasonable estimates of thyroid dose.

References:

Kocher, D. C. 1985. "Dose-Rate Conversion Factors for External Exposure to Photons Emitters in Soil." Health Physics 48:193-205.

Parameter: Plane deposition dose factor

Reference equations: CID-2

Dependencies: radionuclide

Equation symbol: DF_{usl}

Vary: realization

Definition: The external dose to the thyroid resulting from ground surface (upper soil layer) activity.

Units: rem/d per Ci/m^2

Value(s): minimum: 84
maximum: 120

Distribution: uniform

Technical basis: The external dose an individual receives from the airborne release includes the dose from immersion in the semi-infinite plume (see DF_{imm}), soil deposition (see DF_{rz}), and deposition on the ground surface (DF_{usl}).

A U.S. Department of Energy reference document (DOE 1988) indicates a thyroid dose conversion factor of 1.2E2 rem/d per Ci/m^2 for iodine-131. This dose factor represents the dose to the thyroid for exposure 1 m above the ground surface when the area is uniformly contaminated in an infinite plane. The minimum value was derived by assuming a 30% loss of dose due to surface irregularities (DOE 1988).

Kocher (1983) provided effective dose-rate conversion factors for ground surface deposition. The Kocher value for iodine-131 is 1.11E-4 Sv/yr per Bq/cm^2 (1.12E2 rem/d per Ci/m^2), which agrees well with the DOE 1988 value.

References:

Kocher, D. C. 1983. "Dose-Rate Conversion Factors for External Exposure to Photons and Electrons." Health Physics, Vol 45, pp. 665-686.

U.S. Department of Energy (DOE). 1988. External Dose-Rate Conversion Factors for Calculation of Dose to the Public. DOE/EH-0070, U.S. Department of Energy, Office of Environmental Guidance and Compliance, Washington, D.C.

Parameter: Dry-weight to wet-weight conversion factor

Reference equations: CID-4, CID-5

Dependencies: vegetation type

Equation symbol: f_d

Frequency of selection: realization

Definition: The ratio of masses of a dehydrated vegetation sample and its fresh mass.

Units: none

Value(s):

Vegetation Type	Minimum	Maximum
Leafy vegetables	0.05	0.09
Other vegetables	0.04	0.26
Tree fruit	0.13	0.35
Grain	0.85	1.00

Distribution: uniform

Technical basis: The quantity of human food crops consumed must be converted from wet mass to dry mass. The dry-weight to wet-weight conversion factor converts wet weights to dry weights.

A number of sources were consulted for these values. Ensminger et al. (1990) provided the most comprehensive list and is heavily referenced below.

Apple	0.18	Ensminger et al. (1990)
Pear	0.17	"
Asparagus	0.08	"
Bean, kidney	0.89	"
pinto	0.90	"
Brussel sprouts	0.15	"
Carrot	0.16	"
Cauliflower	0.09	"
Red beet	0.13	"
Sugar beet	0.17	"
Broccoli	0.11	"
Carrot	0.11	"
Parsnip	0.17	"
Garden peas	0.89	"
Pea pods, fresh	0.13	"
Grapes	0.87	"
Tomato	0.06	"
Turnip	0.09	"
Cabbage	0.09	"

Lettuce	0.05	Ensminger et al. (1990)
Spinach	0.09	"
Barley, grain	0.89	"
Corn, grain		
(grade 5 - 46#/bu)	0.86	"
sweet	0.91	"
Rye, grain	0.87	"
Wheat, grain	0.88	"
Wheat, immature, fresh	0.22	"
Alfalfa, fresh	0.24	"
Alfalfa silage ,wilted	0.41	"
Alfalfa silage, > 50% dry matter	0.57	"
Alfalfa, sun-cured	0.91	"
Alfalfa-orchard grass, fresh	0.25	"
Alfalfa-orchard grass silage, 30-50% dry matter	0.37	"
Alfalfa-orchard grass, sun-cured	0.89	"
Bermuda-grass, fresh	0.29	"
Bermuda-grass, sun-cured	0.92	"
Cheatgrass, fresh	0.55	"
Crabgrass, fresh	0.30	"
Crabgrass, sun-cured	0.90	"
Dandelion, fresh	0.14	"
Meadow fescue, fresh	0.28	"
Meadow fescue, sun-cured	0.88	"
Grass-hay, all analyses, sun-cured	0.89	"
Orchard grass, sun-cured	0.93	"
Rye-grass, fresh	0.24	"
Wheat hay, sun-cured	0.89	"
Oat straw	0.92	
Rye straw	0.91	"
Russian thistle, fresh	0.30	"
Russian thistle hay, sun-cured	0.86	"
Rabbitbrush, browse	0.38	"
Small rabbitbrush, fresh browse	0.40	"
Big sagebrush, browse	0.65	"
Bud sagebrush, browse	0.27	"
Corn fodder w/ears, sun-cured(mature)	0.90(0.82)	"
Corn silage, mature	0.30	"
Corn silage, >50% dry matter	0.54	"
Apples	0.16	USDA (1982)
Apricots	0.14	"
Cherries	0.19	"
Peaches	0.12	"
Pears	0.16	"
Plums	0.15	"
Strawberries	0.08	"
Watermelon	0.08	"

Raspberries	0.13	USDA (1982)
Blackberries	0.14	"
Strawberries	0.08	"
Pasture	0.35	Hawley et al. (1964)
Barley	0.90	USDA (1939)
Navy beans	0.86	"
Corn	0.88	"
Field peas	0.91	"
Garden peas	0.88	"
Oats	0.90	"
Rye	0.89	"
Wheat	0.89	"
Alfalfa, fresh	0.26	"
Cabbage	0.09	"
Carrot	0.12	"
Potatoes	0.21	"
Rutabagas	0.11	"
Turnips	0.09	"
Apple	0.159	Baes et al. (1984)
Cherry	0.170	"
Peach	0.131	"
Pear	0.173	"
Asparagus	0.070	"
Cucumber	0.039	"
Carrot	0.118	"
Tomato	0.059	"
Bean (dry)	0.878	"
Onion	0.125	"
Peas	0.257	"
Sweet corn	0.261	"
Barley	0.889	"
Corn (for meal)	0.895	"
Wheat	0.875	"

Default values used in other codes included the following:

Dry weight: wet weight		Reference
Leafy vegetables:	0.067	Baes et al. (1984)
Other vegetables:	0.126	"
	0.222	"
Grain:	0.888	"
Green vegetables:	0.10	Grogan (1985)
Root vegetables:	0.15	"
Cereals:	0.89	"
Pasture:	0.25	"

References:

Baes, III, C. F., R. D. Sharp, A. L. Sjoreen, and R. W. Shor. 1984. A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture. ORNL-5786, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Ensminger, M. E., J. E. Oldfield, and W. W. Heinemann. 1990. Feeds and Nutrition, Second edition. Ensminger Publishing Company, Clovis, California.

Grogan, H. A. 1985. Concentration Ratios for BIOPATH: Selection of the Soil-to-Plant Concentration Ratio Database. EIR-Bericht Nr. 575, Swiss Federal Institute for Reactor Research, Wurenlingen, Switzerland.

Hawley, C. A., C. W. Sill, G. L. Voelz, and N. F. Islitzer. 1964. Controlled Environmental Radioiodine Tests, National Reactor Testing Station. IDO-12035, Idaho Operations Office, Office of Technical Services, U.S. Department of Commerce, Washington, D.C.

U.S. Department of Agriculture (USDA). 1982. Composition of Foods, Fruits, and Fruit Juices. Handbook No. 8-9, Human Nutrition Information Service, U.S. Government Printing Center, Washington, D.C.

U.S. Department of Agriculture (USDA). 1939. Food and Life, Yearbook of Agriculture, 1939. House Document No. 28, Washington, D.C.

Parameter: Chicken soil-ingestion rate **Reference equation:** DES-17

Dependencies: none **Equation symbol:** FS_a

Frequency of selection: realization

Definition: The amount of soil that is ingested by a chicken.

Units: kg(wet)/d

Value(s): minimum: 0.006
maximum: 0.012

Distribution: uniform

Technical basis: It will be conservatively (i.e., worst-case) assumed that all chickens in the HEDR study region are free-ranging. These chickens are assumed to be provided with mash and forage *ad libitum* in the open range. The most non-conservative situation, not considered in DESCARTES, would be cooped chickens fed stored mash and grain mixtures.

Poultry do not have teeth to grind their food. The gizzard, a muscular, thick-walled part of the chicken's digestive system, grinds food into a pulp. Poultry consume grit, coarse materials such as small stones, to aid the digestion of food in the gizzard (Ensminger et al. 1990). Grit is not absolutely essential if the animal feed is ground fine enough (Ensminger et al. 1990).

Free-ranging chickens consume soil and small stones as grit during feeding on forage and ground-scattered feed. Little research has been done to quantify the amount of stones and soil consumed by free-ranging poultry. The grit consumed by chickens is modeled in DESCARTES as ingestion of soil in the upper soil layer.

Oyster and clam shells or limestone can be added to mash mixtures as an alternative source of grit, as well as a source of calcium, for cooped poultry (Ensminger et al. 1990). However, the exclusive use of these calcium sources for grit introduces the danger of excess calcium intakes (USDA 1939). Therefore, DESCARTES assumes the minimum amount of soil consumed by free-ranging chickens to be equivalent to the amount of grit used in commercially available mash mixtures.

The following lists the amount of ground limestone or oystershell or granite grit added to mash mixtures. The values vary according to the type of poultry raised: egg-laying, broiler, breeding, or growth stock. Values indicate the percentage (assumed by weight) of the mash mixture that is comprised of the indicated grit.

Type of grit	Feed fraction (%)	Reference
Granite grit	0.12 to 1.0	Winter and Funk (1951)
Ground limestone	1.0 to 3.5	Wilhelm and Carrick (1943)
Ground limestone or oyster-shell	1.0 to 6.8	USDA (1939)

One environmental accumulation model, ECOS, considers soil ingestion by poultry (Thorne 1984). Thorne indicated an absence of soil-ingestion data for poultry, but assumed soil ingestion to be 10% of the dry feed intake.

The lower range of grit intake is obtained by multiplying the minimum poultry feed intake value ($R_{v\_chicken}$), 0.05 kg/d, the feed intake of poultry, by the lowest fractional value listed above, 0.12. The resulting assumed minimum soil-ingestion rate is 0.006 kg/d.

The maximum amount of grit consumed by poultry can be obtained by a similar method. If the maximum feed intake value ($R_{v\_chicken}$), 0.12 kg/d, is multiplied by the maximum fractional value listed in the table above, 6.8, the resulting maximum soil ingestion rate would be assumed to be 0.008 kg/d. The more conservative ECOS model value generates an assumed soil ingestion rate of 0.012 kg/d. Because of the absence of data, DESCARTES uses the conservative soil-ingestion rate of the ECOS model, i.e., 0.012 kg/d.

References:

Ensminger, M. E., J. E. Oldfield, and W. W. Heinemann. 1990. Feeds and Nutrition, Second edition, Ensminger Publishing Company, Clovis, California.

Thorne, M. C. 1984. "ECOS: Values of Parameters to be used for Domestic Animals." ANS Report No. 372, Associated Nuclear Services, Inc., Epsom, Surrey, United Kingdom.

U.S. Department of Agriculture (USDA). 1939. Food and Life, Yearbook of Agriculture, 1939. House Document 28, Washington, D.C.

Wilhelm, L. A., and C. W. Carrick. 1943. "There is an Answer to Poultry Feed Shortages." The U.S. Egg and Poultry Magazine, May 1943, pp. 211-215.

Winter, A. R., and E. M. Funk. 1951. Poultry Science and Practice. Third edition. J.B. Lippincott Company, Chicago.

Parameter: Cow (cattle) soil-ingestion rate **Reference equation:** DES-17

Dependencies: time on pasture **Symbol:** FS_a

Frequency of selection: realization

Definition: The amount of soil that is ingested by a cow or steer under various conditions.

Units: kg(wet)/d

Value(s):

Fraction of time on pasture	Central value	Minimum	Maximum
1.0	0.5	0.25	1.0
0.5	1.0	0.50	1.5
0.0	2.0	1.0	4.0

Distribution: triangular

Technical basis: Beef and dairy cattle are expected to ingest a quantity of soil during their grazing activities. Ingestion of the radionuclide-amended soil in the HEDR study region provides an additional source of radionuclide intake to the cattle. Soil ingested by the cattle is assumed to be restricted to the upper soil layer specified in DESCARTES.

Previous HEDR research investigated the soil-ingestion rates of dairy cattle (Darwin 1990). The methods by which soil-ingestion values were derived are summarized in the following paragraph. Readers can refer to Darwin (1990) for complete details.

The estimated levels of soil ingestion were linked to the four feeding regimes in a straightforward manner. Levels of soil ingestion by cattle on feeding regimes containing pasture follow the changes in pasture quantities that occur during the year. Levels of soil ingestion by cattle on the hay- and grain-feeding regimes were governed by estimates for cattle not on pasture.

References:

Darwin, R. 1990. Soil Ingestion By Dairy Cattle. PNL-SA-17918 HEDR. Presented at the HEDR Technical Steering Panel Meeting, Richland, Washington, February 15-16, 1990.

Parameter: Fraction of day spent outdoors

Reference equation: CID-1, CID-2, CID-3

Dependencies: age, lifestyle, sex, season

Frequency of selection: realization

Equation symbol: f_{time}

Definition: The fraction of the day an individual is outdoors.

Units: none

Value(s):

3 mo to 2 yr old:

Both sexes and lifestyles

	Minimum	Central	Maximum
Winter	0.0	0.0	0.13
Spring	0.0	0.04	0.17
Summer	0.0	0.13	0.29
Fall	0.0	0.04	0.17

2 to 17 yr old:

	Minimum	Central		Maximum
	M & F	M	F	M & F
Urban Winter	0.04	0.1	0.05	0.13
Spring	0.04	0.13	0.08	0.17
Summer	0.08	0.35	0.22	0.38
Fall	0.04	0.13	0.08	0.17
Rural Winter	0.04	0.13	0.08	0.17
Spring	0.04	0.21	0.17	0.23
Summer	0.13	0.34	0.32	0.50
Fall	0.04	0.21	0.08	0.23

Greater than 17 yr old:

	Minimum	Central		Maximum
	M & F	M	F	M & F
Urban Winter	0.0	0.05	0.07	0.17
Spring	0.0	0.18	0.29	0.31
Summer	0.04	0.22	0.29	0.41
Fall	0.0	0.10	0.15	0.31
Rural Winter	0.04	0.33	0.21	0.37
Spring	0.04	0.44	0.36	0.50
Summer	0.06	0.47	0.29	0.50
Fall	0.04	0.34	0.21	0.37

Distribution: triangular

Technical basis: Little literature exists on the amount of time an individual in the 1940s spent outdoors. Subjective estimates of time were made using assumptions listed below. Time spent outdoors is required for both the external-exposure and the inhalation-dose calculations. Because of the shielding effects of buildings, external exposure is reduced when an individual is indoors. Inhalation exposure is reduced for an indoor individual as a result of the lack of free exchange of indoor and outdoor air.

Sex, age, and lifestyle are indicators of the amount of time spent outdoors. All categories of individuals were assumed to spend more time outdoors in the warmer months. In any given month, all categories were also assumed to spend a minimum of 10 hours of the day indoors for sleeping, minimal household maintenance, and personal hygiene activities.

School-age children were assumed to spend a greater majority of their time indoors during the school year. Historic sex roles have encouraged males to enter the work force and females to maintain the household and raise the children. Female adults were, thus, assumed to spend more of their time outdoors with their children and running household errands; male adults were assumed to be employed indoors. Rural lifestyles were assumed to involve farming families, who are required to spend more time outdoors as a consequence of their farming activities.

The U.S. Environmental Protection Agency (EPA) has published a reference source for use in exposure assessments (EPA 1989). The document references two authors who studied the time individuals spent in- and out-of-doors in the early 1970s. The surveyed individuals were estimates based on Washington, D.C., area residents and "worldwide" individuals. These authors indicated an overall annual average of 8% (0.08) of the adult's time was spent outdoors and in transit. This compares well with the urban adult values listed above.

Children's values for the school year are also listed in EPA (1989). The 1985 values listed in this document are listed as hours per week in various activities during the school year. If assumptions are made about whether an activity is done indoors or outdoors, boys 3 to 17 years old spend approximately 0.12 of their time outdoors and girls 3 to 17 years old spend approximately 0.09 of their time outdoors. These EPA values approximate the values listed above (average winter, spring, and summer for boys = 0.09 and for girls = 0.07).

References:

U.S. Environmental Protection Agency (EPA). 1989. Exposure Factors Handbook. EPA/600/8-89-043, Office of Health and Environmental Assessment, Washington, D.C.

Parameter: Translocation fraction

Reference equation: DES-5

Dependencies: vegetation type

Equation symbol: f_{trans}

Frequency of selection: realization

Definition: The fraction of activity moved from the above-ground outer vegetative surfaces to the inner, edible portion of the crop for crop types with an outer and an inner vegetation compartment.

Units: none

Value(s): Other vegetables, grain, fruit — minimum: 0.01; maximum: 0.2

Distribution: loguniform

Technical basis: Previous HEDR codes used a translocation factor to model the translocation of foliage radionuclide deposition. DESCARTES will model other vegetable, grain, and fruit translocation as a rate constant that is calculated from the f_{trans} and λ_{weath} parameters (Equation DES-5).

This parameter applies only to the other vegetable, grain, and fruit vegetation types. All other vegetation types (i.e., leafy vegetables, alfalfa, pasture grass, silage, and sagebrush) "translocate" all surface deposition to the edible portion. Essentially, the f_{trans} parameter is equal to 1 for these latter types, but in order for the calculation of λ_{trans} not to fail (i.e., result in division by zero), the f_{trans} value will not be defined and the λ_{trans} value will be defined as 0 for these particular vegetation types.

Nutrients enter plants by two routes: roots and leaves. The translocation fraction is used to evaluate the fraction of the activity that deposits on the above-ground portion of the vegetation that is available to enter internal plant tissues. The CR, a related parameter, evaluates the plant tissue radionuclide concentration that results from root uptake of radionuclides in the soil. Carbon, hydrogen, and oxygen are the only elements that are predominantly taken in through the leaves and distributed to other plant parts (Bowling 1976). All other essential elements are chiefly taken in through plant roots.

Iodine-131 deposited on plant foliage is not known to translocate significantly from the site of deposition. Autoradiographs of exposed dandelion foliage do, however, indicate that some translocation occurs (Chamberlain and Chadwick 1953).

The translocation fraction is an important parameter for those crop types exhibiting edible portions that are not directly exposed to the atmosphere. To evaluate the translocation fraction for other vegetables, grains, and fruits, the translocation mechanism and experimental values were investigated.

Stomata are pores in plant surfaces that serve to exchange gases. Stomatal diffusion into the plant has been identified as an important foliar entryway for iodine gas (Barry and Chamberlain 1963; Nakamura and Ohmomo 1980). One experimental result indicated that iodine may be found in the waxy leaf cuticle under high humidity (Garland and Cox 1984).

Although gaseous iodine is known to be volatile at ambient temperatures and pressures (Chamberlain and Chadwick 1953), once non-particulate iodine is absorbed onto vegetation, it is strongly bound even after heating to 150°C (Thompson 1965). The observation that mechanical action on barley greenchop does not reduce the iodine concentration of the vegetation (Baes et al. 1984) provides experimental evidence for this statement.

Few experimentally determined translocation factors for iodine are published in the literature. The values that do exist are primarily from leafy vegetation experiments. The following lists experimentally derived values of translocation:

Translocation Fraction	Reference
0.0 to 0.16 (average = 0.04) 0.03	Hungate et al. (1960)
0.02 to 0.05	Hungate et al. (1963)

Default values used in various computer codes are listed below.

Translocation Fraction	Reference
0.01	Schreckhise (1980)

The loguniform distribution of the other vegetable, fruit, and grain vegetation types was resolved from the experimental results of Hungate et al. (1960). The logarithmic scale will result in the selection of more values in the lower end of the indicated range.

References:

Baes, III, C. F., R. D. Sharp, A. L. Sjoreen, and R. W. Shor. 1984. A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture. ORNL-5786, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Barry, P., and A. C. Chamberlain. 1963. "Deposition of Iodine onto Plant Leaves from Air." Health Physics 9:1149-1157.

Bowling, D. J. F. 1976. Uptake of Ions by Plant Roots. John Wiley and Sons, New York.

Chamberlain, A. C., and R. Chadwick. 1953. "Deposition of Airborne Radioiodine Vapor." Nucleonics 11(8):22-25.

Garland, J. A., and L. C. Cox. 1984. "The Uptake of Elemental Iodine Vapor by Bean Leaves." Atmospheric Environment 18(1):199-204.

Hungate, F. P., J. D. Stewart, R. L. Uhler, and J. F. Cline. 1963. "Foliar Sorption of Iodine-131 by Plants." Health Physics 9:1159-1166.

Hungate, F. P., J. D. Stewart, R. L. Uhler, and J. F. Cline. 1960. Iodine-131 Removal From Leaves. HW-65500, Hanford Works, Richland, Washington.

Nakamura, Y., and Y. Ohmomo. 1980. "Factors Used for the Estimation of Gaseous Radioactive Iodine Intake through Vegetation, II. Uptake of Elemental Iodine by Spinach Leaves." Health Physics 38:315-320.

Schreckhise, R. G. 1980. Simulation of the Long-term Accumulation of Radiocontaminants in Crop Plants. PNL-2636, Pacific Northwest Laboratory, Richland, Washington.

Thompson, S. E. 1965. Effective Halflife of Fallout Radionuclides on Plants with Special Emphasis on Iodine-131. TID-4500, University of California, Lawrence Livermore Laboratory, Livermore, California.

Parameter: Growth rate constant

Dependencies: vegetation type

Frequency of selection: N/A

Reference equations: DES-1, DES-2, DES-3

Equation symbol: k_g

Definition: The rate constant used to model the growth of each vegetation type.

Units: d^{-1}

Value(s):

Vegetation Type	Value
Leafy vegetables	0.11
Other vegetables	0.09
Tree fruit	0.09
Grain	0.12
Pasture	0.12
Grass hay	0.12
Alfalfa	0.27
Silage	0.12
Sagebrush	0.15

Distribution: none

Technical basis: Daily biomass is estimated by the use of a cosine function for each vegetation type (see Equations DES-1, DES-2, and DES-3). These functions consider the maximum attainable biomass (B_{max}), the day of the year, and factors that relate to the estimated growth and senescence rates of the vegetation, k_g and k_s, respectively.

The growth-rate constant is indicated by the parameter k_g. The growth-rate constant was introduced in the PATHWAY model (Whicker and Kirchner 1987). Values provided in PATHWAY for grains, silage, pasture, and alfalfa are listed above. Lawn grass was assumed to have the same k_g value as pasture. These values were obtained for PATHWAY by curve-fitting techniques using Utah biomass data.

DESCARTES requires k_g estimates for crops ingested by humans as well as for those used as animal feed. These additional k_g values were estimated by curve-fitting techniques, as was done by Whicker and Kirchner for the PATHWAY model. Daily biomass curves were generated by the use of the minimum and maximum B_{max} values in Equations DES-1, DES-2, and DES-3. The k_g values required to reach the maximum biomass at the "appropriate time" were determined through this curve-fitting exercise. The appropriate time that the maximum biomass was achieved by each vegetation type was established during Phase I work. Shindle et al. (1992) indicated the monthly fraction of biomass for each vegetation type. The curve-fitting was done by altering the k_g value until the maximum biomass was realized at the time indicated in Table 2.1 of Shindle et al. (1992). A similar technique was used to establish k_s values.

References:

Shindle, S. F., T. A. Ikenberry, and B. A. Napier. 1992. Parameters Used in the Environmental and Radiological Dose Modules of the Phase I Air Pathway Code. PNL-8093 HEDR, Pacific Northwest Laboratory, Richland, Washington.

Whicker, F. W., and T. B. Kirchner. 1987. "PATHWAY: A Dynamic Food-Chain Model to Predict Radionuclide Ingestion after Fallout Deposition." Health Physics 52:717-737.

Parameter: Senescence rate constant

Dependencies: vegetation type

Frequency of selection: N/A

Reference equations: DES-2, DES-3, DES-11, DES-12, DES-14

Equation symbol: k_s

Definition: The constant describing the rate at which vegetation types senesce at the end of the growing season.

Units: d^{-1}

Value(s):

Vegetation Type	Value
Leafy vegetables	0.07
Other vegetables	0.08
Tree fruit	0.07
Grain	0.08
Pasture	0.09
Grass hay	0.09
Alfalfa	0.15
Silage	0.09
Sagebrush	0.09

Distribution: none

Technical basis: Daily biomass is estimated by the use of a cosine function for each vegetation type (see Equations DES-1, DES-2, and DES-3). These functions consider the maximum attainable biomass (B_{max}), the day of the year, and factors that relate to the estimated growth and senescence rates of the vegetation. The senescence-rate constant describes the rate at which the above-ground biomass is reduced at the end of the growing season.

The senescence-rate constant is indicated by the parameter k_s. It was first used in the PATHWAY model (Whicker and Kirchner 1987). The k_s values in PATHWAY were derived by curve-fitting techniques using Utah biomass data. The curve-fitting procedure was also used to calculate the k_s values for DESCARTES with the use of HEDR-specific biomass values. A k_s value was determined by the realization of minimum biomass values (B_{max}) by the end of the year.

References:

Whicker, F. W., and T. B. Kirchner. 1987. "PATHWAY: A Dynamic Food-Chain Model to Predict Radionuclide Ingestion after Fallout Deposition." Health Physics 52:717-737.

Parameter: location of interest

Reference equations: DES-16 to 18
CID-1 to 5

Dependencies: none

Equation symbol: 1

Frequency of selection: N/A

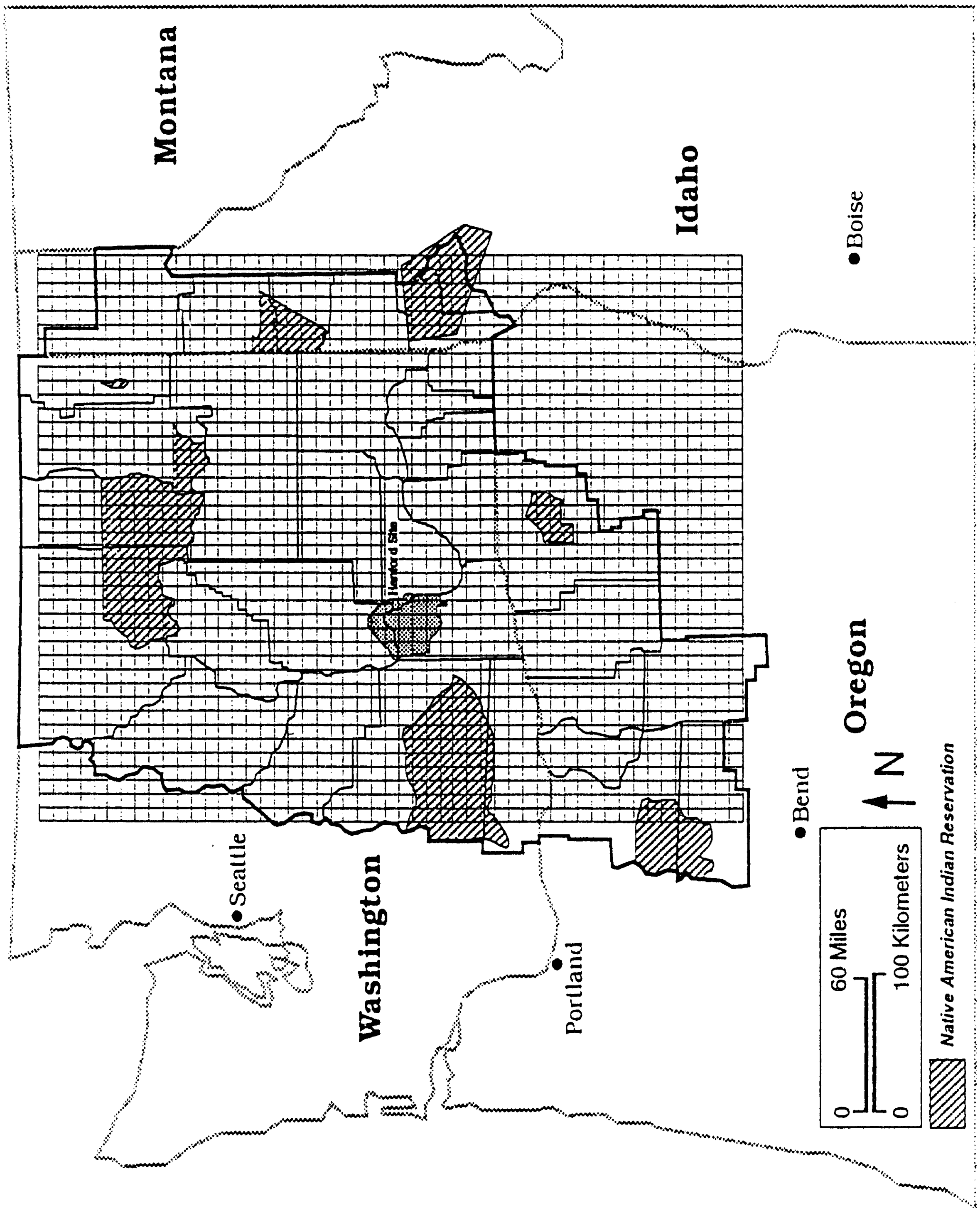
Definition: The location identification for the grid of 41-x-51 squares that identifies the HEDR study region.

Units: none

Value(s): integer values from 1 to 2091

Distribution: none

Comment: The HEDR study was geographically parsed by the use of a 41-square by 51-square grid (see figure). Each square in the grid has a unique identifier. Grid squares are numbered west to east starting in the southwest corner of the grid in the figure on the following page.


Montana
Idaho
Boise
Washington
Seattle
Portland
Oregon
Bend
Hanford Site
N
0
60 Miles
0
100 Kilometers
Native American Indian Reservation

Parameter: Food processing loss fraction **Reference equations:** CID-4

Dependencies: vegetation type, radionuclide **Equation symbol:** L_{proc}

Frequency of selection: realization

Definition: The fraction of activity removed from exterior vegetative surfaces during food processing and preparation.

Units: none

Value(s): Leafy vegetables, fruit minimum: 0.2
maximum: 0.7

Distribution: uniform

Technical basis: The exterior surfaces of crops are typically washed with running water at some point before ingestion. This washing is expected to remove a portion of the particulate activity from food crop surfaces. Leafy vegetation has been identified as the second major contributor to ingestion dose. As a result, some past experimenters conducted research to determine the fraction of iodine that can be expected to be removed from leafy vegetation.

Hungate et al. (1960) investigated the ability of various agents to remove iodine-131 from radish and lettuce surfaces. Five minutes of shaking radish greens and lettuce in distilled water resulted in the removal of 61% and 70% of the activity, respectively. It was noted that the five-minute shaking time was more than twice as long as required for maximum removal of the iodine. Other wash solutions (e.g., salt water, Tide®, acetone-water) removed 67% to 92% of the iodine. Later descriptions of this same experiment (Hungate et al. 1963) reported that a 40% decrease in removable iodine was noted over a 3-d period. Iodine contamination in this experiment was brought about by plant exposure to "conditions resembling a reactor disaster."

Nakamura and Ohmomo (1980) investigated the potential of boiling to remove iodine from spinach leaves. Average removal fractions of 0.33 to 0.58 were reported for elemental-iodine- and methyliodide-contaminated vegetation, respectively. Individual measurements ranged from 0.53 to 0.65 for methyl-iodide and 0.17 to 0.42 for elemental iodine. It is apparent that the chemical form of the contaminant influences the removal fraction parameter.

Garland and Cox (1984) performed a leaf-washing experiment on bean plants. Very low removal rates (2% to 6%) were reported for leaves exposed in light, dry conditions. The low removal rate was attributed to the low deposition levels of iodine on the leaves. The initial iodine levels of the leaves were assumed to be low as a result of volatilization of the iodine from the leaf surface. Bean leaves exposed under humid, dark conditions exhibited a removal rate of 23% to 38%. Washing in this experiment was less vigorous than the Hungate et al. (1960 and 1963) experiments. Garland and Cox washed the bean leaves with 5 ml of distilled water with a pipette, "until the leaf had been thoroughly wetted," to simulate rainfall. Bean leaves were exposed to iodine vapor in a wind tunnel for one hour.

Thompson (1967) summarized that various experiments reported reductions of spinach and lettuce activity from 50% to 85% as a result of washing. A fractional loss value of 0.65 was suggested for use for all fruits and vegetables.

Others have included washing losses in computer codes similar to DESCARTES. Boone et al. (1981) listed values of the fractional retention (1-removal fraction) rates of activity after crop or animal product "processing." These values for iodine, converted from retention fraction to removal fraction, are listed below. These values were initially documented in Ng et al. (1978). Their origin is unclear.

Food Product	Removal Fraction
Sweet corn	0.0
Cantaloupes, watermelons, potatoes, tomatoes, sweet potatoes	0.2
Apples, peaches, cabbage, snap beans	0.5
Wheat	0.33

The experimental evidence shows that only incomplete removal of deposited iodine occurs as a result of washing and food preparation. The range of values to be used in DESCARTES reflects the range of values determined experimentally. The randomly selected L_{proc} value chosen for each realization is kept constant for each food category. It was assumed that the L_{proc} value reflects, to some extent, the typical vigor with which an individual washes his or her produce. Therefore, it was desirable to maintain the constant WFA value in each realization.

References:

Boone, F. W., and Y. C. Ng. 1981. "Terrestrial Pathways of Radionuclide Particulates." Health Physics 41:735-747.

Garland, J. A., and L. C. Cox. 1984. "The Uptake of Elemental Iodine Vapour by Bean Leaves." Atmospheric Environment 18(1):199-204.

Hungate, F. P. J. F. Cline, R. L. Uhler, and A. A. Selders. 1963. "Foliar Sorption of Iodine-131 by Plants." Health Physics 9:1159-1166.

Hungate, F. P., J. D. Stewart, R. L. Uhler, and J. F. Cline. 1960. Iodine-131 Removal From Leaves. HW-65500, Hanford Works, Richland, Washington.

Nakamura, Y., and Y. Ohmomo. 1980. "Factors Used for the Estimation of Gaseous Radioactive Iodine Intake through Vegetation -- II. Uptake of Elemental Iodine by Spinach Leaves." Health Physics 38:315-320.

Ng, Y. C., W. A. Phillips, Y. E. Ricker, R. K. Tandy, and S. E. Thompson. 1978. Methodology for Assessing Dose Commitment to Individuals and to the Population from the Ingestion of Terrestrial Foods Contaminated by Emissions from a Nuclear Fuel Processing Plant at the Savannah River Plant. UCID-17743, Lawrence Livermore Laboratory, Livermore, California.

Thompson, Jr., J. C. 1967. "Reconsideration of the Iodine-131 Contribution from Fruits and Vegetables." Health Physics 13:883-887.

Parameter: Mass loading

Reference equations: DES-10
CID-3

Dependencies: none

Equation symbol: ML

Frequency of selection: realization

Definition: The mass of particulates in a m^3 of outdoor air.

Units: kg(dry)/m^3

Value(s): central value: 7E-8
minimum: 8E-9
maximum: 6E-7

Distribution: lognormal

Technical basis: Mass loading values indicate the amount of particulates that occur in outdoor air. Mass loading is used by DESCARTES to estimate the foliar deposition of radionuclides resulting from soil resuspension (Equation DES-10). CIDER uses mass loading values as a part of the inhalation dose calculation (Equation CID-3).

Airborne iodine can be found in two major physical forms: gaseous and absorbed onto particulates (Black and Barth 1976). The iodine particulates form as either the attachment of airborne iodine-131 gases to dusts and particulates in the air or as resuspension of soil particles containing iodine-131.

Resuspended soil from the upper soil layer is assumed to account for all of the activity in the airborne particulates. The airborne activity from the passing Hanford-originating plume is accounted for by other means. The activity concentration in the upper soil layer is modeled to be equivalent to the activity concentration of airborne particulates.

Particulate levels in the HEDR study region were determined by the evaluation of data collected by the Environmental Protection Agency's National Air Data Branch (EPA 1992). The data indicate the median and geometric standard deviation of total suspended particulates for each location where data were recorded. Total suspended particulate measurements were taken an average of 8 m above the ground. The fact that the EPA (1992) data were recorded as median and geometric standard deviations led to the presumption of a lognormal distribution for this parameter.

Minimum and maximum values of ML indicate the 0.1 and 99.9th percentile values, respectively, for a geometric standard deviation of 2.0.

References:

Black, S. C., and D. S. Barth. 1976. Radioiodine Prediction for Nuclear Tests. EPA-600/4-76-027, Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Las Vegas, Nevada.

U.S. Environmental Protection Agency (EPA). 1992. National Air Data Branch, Aerometric Information Retrieval System. Total Suspended Particulate Information for:
Pendleton, OR (1 location, 1985-87)
Kennewick, WA (1 location, 1985-88), and
Spokane, WA (12 locations, 1985-88).

Parameter: Indoor-to-outdoor air activity ratio **Reference equation:** CID-1 CID-3

Dependencies: none

Equation symbol: R_{io}

Frequency of selection: daily

Definition: The ratio of the activity in indoor air to the activity in outdoor air.

Units: none

Value(s): minimum: 0.35
maximum: 1.0

Distribution: uniform

Technical basis: The calculation of inhalation dose considers the inhalation of outdoor air and air inside a residence or other building. The air inside the residence is not expected to have the same concentration of activity as the outdoor air, unless free air exchange occurs through windows or other openings. Experiments investigating the dust-loading of air inside and outside of residences (Hawley 1985) have found that the ratio of particulates in indoor to outdoor air can vary by 35% to 85%.

Christensen and Mustonen (1987) investigated the indoor-air-to-outdoor-air ratio of beryllium. They measured the beryllium levels in wooden Norwegian houses built in 1954. The indoor-to-outdoor ratios ranged from 0.40 to 0.86.

Kocher (1978) modeled the R_{io}. The Kocher model accounted for various rates of air exchange between the indoor and outdoor air, deposition onto interior room surfaces, and a range of deposition velocities and room sizes. The Kocher values ranged from 0.01 to 0.75 for modeled rooms (5-m radius hemisphere) with interior deposition rates of 0.01 to 0.1, and air exchange rates of 0.2 to 1 per hour. Rooms with free air exchange, five exchanges per hour, were found to have R_{io} values close to 1.

The maximum value was chosen to be 1.0 to emulate free air exchange. The minimum value was chosen as the minimum, measured ratio found in the scientific literature (Hawley 1985).

References:

Christensen, G. C., and R. Mustonen. 1987. "The Filtering Effect of Buildings on Airborne Particles." Radiation Protection Dosimetry 21(1/3):125-128.

Hawley, J. K. 1985. "Assessment of Health Risk from Exposure to Contaminated Soil." Risk Analysis 5(4):289-302.

Kocher, D. C. 1978. Effects of Man's Residence Inside Building Structures on Radiation Doses from Routine Releases of Radionuclides to the Atmosphere. ORNL/TM-6526, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Parameter: Daily food consumption by chickens **Reference equation:** DES-16

Dependencies: none **Equation symbol:** R_{v_a}

Frequency of selection: realization

Definition: The mass of food a chicken consumes in a day.

Units: kg(dry)/d

Value(s): minimum: 0.05
maximum: 0.12

Distribution: uniform

Technical basis: Consumption of chicken by humans has greatly increased since the 1940s. A U.S. program known as the "Chicken of Tomorrow" began contests in 1945 to promote more efficient poultry and egg production (Pierce 1951). Prior to this program, chicken meat was consumed on special occasions (e.g., Sundays and holidays) (Pierce 1951).

The 1950s saw a greater efficiency in the amount of feed required to produce a pound of poultry. Estimates from 1947 indicated that 4 pounds of feed were required to produce 1 pound of chicken (Pierce 1951). Better breeding, management, and feeding were able to produce a pound of chicken for 3 or fewer pounds of feed by 1951. Assuming 1946 dressed chickens weighed 3 to 7 pounds, the feed requirements of the chicken were approximately 12 to 28 pounds (5.5 to 12.7 kg) of feed per pound of chicken over an average of 22 weeks of growth. This estimate of feed intake assumes four pounds of feed per pound of chicken meat.

The literature indicates that mash was the typical feed given to chickens during the 1940s. The mash mixture varied, but it usually consisted of grains such as corn, oats, wheat, dried or fresh milk, limestone, fishmeal, and dehydrated alfalfa (Wilhelm and Carrick 1943). In addition, the poultry in the Columbia Basin were assumed to consume range grasses ad libitum during the late 1940s and early 1950s because the land was available for such purposes.

Mash was assumed to be consistently available to the ranging chickens of the Columbia Basin. The daily minimum and maximum feed-consumption rates listed above are consistent with the values reported by Vondell and Pierce. Pasture grasses were estimated to consist of 5 (Vondell 1943) to 20% (Wilhelm and Carrick 1943) of the feed intake without affecting poultry quality.

References:

Pierce, H. C. 1951. "Meat-type Chickens Open New Markets." Broiler Growing pp. 16-17, 48-49.

Vondell, J. H. 1943. "Range Utilization by Growing Chickens." The U.S. Egg and Poultry Production Magazine. October 1943, pp. 464-466.

Wilhelm, L. A., and C. W. Carrick. 1943. "There is an Answer to Poultry Feed Shortages." The U.S. Egg and Poultry Magazine, May 1943, pp. 211-215.

Parameter: Shielding factor

Dependencies: radionuclide

Frequency of selection: realization

Reference equations: CID-1
CID-2

Equation symbol: Shl

Definition: The external dose reduction factor for an individual located in a building.

Units: none

Value(s): minimum: 0.05
maximum: 0.93

Distribution: uniform

Technical basis: Radionuclides in the outdoor environment create an external exposure pathway. External dose factors, DF_{imm}, DF_{usl}, and DF_{rz}, are used to calculate the dose from immersion in the plume and from ground deposition. Use of these dose factors assumes the individual is located outdoors. Indoor exposure to the decay energy of the radionuclides in the outdoor air and soil must also be considered in external dose calculations. A correction factor to the external dose equations must account for the shielding effects of the building in which an individual is located.

The shielding correction factor is a function of the photon energy of the radionuclide, structural materials of the building, and an individual's distance and shielding from the building exterior walls. A minimum immersion shielding factor would be zero: none of the decay energy from the radionuclides in the outdoor air or in the soil would reach the indoor individual. This case would exist if an individual always remained well within a building that was constructed of dense materials. Such a situation holding true throughout the entire study period, however, is extremely unlikely; therefore, a more reasonable minimum value was sought. Block and brick structures that would provide the greatest shielding are reported to have shielding reduction factor values of 0.15 to 0.30 (Burson and Profio 1977). Large wood frame structures are reported to have a minimum shielding reduction factor of 0.05 (Burson and Profio 1977). The minimum value, 0.05, will be used as the minimum shielding factor in DESCARTES. Lower shielding factors indicate more attenuation of photon energy and, therefore, less exposure.

The maximum immersion shielding factor would result from low-density building materials and from the individual remaining near an exterior wall. A higher shielding factor indicates little attenuation and, therefore, more exposure. The minimum shielding factor was derived by calculating an attenuation factor for a wall constructed of 3-mm thick glass. The attenuation calculation, listed below, produced the maximum immersion shielding value of 0.93. As a comparison, a maximum value obtained by a model building constructed of 3-cm-thick pine produces a maximum immersion shielding value of 0.90. The equation used to calculate the maximum immersion shielding factors is listed below.

$$Shl = e^{-(\mu \cdot x \cdot \rho)}$$

where μ = mass attenuation coefficient, cm^2/g (0.1 for glass and wood)
x = thickness of the material, cm
ρ = density of the material, g/cm^3 (0.35 for wood and 2.4 for glass).

Values in the literature for fallout calculations indicate shielding factors of 0.05 to 0.65 for wood frame houses and 0.3 to 0.7 for automobiles (Burson and Profio 1977).

Although the energy spectrum of the radionuclides incorporated in the soil would be different than that of the radionuclides dispersed in the air, the same shielding correction factor is used for both cases.

Individuals are mobile within a building and among buildings. To represent this mobility, a uniform distribution was selected for this parameter. Selection of a single Shl value in a realization would represent an average Shl value over the time period evaluated.

References:

Burson, Z. G., and A. E. Profio. 1977. "Structure Shielding in Reactor Accidents." Health Physics 33:287-229.

Parameter: Transfer factor for beef

Reference equation: DES-17

Dependencies: radionuclide

Equation symbol: TF_{ap}

Frequency of selection: realization

Definition: The fraction of the bovine's daily intake of activity that can be found in a kg of beef.

Units: Ci_{beef}/kg_{beef} per Ci_{intake}/d = d/kg(wet)

Value(s): minimum: 0.002
maximum: 0.054

Distribution: uniform

Technical basis: Iodine-131 will be absorbed into the bloodstream through both ingestion and inhalation routes. The blood circulates the iodine-131 through the biological system. This will result in the presence of iodine-131 in the muscle of beef cattle.

A value of 1.0E-2 is the recommended beef transfer factor published in a recent NCRP document (NCRP 1989). This value can be thought of as an upper bound value, because its use is intended to produce a conservative dose estimate.

In an National Academy of Sciences/National Research Council (NAS-NRC) publication (NAS-NRC 1963) the muscle radionuclide concentration was indicated as being equivalent to blood concentrations on a mass basis. Table XVII of NAS-NRC (1963) indicates a beef transfer factor of 4E-3 (C_c = 1.8 for muscle ÷ assumed 450 kg weight of the animal), reported to be the result of chronic-dose experiments.

The International Atomic Energy Agency (IAEA) indicated (1982) a beef transfer factor of 0.01 d/kg. An additional model value reported by Ashton and Sumerling (1988) indicated that an appropriate beef transfer factor would be 8.0E-3 Bq/kg(wet) per Bq/d. This value reduces to 8E-3 d/kg(wet). Zach (1980) used a beef transfer factor of 0.02 d/kg in the FOOD III model.

References:

Ashton, J., and T. J. Sumerling. 1988. Biosphere Database for Assessments of Radioactive Waste Disposals (Edition 1). DOE/RW/88.083, ANS Report No. 595-13, Associated Nuclear Services, Epsom, U.K. for the U.K. Department of the Environment.

International Atomic Energy Agency (IAEA). 1982. Generic Models and Parameters for Assessing the Environmental Transfer of Radionuclides from Routine Releases. Safety Series No. 57, Vienna, Austria.

National Academy of Sciences/National Research Council (NAS-NRC). 1963. Damage to Livestock from Radioactive Fallout in the Event of Nuclear War. Publication 1078, Washington, D.C.

National Council on Radiation Protection and Measurements (NCRP). 1989. Screening Techniques for Determining Compliance with Environmental Standards. NCRP Commentary No. 3, Bethesda, Maryland.

Zach, R. 1980. Sensitivity Analysis of the Terrestrial Food Chain Model FOOD III. AECL-6794, Atomic Energy of Canada Limited, Whiteshell Nuclear Research Establishment, Manitoba, Canada.

Parameter: Transfer factor for eggs

Reference equation: DES-17

Dependencies: radionuclide

Equation symbol: TF_{ap}

Frequency of selection: realization

Definition: The ratio of the activity found in an egg to the daily activity taken in by a laying hen.

Units: Ci_{egg}/kg_{egg} per Ci_{intake}/d = d/kg(wet)

Value(s): minimum: 3.5
maximum: 6.0

Distribution: uniform

Technical basis: Results of the Windscale nuclear accident showed eggs to be the greatest animal-product source of iodine-131 next to milk (Okonski et al. 1961). Okonski et al. (1961) results indicate an equilibrium TF_{eggs} for egg contents of 5.31 d/kg during a chronic intake experiment. Equilibrium was found to be established after seven days. The variance about Okonski et al. (1961) values was approximately 10% of the equilibrium transfer factor. Most of the iodine-131 was found by Okonski et al. to be in the yolk.

Experimental results presented by Mraz et al. (1964) indicated that during acute (single) intake events, iodine was initially found in higher concentrations in the albumen than in the yolk. Several days after the acute intake, however, iodine concentrations were greater in the yolk than in the albumen. DESCARTES models an equilibrium transfer factor for eggs; the quantity of iodine in the egg is assumed to be in equilibrium with the daily iodine intake.

Ng et al. (1979) summarized the results of 5 observations of egg transfer factor values. The values ranged from 3.7 to 5.2, with a suggested transfer factor (TF) value of 4.4.

The TF results were reported as average values for experiments in the scientific literature, with no information provided about the probability distribution of the TF values. A uniform distribution will be assumed with the minimum and maximum set at values encompassing the Ng et al. (1979) and Okonski et al. (1961) results.

Zach (1980) uses an egg TF value of 1.6 d/kg in the FOOD III model.

References:

Mraz, R. F., P. L. Wright, T. M. Ferguson, and D. L. Anderson. 1964. "Fission Product Metabolism in Hens and Transference to Eggs." Health Physics 10:777-782.

Ng, Y. C., C. S. Colsher, and S. E. Thompson. 1979. "Transfer Factors for Assessing the Dose from Radionuclides in Agricultural Products." Presented at the International Atomic Energy Agency Symposium on Biological Implications of Radionuclides Released from Nuclear Industries, March 26-30, 1979, Vienna.

Okonski, J., F. W. Lengemann, and C. L. Comar. 1961. "Incorporation of Iodine-131 into Chicken Eggs." Health Physics 6:27-31.

Zach, R. 1980. Sensitivity Analysis of the Terrestrial Food Chain Model FOOD III. AECL-6794, Atomic Energy of Canada Limited, Whiteshell Nuclear Research Establishment, Manitoba, Canada.

Parameter: Transfer factor for milk, herd **Reference equation:** DES-17

Dependencies: radionuclide **Equation symbol:** TF_{ap}

Frequency of selection: realization

Definition: When a dairy herd's milk is pooled, the collective fraction of the daily intake of activity that can be found in a liter of the pooled milk.

Units: Ci/L per Ci/d = d/L

Value(s): central value: 0.012
minimum: 0.006
maximum: 0.018

Distribution: normal

Technical basis: Although not so for plants, iodine is a nutritional requirement for animals. Iodine is required for the production of thyroid hormones, which are important in regulating metabolism and heat production. The thyroid has developed a mechanism of concentrating the iodine. In addition, secretory glands (e.g., gastric mucosa, salivary glands, mammary glands) will also concentrate iodine (Silva 1985). The ability of iodine to concentrate in the mammary gland has created a need to study the iodine transfer factor values. Milk obtained from cows that consumed radioiodine will contain a fraction of the radioiodine intake.

The iodine-131 inhalation intake of cows will not be evaluated in the HEDR Project. Ingestion intakes are expected to be significantly greater than inhalation intakes. Hawley et al. (1964) found that inhalation intakes are 1/12 to 1/65 the ingestion intake of pasture intakes. Booth et al. (1971) reported investigating the inclusion of respiration and skin absorption contributions in their model, but found them to be unimportant in comparison to the forage intake.

The biological availability of ingested iodine is independent of its chemical form at consumption (Garner et al. 1960; Bretthauer et al. 1972). Ingested iodine is absorbed from the gastrointestinal tract into the blood stream. The circulating iodine is then taken up by the thyroid, kidney, and various excretory organs (Silva 1985).

Beginning approximately in 1954 (Glascock 1954), numerous experiments have been conducted on the transfer factor (TF) of radioiodine to milk. These experiments have tested a variety of variables that may influence the ability of iodine to concentrate in the milk. In addition to the controllable variables, the ability of a cow to concentrate the iodine in the milk varies among cows (e.g., Kirchmann and Boulenger 1963; Lengemann et al. 1957).

Many TF experiments were single-dose experiments. This situation differs from the HEDR Project scenario of multiple (daily) intakes of iodine-131. Garner and Jones (1960) state that the single-dose experiments would be expected to underestimate slightly the equilibrium TF resulting from multiple doses of iodine-131.

Experimentally derived TF values are listed below. Single-dose experiments are noted; listed single-dose values are the maximum TF recorded over the collection period. Approximate values are indicated where the data presented in the literature were converted to days/liter units used in the HEDR code.

Transfer Factor	Reference
approx. 7E-3 d/L (single)	Garner et al. (1960)
approx. 8E-3 d/L (single)	Comar et al. (1967)
approx. 1E-2 d/L (single)	Lengemann (1963)
approx. 3E-3 d/L (single)	Auraldsson et al. (1971)
approx. 3E-3 d/L (single)	Bretthauer et al. (1972)
approx. 2.9E-2 d/L (single) approx. 3.4E-2 d/L	Garner and Jones (1960)
approx. 1.1E-2 d/L	Lengemann and Comar (1964)
approx. 5.0E-3 to 1.7E-2 d/L	Lengemann (1965)

(contd)

Transfer Factor	Reference
approx. 4.5E-2 to 6.1E-2 d/L	Douglas et al. (1971)
approx. 2.2E-2 to 6E-3 d/L	Mason et al. (1971)
3.5E-3 d/L	Hawley et al. (1964)
1.4E-3 to 7.6E-3 d/L	Black et al. (1971)
1.0E-3 to 1.3E-2 d/L	"
1.0E-3 to 2.9E-3 d/L	"
3.5E-3 to 8.8E-2 d/L	"
8.3E-4 to 1.5E-2 d/L	"
4.7E-3 to 2.2E-2 d/L	"

The TFs used for an individual cow and a herd of cows are evaluated separately in the HEDR code. The individual cow milk TF value is selected from within the range of values reported in the scientific literature for individual cows. The distribution of TF_{milk_herd} can be determined by randomly assuming a herd size of 25. The random selection of 25 individual cow transfer factor values (TF_{milk_ind}) would be averaged and plotted. This procedure could continue until a normal distribution is evident.

The consideration of milk from a collection of cows will narrow the variance of the TF value according to the central limit theorem (Remington and Schork 1985). The standard deviation of the TF_{milk_ind} distribution is 0.01. The central limit theorem narrows this distribution by the square root of the herd size, 5. The calculated standard deviation of TF_{milk_herd} is, therefore, 0.002. Minimum and maximum TF_{milk_herd} values were calculated as the 0.1 and 99.9th percentile values, respectively.

References:

Auraldsson, H-A., L. Ekman, A. Eriksson, and U. Greits. 1971. A Simultaneous Study on the Transfer of Radioiodine from Pasture to Milk and from a Single Oral Intake to Milk. FOA Rapport C 4478-A3, The Research Institute of National Defense, Stockholm, Sweden.

Black, S. C., R. E. Engel, V. W. Randecker, and D. S. Barth. 1971. Radioiodine Studies in Dairy Cows Following Project Palanquin. U.S.

Environmental Protection Agency, Southwestern Radiological Health Laboratory, Las Vegas, Nevada.

Booth, R. S., O. W., Burke, and S. V. Kaye. 1971. "Dynamics of the Forage-Cow-Milk Pathway for Transfer of Radioactive Iodine, Strontium, and Cesium to Man." Presented at the American Nuclear Society Meeting, August 22-25, 1971, Columbia, Missouri.

Bretthauer, E. W., A. L. Mullen, and A. A. Moghissi. 1972. "Milk Transfer Comparisons of Different Chemical Forms of Radioiodine." Health Physics 22:257-260.

Comar, C. L., R. A. Wentworth, and F. W. Lengemann. 1967. A Study of Metabolism of Selected Radionuclides Fed in Various Physical Forms to Dairy Cows. TRC-67-33, Cornell University, Ithaca, NY, under contract by Office of Civil Defense, Washington, D.C.

Douglas, R. L., S. C. Black, and D. B. Barth. 1971. Iodine-131 Transport Through the Air-Forage-Cow-Milk System Using an Aerosol Mist, (Project Rainout). SWRHL-43r, U.S. Environmental Protection Agency, Las Vegas, Nevada.

Garner, R. J., and H. G. Jones. 1960. "Fission Products and the Dairy Cow,IV. The Metabolism of Iodine-131 Following Single and Multiple Doses." Journal of Agricultural Science 55:387-390.

Garner, R. J., B. F. Sansom, and H. G. Jones. 1960. "Fission Products and the Dairy Cow, III. Transfer of Iodine-131 to Milk following Single and Daily Dosing." Journal of Agricultural Science 55(2):283-286.

Glascock, R. F. 1954. "The Secretion of a Single Tracer Dose of Labelled Iodine in the Milk of the Lactating Cow." Journal of Dairy Research 21:318-322.

Hawley, Jr., C. A., C. W. Sill, G. L. Voelz, and N. F. Islitzer. 1964. Controlled Environmental Radioiodine Tests, National Reactor Testing Station. IDO-12035, Idaho Operations Office, Office of Technical Services, U.S. Department of Commerce, Washington, D.C.

Kirchmann, R. J., and R. R. Boulenger. 1963. "Radioactive Contamination in Gaseous Media: Contamination of Milk After an Accidental Atmospheric Fallout of Iodine-131." Translation of Saclay Symposium paper, November 12-16, 1963, Hanford document number HW-TR-67, Richland, Washington.

Lengemann, F. W. 1965. "Factors Affecting Iodine Concentration in Bovine Milk." Journal of Dairy Science 48:197-202.

Lengemann, F. W. 1963. "Iodine-131 Concentrations in Blood, Milk, Urine, and Faeces of Dairy Cows Following a Single Dose of Radioiodine." Journal of Agricultural Science 61:375-379.

Lengemann, F. W., and C. L. Comar. 1964. "Metabolism of Iodine-131 by Dairy Cows during Long Term Daily Administration of the Radioisotope." Health Physics 10:55-59.

Lengemann, F. W., E. W. Swanson, and R. A. Monroe. 1957. "Effect of Season on Secretion of Iodine in Milk." Journal of Dairy Science 40:387-393.

Mason, B. J., S. C. Black, and D. S. Barth. 1971. Iodine-131 Dairy Cow Uptake Studies Using a Submicrometer Synthetic Dry Aerosol (Project SIP). SWRHL-39r, Southwestern Radiological Health Laboratory, Las Vegas, Nevada.

Remington, R. D., and M. A. Schork. 1985. Statistics with Applications to the Biological and Health Sciences. Second edition. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Silva, J. 1985. "Effects of Iodine and Iodine-Containing Compounds on Thyroid Function." Medical Clinics of North America 69(5).

Parameter: Transfer factor for milk, individual cow

Reference equation: DES-17

Equation symbol: TF_{ap}

Dependencies: radionuclide

Frequency of selection: realization

Definition: The fraction of the individual cow's daily intake of activity that can be found in a liter of milk.

Units: Ci/L per Ci/d = d/L

Value(s): median: 9.2E-3
minimum: 9.3E-4
maximum: 9.1E-2

Distribution: lognormal

Technical basis: While not so for plants, iodine is a nutritional requirement of animals. Iodine is required for the production of thyroid hormones, which are important in regulating metabolism and heat production. The thyroid has developed a mechanism of concentrating the iodine. In addition, secretory glands (e.g., gastric mucosa, salivary glands, mammary glands) will also concentrate iodine (Silva 1985). The ability of iodine to concentrate in the mammary gland has created a need to study the iodine transfer factor (TF) values. Milk obtained from cows that consumed radioiodine will contain a fraction of the radioiodine intake.

The iodine-131 inhalation intake of cows will not be evaluated in the HEDR Project. Ingestion intakes are expected to be significantly greater than inhalation intakes. Hawley et al. (1964) found that inhalation intakes are 1/12 to 1/65 the ingestion intake of pasture intakes. Booth et al. (1971) reported investigating the inclusion of respiration and skin-absorption contributions in their model, but found them to be unimportant in comparison with the forage uptake.

The biological availability of ingested iodine is independent of its chemical form at consumption (Garner et al. 1960; Bretthauer et al. 1972). Ingested iodine is absorbed from the gastrointestinal tract into the bloodstream. The circulating iodine is then taken up by the thyroid, kidney, and various excretory organs (Silva 1985).

Beginning approximately in 1954 (Glascock 1954), numerous experiments have been conducted on the radioiodine TF to milk. These experiments have tested a variety of variables that may influence the ability of iodine to concentrate in the milk. In addition to the controllable variables, the ability of a cow to concentrate the iodine in the milk varies among cows (e.g., Kirchmann and Boulenger 1963; Lengemann et al. 1957).

Many TF experiments were single-dose experiments. This situation differs from the HEDR Project scenario of multiple (daily) intakes of iodine-131. Garner and Jones (1960) state that the single-dose experiments would be expected to slightly underestimate the equilibrium TF resulting from multiple doses of iodine-131.

Experimentally derived TF values are listed below. Single-dose experiments are noted; listed single-dose values are the maximum TFs recorded over the collection period. Approximate values are indicated where the data presented in the literature were converted to days/liter units used in the HEDR code.

Transfer Factor	Reference
approx. 7E-3 d/L (single)	Garner et al. (1960)
approx. 8E-3 d/L (single)	Comar et al. (1967)
approx. 1E-2 d/L (single)	Lengemann (1963)
approx. 3E-3 d/L (single)	Auraldsson et al. (1971)
approx. 3E-3 d/L (single)	Bretthauer et al. (1972)
approx. 2.9E-2 d/L (single) approx. 3.4E-2 d/L	Garner and Jones (1960)
approx. 1.1E-2 d/L	Lengemann and Comar (1964)
approx. 5.0E-3 to 1.7E-2 d/L	Lengemann (1965)

(contd)

Transfer Factor	Reference
approx. 4.5E-2 to 6.1E-2 d/L	Douglas et al. (1971)
approx. 6E-3 to 2.2E-2 d/L	Mason et al. (1971)
3.5E-3 d/L	Hawley et al. (1964)
1.4E-3 to 7.6E-3 d/L	Black et al. (1971)
1.0E-3 to 1.3E-2 d/L	"
1.0E-3 to 2.9E-3 d/L	"
3.5E-3 to 8.8E-2 d/L	"
8.3E-4 to 1.5E-2 d/L	"
4.7E-3 to 2.2E-2 d/L	"
0.01 d/L	Michon and Jeanmaire (1963)
2.0E-3 to 1.8E-2 d/L	Bertilsson et al. (1988)

The lognormal distribution is used as a result of evidence provided by Hoffman (1979). A geometric standard deviation of 2.1 was assumed from the values listed above. Minimum and maximum values were calculated as the 0.1 and 99.9th percentile values, respectively.

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Parameter: Transfer factor for poultry

Reference equation: DES-17

Dependencies: radionuclide

Equation symbol: TF_{ap}

Frequency of selection: realization

Definition: The fraction of a poultry intake of activity that can be found in chicken meat.

Units: $Ci_{chicken}/kg_{chicken}$ per Ci_{intake}/d = d/kg(wet)

Value(s): minimum = 0.004
maximum = 0.094

Distribution: uniform

Technical basis: Little information is available on the translocation of iodine-131 intakes of poultry to their muscle. Most iodine transfer factor (TF) research has concentrated on the dairy products.

Ennis et al. (1988) specifically addressed the question of chicken meat transfer factors. Their acute dose research indicated an average TF of 1.1E-2 d/kg.

Okonski et al. (1961) performed a study that focused on the transloca-tion of iodine-131 to eggs. Over 90% of the iodine-131 taken in by poultry was reported to be excreted in the feces or incorporated into the egg yolk. Okonski et al. suggested that transfer factors to egg albumin would be indicative of $TF_{poultry}$ values. Their research reported an average albumin TF of 1% of the daily intake per 100 g (1E-1 d/kg) with a standard deviation of ±30%.

The NRC regulatory guide 1.109 (NRC 1977) recommends a value of 2.9E-3 d/kg for use for all meat products. Zach (1980) uses a poultry TF value of 4E-3 d/kg in the model FOOD III. Both of these TF values are lower than the experimentally derived values.

Due to a lack of experimental data, a uniform distribution was chosen to describe the probability distribution of the poultry TF value.

References:

Ennis Jr., M. E., G. M. Ward, J. E. Johnson, and K. N. Boamah. 1988. "Transfer Coefficients of Selected Radionuclides to Animal Products. II. Hen Eggs and Meat." Health Physics 54:167-170.

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Parameter: Holdup time **Reference equations:** CID-4
CID-5

Dependencies: crop or animal product, month of consumption

Equation symbol: th_p

Frequency of selection: realization

Definition: The time between h rvest of the food type (crop or animal product) and ingestion.

Units: d

Value(s):

Food Type	Minimum	Maximum
* Leafy vegetables, other vegetables, fruit, grain	0.0	7.0
Backyard cow milk	1.0	3.0
Commercial cow milk	4.0	10.0
Stored milk products	14.0	60.0
Beef	7.0	21.0
Poultry	2.0	10.0
Eggs	0	21.0

* During fresh-harvest months

Distribution: uniform

Technical basis: Upon harvest of crops or animal products, the radionuclide content of a food type will continue to decrease as a result of radioactive decay. The amount of time between harvest and food consumption varies for the different food types.

An estimate of the amount of time between dairy product harvest and consumption was investigated during HEDR Phase I (Beck et al. 1992). Discrete values were used during Phase I. Those discrete values were minimum hold-up times in order that a conservative amount of radiologic decay would result. DESCARTES parameters are preferentially ranges when the variable is known to vary. The Phase I values are used to define the minimum values of fresh backyard cow and commercial cow milk in DESCARTES. Subjective estimates of the maximum values were developed for both fresh milk categories. Stored milk products (butter, cheese) represent a variety of dairy products. The minimum value and maximum values were subjectively chosen about the value used in the Phase I code, 30 days.

The food crops, meat, and egg hold-up times were subjectively estimated. The food crop hold-up times listed above are relevant to the period of time when these crops are freshly harvested. The fresh harvest periods are listed below:

Vegetation Type	Fresh-Harvest Months
Leafy vegetables	June through September
Other vegetables	June through September
Fruits	June through October
Grains	July through September

During non-fresh-harvest months, the food crop hold-up time is determined by the time between the final harvest date and the date of consumption.

The meat and egg holdup times were subjectively determined and apply year-round. The holdup times reflect processing time for these various animal products.

The uniform distribution was chosen for this parameter due to the subjective development of the holdup time estimates.

References:

Beck, D. M., R. F. Darwin, A. R. Erickson, and R. L. Eckert. 1992. Milk Cow Feed Intake and Milk Production and Distribution Estimates for Phase I. PNL-7227, Pacific Northwest Laboratory, Richland, Washington.

Parameter: Deposition velocity of resuspension **Reference equation:** DES-10

Dependencies: none **Equation symbol:** V_d

Frequency of selection: realization

Definition: The deposition velocity of the resuspended upper soil layer material onto vegetative surfaces.

Units: $\mu Ci/s\text{-}m^2$ per $\mu Ci/m^3$ = m/s x s/d = m/d

Value(s): minimum = 0.1 m/s = 8.64E+3 m/d
maximum = 3.0 m/s = 2.59E+5 m/d

Distribution: uniform

Technical basis: The local deposition velocity reflects the rate at which airborne soil particles will accumulate onto the vegetative surfaces. This process is one of the three that accumulate radionuclides on vegetative surfaces (deposition from the passing plume, rainsplash, and deposition of resuspended soil particles). In the HEDR code, resuspended material is assumed to originate in the upper soil layer. This resuspended material is in particulate form and typically less than 50 μm in diameter (Whicker and Schultz 1982).

Great quantities of information are available on deposition velocity. Sehmel (1980) provides a comprehensive discussion of particulate and gaseous deposition. Particulate-deposition velocities are important to the V_d parameter. Particulate-deposition velocity values found in the literature are listed below. The indicated particle diameter is in units of μm, unless otherwise specified.

Particle Diameter	Value (cm/s)	Reference
32	0.7 to 3.5	Sehmel (1980)
32	0.7 to 3.5	"
2	0.003 to 10	"
5	1.5 to 3.4	"
3 to 7	0.015 to 0.15	"
	0.018 to 0.15	"
	0.01 to 0.05	"
2.5	0.5	"
1 to 10	0.8	"
1 to 2 AMAD	0.004 and 0.008	"
< 1	0.03 to 0.3	"
0.08	0.004	"
0.05 to 0.1	0.1 to 1.1	"
2.5	0.5	Gifford (1962)

A minimum deposition velocity for particulates would occur as the result of the single influence of brownian motion. This value, analyzed by Sehmel (1980), was reported to be 0.03 for a stable atmosphere and a 3 cm roughness height. This value does not recognize the influence of wind speed and, therefore, is to be considered below the range of values to be used in the HEDR code because the presence of wind is a requirement for resuspension.

The terminal velocity of a particle represents its maximum deposition velocity. The terminal velocity reported for fog water particles (approximately 10 μm diameter) is reported to be 1.2 cm/s (Chamberlain et al. 1963). The terminal velocities for 20 μm and 100 μm fallout particles (density = 2.5 g/cm^3) are estimated to be 3 cm/s and 50 cm/s, respectively (Fisher 1966).

Although the resuspended material is primarily in the particulate form, a fraction of the iodine-131 may disassociate from the particulate to exist in a gaseous form. Reported gaseous iodine-131 deposition velocities range from 0.09 to 3.3 (Sehmel 1980) and 1.0 to 2.4 (Hoffman 1977). The minimum and maximum deposition velocities were chosen to represent the ranges provided by Sehmel and Hoffman.

No information is available on the distribution of deposition velocity values for the variety of meteorological conditions that can occur. Therefore, a uniform distribution was chosen for this parameter.

References:

Chamberlain, A. C., A. E. J. Eggleton, W. J. Megaw, and J. B. Morris. 1963. "Physical Chemistry of Iodine and Removal of Iodine from Gas Streams." Reactor Science and Technology, Journal of Nuclear Energy Parts A/B 17:519-550.

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APPENDIX

PARAMETER SUMMARY

TABLE A.1. Environmental Pathways and Dose Assessment Parameter Summary

Parameter	Units	Distribution	Central Value	Minimum	Maximum	Dependencies	Frequency of Selection
α	$m^2/kg(dry)$	uniform		1.0	4.0	none	realization
$^{131}I\ \lambda_{leach}$	d^{-1}	uniform		4.0E-6	5.0E-3	radionuclide	realization
$^{131}I\ \lambda_{perc}$	d^{-1}	uniform		0.14	8.2	radionuclide	realization
$^{131}I\ \lambda_{rad}$	d^{-1}	none	0.086			radionuclide	N/A
$^{131}I\ \lambda_{splash}$	d^{-1}	none	0			radionuclide	N/A
λ_{trans}	d^{-1}					vegetation type	N/A
leafy veg, alfalfa, grass hay, pasture, silage, sagebrush		none	0				
other veg, fruit, grain		calculated	calculated				
λ_{weath}	d^{-1}	triangular	0.0495	0.0347	0.0866	none	realization
ρ_{rz}	$kg(wet)/m^2$	uniform		186	230	none	realization
ρ_{usl}	$kg(wet)/m^2$	uniform		1.10	1.45	none	realization
B_{max}	$kg(dry)/m^2$	triangular				vegetation type	year
leafy veg			0.2	0.07	0.6		
other veg			0.5	0.17	1.2		
fruit			0.54	0.3	2.0		
grain			0.14	0.09	0.3		
pasture			0.3	0.1	0.7		
grass hay			0.3	0.1	0.6		
alfalfa			0.2	0.07	0.4		
silage			0.3	0.1	0.6		
sagebrush			0.01	0.008	0.052		

TABLE A.1. (contd)

Parameter	Units	Distribution	Central Value	Minimum	Maximum	Dependencies	Frequency of Selection
B_{min}	$kg(dry)/m^2$	none				vegetation type	N/A
leafy veg			0.01				
other veg			0.01				
fruit			0.27				
grain			0.01				
pasture			0.04				
grass hay			0.03				
alfalfa			0.01				
silage			0.01				
sagebrush			0.01				
BR	m^3/d	triangular				age	daily
3 mo			1.62	0.5	4.9		
1 yr			5.14	1.7	15.4		
5 yr			8.71	2.9	26.1		
10 yr			15.3	5.1	45.9		
15 yr			17.7	5.9	53.9		
adult			22	7.3	66.0		
^{131}I CR	$Ci/kg_{vegetation}(dry)$ per $Ci/kg_{soil}(wet)$	loguniform		0.01	0.25	radionuclide	realization
$^{131}I\ DF_{imm}$	$rad_{thyroid}/d$ per Ci/m^3	uniform		5.7E+3	3.6E+4	radionuclide	realization
$^{131}I\ DF_{ing}$	$rad_{thyroid}/Ci_{ingested}$	lognormal				age, sex, radionuclide	realization
3 mo			1.4E+7	1.6E+6	1.2E+8		
1 yr			1.3E+7	1.5E+6	1.1E+8		
5 yr			7.8E+6	9.2E+5	6.6E+7		
10 yr			4.1E+6	4.8E+5	3.5E+7		
15 yr			2.5E+6	2.9E+5	2.1E+7		
adult-male			1.4E+6	1.6E+5	1.2E+7		
female			1.7E+6	2.0E+5	1.4E+7		
$^{131}I\ DF_{inh}$	$rad_{thyroid}/Ci_{inhaled}$	lognormal				age, sex, radionuclide	realization
3 mo			1.1E+7	1.3E+6	9.4E+7		
1 yr			8.1E+6	9.5E+5	6.9E+7		
5 yr			4.8E+6	5.6E+5	4.1E+7		
10 yr			2.7E+6	3.2E+5	2.3E+7		
15 yr			1.3E+6	1.5E+5	1.1E+7		
adult-male			1.0E+6	1.2E+5	8.5E+6		
female			1.2E+6	1.4E+5	1.0E+7		
$^{131}I\ DF_{rz}$	rem/d per Ci/m^2	uniform		49	88	radionuclide	realization

TABLE A.1. (contd)

Parameter	Units	Distribution	Central Value	Minimum	Maximum	Dependencies	Frequency of Selection
$^{131}I\ DF_{usl}$	rem/d per Ci/m^2	uniform		84	120	radionuclide	realization
f_d	none	uniform				vegetation type	realization
leafy veg				0.05	0.09		
other veg				0.04	0.26		
fruit				0.13	0.35		
grain				0.85	1.00		
$FS_{chicken}$	kg(wet)/d	uniform		0.006	0.012	none	realization
FS_{cow}	kg(wet)/d	triangular				time on pasture	realization
all pasture			0.5	0.25	1.0		
half pasture			1.0	0.50	1.5		
no pasture			2.0	1.0	4.0		
f_{time}	none	triangular				age, lifestyle, sex, season	realization
3 mo - 2 yr							
winter			0.0	0.0	0.13		
spring			0.04	0.0	0.17		
summer			0.13	0.0	0.29		
fall			0.04	0.0	0.17		
2 - 17 yr							
urban			male female				
winter			0.1 0.05	0.04	0.13		
spring			0.13 0.08	0.04	0.17		
summer			0.35 0.22	0.08	0.38		
fall			0.13 0.08	0.04	0.17		
rural							
winter			0.13 0.08	0.04	0.17		
spring			0.21 0.17	0.04	0.23		
summer			0.34 0.32	0.13	0.50		
fall			0.21 0.08	0.04	0.23		
> 17 yr							
urban							
winter			0.05 0.07	0.0	0.17		
spring			0.18 0.29	0.0	0.31		
summer			0.22 0.29	0.04	0.41		
fall			0.10 0.15	0.0	0.31		
rural							
winter			0.33 0.21	0.04	0.37		
spring			0.44 0.36	0.04	0.50		
summer			0.47 0.29	0.06	0.50		
fall			0.34 0.21	0.04	0.37		

TABLE A.1. (contd)

Parameter	Units	Distribution	Central Value	Minimum	Maximum	Dependencies	Frequency of Selection
$^{131}I\ f_{trans}$	none	loguniform				vegetation type, radionuclide	realization
other veg, grain, fruit				0.01	0.2		
k_g	d^{-1}	none				vegetation type	N/A
leafy veg			0.11				
other veg			0.09				
fruit			0.09				
grain			0.12				
pasture			0.12				
grass hay			0.12				
alfalfa			0.27				
silage			0.12				
sagebrush			0.15				
k_s	d^{-1}	none				vegetation type	N/A
leafy veg			0.07				
other veg			0.08				
fruit			0.07				
grain			0.08				
pasture			0.09				
grass hay			0.09				
alfalfa			0.15				
silage			0.09				
sagebrush			0.09				
$^{131}I\ L_{proc}$	none	uniform				vegetation type, radionuclide	realization
leafy veg, fruit				0.2	0.7		
ML	$kg(dry)/m^3$	lognormal	7E-8	8E-9	6E-7	none	realization
R_{io}	none	uniform		0.35	1.0	none	daily
R_v chicken	kg(dry)/d	uniform		0.05	0.12	none	realization
^{131}I Sh1	none	uniform		0.05	0.93	radionuclide	realization
$^{131}I\ TF_{beef}$	d/kg(wet)	uniform		0.002	0.054	radionuclide	realization
$^{131}I\ TF_{eggs}$	d/kg(wet)	uniform		3.5	6.0	radionuclide	realization

TABLE A.1. (contd)

Parameter	Units	Distribution	Central Value	Minimum	Maximum	Dependencies	Frequency of Selection
$^{131}I\ TF_{milk\_herd}$	d/L	normal	0.012	0.006	0.018	radionuclide	realization
$^{131}I\ TF_{milk\_ind}$	d/L	lognormal	9.2E-3	9.3E-4	9.1E-2	radionuclide	realization
$^{131}I\ TF_{poultry}$	d/kg(wet)	uniform		0.004	0.094	radionuclide	realization
th_p	d	uniform				crop or animal product, month of consumption	realization
*leafy veg, other veg, fruit, grain				0	7		
backyard cow milk				1	3		
commercial cow milk				4	10		
stored milk products				14	60		
beef				7	21		
poultry				2	10		
eggs				0	21		
V_d	m/d	uniform		8.64E+3	2.59E+5	none	realization

* During fresh-harvest months.

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