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

Hanford Environmental Dose Reconstruction Project

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Letter report for the Technical Steering Panel
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PREFACE

In 1987, the U.S. Department of Energy (DOE) directed the Pacific Northwest Laboratory, which is operated by Battelle Memorial Institute, to conduct the Hanford Environmental Dose Reconstruction (HEDR) Project. The DOE directive to begin project work followed a 1986 recommendation by the Hanford Health Effects Review Panel (HHERP). The HHERP was formed to consider the potential health implications of past releases of radioactive materials from the Hanford Site near Richland, Washington.

Members of a Technical Steering Panel (TSP) were selected to direct the HEDR Project work. The TSP consists of experts in the various technical fields relevant to HEDR Project work and representatives from the states of Washington, Oregon, and Idaho; Native American Tribes; and the public. The technical members on the panel were selected by the vice presidents for research at major universities in Washington and Oregon. The state representatives were selected by the respective state governments. The Native American tribes and public representatives were selected by the other panel members.

A December 1990 Memorandum of Understanding between the Secretaries of the DOE and the U.S. Department of Health and Human Services (DHHS) transferred responsibility for managing the dose reconstruction and exposure assessment studies to the DHHS. This transfer resulted in the current contract between Battelle, Pacific Northwest Laboratories (BNW) and the Centers for Disease Control and Prevention, an agency of the DHHS.

The purpose of the HEDR Project is to estimate the radiation dose that individuals could have received as a result of radionuclide emissions since 1944 from the Hanford Site. The HEDR Project work is conducted under several technical and administrative tasks, among which is the Environmental Pathways and Dose Estimates Task. The staff on this task provide the computer codes

and dose calculation tools required for estimating doses to individuals who may have been exposed to radioactive releases from the atmospheric and Columbia River pathways.

Four computer codes were developed to estimate the radiation dose from releases to the air: STRM, RATCHET, DESCARTES, and CIDER. STRM is the source term computer code described in Heeb (1993). RATCHET is the atmospheric transport computer code described in Ramsdell et al. (1994). DESCARTES and CIDER are the atmospheric computer codes described in this report. DESCARTES and CIDER were developed to evaluate environmental accumulation and estimate doses to individuals from the atmospheric pathway.

Three computer codes were used to estimate the radiation dose from releases to the Columbia River: STRRM, WSU-CHARIMA, and CRD. STRRM is the source term computer code described in Heeb and Bates (1994). WSU-CHARIMA is the Columbia River transport computer code described in Walters et al. (1994). CRD is the Columbia River dose computer code described in this report. CRD was developed to evaluate environmental accumulation and estimate doses to individuals from the Columbia River pathway.

The suite of HEDR computer codes are known as HEDRIC, the Hanford Environmental Dose Reconstruction Integrated Codes. The integration, however, is only among the codes used for a particular pathway. The atmospheric pathway codes have not been integrated with the Columbia River codes. Doses resulting from the atmospheric pathway have been estimated separately from doses resulting from the Columbia River pathway.

This report is a revision of Snyder et al. (1992). Snyder et al. (1992) prepared the parameters in the DESCARTES and CIDER computer codes. This report includes the parameters in the CRD computer code and incorporates the comments from the TSP on Snyder et al. (1992). The TSP comments and BNW responses are in Appendix C. The page and paragraph references indicated in the table in Appendix C are applicable to Snyder et al. (1992) and may no longer apply to this revised document.

Rather than write a separate report for Milestone 0703C, it was decided to revise Snyder et al. (1992), which was the Milestone 0703B report. This revision then fulfills Milestone 0703C.

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 during the period of 1944 to 1992. This work is being done by staff at Battelle, Pacific Northwest Laboratories under a contract with the Centers for Disease Control and Prevention with technical direction provided by an independent Technical Steering Panel (TSP).

SCOPE

Computer codes were developed to estimate the radiation dose from releases to the atmosphere and the Columbia River. The suite of HEDR computer codes used to estimate the doses is called HEDRIC (Hanford Environmental Dose Reconstruction Integrated Codes). The set of interrelated and coupled computer codes for the atmospheric pathway consists of source term (STRM), atmospheric transport (RATCHET), environmental accumulation (DESCARTES), and individual dose modules (CIDER). The set of interrelated and coupled computer codes for the Columbia River pathway combines the Columbia River source term (STRRM) and transport (WSU-CHARIMA) codes with the environmental accumulation and individual dose modules (CRD). The main objective of this report is to document the parameters used in the DESCARTES (Dynamic Estimates of Concentrations and Accumulated Radionuclides in Terrestrial Environments), CIDER (Calculation of Individual Doses from Environmental Radionuclides), and CRD (Columbia River Doses) computer codes. For reference purposes, the baseline equations of the codes are presented. The rationale behind the equation selections is described in other documents. These other documents are referenced in this report.

TECHNICAL APPROACH

The TSP indicated two levels-of-effort for parameter research for the air pathway and Columbia River pathway codes. The air pathway contributed, in general, higher doses than the river pathway to a greater number of individuals in the HEDR study area. The river pathway contributed, in general, smaller doses than the air pathway to more limited populations along and near the mouth of the Columbia River. Therefore, greater emphasis was placed on generating air pathway parameters than on river pathway parameters. Independent validation of the DESCARTES and CIDER parameters via references in the open scientific literature was of considerable importance to the TSP as these parameters were being developed. Because of the scarcity of applicable parameter values for CRD in the scientific literature, some Hanford environmental measurements (Thiede and Duncan 1994) were compiled, analyzed, and used to generate bioconcentration factors for fish and other aquatic biota.

ACKNOWLEDGEMENTS

The first version of this document evolved from the contributions of a number of people. These experts contributed their time, expertise, and experience to various specific portions of that first version. J. K. Soldat, J. C. Simpson, D. A. Baker, J. V. Ramsdell, Jr., and D. A. Cataldo of Battelle, Pacific Northwest Laboratories, and T. B. Kirchner of Colorado State University are gratefully acknowledged for their assistance in identifying the most robust bases, information, and methodology for determining various parameter values.

The second version of this document profited from the publication of the first. The supplementation of the air pathway parameter documentation with that of the Columbia River pathway broadened the sphere of experts from which technical advice was obtained. In addition, publication of an updated version permitted the comments from interested parties, including the Technical Steering Panel and nationally and internationally recognized experts, to be incorporated. These parties are gratefully acknowledged for their contributions.

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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 (1944-1992) emissions of radioactive materials from the Hanford Site.

Mathematical models and computer codes have been developed to estimate the historical radiation doses. This report documents the parameters used as input to the DESCARTES (Dynamic ESTimates of Concentrations and Accumulated Radionuclides in Terrestrial Environments), CIDER (Calculation of Individual Doses from Environmental Radionuclides), and CRD (Columbia River Doses) computer codes.

Preliminary dose estimates were calculated in an early phase of the work (termed Phase I) and reported in PNL (1991a, 1991b). 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 parameters used to determine these final doses are being documented in this report.

The HEDR atmospheric and Columbia River pathway codes have been designed to incorporate the uncertainty in the estimated doses. The uncertainty in the estimated doses is reported in Farris et al. (1994a, 1994b). The process of incorporating the uncertainty in the estimated doses was accomplished by varying the numerical value assigned to a particular parameter from one stochastic realization to the next by separate uncertainty analyses. The codes were run at least 100 times. Each realization produced 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 because of a lack of

information. This stochastic dose-assessment process required that the uncertainty in each input parameter be estimated. This report documents the individual parameter values and the probability distribution that was used for the DESCARTES, CIDER, and CRD parameters.

The sensitivity analysis, which determined the parameters and exposure pathways that contributed the most to dose uncertainties, is reported in Farris et al. (1994a, 1994b). If the uncertainty of a parameter was found to contribute significantly to the uncertainty in the dose estimate, then the uncertainty of that parameter was better defined. The sensitivity analysis in Farris et al. (1994a, 1994b) shows that uncertainties associated with some parameters contribute more significantly to the uncertainties in the dose estimates than other parameters. Only a few key parameters contribute significantly to uncertainty in dose.

The approach to sensitivity analysis for the thyroid dose to an adult male milk-drinker was included in the HEDR Uncertainty and Sensitivity Analyses Plan (Simpson and Ramsdell 1993). The review of this sensitivity analysis is reported in Hoffman (1993). Two types of cow milk were evaluated: individual cow milk (i.e., a backyard cow) and herd milk (i.e., a mixture of several cows' milk). The results (Farris et al. 1994a) of the sensitivity analysis show that:

- When a person consumed milk from an individual cow that fed on fresh pasture containing iodine-131, almost 65 percent of the uncertainty in the thyroid dose is due, almost equally, to the uncertainty in two parameters: DF_{ing} , the ingestion dose factor (DF) and TF_{milk_ind} , the feed-to-milk transfer factor (TF) for the individual cow.
- When a person consumed milk from a herd of cows that fed on fresh pasture containing iodine-131, over 53 percent of the uncertainty in the thyroid dose is due to the uncertainty in the DF_{ing} ; the uncertainty in the feed-to-milk transfer factor for the herd (TF_{milk_herd}) accounts for less than 2 percent of the uncertainty in this dose.

The parameters described in this report include those that have been used in DESCARTES and CIDER to estimate doses from historical releases of

iodine-131 to the atmosphere. In addition, the parameters used in the CRD code to estimate doses from radionuclides released to the Columbia River are also described. The parameter values used in the sensitivity analysis of the CRD code are described in Section 7.0 with the deterministic parameters used for representative individual estimates.

For the purposes of estimating the uncertainty in dose estimates and for performing the sensitivity analysis, when possible, only original data sources have been used. This original source criterion has eliminated 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. However, only limited use has been made of these data compilations to supplement original data either because they do not contain original data or because they contain data that are not directly applicable to the Hanford Site or the environmental accumulation or dose models used in this study. This document contains information with sufficient detail to support and justify the parameters used in the environmental accumulation and dose estimation portions of DESCARTES, CIDER, and CRD.

The code equations implemented in the DESCARTES, CIDER, and CRD modules of HEDRIC are provided in Section 2.0 of this document. Section 3.0 explains the reasoning behind the choices made for the ranges defined for parameter values, the frequency of selection, and the indicated parameter distribution in the model. Section 4.0 describes how the data quality objectives were met, while Section 5.0 lists references for the first four sections. The relevant references for each individual parameter are listed at the end of each parameter discussion. Section 6.0 constitutes the main part of this document, the detailed discussions of individual parameters used in the DESCARTES and CIDER codes. The individual descriptions of the DESCARTES and CIDER parameters are presented together in Section 6.0 of this report because these codes are implemented in series for airborne release estimates. The individual

descriptions of the CRD parameters are presented in Section 7.0 of this document. For the reader's convenience, Appendixes A and B summarize the parameter values from Sections 6.0 and 7.0 in tabular form. Appendix C contains the comments from the Technical Steering Panel (TSP) on the earlier versions of this report (Snyder et al. 1992) and responses by Battelle, Pacific Northwest Laboratories responses.

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 for some references.

2.0 MODEL EQUATIONS AND RELATED DATABASES

The fundamental equations of the DESCARTES, CIDER, and CRD codes are presented in this section. Section 2.1 reviews the parameters of the two air pathway codes. Section 2.2 reviews the parameters for the Columbia River code, CRD.

2.1 AIR PATHWAY

The computer code DESCARTES uses several basic equations to estimate the environmental accumulation of iodine-131 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 2.1.3 lists all the equations used to estimate the amount of radioactivity accumulated in the environment around the Hanford Site from historical atmospheric 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 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 were used by the HEDR environmental accumulation and dose assessment models is included below. These related databases are documented in other HEDR reports. Thus, a complete listing of the values from the related databases is not presented here.

2.1.1 DESCARTES and CIDER Computer Codes

The environmental accumulation and individual dose assessment model equations that are currently implemented in the DESCARTES and CIDER computer codes are listed in Section 2.1.3. For a discussion of the early development of the equations, refer 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 models and codes since the publication of that report. The equations and parameters presented here represent the most current mathematical models contained in the computer codes.

A number of input variables (parameters) is required to execute the DESCARTES and CIDER computer codes. A complete list of these parameters is included in Section 2.1.3.3. Many input variables were either developed outside of the computer code or were 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 an intermediate value in DESCARTES.

2.1.2 Related Databases

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

Air Transport Data - The atmospheric transport code, RATCHET (Regional Atmospheric Transport Code for Hanford Emission Tracking) (Ramsdell et al. 1994), provided daily integrated radionuclide air concentrations and surface deposition rates. These data were used as input to the DESCARTES and CIDER codes: the deposition rates were used in the DESCARTES code; the daily average air concentrations were 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.

Animal Feeding Regimes - Radionuclide concentrations in animal products (i.e., cow and goat milk, meat, poultry, and eggs) were estimated as the product of the ingested activity and the animal-product transfer factor. DESCARTES is based on the concept of feeding regimes to account for the various types of feeds eaten by livestock. Beck et al. (1992) and D. W. Price (TSP)^(a) describe each of the feeding regimes considered for dairy cows, which contribute the greatest to dose in the HEDR study region. A submodel, ADIETP, developed the daily ingestion rates of the various types of vegetation consumed by animals, based on the generalized feeding regime data of Beck et al. (1992) and D. W. Price (TSP).^(a)

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 used a sub-model to calculate representative daily diets for each animal type. These diets were then stored in a database that was accessed by DESCARTES. During a given run of the DESCARTES computer code, these databases were accessed and a realistic diet randomly selected for each location and season.

Milk and Vegetable Production and Distribution - Data about the production and distribution of milk and vegetables within the project domain were collected by the HEDR Demography, Food Consumption and Agriculture Task staff. This information allowed the estimation of radiation doses from ingestion of a food type grown in one part of the region and consumed in another. This information was input to a database that was accessed by DESCARTES. These data have been published in Deonigi et al. (1994) and Marsh et al. (1992).

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 food types considered were leafy vegetables, other vegetables, tree fruits,

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(a) Letter transmitting the revisions to the dairy cow feeding regimes (HEDR Project Document No. 03940425), from J. E. Till (TSP) to D. B. Shieler (BNW), March 4, 1994.

grains, fresh dairy products, stored dairy products, meat, poultry, and eggs. Ranges of intake rates were established by evaluation of United States 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 was selected in CIDER from a pre-existing database. For each age and demographic group, this database contains realistic diets that preserve the correlations between the consumption rates of all food types. This dietary database was established using actual daily dietary information from USDA data. The dietary information contained in this database was published by Anderson et al. (1993).

2.1.3 Equations and Variables

The code equations and brief parameter descriptions are listed below; to explicitly relate the DESCARTES and CIDER parameters and equations, the DESCARTES and CIDER equations are listed separately. After the CIDER equations, an alphabetic summary lists the parameters used in the equations.

2.1.3.1 DESCARTES Equations

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

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

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

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

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:

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

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

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

DES-7. Root zone activity rate of change:

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

DES-8. Outer vegetation activity rate of change:

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

DES-9. Inner vegetation activity rate of change:

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

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

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

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

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

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

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

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

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

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

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

DES-15. Quantity-to-concentration conversion:

- Other vegetables, grain, pasture, alfalfa, and silage

$$C_p = \frac{Q_{\text{iv}} + Q_{\text{ov}}}{B}$$

- Leafy vegetables and fruit

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

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

DES-16. Quantity of nuclide consumed by an animal at location 1 and day t:

$$A_{cons}(t,1) = \sum_{v=1}^V R_{v,a} C_v(h_v,1) e^{-\lambda_{rad} t h_s}$$

DES-17. Animal-product concentration at location 1 and day t:

$$C_{ap}(t,1) = TF_{ap} \left\{ A_{cons}(t,1) + FS_a \left[\frac{f_{usl} Q_{usl}(t,1)}{\rho_{usl}} + \frac{f_{rz} Q_{rz}(t,1)}{\rho_{rz}} \right] \right\} + TF_{ap}(I)(M + 0.001 S)$$

DES-18. Undecayed concentration in a commercially available milk:

- Creamery milk concentration at creamery X:

$$C_{cream,X}(t) = \sum_{l=1}^{L(X)} f_{cream,X}(t,l) \sum_{r=1}^4 f_r(t,l) C_r(t,l)$$

- Grocery milk concentration at location 1:

$$C_{groc}(t,1) = \left[\sum_{x=1}^{X(1)} f_{groc,x}(t,1) C_{cream,x}(t) \right] + f_u(t,1) C_u(t,1) + f_{other}(t,1) C_{other}(t,1)$$

DES-19. Undecayed concentration in commercially available leafy vegetables:

- Inner vegetation compartment

$$C_{comlv,iv}(t,l) = \sum_{m=1}^{M(l)} f_{lv}(l,m) C_{lv,iv}(t,m)$$

- Outer vegetation compartment

$$C_{comlv,ov}(t,l) = \sum_{m=1}^{M(l)} f_{lv}(l,m) C_{lv,ov}(t,m)$$

2.1.3.2 CIDER Equations

CID-1. Immersion dose:

$$D_{imm}(t,l) = \frac{DF_{imm} X(t,l) [f_{time} + (1 - f_{time}) Shl]}{86,400}$$

CID-2. Groundshine dose:

$$D_{grd}(t,l) = f_{time} A_{grd} + (1 - f_{time}) Shl A_{grd}$$

$$\text{where } A_{grd} = Q_{usl}(t,l) DF_{usl} + Q_{rz}(t,l) DF_{rz}$$

CID-3. Inhalation dose:

$$D_{inh}(t,l) = BR DF_{inh} [f_{time} A_{inh} + (1 - f_{time}) R_{lo} A_{inh}]$$

$$\text{where } A_{inh} = \frac{X(t,l)}{86,400} + Q_{usl} \left(\frac{ML}{\rho_{usl}} \right)$$

CID-4. Ingestion dose for foods with inner and outer vegetation compartment concentrations accounted for in combination (other vegetables and grains) or existing only as a single concentration compartment (animal products):

- Other vegetables and grain

$$D_{\text{ing,veg1}}(t,1) = DF_{\text{ing}} \sum_p C_p(t - th_p,1) R_p f_d e^{-\lambda_{\text{rad}} th_p}$$

- Meat, milk, and eggs

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

CID-5. Ingestion dose from crops with inner and outer vegetation compartment concentrations accounted for separately (leafy vegetables and fruit):

$$D_{\text{ing,veg2}}(t,1) = DF_{\text{ing}} \sum_p [C_{p,lv}(t - th_p,1) + C_{p,ov}(t - th_p,1) L_{\text{proc}}] R_p f_d e^{-\lambda_{\text{rad}} th_p}$$

CID-6. External exposure dose to mother, fetus, and nursing baby from immersion and groundshine:

$$D_{\text{ext,bfeed}}(1) = DF_{\text{imm}} A_{\text{ext}} + DF_{\text{usl}} B_{\text{ext}} + DF_{\text{rz}} C_{\text{ext}}$$

$$\begin{aligned} \text{where } A_{\text{ext}} &= \sum_{t=0}^T \frac{X(t,1)[f_{\text{time}} + (1 - f_{\text{time}}) Sh1]}{86,400} \\ B_{\text{ext}} &= \sum_{t=0}^T Q_{\text{usl}}(t,1)[f_{\text{time}} + (1 - f_{\text{time}}) Sh1] \\ C_{\text{ext}} &= \sum_{t=0}^T Q_{\text{rz}}(t,1)[f_{\text{time}} + (1 - f_{\text{time}}) Sh1] \end{aligned}$$

CID-7. Inhalation dose to mother, fetus, and nursing baby:

- Dose to mother

$$D_{\text{inh,mother}}(1) = DF_{\text{inh}} A_{\text{inh,mother}}(1)$$

- Dose to fetus

$$D_{inh,fetus}(1) = DF_{pre} A_{inh,mother}(1)$$

- Dose to the nursing baby

$$D_{inh,baby}(1) = [DF_{inh,baby} A_{inh,baby}(1)] + [DF_{nurs} A_{inh,mother}(1)]$$

$$\begin{aligned} \text{where } A_{inh,x}(1) = & \sum_{t=1}^T BR Q_{usl}(t,1) \frac{ML}{\rho_{usl}} [f_{time} + (1 - f_{time}) R_{io}] \\ & + \sum_{t=1}^T BR \frac{X(t,1)}{86,400} [f_{time} + (1 - f_{time}) R_{io}] \end{aligned}$$

CID-8. Ingestion dose to mother, fetus, and nursing baby.

- Dose to mother

$$D_{ing,mother}(1) = DF_{ing} A_{ing,mother}(1)$$

- Dose to fetus

$$D_{ing,fetus}(1) = DF_{ing,pre} A_{ing,mother}(1)$$

- Dose to the nursing baby

$$D_{ing,baby}(1) = [DF_{ing,baby} A_{ing,baby}(1)] + [DF_{nurs} A_{ing,mother}(1)]$$

$$\text{where } A_{ing,x}(1) = \sum_{t=1}^T [C_p(t,1) + C_{ap}(t,1)] f_d R_p e^{-\lambda_{rad} t h_p}$$

2.1.3.3 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, $\text{m}^2/\text{kg}(\text{dry})$
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}	(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, $\text{kg}(\text{wet})/\text{m}^2$
ρ_{usl}	(D) upper soil layer areal density to a depth of 1 mm, $\text{kg}(\text{wet})/\text{m}^2$
τ	(R) beginning of the exposure period of fetus, nursing baby, or lactating mother, Julian d
$\chi(t, l)$	(R) integrated daily radionuclide air concentration on day t at location l, $\text{Ci}\cdot\text{s}/(\text{m}^3\cdot\text{d})$

$A_{\text{cons}}(t, l)$	(C) animal radionuclide consumption rate on day t at location l , Ci/d
$A_{\text{ing}, x}(l)$	(C) radionuclide intake rate via ingestion for individual x at location l , where x = fetus, nursing baby, or lactating mother, Ci
$A_{\text{inh}, x}(l)$	(C) radionuclide intake rate via ingestion for individual x at location l , where x = fetus, nursing baby, or lactating mother, Ci
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
$C_{\text{ap}}(t, l)$	(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)
$C_{\text{comlv}, \text{iv}}(t, l)$	(C) radionuclide concentration in the inner compartment of commercially available leafy vegetables on day t at location l , Ci/kg(wet)
$C_{\text{comlv}, \text{ov}}(t, l)$	(C) radionuclide concentration in the outer compartment of commercially available leafy vegetables on day t at location l , Ci/kg(wet)
$C_{\text{cream}, X}(t)$	(C) radionuclide concentration in milk from creamery X on day t , Ci/L
$C_{\text{groc}}(t, l)$	(C) radionuclide concentration for cow milk at all grocery stores at location l on day t , Ci/L
$C_{\text{lv}, \text{iv}}(t, m)$	(C) radionuclide concentration in the inner vegetation compartment of leafy vegetables on day t that were grown at location m , Ci/kg(wet)
$C_{\text{lv}, \text{ov}}(t, m)$	(C) radionuclide concentration in the outer vegetation compartment of leafy vegetables on day t that were grown at location m , Ci/kg(wet)

$C_{\text{other}}(t, l)$	radionuclide concentration of milk from a known source outside of the HEDR study region (always assigned a value of zero), 0 Ci/L
C_p	(C) food or feed crop radionuclide concentration, where p = other vegetables, grain, pasture, alfalfa, and silage, Ci/kg(dry)
$C_{p,iv}$	(C) radionuclide concentration of the inner vegetation compartment for leafy vegetables and fruit, Ci/kg(dry)
$C_{p,ov}$	(C) radionuclide concentration of the outer vegetation compartment for leafy vegetables and fruit, Ci/kg(dry)
$C_r(t, l)$	(C) radionuclide concentration in milk from a herd of cows fed according to feeding regime r at location l on day t, Ci/L
$C_u(t, l)$	(C) radionuclide concentration of milk of unknown origin at grocery location l on day t (computed as milk from a dairy herd fed according to feeding regime 1 at location l), Ci/L
$C_v(h_v, l)$	(C) animal feed radionuclide concentration harvested on date h at location l, where v = grain, pasture, grass hay, alfalfa, manger hay, and silage, Ci/kg(dry)
CR	(D) plant-to-soil concentration ratio, Ci/kg _{vegetation} (dry) per Ci/kg _{soil} (wet)
$D_{\text{ext},b\text{feed}}$	(C) external exposure dose to the fetus, nursing baby, or lactating mother from immersion and groundshine, rad _{thyroid} or rem _{EDE}
$D_{\text{grd}}(t, l)$	(C) dose from groundshine on day t at location l, rem
$D_{\text{ing}}(t, l)$	(C) ingestion dose from local or commercial foods on day t at location l, rad _{thyroid} or rem _{EDE}
$D_{\text{ing},ap}(t, l)$	(C) ingestion dose from animal product ap on day t at location l, where ap = beef, poultry, eggs, or milk, rad _{thyroid} or rem _{EDE}
$D_{\text{ing},veg1}(t, l)$	(C) ingestion dose from local food crops with a single compartment on day t at location l, rad _{thyroid} or rem _{EDE}
$D_{\text{ing},veg2}(t, l)$	(C) ingestion dose from local food crops with two compartments on day t at location l, rad _{thyroid} or rem _{EDE}

$D_{ing,x}(1)$	(C) ingestion dose to individual x at location 1 during the exposure period, where x = fetus, nursing baby, or lactating mother, $rad_{thyroid}$
$D_{inh}(t,1)$	(C) inhalation dose on day t at location 1, $rad_{thyroid}$ or rem_{EDE}
$D_{inh,x}(1)$	(C) inhalation dose to individual x at location 1 during the exposure period, where x = fetus, nursing baby, or lactating mother, $rad_{thyroid}$
$D_{imm}(t,1)$	(C) air-immersion dose on day t at location 1, $rad_{thyroid}$ or rem_{EDE}
DF_{imm}	(D) immersion dose rate factor, $rad_{thyroid}/d$ per Ci/m^3 or rem_{EDE}/d per Ci/m^3
DF_{ing}	(D) ingestion dose factor, $rad_{thyroid}/Ci_{ingested}$ or $rem_{EDE}/Ci_{ingested}$
DF_{inh}	(D) inhalation dose factor, $rad_{thyroid}/Ci_{inhaled}$ or $rem_{EDE}/Ci_{ingested}$
DF_{nurs}	(D) dose factor relating the dose to the nursing baby resulting from intakes of the mother, $rad_{thyroid,infant}/Ci_{intake,mother}$
DF_{pre}	(D) dose factor relating the dose to the fetus (i.e., prenatal) from intakes of the mother, $rad_{thyroid,fetus}/Ci_{intake,mother}$
DF_{rz}	(D) dose rate factor for radionuclides in the soil root zone, rem/d per Ci/m^2
DF_{usi}	(D) dose rate factor for upper soil layer or surface activity, rem/d per Ci/m^2
$f_{cream,x}(t,1)$	(R) fraction of milk at creamery X that came from a dairy at location 1 on day t, dimensionless
f_d	(D) dry-weight to wet-weight conversion factor, $kg(dry)/kg(wet)$
$f_{groc,x}(t,1)$	(R) fraction of grocery milk available at location 1 on day t that came from creamery X, dimensionless
$f_{lv}(1,m)$	(R) fraction of leafy vegetables purchased from a retail or wholesale distributor at location 1 that was grown at location m, dimensionless

$f_{\text{other}}(t,l)$	(R) fraction of milk at grocery location l on day t that came from a known source outside of the HEDR study region, dimensionless
$f_r(t,l)$	(R) fraction of milk from a herd of cows fed according to feeding regime r from a dairy at location l on day t , dimensionless
f_{rz}	(R) fraction of root-zone soil consumed by an animal in a day, equal to $1 - f_{usl}$, dimensionless
f_s	(C) soil deposition fraction, equal to $1 - f_v$, dimensionless
FS_a	(D) animal soil ingestion rate, where a = chicken, cattle, or goat, 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, dimensionless
$f_u(t,l)$	(R) fraction of milk at grocery location l on day t that came from an unknown source, dimensionless
f_{usl}	(R) fraction of upper-soil-layer soil consumed by an animal in a day, equal to $1 - f_{rz}$, dimensionless
f_v	(C) vegetation foliar interception fraction, dimensionless
h_v	(R) Julian day on which feed type v was most recently harvested
I	(R) areal deposition rate (from RATCHET), Ci/(m ² ·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 retention fraction, dimensionless
M	(R) surface area of cattle manger directly exposed to atmospheric deposition, m ²
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_{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_{bmilk}	(R) breastmilk consumption rate for a nursing infant, L/d
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 ·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 ·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 ·d
R_{root}	(C) rate of radionuclide uptake through roots, Ci/(m ² ·d)
R_{v_a}	(R) quantity of feed type v that animal a consumes in a day, kg(dry)/d
S	(D) stock tank dilution factor, m ⁻¹
Shl	(D) shielding factor for semi-infinite plumes, dimensionless
t	(R) day of interest, Julian day (number of days since the start of the year)
T	(R) end of the exposure period of the fetus, nursing baby, or lactating mother, Julian d
t_{tot}	total number of days in the year being evaluated, 365 or 366 (leap years)

TF_{ap}	(D) animal product transfer factor, where ap = milk_goat, milk_ind, milk_herd, beef, poultry, or eggs, d/L for milk or d/kg(wet) for beef, poultry, eggs
th_p	(D) holdup time from collection or harvest to consumption, where p is a food crop or animal product, d
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

2.2 RIVER PATHWAY

The environmental accumulation and dose modules for the Columbia River pathway are combined in a single code, CRD, rather than in a series of codes, as was done for the atmospheric pathway. Other major differences between the approach used in the atmospheric pathway and river pathway are the monthly time step and the consideration of more than one radionuclide. The basic equations implemented in the CRD code are shown below, followed by an alphabetic listing and brief description of the parameters.

2.2.1 CRD Equations

CRD-1. Radionuclide concentration in untreated Columbia River water relative to the plume location during month m at location x:

$$C_{w1,j}(m,x) = C_{w\bar{x},j}(m,x) P_{corr}(m,x) (1E-6)$$

CRD-2. Radionuclide concentration in muscle of freshwater fish during month m at location x:

$$C_{fw1,j}(m,x) = C_{w\bar{x},j}(m,x) BCF_{fw1,j} (1E-6)$$

- CRD-3. Radionuclide concentration in muscle of waterfowl during month m at location x:

$$C_{b,j}(m,x) = C_{w\bar{x},j}(m,x) BCF_{b,j} P_{act} (1E-6)$$

- CRD-4. Monthly dose to organ o from ingestion of freshwater fish during month m at location x:

$$D_{fw1,o}(m,x) = \sum_{j=1}^5 \sum_{i=1}^3 C_{fw1,j}(m,x) R_{fw1} e^{-\lambda_j t_{hfw1}} DF_{ing,j,o}$$

- CRD-5. Monthly dose to organ o from waterfowl ingestion during month m at location x:

$$D_{b,o}(m,x) = \sum_{j=1}^5 C_{b,j}(m,x) R_b e^{-\lambda_j t_{hb}} DF_{ing,j,o}$$

- CRD-6. Monthly dose to organ o from untreated water ingestion during month m at location x:

$$D_{w1,o}(m,x) = \sum_{j=1}^5 C_{w\bar{x},j}(m,x) P_{corr}(m,x) e^{-\lambda_j t_{hw1}} R_{w1} DF_{ing,j,o} (1E-6)$$

- CRD-7. Monthly dose to organ o from treated water ingestion during month m at location x:

$$D_{w2,o}(m,x) = \sum_{j=1}^5 C_{w\bar{x},j}(m,x) P_{corr}(m,x) F(x) e^{-\lambda_j t_{hw2}} R_{w2} DF_{ing,j,o} (1E-6)$$

- CRD-8. Monthly external dose (non-submersion) to organ o from the Columbia River during month m at location x:

$$D_{d,o}(m,x) = \sum_{j=1}^5 C_{w\bar{x},j}(m,x) P_{corr}(m,x) E_d DF_{sub,j,o} 0.5 (1E-6)$$

CRD-9. Monthly external dose (submersion) to organ o from swimming in the Columbia River during month m at location x:

$$D_{\text{sub},o}(m,x) = \sum_{j=1}^5 C_{wX,j}(m,x) P_{\text{corr}}(m,x) E_{\text{sub}} DF_{\text{sub},j,o} (1E-6)$$

CRD-10. Annual dose from oyster consumption during year y:

$$D_{\text{oys},o}(y) = \sum_{j=1}^2 C_{\text{oys},j}(y) R_{\text{oys}} DF_{\text{ing},j,o}$$

CRD-11. Annual dose from salmon consumption during year y:

$$D_{\text{sal},o}(y) = \sum_{j=1}^2 C_{\text{sal},j}(y) R_{\text{sal}} DF_{\text{ing},j,o}$$

2.2.2 CRD 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 and technical basis are detailed within this document.
- C: The parameter value is calculated by the CRD codes.
- R: The parameter value is obtained from a related database of values separate from CRD.

1E-6 conversion factor, $\mu\text{Ci}/\text{pCi}$

0.5 dose-factor correction factor for non-submersion external dose, dimensionless

λ_j (D) radionuclide decay constant for radionuclide j, d^{-1}

$BCF_{p,j}$	(D) bioconcentration factor for food type p, radionuclide j; p is limited to fw 1 and b, L/kg(wet)
$C_{p,j}(m,x)$	(C) concentration of radionuclide j in food type p during month m at river segment x, $\mu\text{Ci/L}$ ($W\bar{x}$) pCi/L (treated and untreated water), or pCi/kg(wet) (others)
$C_{p,j}(y)$	(R) concentration of radionuclide j in food type p, where j is limited to zinc-65 and phosphorous-32 and p is limited to oysters and salmon, pCi/kg(wet)
$D_{d,o}(m,x)$	(C) monthly external dose (non-submersion) to organ o from the Columbia River during month m at location x, mrem
$D_{p,o}(m,x)$	(C) monthly dose from the ingestion of food type p, during month m at river segment x, mrem
$D_{p,o}(y)$	(C) annual dose from the ingestion of food type p, where p is limited to oysters and salmon, mrem
$D_{sub,o}(m,x)$	(C) monthly external dose (submersion) to organ o from the Columbia River during month m at location x, mrem
$DF_{ing,j,o}$	(D) dose equivalent factor for ingestion of radionuclide j for organ o, mrem/pCi _{ingested}
$DF_{sub,j,o}$	(D) external exposure dose factor for submersion in water dispersed with radionuclides for organ o, mrem/h per pCi/L
E_x	(D) time spent doing x, where x = d (fishing or boating) or "sub" (swimming), h/mo
f_{w2}	(D) water treatment retention fraction, dimensionless
j	radionuclides modeled in CRD: sodium-24, phosphorus-32, arsenic-76, zinc-65, and neptunium-239
o	organ types considered in CRD, where 1 = gastrointestinal tract, 2 = red marrow, or 3 = whole body
P_{act}	(D) probability the bagged waterfowl was a year-round resident, dimensionless
$P_{corr}(m,x)$	(R) plume correction factor during month m for river segment x, dimensionless

p	food types considered in CRD:	
	b	waterfowl
	fw i	Columbia River freshwater fish i, where i = omnivore, predator1, or predator2
	oys	Willapa Bay oysters
	sal	salmon from the Columbia River
	W1	untreated Columbia River water considering plume location
	W2	treated Columbia River water considering plume location
	$\bar{W}$	modeled average Columbia River water concentration (from a related database)
R_p	(D) ingestion rate of food type p, kg(wet)/y (oysters and salmon) or L/mo (water) or kg(wet)/mo (others)	
th_p	(D) food type p holdup time, d	
y	year of interest, dimensionless	

3.0 PARAMETER DEFINITION STRATEGY

The precise limits on the ranges of values appropriate to the HEDR DESCARTES and CIDER code parameters are not completely known. The imprecision results from a lack of complete 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. Section 3.1 documents the process used to assess and specify the uncertainty (i.e., parameter ranges and distribution) in the air pathway DESCARTES and CIDER 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. Section 3.2 details the strategy used to define the CRD parameters. The river pathway parameters are deterministic (i.e., single-valued).

3.1 AIR PATHWAY PARAMETER DISTRIBUTION AND SELECTION STRATEGY

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 air pathway modules (Napier et al. 1992) at least 100 times to generate 100 or more estimates of dose for a specific individual. Each repetition of the air pathway modules (i.e., STRM, RATCHET, DESCARTES, and CIDER) for the multi-year 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), 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 the air pathway doses.

Because of the relationship between parameter uncertainties and dose uncertainties, the methods used to specify parameter pdfs must be well understood. Below are definitions of terms used to define specific aspects of the air pathway parameter distribution and selection strategy.

3.1.1 Definitions

Computer Simulation Study

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 the distribution of dose estimates are investigated by repeated random sampling from the assigned pdfs of the uncertain parameters in the models.

Expert

Person with background in the subject area at the desired level of detail, who is recognized by her or his peers or those conducting the study as qualified to answer questions (Meyer and Booker 1991).

Expert Judgment

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

Informal Solicitation of Expert Opinion

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 (pdf)

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 (1991b); and Gilbert (1987).

Loguniform Probability Density Function (pdf)

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 (1991b).

Normal Probability Density Function (pdf)

Normal (Gaussian) pdf is symmetrical 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 textbooks.

Piecewise Uniform Probability Density Function (pdf)

Situation where the allowable values for the model parameter are a set of discrete values that can have different probability levels. This pdf is often selected when data come from a mixture of sources and each source has a small amount of variability.

Probability

Chance of something occurring. Probabilities are expressed as 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 (pdf) of a Parameter (Random Variable)

Real-valued function for assigning probabilities to the possible values of a model parameter (random variable). A real-valued function is a mathematical equation that, for specified inputs (e.g., parameter values) yields real numbers (i.e., integers or fractions). A pdf yields real numbers when plotted on paper for all possible values of the random variable and gives the shape of the distribution of the random variable.

Probability Encoding

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

Function that assigns real numbers to the outcomes of an experiment.

Range of a Model Parameter

Difference between the maximum and minimum possible values of the parameter.

Self-Assessment

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 (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), and in IAEA (1989).

Uniform Probability Density Function (pdf)

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) and in IAEA (1989).

3.1.2 Methods for Obtaining Expert Opinion

The following discussion of the four 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 used for the air pathway parameter selection process.

3.1.2.1 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.

3.1.2.2 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 as well as increased cost and potentially poor problem definition.

3.1.2.3 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.

3.1.2.4 Probability Encoding

Probability encoding (Spetzler and von Holstein 1972; Zamora 1975; von Holstein and Matheson 1979; 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.

3.1.3 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.

3.1.3.1 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:

- computerized search of the radiation protection literature citation databases, such as QUEST (Schadt and Kellogg 1991)
- review of relevant reports, papers, and books that originated at Hanford or were authored by acknowledged experts in the subject area of interest
- review of recently issued scientific journals for relevant papers and information
- review of 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 the parameter for the HEDR Project study region and time period could be larger than the (revised) maximum value or smaller than the (revised) minimum value.

3.1.3.2 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, the pdf of each uncertain parameter must be shown.

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, which is also information required for specifying the pdf:

- self-assessment
- informal solicitation of expert opinion
- review of scientific literature
- probability encoding.

The three options of self-assessment, informal solicitation of expert opinion, and information from the scientific literature were primarily relied upon to determine the most appropriate pdf. A fourth option, 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 fifth option for identifying a parameter pdf, calibrated assessment, is also expensive and, therefore, may be difficult for the objective determination of calibration factors for some or most parameters. For these reasons, calibrated assessment is not being used by the HEDR Project.

The critically important parameters, those for which probability encoding was used, were determined on the basis of a 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 letter report, Uncertainty and Sensitivity Analyses Plan (Simpson and Ramsdell 1993),

describes the sensitivity analyses plan for the HEDR Project. Farris et al. (1994a) describe the sensitivity in the estimated doses resulting from the atmospheric pathway.

Because 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.

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, researchers on the HEDR Project preferred probability encoding elicitation techniques for some model parameters.

3.1.3.3 Selecting a Probability Density Function (pdf)

A particular pdf for each uncertain parameter is selected using information obtained from the literature search and the assessment of subjective opinions obtained by other means. The six pdfs considered for use by HEDR

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FIGURE 3.1. The Six Probability Density Functions Used for Uncertain Parameters

Project staff are displayed in Figure 3.1 and defined in this section. These six pdfs are the uniform, piecewise uniform, loguniform, triangular, normal (Gaussian), and lognormal. 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 the 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.
- 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 exist 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, frequently 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 judgment of all reviewers.

3.1.4 Parameter Selection Frequency

In addition to selecting a pdf for each model parameter, as discussed in Section 3.1.3, 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 the air pathway modules, the environmental concentrations of radionuclides (i.e., those in soil, plants, and animal products) are computed at many different locations (see parameter "1" in Section 2.1.3.3) in the study area for each day of the multi-year 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 was made on the basis of literature reviews, self-assessment, or informal solicitation of expert opinion. In general, the pdf for a given parameter was not changed over space and time unless there was a compelling reason to do so.

When the pdf of a parameter did not change over space and time, either a new random value from the pdf for each different time and location was selected or a single value was selected and used for all times and locations in a realization. The answer depended on how the parameter was expected to

vary in reality. For example, the ratio of the indoor air concentration relative to the outdoor air concentration (parameter $R_{i,o}$ in Section 2.1.3.3) varies on a daily basis. Hence, although the same pdf is used for all days, a new random value from the pdf was 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, provided daily estimates of air concentrations and depositions of radionuclides (Ramsdell et al. 1994). Hence, parameters in the environmental accumulation model, DESCARTES, and the dose model, CIDER, that use the estimated air concentrations and depositions from RATCHET were not varied more frequently than daily.

3.2 RIVER PATHWAY PARAMETER SELECTION STRATEGY

The river pathway parameter selection strategy differed from that of the air pathway parameters. The radiation dose which people received as a result of Columbia River exposure pathways was significantly lower than that of the air pathway. Therefore, relatively more effort and energy was spent investigating values for air pathway parameters. The effort for defining the CRD parameters does not presuppose less accurate parameter values. Also, because of the lower magnitude of the river pathway doses, the river pathway doses were calculated deterministically rather than stochastically. Only a single value of each parameter was selected rather than a pdf. Therefore, it was necessary to implement other methods for defining the uncertainty of dose estimates (Farris et al. 1994b).

There were several strategies used to select CRD parameter values:

- compilation and evaluation of historic monitoring data
- review of published Hanford annual report assumptions

- citation of nationally or internationally accepted values for dose factors.

A value of information (VOI) decision-analysis tool was applied to the question of the amount of resources to spend on developing the HEDRIC river pathway code parameters (Napier and Brothers 1992). Resolutions were developed to indicate the "level of effort" expended on various parameters. An intermediate level of effort would be dedicated to reconstruct radionuclide concentrations in Columbia River freshwater fish and waterfowl. A low level of effort would be dedicated to reconstruct radionuclide concentrations in Columbia River salmon and shellfish residing near the mouth of the Columbia River.

An intermediate level of effort was expended on the development of bioconcentration factors; i.e., the ratio of the radionuclide concentration in the animal to that of the water. Bioconcentration factors were developed for freshwater fish that were year-round residents of the Columbia River. Bioconcentration factors were compiled using historical Hanford environmental monitoring program measurements of radionuclide concentrations in fish muscle and modeled values of radionuclide concentrations in Columbia River water. These values were determined on a seasonal basis for several types of fish, which were further delimited by the type of food on which they fed.

A low level of effort was expended on the development of radionuclide concentrations in salmon and shellfish. These species spend the majority of their lives in the ocean but are exposed to Hanford effluent during a portion of their life cycle. The radionuclide concentrations for salmon and shellfish were determined on an average annual basis from historical measurements. The methodology used to determine the bioconcentration factors for resident fish from monitoring and modeled data is documented in Thiede et al. (1994).

4.0 DATA QUALITY OBJECTIVES

The following data quality objectives (DQOs) for this effort were originally presented by Shipler (1993, p. 8.6).

Accuracy   The objective is to develop best estimates or ranges of parameter values that are consistent with available data, information, and expert opinion. The attainment of this objective was assessed by peer reviews. The results of these reviews were documented in project files, and changes were 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 was assessed by peer reviews. The results of these reviews were documented in project files, and changes were 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 was done by refining and agreeing on the parameters and literature to be searched. Completeness was verified by expert judgment and peer review. The results of these reviews were documented in project files, and changes were made to individual parameter descriptions as required.

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

The DQOs for this work were met through discussions with experts and peer review. Both the experts listed as authors and cited in the Acknowledgments contributed to the parameter discussions. A peer review was conducted prior to the issuance of this report. Additional comments have been received from experts on the Technical Steering Panel and other scientists. In addition, sensitivity and uncertainty analyses in Farris et al. (1994a, 1994b) help verify attainment of these DQOs.

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6.0 ATMOSPHERIC PATHWAY 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. The environmental and dose parameters included are only those required to estimate doses from historical airborne releases of iodine-131.

6.1 TECHNICAL APPROACH

Only original data sources are included when possible 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 or references to previous work, but very few of these references contain original data. Only data that are believed to be directly applicable to the HEDR environmental accumulation or dose models were used in this study.

This criterion is, admittedly, violated in two situations: 1) when a significant amount of research has been conducted and summarized by an international board of experts and 2) when an extensive review was conducted by a nationally or internationally recognized expert. The first violation applies to the dose and dose rate factors (DF_{inn} , DF_{ing} , DF_{inh} , DF_{rz} , and DF_{usl}). The second situation applies to the deposition velocity of resuspended material (V_d).

While this document is intended to be comprehensive, it does not include every published reference for every parameter. Based upon the results of the structured sensitivity analysis, more resources were 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. 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 dairy-cow ingestion of iodine (e.g., see $TF_{\text{milk\_ind}}$ parameter) (Bretthauer et al. 1972). Much less is known about the effects of chemical form for all other pathways. As a result of this lack of information, the DESCARTES and CIDER codes assume one chemical form. Most iodine research was conducted using the most reactive form of iodine, iodide. Use of iodide research results 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.

Parameter discussions have a uniform format. Radionuclide-dependent parameters indicate the radionuclide of interest. Format subheadings are listed and described as follows.

Parameter: Brief, descriptive name for 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: 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. One of the options is "realization." A realization is a single simulation of HEDRIC (air pathway) for a single individual from the first modeled day to the last modeled day.

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

Equation symbol: Generic form of the parameter. Parameter subscripts are those used in the DESCARTES and CIDER reference equations (see

Section 2.1.3). The subscript of the parameter being discussed may differ. Parameter discussions address specific cases of the generic form.

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

Units: Units for the parameter values.

Values: Values used for the parameter in DESCARTES and CIDER. Scientific notation is often used; e.g., 2E-7 is equivalent to 2×10^{-7} .

Distribution: Probability density function (pdf) of the parameter (see Section 3.1.1).

Technical basis: Summary of 1) the available literature that discusses experimental data reported for the parameter, 2) the 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: List of references cited in the Technical basis section.

6.2 REFERENCES

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6.3 DESCARTES AND CIDER PARAMETERS

Parameter Symbol	Parameter Description
a	Empirical foliar interception
$^{131}\text{I } \lambda_{\text{leach}}$	Leaching rate from root zone to deep soil
$^{131}\text{I } \lambda_{\text{perc}}$	Percolation rate from upper soil layer to root zone
$^{131}\text{I } \lambda_{\text{rad}}$	Radiological decay
$^{131}\text{I } \lambda_{\text{splash}}$	Rainsplash rate
λ_{weath}	Weathering rate
ρ_{rz}	Root zone soil areal density from 1 mm to 15 cm depth
ρ_{usl}	Upper soil layer areal density to a depth of 1 mm
B_{max}	Maximum potential biomass
B_{min}	Minimum (winter) biomass
BR	Age-dependent breathing rate
$^{131}\text{I } \text{CR}$	Plant-to-soil concentration ratio
$^{131}\text{I } \text{DF}_{\text{imm}}$	Immersion dose rate factor
$^{131}\text{I } \text{DF}_{\text{ing}}$	Ingestion dose factor
$^{131}\text{I } \text{DF}_{\text{inh}}$	Inhalation dose factor
$^{131}\text{I } \text{DF}_{\text{nurs}}$	Nursing baby dose factor
$^{131}\text{I } \text{DF}_{\text{pre}}$	Prenatal (fetus) dose factor
$^{131}\text{I } \text{DF}_{\text{rz}}$	Dose rate factor for radionuclides in the soil root zone
$^{131}\text{I } \text{DF}_{\text{usl}}$	Dose rate factor for upper soil layer or surface activity
f_{d}	Dry weight to wet weight conversion factor
$\text{FS}_{\text{chicken}}$	Chicken soil-ingestion rate
FS_{cow}	Cow soil-ingestion rate
f_{time}	Fraction of day spent outdoors
$^{131}\text{I } f_{\text{trans}}$	Translocation fraction
k_{g}	Growth rate
k_{s}	Senescence rate
l	Location of interest
$^{131}\text{I } L_{\text{proc}}$	Food processing retention fraction
ML	Mass loading factor for local soil in air
R_{io}	Ratio of indoor-air to outdoor-air activity
S	Stock tank dilution factor
$^{131}\text{I } \text{Shl}$	Shielding factor, dimensionless

Parameter Symbol	Parameter Description
¹³¹ I TF _{beef}	Beef transfer factor
¹³¹ I TF _{eggs}	Egg transfer factor
¹³¹ I TF _{milk_goat}	Goat milk transfer factor
¹³¹ I TF _{milk_herd}	Accumulated cow milk transfer factor
¹³¹ I TF _{milk_ind}	Individual cow milk transfer factor
¹³¹ I TF _{poultry}	Poultry transfer factor
th _p	Holdup time, from collection or harvest to consumption, where p is a food crop or animal product
V _d	Local deposition velocity of resuspended soil back to soil or vegetation

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: $\text{m}^2/\text{kg}(\text{dry})$

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 the 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 (desert) types.

Pinder et al. (1989) evaluated this parameter for corn and estimated an α 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 log-normal distribution described this parameter. The indicated transformed median for pasture was 0.61 with a geometric standard deviation 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 (Chamberlain and Garland 1991). Therefore, the α values derived for grasses and corn will be used across all vegetation types. The range identified by Miller (1979), 1 to 4, is representative of the 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.

Chamberlain and Garland (1991) recently reviewed the literature concerning wet and dry interception by vegetation. Table 1 of their report listed various values of α in the literature. These ranged from 0.2 (for 100-200 μm sand particles on grass) to 9.6 (for *Lycopodium* spores on moist wheat). The next highest tabulated α was 3.6 for particulate deposition on corn. The HEDR model applies primarily to dry deposition (see λ_{splash}). Therefore, the range of values selected for use is consistent with those listed in Chamberlain and Garland (1991).

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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, pp. 31-42, F.O. Hoffman and C.F. Baes III, eds. NUREG/CR-1004. 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(4):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 ^{131}I 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 phosphorus) 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:

$$\lambda_{\text{leach}} = \frac{P + I - E}{d \left[1 + \frac{\rho K_d}{\theta} \right]}$$

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/cm³)

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

θ = soil volumetric water content (mL/cm³).

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 percent. 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).

<u>County</u>	<u>Average Irrigation Rate</u>	
	<u>ft/yr</u>	<u>cm/yr</u>
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 percent, the volume of surplus irrigation water applied in the listed counties ranges from approximately 6.1 to 9.8 cm/yr (0.05 to 0.08 cm/day for a 120-day 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 values was determined by assigning values to the variables in the above equation as follows:

$$\begin{aligned} P &= 0 \\ \text{daily } I &= 0.05 \text{ to } 0.08 \\ E &= 0 \\ \rho &= 1.25 \text{ to } 1.55 \text{ (SCS 1992)} \\ K_d &= 0 \text{ to } 5 \text{ (Sheppard and Thibault 1990)} \\ \theta &= 0.05 \text{ to } 0.2 \text{ (SCS 1982).} \end{aligned}$$

The minimum and maximum values derived for the leaching rate 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 modelled 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 et al. (1985) range from $2.1\text{E-}7$ to $5.7\text{E-}2$ per day, with a best estimate of $3.2\text{E-}4$ per day. This best estimate lies within the range 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-810606-44, 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, Vol. 3, A.A. Balkema, Rotterdam, Netherlands.
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- Price, K.R. 1965. "Uptake of Iodine-131 from the Soil as Related to Root Distribution and Phenology in Sagebrush Vegetation." Ph.D. Dissertation, Washington State University, Pullman, Washington.
- SCS - U.S. Soil Conservation Service. 1982. Soil Survey of Stevens County, Washington. Soil Conservation Service, Washington, D.C.
- SCS - U.S. Soil Conservation Service. 1992. Soil Interpretation Records for Franklin County. Soil Conservation Service, Washington, D.C. (See parameter ρ_{rz} for complete listing.)
- Sheppard, M.I., and D.H. Thibault. 1990. "Default Soil Solid/Liquid Partition Coefficients, K_d s, for Four Major Soil Types: A Compendium." Health Physics 59(4):471-482.
- USDA - U.S. Department of Agriculture. 1974. 1974 Census of Agriculture, Washington State and County Data. Vol. I, Part 47, USDA, Washington, D.C.

Parameter: Percolation rate

Reference equations: DES-6
DES-7

Dependencies: radionuclide

Equation symbol: λ_{perc}

Frequency of selection: realization

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 0.91375

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 is inversely proportional to the residence halftime of the element in the upper soil layer.

The percolation rate was derived by the use of the following equation presented by Baes and Sharp (1981):

$$\lambda_{\text{leach}} = \frac{P + I - E}{d \left[1 + \frac{\rho K_d}{\theta} \right]}$$

where P = precipitation rate (cm/yr)

I = irrigation rate (cm/yr)

E = evapotranspiration rate (cm/yr)

d = depth to root zone (0.1 cm)

ρ = soil bulk density (g/cm³)

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

θ = soil volumetric water content (mL/cm³).

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 iodine-131:

$P = 0$

daily $I = 0.51$ to 0.82

$E = 0$

$\rho = 1.2$ to 1.4 (SCS 1992)

$K_d = 0$ to 5 (Sheppard and Thibault 1990)

$\theta = 0.2$.

By implementing the above values into the Baes and Sharp (1981) equation, the percolation rate ranges from 0.14 to 8.2 d^{-1} . The maximum analytical solution derived in this way is not realistically meaningful, as a result of both the very small depth of the upper soil layer and the relatively long time step used for the evaluation (i.e., 1 day). Any percolation rate constant over 1 d^{-1} essentially theorizes the percolation of iodine that was not present in the soil. Therefore, the maximum percolation rate was truncated to 1.0 .

Additional adjustments were made to the maximum λ_{perc} value as a result of the implementation of code equation DES-6. Because λ_{perc} , λ_{rad} , and λ_{splash} must

add up to 1 in this equation, the maximum λ_{perc} value was considered equivalent to $1 - \lambda_{\text{rad}} - \lambda_{\text{splash}}$. This was justified since both λ_{rad} and λ_{splash} are constants.

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-810606-44, 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, Southwestern Radiological Health Laboratory, Las Vegas, Nevada.
- SCS - U.S. Soil Conservation Service. 1992. Soil Interpretation Records for Franklin County. Soil Conservation Service, Washington, D.C. (See parameter ρ_{rz} for complete listing.)
- Sheppard, M.I., and D.H. Thibault. 1990. "Default Soil Solid/Liquid Partition Coefficients, K_d s, for Four Major Soil Types: A Compendium." Health Physics 59(4):471-482.

Parameter: Radiological decay constant

Reference equations: DES-6

Dependencies: radionuclide

DES-7

DES-8

DES-9

Frequency of selection: N/A

DES-16

CID-4

CID-5

CID-8

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): 8.625E-2

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 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:

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

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, eds. 1978. Table of Isotopes. 7th ed. John Wiley and Sons, New York.

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

Parameter: Rainsplash rate

Reference equations: DES-6
DES-8

Dependencies: none

Equation symbol: λ_{splash}

Frequency of selection: N/A

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, under some circumstances, 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-life 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 half-life 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 may be reintroduced when the crop concentrations of longer lived radionuclides are evaluated.

Reference:

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(1):177-187.

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 on the vegetation (Miller and Hoffman 1983). The weathering halftime describes the amount of time it takes 50 percent of the deposited radionuclides to be removed by weathering processes.

The weathering rate is calculated from the weathering halftime:

$$\lambda_{\text{weath}} = \frac{\ln 2}{T_{\text{weath}}}$$

where $\ln 2$ = natural logarithm of 2 = 0.693

T_{weath} = weathering halftime, days.

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 radiological half-life of a radionuclide permits the calculation of the weathering halftime as follows:

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

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:

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

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

Default Values of Other Models
(days)

Reference

14	BIOMOVs (1990)
8.1	"
10	"
11.5	"
9.1	"
14	Schreckhise (1980)
14	Napier et al. (1988)
14	NRC (1977)
12 to 14	Summarized by Hoffman (1977)
14	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. BIOMOVs Technical Report 8, Scenario B1: Atmospheric Deposition. Swedish National Institute of Radiation Protection, Stockholm, Sweden.
- Coughtrey, P.J., J.A. Kirkton, and N.G. Mitchell. 1991. "Evaluation of Food Chain Transfer Data for Use in Accident Consequence Assessment." Methods and Codes for Assessing the Off-Site Consequences of Nuclear Accidents, Vol. 1. EUR-13013/1:175-208, Athens, Greece.

- Douglas, R.L., S.C. Black, and D.S. Barth. 1971. Iodine-131 Transport Through the Air-Forage-Cow-Milk System Using an Aerosol Mist (Project Rainout). SWRHL-43r, Southwestern Radiological Health Laboratory, 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(5):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. BIOMOV5 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(12):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(3):731-744.
- Napier, B.A., D.L. Streng, R.A. Peloquin, and J.V. Ramsdell. 1988. GENII - The Hanford Environmental Radiation Dosimetry Software System, Volume 1: Conceptual Representation. PNL-6584, Vol. 1, Pacific Northwest Laboratory, Richland, Washington.
- NRC - U.S. Nuclear Regulatory Commission. 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 1. Regulatory Guide 1.109, U.S. Nuclear Regulatory Commission, Washington, D.C.
- 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 Long-Term Accumulation of Radio-contaminants 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(12):1167-1171.
- Soldat, J.K. 1965. "Environmental Evaluation of an Acute Release of ^{131}I to the Atmosphere." Health Physics 11(10):1009-1015.
- Till, J.E., and H.R. Meyer, eds. 1983. Radiological Assessment, A Textbook on Environmental Dose Analysis. 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, Pinawa, Canada.

Parameter: Root zone soil density

Reference equations: DES-14
DES-17

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)/m²

Value(s): minimum 186
maximum 230

Distribution: uniform

Technical basis: The bulk density of the soil root zone is required to determine the percolation rate, 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 Undated). The soil types evaluated are IRR = irrigated and NIRR = not irrigated.

Reference:

U.S. Department of Agriculture, Soil Conservation Service (SCS). Undated.
Soil Interpretation Records.

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: Upper soil layer density

Reference equation: DES-10
DES-17
CID-7

Dependencies: none

Frequency of selection: realization

Equation symbol: ρ_{us1}

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

Units: kg(wet)/m²

Value(s): minimum 1.10
maximum 1.45

Distribution: uniform

Technical basis: Resuspended material and a portion of the animal-ingested soil originate 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 Undated) 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/m² 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 unirrigated. The soil types evaluated are IRR = irrigated and NIRR = not irrigated.

Reference:

U.S. Department of Agriculture, Soil Conservation Service (SCS). Undated.
Soil Interpretation Records.

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)/m²

Value(s): <u>Vegetation Type</u>	<u>Central Value</u>	<u>Minimum</u>	<u>Maximum</u>
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 parameters Y (maximum wet available biomass), f_s (available monthly fraction of maximum wet biomass), and f_d (dry weight:wet weight ratio) were 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 table lists the derived average percent increase of the maximum B_{max} over the average B_{max}, as determined from the CYRs:

<u>Vegetation Type</u>	<u>Average Increase</u>	<u>Crops Used in Derivation</u>
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 non-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 tabulated below. The wet-biomass-per-acre values listed in the soil surveys were converted to the dry-kilogram-per-m² units used in DESCARTES:

<u>Crop</u>	<u>Irrigated</u>	<u>Biomass (kg/m²)</u>
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 non-irrigated wheat values. Therefore, the lower end of the listed non-irrigated wheat biomass value will be used for the minimum B_{max} value for grain in the DESCARTES code.

Minimum B_{max} values were established for pasture and grain. Information by which to empirically derive the minimum B_{max} values for other vegetation types is not readily available. Therefore, the values for the other vegetation types were inferred from the pasture and grain B_{max} values. The minimum pasture value is 33 percent of its central value, and the minimum grain value

is 64 percent of its central value. It was assumed that the minimum B_{max} values for the other vegetation types, except fruits, would be 33 percent (the more conservative of the 33 percent and 64 percent 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 percent (the rounded average of the 33 percent and 64 percent 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.
- BOR - U.S. Bureau of Reclamation. 1944. Crop Yield Reports for the Yakima Irrigation Project. Department of the Interior, Washington, D.C.
- BOR - U.S. Bureau of Reclamation. 1945. Crop Yield Reports for the Yakima Irrigation Project. Department of the Interior, Washington, D.C.
- USDA - U.S. Department of Agriculture. 1982. Soil Survey of Stevens County, Washington. Soil Conservation Service, Washington, D.C.
- USDA - U.S. Department of Agriculture. 1985. Soil Survey of Yakima County, Washington. Soil Conservation Service, Washington, D.C.
- USDA - U.S. Department of Agriculture. 1988. Soil Survey of Umatilla County, Oregon. Soil Conservation Service, Washington, D.C.

Parameter: Minimum (winter) biomass

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

Dependencies: vegetation type

Frequency of selection: N/A

Equation symbol: B_{min}

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

Units: kg(dry)/m²

Value(s):	<u>Vegetation Type</u>	<u>Central Value</u>
	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	0.008

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; Price 1965). 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:

- Price, K.R. 1965. "Uptake of Iodine-131 from the Soil as Related to Root Distribution and Phenology in Sagebrush Vegetation." Ph.D. Dissertation, Washington State University, Pullman, Washington.
- 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
CID-7

Dependencies: age

Equation symbol: BR

Frequency of selection: daily

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

Units: m³/d

Value(s):	Age (years)	Central Value	Minimum	Maximum
	0 to 0.5	1.62	0.5	4.9
	0.5 to 2	5.14	1.7	15.4
	2 to 7	8.71	2.9	26.1
	7 to 12	15.3	5.1	45.9
	12 to 17	17.7	5.9	53.9
	17+	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 1975). However, Reference Man values are presented for only a limited number of age categories; i.e., adult, 10-year-old, 1-year-old, and newborn.

The adult central value listed above assumes 16 hours of light activity and 8 hours of resting. The U.S. Environmental Protection Agency (EPA 1991) recommends a similar adult value to that listed above. The EPA (1991) also states that an inhalation rate of 20 m³/d represents a reasonable upper bound for the segment of the population that spends a majority of their time at

home; e.g., housewives and househusbands, service and household workers, retired people. A breathing rate of 30 m³/d was recommended by EPA (1989) for use as a reasonable upper bound breathing rate value for the entire adult population.

The central values of the non-adult 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) summarized 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 m³/d. Central values were determined by assuming 8 hours of rest, 8 hours of light activity, and 8 hours of moderate activity. Minimum values assumed 8 hours of rest and 16 hours of light activity. Maximum values assumed 8 hours of rest and 16 hours of moderate activity. Results, in m³/d, are listed below:

<u>Age Group</u>	<u>Central Value</u>	<u>Minimum Value</u>	<u>Maximum Value</u>
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 (1991) 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 values. The Roy and Courtay values are assumed to be more reliable as a result of their greater consideration of realistic activity levels.

The range of breathing rate values defined for each age category accounts for the uncertainties in the sizes of the individuals and their activity levels. A triangular distribution was assumed to reflect the values from Anderson et al. (1985) 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, E., N. Browne, S. Duletsky, J. Ramig, and T. Warn. 1985. Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments. EPA-600/8-85-010, U.S. Environmental Protection Agency, Office of Health and Environmental Assessment, Washington, D.C.
- ICRP - International Commission on Radiological Protection. 1975. 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.
- EPA - U.S. Environmental Protection Agency. 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.

EPA - U.S. Environmental Protection Agency. 1991. Risk Assessment Guidance For Superfund. Volume I: Human Health Evaluation Manual. Supplemental Guidance: Standard Default Exposure Factors. OSWER-9285.6-03. U.S. Environmental Protection Agency, 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): minimum 0.01
maximum 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 translocate significantly 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 CR measurements using the following ratios:

- the activity in a unit mass of plant to the initial activity uniformly amended into the soil at the beginning of the experiment
- the activity in a unit mass of plant to the final activity of the soil at the end of the experiment
- the activity in a unit mass of plant to the activity input into the hydroponic system into which the plant was grown
- the activity in a unit mass of plant to the average activity over the rooting zone for soil-surface-deposited radionuclides

Plant radionuclide concentrations used in CR measurements 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). These values should be used cautiously, however, because increased uptake is to be expected from nutrient-solution experiments (compared to pot experiments), and increased uptake is often observed in pot tests (compared field tests) (Routson 1973).

A majority of CR experiments uniformly amend the growth media when determining the CR value. However, these situations are not like that considered by the HEDR Project. In the HEDR Project, the incoming radionuclides are deposited 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 to reach the rooting zone and to be taken up by the rooting system. The residence time of iodine in the top 5 centimeters of soil is reported to be approximately 2.4 years (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 radionuclide. As a result of these considerations, some consider root uptake from the soil to be an insignificant pathway of entry into the food chain (Russell 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:

<u>Values</u>	<u>Reference</u>
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 roots in bean plants grown in an iodine-131-amended hydroponic solution. In this experiment, McFarlane and Mason (1970) indicated that 96.5 percent of the uptake was found in the roots; 2.1 percent was found in the stem; 1.1 percent was found in the leaves; and 0.2 percent 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 following table:

AIM

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Centimeter

Inches

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<u>Leafy Vegetables</u>	<u>Fruit</u>	<u>Pasture</u>	<u>Other Crops</u>	<u>Reference</u>
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 et al. (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 is summarized in Ng et al. (1982).

References:

- Ashton, J., and T.J. Sumerling. 1988. Biosphere Database for Assessments of Radioactive Waste Disposals (Edition 1). DOE/RW/88.083, Associated Nuclear Services, Epsom, United Kingdom.
- Baes, C.F., III, R.D. Sharp, A.L. Sjoeren, 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, 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 Surface Soils Based on Measured Soil Concentration Profiles." Health Physics 48(4):401-413.
- Bowling, D.J.F. 1976. Uptake of Ions by Plant Roots. Chapman and Hall, 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. A.A. Balkema, Rotterdam, Netherlands.
- Grogan, H.A. 1985. Concentration Ratios for BIOPATH: Selection of the Soil-to-Plant Concentration Ratio Database. EIR-575, Swiss Federal Institute for Reactor Research, Wuerenlingen, Switzerland.
- IUR - International Union of Radioecologists. 1989. "VIth Report of the Working Group Soil-to-Plant Transfer Factors." Report of the Working Group meeting, May 24-26, 1989, Guttannen, Grimselpass, Switzerland.
- Klepper, E.L. 1976. Radioiodine Uptake by Wheat Plants with Time After Amendment to Soil. BNWL-SA-5682, Battelle Northwest Laboratory, 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(12):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.
- NRC - U.S. Nuclear Regulatory Commission. 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, Rev. 1, U.S. Nuclear Regulatory Commission, Washington, D.C.
- Routson, R.C. 1973. A Review of Studies on Soil-Waste Relationships on the Hanford Reservation from 1944 to 1947. BNWL-1464, Battelle Northwest Laboratory, Richland, Washington.

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

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

Parameter: Immersion dose rate factor

Reference equation: CID-1
CID-6

Dependencies: radionuclide

Equation symbol: ^{131}I DF_{imm}

Frequency of selection: realization

Definition: The external dose from exposure to airborne radioactive materials.

Units: $\text{rad}_{\text{thyroid}}/\text{d}$ per Ci/m^3 and $\text{rem}_{\text{EDE}}/\text{d}$ per Ci/m^3

Value(s):

	<u>Thyroid</u>	<u>Effective Dose Equivalent</u>
minimum	2.8E+3	2.6E+3
maximum	1.1E+4	1.0E+4

Distribution: uniform

Technical basis: When an individual stands in air containing radionuclides, he or she is exposed to the decay energy of those radionuclides. The individual will thus receive a dose from the radioactive 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 (DF_{usl}) and in the soil profile (DF_{rz}).

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 $5.68\text{E}3$ rad/d per Ci/m^3 (DOE 1988). The immersion dose

conversion factor for effective dose equivalent (EDE) is $5.23\text{E}3$ rad/d per Ci/m^3 (DOE 1988). These values estimate the dose resulting from exposure to outdoor air 100 percent of the time.

DF_{imm} values are proportional to variations in the air density and the tissue mass thickness between the skin surface and the thyroid. The DF_{imm} for wholebody and EDE, as defined by DOE (1988), are assumed to be accurate. The minimum and maximum values for CIDER are assumed to differ from the central value by a factor of 2. Because DF_{imm} is not a sensitive CIDER parameter (Napier 1992), this approximation of the variation is considered adequate. A uniformly distributed range of values was chosen because little information is known about the distribution of this parameter.

References:

- DOE - U.S. Department of Energy. 1988. External Dose-Rate Conversion Factors for Calculation of Dose to the Public. DOE/EH-0070, U.S. Department of Energy, Washington, D.C.
- Napier, B.A. 1992. Determination of Radionuclides and Pathways Contributing to Dose in 1945. BN-SA-3674 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Parameter: Ingestion dose conversion factor**Reference equations:** CID-4

CID-5

Dependencies: age, sex, radionuclide

CID-8

Frequency of selection: realization**Equation symbol:** DF_{ing} **Definition:** The age- and sex-dependent thyroid dose per unit intake via ingestion.**Units:** $\text{rad}_{\text{thyroid}}/\text{Ci}_{\text{ingested}}$ or $\text{rem}_{\text{EDE}}/\text{Ci}_{\text{ingested}}$ **Value(s):**

Thyroid:	<u>Age (years)</u>	<u>Mean</u>	<u>Minimum</u>	<u>Maximum</u>
	0.25	1.4E+7	2.2E+6	5.5E+7
	1	1.3E+7	2.0E+6	5.1E+7
	5	7.8E+6	1.2E+6	3.1E+7
	10	4.1E+6	6.4E+5	1.6E+7
	15	2.5E+6	3.9E+5	9.9E+6
	Adult-male	1.4E+6	2.2E+5	5.5E+6
	Adult-female	1.7E+6	2.7E+5	6.7E+6

Effective Dose Equivalent:	<u>Age (years)</u>	<u>Mean</u>	<u>Minimum</u>	<u>Maximum</u>
	0.25	4.1E+5	6.4E+4	1.6E+6
	1	4.1E+5	6.4E+4	1.6E+6
	5	2.3E+5	3.6E+4	9.1E+5
	10	1.2E+5	1.9E+4	4.7E+5
	15	7.8E+4	1.2E+4	3.1E+5
	Adult-male	4.8E+4	7.5E+3	1.9E+5
	Adult-female	5.8E+4	9.1E+3	2.3E+5

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 concentrates 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 up to a level of saturation. Biofeedback mechanisms control the release of iodinated hormones into the blood stream.

The dose conversion factors have been 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 thyroid saturation level), and the halftime over which the iodine is stored in the thyroid (Dunning and Schwarz 1981). These factors vary among individuals and among individuals of different ages.

The ICRP recently published age-dependent dose factors for the ingestion of iodine-131 (ICRP 1990). These factors represent the internationally accepted age-dependent values and will be used in the HEDR model and, for conservatism, are considered mean values of a log (base e) distributed parameter. 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 thyroid values DF_{ing} 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 1st and 99th percentile values, respectively.

The DF_{ing} EDE normalizes the radiation dose over a number of body organs (e.g., thyroid, bone, liver). The great majority of iodine-131 in the body is found in the thyroid. When the exposure is distributed over a number of organs, the DF_{EDE} value is less than the $\text{DF}_{\text{thyroid}}$ value. The DF_{ing} EDE for adult males is that found in ICRP (1990). The adult female DF_{ing} EDE was calculated using the same male-to-female ratio of the DF_{ing} of the thyroid.

References:

- Dunning, D.E., and G. Schwarz. 1981. "Variability of Human Thyroid Characteristics and Estimates of Dose from Ingested Iodine-131." Health Physics 40(5):661-675.
- ICRP - International Commission on Radiological Protection. 1990. Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 1. ICRP Publication 56, Pergamon Press, New York.
- Ingbar, S., and L. Braverman. 1986. Werner's The Thyroid: A Fundamental and Clinical Text. 5th edition, Lippincott, Philadelphia, Pennsylvania.
- Johnson, J.R. 1982. "Fetal Thyroid Dose from Intakes of Radioiodine by the Mother." Health Physics 43(4):573-582.
- Linder, M. 1985. Nutritional Biochemistry and Metabolism. Elsevier, New York.

Parameter: Inhalation dose conversion factor

Reference equation: CID-3
CID-7

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: $\text{rad}_{\text{thyroid}}/\text{Ci}_{\text{inhaled}}$ or $\text{rem}_{\text{EDE}}/\text{Ci}_{\text{inhaled}}$

Value(s):

Thyroid:	<u>Age (years)</u>	<u>Mean</u>	<u>Minimum</u>	<u>Maximum</u>
	0.25	8.5E+6	1.3E+6	3.3E+7
	1	8.1E+6	1.3E+6	3.2E+7
	5	4.8E+6	7.5E+5	1.9E+7
	10	2.4E+6	3.8E+5	9.5E+6
	15	1.5E+6	2.3E+5	5.9E+6
	Adult-male	1.0E+6	1.6E+5	3.9E+6
	Adult-female	1.2E+6	1.9E+5	4.7E+6
EDE:	<u>Age (years)</u>	<u>Mean</u>	<u>Minimum</u>	<u>Maximum</u>
	0.25	2.5E+5	3.9E+4	9.9E+5
	1	2.5E+5	3.9E+4	9.9E+5
	5	1.4E+5	2.2E+4	5.5E+5
	10	7.4E+4	1.2E+4	2.9E+5
	15	4.8E+4	7.5E+3	1.9E+5
	Adult-male	3.0E+4	4.7E+3	1.2E+5
	Adult-female	3.6E+4	5.6E+3	1.4E+5

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, thereby not contributing 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 International Commission on Radiological Protection (ICRP) published age-dependent dose factors for the inhalation of iodine-131 (ICRP 1990). The dose factors were based on an activity median aerodynamic diameter (AMAD) of 1 μm . Future ICRP dose factor calculations may be reported for a variety of particle sizes once the new ICRP lung model is published. However, current information is based only on the one particle size. These values, assumed to be means, will be used in the CIDER calculations.

Sex-dependent dose factor (DF) 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 DF and applying that same ratio to the inhalation DF. The literature value of DF was assumed to represent the male.

The National Radiation Protection Board (NRPB) of the United Kingdom has also calculated age-dependent inhalation doses for iodine-131 (Phipps et al. 1991) in accordance with the dosimetric methodology of ICRP 56 (ICRP 1990). These values are slightly higher than the ICRP values by a factor of approximately 2 but are comparable to the reported ICRP values.

Others (Killough et al. 1978) also previously published similar values for adult thyroid inhalation DF, $1.13\text{E}6$ rad/Ci.

The DF_{EDE} normalizes the radiation dose over a number of body organs (e.g., thyroid, bone, liver). The great majority of iodine-131 in the body is found in the thyroid. When the exposure is distributed over a number of organs, the DF_{EDE} value is less than the $\text{DF}_{\text{thyroid}}$ value.

The indicated distribution, lognormal, was chosen in accordance with the distribution of the ingestion dose conversion factor. Dunning and Schwartz (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.

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 1st and 99th percentile values, respectively.

References:

- Dunning, D.E., and G. Schwartz. 1981. "Variability of Human Thyroid Characteristics and Estimates of Dose from Ingested Iodine-131." Health Physics 40(5):661-675.
- ICRP - International Commission on Radiological Protection. 1990. Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 1. ICRP 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. Vol. 1. ORNL/NUREG/TM-190, 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: Breastmilk dose factor for
a nursing baby

Reference equation: CID-7
CID-8

Dependencies: radionuclide

Equation symbol: DF_{nurs}

Frequency of selection: realization

Definition: The dose to the nursing infant per unit intake of iodine-131 by the mother.

Units: $\text{rad}_{\text{thyroid,baby}}/\text{Ci}_{\text{intake,mother}}$ or $\text{rem}_{\text{EDE,baby}}/\text{Ci}_{\text{intake,mother}}$

Value(s):	<u>Thyroid</u>	<u>EDE</u>
mean	2.4E+6	7.0E+4
minimum	3.3E+5	9.4E+3
maximum	1.0E+7	3.0E+5

Distribution: lognormal

Technical basis: This parameter is a composite of several input parameters detailed here. If compared to methodology used to calculate the dose from backyard-cow-milk ingestion, this single parameter is essentially the product of the DF_{ing} , the $\text{TF}_{\text{milk\_ind}}$, and the daily intake rate of breastmilk. The " $\text{TF}_{\text{milk\_lactating-mother}}$ " value is used instead of the $\text{TF}_{\text{milk\_ind}}$ in the evaluation of this DF_{nurs} parameter.

The appropriate values for this DF_{nurs} were resolved by separate evaluation of the lactating mother transfer factor (TF) values, use of the previously defined DF_{ing} values for a 3-month old, and literature estimates in breastmilk intake rates. The product of these three input parameters determines the DF_{nurs} parameter value.

Little research has been conducted on the lactating mother TF. The most comprehensive list of experimentally resolved values was found in Weaver et al. (1960). Adequate information to calculate TF values was

available on only four of the six patients described in the paper. The TF values are derived as follows:

$$TF = \frac{Ci_{\text{bmlk}}/L_{\text{bmlk}}}{Ci_{\text{in,mother}}/d}$$

where Ci_{bmlk} = iodine-131 activity found in the breastmilk over a 24-hour period

L_{bmlk} = liters of breastmilk collected over a 24-hour period

$Ci_{\text{in,mother}}/d$ = activity of the single iodine-131 intake of the mother per day.

The following table lists the derivational TF values for the first 24 hours of the 2-day experiment described by Weaver et al. (1960):

<u>Patient</u>	<u>mCi_{bmlk}</u>	<u>L_{bmlk}</u>	<u>mCi_{in,mother}/d</u>	<u>TF</u>
1	6.99	0.642	30	0.36
2	0.124	0.180	10	0.07
3	0.28	0.110	10	0.25
6	0.553	0.345	10	0.16

The DF_{ing} values for the 3-month old can be found on the pages describing that parameter. Infant breastmilk intake rates vary widely according to the needs of the infant, suckling ability of the infant, and the supply of milk by the mother. Over the baby's first year, daily intakes range from 0.450 liter to 1.2 liters (U.S. Institution of Medicine 1991).

These values were evaluated stochastically using the Crystal Ball utility software (Decisioneering 1993). The lactating mother TF was defined as a uniformly distributed parameter with a minimum of 0.07 and a maximum of 0.36. A uniform distribution for this parameter was chosen because of a lack of any more detailed knowledge. The DF_{ing} was defined as a lognormally distributed

parameter with a central value of $1.4\text{E}7$ rad/Ci and a geometric standard deviation of 2.0 (truncated at the 1st and 99th percentile values). The breastmilk intake rate of the infant was defined by a triangular distribution with a mode of 0.775 liters, a minimum of 0.450 liters, and a maximum of 1.2 liters. The resulting DF_{nurs} values derived by the Crystal Ball software evaluation of the product of the lactating mother TF, the 3-month-old DF_{ing} , and the breastmilk intake rate were found to be lognormally distributed with means as listed above and a geometric standard deviation of 2.1. The minimum and maximum values are the 1st and 99th percentile values of the DF_{nurs} distribution.

References:

- Decisioneering. 1993. Crystal Ball, Ver. 3. Decisioneering, Incorporated, Denver, Colorado.
- U.S. Institution of Medicine. 1991. Nutrition During Lactation. National Academy Press, Washington, D.C.
- Weaver, J.C., M.L. Kamm, and R.L. Dobson. 1960. "Excretion of Radioiodine in Human Milk." Journal of the American Medical Association 173(8):872-875.

Parameter: Dose factor for a
prenatal infant (fetus)

Reference equation: CID-7

Dependencies: radionuclide

Equation symbol: DF_{pre}

Frequency of selection: realization

Definition: The dose to a fetus per unit intake of iodine-131 by the mother.

Units: rad_{thyroid, fetus}/Ci_{intake, mother}

Value(s):	central value	2.3E+6
	minimum	1.1E+6
	maximum	4.6E+6

Distribution: triangular

Technical basis: When a pregnant woman consumes iodine-131 via inhalation or ingestion, all inorganic iodine-131 in the bloodstream freely exchanges through the placenta to the fetus. This inorganic iodine-131 is concentrated by the fetal thyroid after the 90th day of gestation. The dose to the fetal thyroid from a unit intake of iodine-131 by the mother was extensively investigated by Johnson (1982). The doses were found to increase from a 90-day to 130-day gestation, then fall steadily to the end of term. The minimum and maximum values over the gestation period ranged from 4.3E5 to 3.6E6 rad_{thyroid}/Ci_{intake, mother}.

CIDER assigns only one dose factor for the entire gestation period. The gestation period was modeled as 90 days shorter than its actual length because of the lack of a fetal thyroid activity in the first 90 days of gestation. Therefore, the modeled gestation period will be 190 days. The single dose factor used in a CIDER code realization will be the average dose factor over the 190-day gestation period. Using a weighted average approach with the Johnson (1982) values and approximating the average daily DF for gestational

days 90 to 130 ($1.8\text{E}6$ rad/Ci) and for gestational days 130 to 280 ($2.5\text{E}6$ rad/Ci), the average daily DF_{pre} for the modeled 190-day gestation period is calculated to be $2.3\text{E}6$ rad_{thyroid}/Ci_{intake, mother}.

The uncertainty of the DF_{pre} parameter is believed to be about the same order of magnitude as the postnatal dose factors (Johnson 1982). The uncertainty assigned to the lognormally distributed HEDR postnatal internal DFs (DF_{ing} and DF_{inh}) was a geometric standard deviation of 2. Therefore, due to the lack of better information this value was used to define the minimum and maximum DF_{pre} values. The minimum DF_{pre} was defined as half the calculated central value and the maximum as twice the central value. Although the postnatal internal DFs are defined as lognormally distributed, according to information presented by Dunning and Schwarz (1981), the information available on the prenatal DFs is less certain. Therefore, a less complex triangular distribution was chosen for this parameter.

References:

- Dunning, D.E., and G. Schwartz. 1981. "Variability of Human Thyroid Characteristics and Estimates of Dose from Ingested Iodine-131." Health Physics 40(5):661-675.
- Johnson, J.R. 1982. "Fetal Thyroid Dose from Intakes of Radioiodine by the Mother." Health Physics 43(4):573-582.

Parameter: Soil activity dose
conversion factor

Reference equation: CID-2
CID-6

Dependencies: radionuclide

Equation symbol: DF_{rz}

Frequency of selection: realization

Definition: The external dose 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 submersion 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 and Sjoeren (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} , the soil radionuclide was assumed to be exponentially distributed throughout the root zone for the minimum value and throughout the top 5 centimeters 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 DF_{us1} values (see DF_{us1}) because of the soil shielding consideration for radionuclides incorporated into the root zone. In fact, the independently calculated DF_{us1} values are higher than the DF_{rz} values and, therefore, will be used as reasonable estimates of thyroid dose. The DFs for the thyroid and EDE are considered equivalent.

Reference:

Kocher, D.C., and A.L. Sjoeren. 1985. "Dose-Rate Conversion Factors for External Exposure to Photons Emitters in Soil." Health Physics 48(2):193-205.

Parameter: Plane deposition dose factor

Reference equations: CID-2
CID-6

Dependencies: radionuclide

Equation symbol: DS_{us1}

Vary: realization

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

Units: $\text{rem}_{\text{thyroid}}/\text{d}$ per Ci/m^2 or $\text{rem}_{\text{EDE}}/\text{d}$ per Ci/m^2

Value(s):	Thyroid	EDE
minimum	84	77
maximum	120	110

Distribution: uniform

Technical basis: The external dose an individual receives from airborne releases includes the dose from immersion in the semi-infinite plume (see DF_{imm}), soil deposition (see DF_z), and deposition on the ground surface (DF_{us1}).

The U.S. Department of Energy reference document (DOE 1988) indicates a thyroid dose conversion factor of $1.20 \text{ rem/d per Ci/m}^2$ for iodine-131. This dose factor represents the dose to the thyroid for exposure 1 meter above the ground surface when the area is uniformly contaminated in an infinite plane. The minimum value was derived by assuming a 30-percent loss of dose due to surface irregularities (DOE 1988).

The EDE DF_{us1} values were calculated in the same manner as the thyroid DF_{us1} values. DOE (1988) indicates all EDE ground-surface DF of $110 \text{ rem/d per Ci/m}^2$ for iodine-131. The minimum value was derived assuming a 30-percent loss due to surface irregularities.

Reference:

DOE - U.S. Department of Energy. 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
CID-8

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):	<u>Vegetation Type</u>	<u>Minimum</u>	<u>Maximum</u>
	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 conversion factor values. Ensminger et al. (1990) provided the most comprehensive list.

<u>Crops</u>	<u>Ratio of Dry Weight to Wet Weight</u>	<u>Reference</u>
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	"

Crops	Ratio of Dry Weight to Wet Weight	Reference
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	"
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-orchardgrass,		"
fresh	0.25	"
Alfalfa-orchardgrass		"
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	"
Orchardgrass, 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	"

<u>Crops</u>	<u>Ratio of Dry Weight to Wet Weight</u>	<u>Reference</u>
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	"
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:

<u>Crops</u>	<u>Ratio of Dry Weight to Wet Weight</u>	<u>Reference</u>
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, C.F., III, 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, 2nd ed. Ensminger Publishing Company, Clovis, California.

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

Hawley, C.A., C.W. Sill, G.L. Voelz, and N.F. Isplitzer. 1964. Controlled Environmental Radioiodine Tests at the National Reactor Testing Station. IDO-12035, Idaho Operations Office, U.S. Atomic Energy Commission, Idaho Falls, Idaho.

USDA - U.S. Department of Agriculture. 1982. Composition of Foods: Fruits, and Fruit Juices: Raw, Processed, Prepared. U.S. Department of Agriculture, Washington, D.C.

USDA - U.S. Department of Agriculture. 1939. Food and Life. U.S. Government Printing Office. 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 over time by a chicken.

Units: kg(wet)/d

Value(s): minimum 6E-5
maximum 1.2E-2

Distribution: uniform

Technical basis: It will be conservatively assumed (i.e., worse-case) 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 least 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. 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 the 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 composed of the indicated grit.

<u>Type of Grit</u>	<u>Percent of Feed</u>	<u>Reference</u>
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 percent of the dry feed intake.

The lower range of grit intake is obtained by multiplying the minimum poultry feed intake value ($R_{v\_chicken}$ for Equation DES-16) of 0.05 kg/d by the lowest grit percentage listed above, 0.12 percent. The resulting assumed minimum soil ingestion rate is 6E-5 kg/d.

The maximum amount of grit consumed by poultry can be obtained by a similar method. If the maximum feed intake value ($R_{v\_chicken}$ for

Equation DES-16) of 0.12 kg/d is multiplied by the maximum value listed in the table above, 6.8 percent, 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. Due to the absence of data, the most conservative 0.012 kg/d soil ingestion rate is used in DESCARTES.

References:

- Ensminger, M. E., J. E. Oldfield, and W. W. Heinemann. 1990. Feeds and Nutrition, 2nd ed. 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, United Kingdom.
- USDA - U.S. Department of Agriculture. 1939. Food and Life. U.S. Government Printing Office, Washington, D.C.
- Wilhelm, L.A., and C.W. Carrick. May 1943. "There is an Answer to Poultry Feed Shortages." The U.S. Egg and Poultry Magazine, pp. 211-215.
- Winter, A.R., and E.M. Funk. 1951. Poultry, Science and Practice, 3rd ed. J.B. Lippincott Company, Chicago, Illinois.

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 over time by a cow or steer under various conditions.

Units: kg(wet)/d

Value(s):	Fraction of Time on Pasture (days)	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 radionuclides in the 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 various 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.

Reference:

Darwin, R. 1990. Soil Ingestion by Dairy Cattle. PNL-SA-17918 HEDR, Pacific Northwest Laboratory, Richland, Washington.

f_{time}

Parameter: Fraction of day spent outdoors

Reference equation: CID-1

Dependencies: age, lifestyle, sex, season

CID-2

CID-3

CID-6

Frequency of selection: realization

CID-7

Equation symbol: f_{time}

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

Units: none

Value(s): days 3-mo to 2-yr old (M & F)

<u>Season</u>	<u>Minimum</u>	<u>Central</u>	<u>Maximum</u>
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

<u>Season</u>	<u>Minimum</u>	<u>Central</u>		<u>Maximum</u>
	<u>M & F</u>	<u>M</u>	<u>F</u>	<u>M & F</u>
Urban winter	0.04	0.10	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

Older than 17 yr

<u>Season</u>	<u>Minimum</u>	<u>Central</u>		<u>Maximum</u>
	<u>M & F</u>	<u>M</u>	<u>F</u>	<u>M & F</u>
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: Few data exist 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 are 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. Historical 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 (Konz et al. 1989). The document references two authors who studied the time individuals spent indoors and outdoors in the early 1970s. The survey included Washington, D.C., area residents and "worldwide" individuals. These authors indicated an overall annual average of 8 percent (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 Konz et al. (1989). The 1985 values listed in this document are listed as hours per week in various activities during the school year. Based on assumptions about whether an activity is done indoors or outdoors, boys 3 to 17 years old spend approximately 12 percent of their time outdoors and girls 3 to 17 years old spend approximately 9 percent of their time outdoors. These EPA values reinforce approximated values listed above (average winter, spring, and summer for boys = 9 percent and for girls = 7 percent).

Reference:

Konz, J., K. Lisi, E. Friebele, and D.A. Dixon. 1989. Exposure Factors Handbook. EPA/600/8-89-043, U.S. Environmental Protection Agency, Washington, D.C.

Parameter: Translocation fraction

Reference equation: DES-5

Dependencies: radionuclide

Equation symbol: f_{trans}

Frequency of selection: realization

Definition: The fraction of activity moved from the outer vegetation compartment to the inner vegetation compartment.

Units: none

Value(s):	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 models translocation as a rate constant that is calculated from the f_{trans} and λ_{weath} parameters (Equation DES-5).

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. CR, a related parameter, evaluates the plant tissue radionuclide concentration that results primarily 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, the translocation mechanism and experimental values were investigated.

Stomata are pores in plant surfaces that exchange gases. Stomatal diffusion into the plant has been identified as an important foliar entry way 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 nonparticulate 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 table lists experimentally derived values of translocation:

<u>Translocation Fraction</u>	<u>Reference</u>
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.

<u>Translocation Fraction</u>	<u>Reference</u>
0.01	Schreckhise (1980)

The range of values was selected to reflect the range of experimental values reported in the literature. The loguniform distribution was selected based on 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, C.F., III, 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(12):1149-1157.
- Bowling, D.J.F. 1976. Uptake of Ions by Plant Roots. Chapman and Hill, 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. 1960. Iodine-131 Removal From Leaves. HW-65500, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.
- Hungate, F.P., A. Selders, R.L. Uhler, and J.F. Cline. 1963. "Foliar Sorption of Iodine-131 by Plants." Health Physics 9(12):1159-1166.
- 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(3):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 Half Life of Fallout Radionuclides on Plants with Special Emphasis on Iodine-131. UCRL-12388, University of California, Lawrence Livermore Laboratory, Livermore, California.

Parameter: Growth rate constant

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

Dependencies: vegetation type

Frequency of selection: N/A

Equation symbol: k_g

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

Units: d^{-1}

Value(s):	<u>Vegetation Type</u>	<u>Value</u>
	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_g values.

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.
- Whicker, F.W., and T.B. Kirchner. 1987. "PATHWAY: A Dynamic Food-Chain Model to Predict Radionuclide Ingestion after Fallout Deposition." Health Physics 52(6):717-737.

k_s

Parameter: Senescence rate constant

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

Dependencies: vegetation type

Frequency of selection: N/A

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):	<u>Vegetation Type</u>	<u>Value</u>
	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.

Reference:

Whicker, F.W., and T.B. Kirchner. 1987. "PATHWAY: A Dynamic Food-Chain Model to Predict Radionuclide Ingestion after Fallout Deposition." Health Physics 52(6):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 cells that identifies the HEDR study region.

Units: none

Value(s): integer values from 1 to 1102

Distribution: none

Comment: The HEDR study area (Figure 6.1) was originally divided into 2091 cells with a uniform grid of 41 squares by 51 squares. This original grid blocked the HEDR study region into approximately 6-x-6-mile squares. Based on the level of detail required to estimate doses, the 2091 cells were reduced to a total of 1102 cells. The outer six layers of squares on the west and south sides of the region and the outer nine layers of blocks on the north and east sides of the region were modified into larger blocks. Each of the larger blocks are composed of a 3-x-3 square block of the original, smaller squares (see Figure 6.1). The larger squares are approximately 18 x 18 miles.

Each square in the figure is identified by a unique integer label. Grid squares are numbered west to east starting in the southwest corner of the HEDR study region.

FIGURE 6.1. Hanford Environmental Dose Reconstruction Project Study Area

Parameter: Food processing retention fraction

Reference equations: CID-5

Dependencies: vegetation type, radionuclide

Equation symbol: L_{proc}

Frequency of selection: realization

Definition: The fraction of activity retained by the exterior vegetative surfaces of leafy vegetables and fruits during food processing and preparation.

Units: none

Value(s):   Leafy vegetables, fruit   minimum   0.15
                                                                 maximum   0.75

Distribution: uniform

Technical basis: The exterior surfaces of crops are typically washed with running water at some point before ingestion. This washing is assumed to remove a portion of the particulate and water-soluble activity from food crop surfaces. 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 percent and 70 percent of the activity, respectively. It was noted that the 5-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 percent of the iodine. Later descriptions of this same experiment (Hungate et al. 1963) reported that a 40-percent decrease

in removable iodine was noted over a 3-day 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 vegetation contaminated with elemental iodine and methyl iodide, 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 percent) 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 percent. Washing in this experiment was less vigorous than the Hungate et al. experiments (1960, 1963). Garland and Cox (1984) washed the bean leaves with 5 milliliters 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 1 hour.

Thompson (1967) summarized that various experiments reported reductions of spinach and lettuce activity from 50 to 85 percent as a result of washing. A fractional loss value of 0.65 (65 percent) was suggested for use for all fruits and vegetables.

Others have included washing losses in computer codes similar to DESCARTES. Boone and Ng (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.

<u>Food Product</u>	<u>Removal Fraction</u>
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 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 produce. Therefore, it was desirable to maintain the constant L_{proc} 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.D. Stewart, R.L. Uhler, and J.F. Cline. 1960. Iodine-131 Removal from Leaves. HW-65500, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.
- Hungate, F.P., A. Selders, R.L. Uhler, and J.F. Cline. 1963. "Foliar Sorption of Iodine-131 by Plants." Health Physics 9(12):1159-1166.
- 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(3):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, J.C., Jr. 1967. "Reconsideration of the Iodine-131 Contribution from Fruits and Vegetables." Health Physics 13(8):883-887.

ML

Parameter: Mass loading

Reference equations: DES-10
CID-3
CID-7

Dependencies: none

Frequency of selection: realization

Equation symbol: ML

Definition: The mass of particulates in 1 m³ of outdoor air.

Units: kg(dry)/m³

Value(s):	median	7E-8
	minimum	1.4E-8
	maximum	3.5E-7

Distribution: lognormal

Technical basis: Mass loading (ML) 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 ML values as a part of the inhalation dose calculation (Equation CID-3).

Airborne iodine can be found in two major physical forms: gaseous iodine and iodine 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 resuspended activity. 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 EPA's National Air Data Branch (EPA 1992). The data indicate the median and geometric standard deviation of total suspended particulates (TSP) for each location where data were recorded. The TSP measurements were taken an average of 8 meters 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 1st and 99th 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, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Las Vegas, Nevada.
- EPA - U.S. Environmental Protection Agency. 1992. National Air Data Branch, Aerometric Information Retrieval System. Total suspended particulate information for Pendleton, OR (1 location, 1985-1987), Kennewick, WA (1 location, 1985-1988), and Spokane, WA (12 locations, 1985-1988).

R_{io}

Parameter: Indoor-to-outdoor air activity ratio   Reference equation: CID-3
CID-7

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 radionuclide concentration 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 percent.

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-meter 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_{10} 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); i.e., 0.35.

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: Stock tank dilution factor

Reference equations: DES-17

Dependencies: none

Frequency of selection: realization

Equation symbol: S

Definition: The factor accounting for dilution of atmospheric deposits in water in farm animal drinking supplies.

Units: m^{-1}

Values:	central value	1.0
	minimum	0.2
	maximum	1.6

Distribution: triangular

Technical basis: Ikenberry (1992) prepared an algorithm for estimating the concentration of atmospherically deposited radionuclides in the water consumed by farm animals. This algorithm considered both the surface area of the pond or stock tank and the volume. Because it is not possible to adequately model the various sizes and shapes of all ponds and stock tanks, a simplified version of the Ikenberry (1992) algorithm was implemented in the DESCARTES computer code. For a container of uniform shape, the ratio of area to volume is the depth. In the simplified implementation, the inverse of the depth is used as a multiplier rather than dividing by the depth.

Farm animals may obtain water from various sources. This may be a man-made tank, a small pond, or other natural water body. The depth of the water may range from shallow (as in a small tank) to quite deep (as in a large pond or lake). The range of inputs was subjectively selected to encompass these possible differences. The central value of 1.0 meter is intended to resemble a standard stock tank. The maximum depth of 5 meters (corresponding to the

minimum dilution factor of 0.2 m^{-1}) was chosen as a reasonable maximum average depth of a large pond. The minimum depth of 0.6 meters (corresponding to the maximum dilution factor of 1.6 m^{-1}) represents a shallow source.

Reference:

Ikenberry, T.A. 1992. Determination of the Contribution from Livestock Water Ingestion to Dose from the Cow-Milk Pathway. BN-SA-3672 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Parameter: Shielding factor

Reference equations: CID-1
CID-2
CID-6

Dependencies: radionuclide

Frequency of selection: realization

Equation symbol: Sh1

Definition: The 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 for individuals who are 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 be applied to account for the shielding provided by the building in which an individual is located.

This factor also incorporates the effect of the non-uniform mixing of indoor and outdoor air in Equation CID-1. The ventilation rate of the occupied room or building is indicative of the ratio of the indoor-to-outdoor air concentrations, the R_{i0} parameter of Equation CID-3. There is a wide margin of uncertainty about the estimates of both the shielding factor and the

ratio of indoor-to-outdoor air concentrations of radionuclides. Therefore, these two variables are considered together in the shielding factor parameter of Equation CID-1.

The shielding 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; i.e., none of the outdoor air and soil decay energy reaches the indoor individual. This case would exist if an individual always remained well within a building that was constructed of dense materials. This situation is extremely unlikely throughout the entire study period; 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); i.e., the indoor level is reduced to 15 to 30 percent of the outdoor level. Lower shielding factors indicate more attenuation of photon energy and, therefore, less exposure. 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.

The maximum immersion shielding factor would result from low-density building materials and the individual remaining near an exterior wall. A higher shielding factor indicates little attenuation and, therefore, more exposure. To calculate the minimum shielding factor for iodine-131, a building was assumed to be constructed of 3-millimeter-thick glass. The attenuation calculation, listed below, produced the immersion shielding value of 0.93. As a comparison, a maximum value obtained by a model building

constructed of 3-centimeter-thick pine produces a maximum immersion shielding value of 0.90. The equation used to calculate the maximum immersion shielding factors is:

$$\text{Sh1} = e^{-(\mu \cdot x \cdot \rho)}$$

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 will be used for both cases.

Individuals are mobile within a building and among buildings. A uniform distribution was selected for this parameter to represent this mobility. Selection of a single Sh1 value in a realization would represent an average Sh1 value over the time period evaluated.

Reference:

Burson, Z.G., and A.E. Profio. 1977. "Structure Shielding in Reactor Accidents." Health Physics 33(3):287-299.

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 per Ci_{intake}/d = d/kg(wet)

Value(s): minimum 0.004
maximum 0.054

Distribution: uniform

Technical basis: Iodine-131 will be absorbed into the bloodstream through both ingestion and inhalation routes of beef cattle. The blood circulates the iodine-131 through the biological system. This results in the presence of iodine-131 in the muscle of beef cattle through which the blood circulates. Transfer factor values for beef indicate the ratio of the iodine-131 activity in the muscle to the daily iodine-131 activity intake.

Much less experimental research has been conducted on the transfer factor for beef compared to that of milk. This is primarily a result of the lower intake rates of beef.

A value of 1.0E-2 is the recommended beef transfer factor published in a recent National Council on Radiation Protection and Measurements (NCRP) document (NCRP 1986). This value can be thought of as an upper-bound value because its use is intended to produce a conservative dose estimate.

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

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

A recent experiment (Handl and Pfau 1989) reported iodine transfer factors for beef ranging from $7.3\text{E-}3$ d/kg(wet) to $5.4\text{E-}2$ d/kg(wet). These values resulted from long-term feeding (53 days) of iodine-129.

The few experiments investigating the TF_{beef} were summarized to produce the minimum and maximum values listed. A uniform distribution was chosen due to lack of information to justify a more complex distribution.

References:

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

- NCRP - National Council on Radiation Protection and Measurements. 1986. Screening Techniques for Determining Compliance with Environmental Standards. NCRP Commentary No. 3, Bethesda, Maryland.
- NRC - National Research Council. 1963. Damage to Livestock from Radioactive Fallout in the Event of Nuclear War. Publication 1078, National Academy of Sciences, 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, Pinawa, 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 per Ci_{intake}/d = d/kg(wet)

Value(s): minimum 1.5
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). The results in Okonski et al. (1961) indicate an equilibrium TF_{eggs} for egg contents of 1.7 d/kg during a chronic intake experiment; equilibrium was found to be established after 7 days. The variance about Okonski et al. (1961) values was approximately 10 percent 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 (TF) 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 five observations of egg transfer factor values. The values ranged from 3.7 to 5.2, with a suggested 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 density function 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, F.R., P.L. Wright, T.M. Ferguson, and D.L. Anderson. 1964. "Fission Product Metabolism in Hens and Transference to Eggs." Health Physics 10(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." UCRL-82545-Rev. 1. University of California, Lawrence Livermore Laboratory, Livermore, California.
- Okonski, J., F.W. Lengemann, and C.L. Comar. 1961. "Incorporation of Iodine-131 into Chicken Eggs." Health Physics 6(1/2):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, Pinawa, Canada.

Parameter: Transfer factor for goat milk

Reference equation: DES-17

Dependencies: radionuclide

Equation symbol: TF_{ap}

Frequency of selection: realization

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

Units: $\text{Ci}_{\text{milk\_goat}}/\text{L}$ per $\text{Ci}_{\text{intake}}/\text{d} = \text{d/L}$

Value(s):	mean	0.27
	minimum	0.04
	maximum	1.15

Distribution: lognormal

Technical basis: 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 TF values. Milk obtained from goats that consumed radioiodine will contain a fraction of that radioiodine intake.

The iodine-131 inhalation intake of goats was not evaluated in the HEDR Project. Ingestion intakes are expected to be significantly greater than inhalation intakes. Hawley et al. (1964) found that inhalation intakes for cows are 1/12 to 1/65 the ingestion intake from pasture consumption. Booth et al. (1971) reported investigating the inclusion of cow respiration and

skin absorption contributions in their model, but found them to be unimportant in comparison with the forage uptake. These findings for cows are assumed to hold true for goats.

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).

Much less research has been conducted to identify the TF of goat milk, compared to that for cow milk. This resulted from their relative rates of consumption in the general population. Most of the research identified higher TF values for goats, which can lead to higher milk ingestion doses for the segment of the population that consumes goat milk instead of cow milk.

Experiments by Bondietti and Garten (1984) indicated the TF as $\text{kg}_{\text{intake.pasture}}/\text{L}_{\text{milk}}$. To determine the TF value in the d/L units used in the HEDR model, the Bondietti and Garten (1984) values were divided by the goat feed intake rates assumed in the HEDR model (1.2 to 4.5 kg/d). The average TF rates for the 12 goats ranged from 0.04 to 0.5 d/L. The lower end of this range includes some error because the goats escaped from their confinement and consumed some uncontaminated pasture.

Lengemann and Wentworth (1966) conducted experiments using up to 14 goats. Their results indicated average TF rates ranging from 0.06 to 0.3 d/L.

Lengemann (1970) also conducted several chronic intake experiments on 22 goats. Average TF values ranged from 0.37 to 0.62 d/L. The entire range of average values found in nine goats over the experimental period varied from approximately 0.08 to 0.5 d/L. A relatively large variation of TF values was found among goats, greater than that found in dairy cows.

Average TF rates for two of the above experiments were 0.3 d/L and 0.12 d/L (Bondietti and Garten 1984) and 0.4 d/L (Lengemann 1970). The average of these values was found to be 0.27 d/L. This also is the average of the midpoints of the ranges for all three of the above citations and will be used as the mean $\text{TF}_{\text{milk\_goat}}$ value. This value is within the range of those used or recommended by others; e.g., 0.21 d/L (Stevens et al. 1992) and 0.43 (Hoffman 1979).

There is no indication that the distribution of $\text{TF}_{\text{milk\_goat}}$ values would differ from that of cows, since the biologic and physiologic process of milk production in each animal is the same. Therefore, a lognormal distribution was chosen for this parameter as indicated by Hoffman and Baes (1979) for the cow milk TF.

The range of TF values of different goats is said to be wider than that found in dairy cows. This was interpreted to mean that the absolute variability rather than the relative variability, was greater. Therefore, the same geometric standard deviation (2.1) was used for the $\text{TF}_{\text{milk\_goat}}$ as was used for $\text{TF}_{\text{milk\_ind}}$. The greater mean TF for goat milk results in a greater range of goat milk TF values. The minimum and maximum values were calculated as the 1st and 99th percentile values, respectively. A transfer factor greater

than 1, as indicated for the 99th percentile value, is valid in situations where the goat produces less than 1 L/d of milk.

References:

- Bondietti, E.A., and C.T. Garten, Jr. 1984. Transfer of ^{131}I and ^{95m}Tc from Pasture to Goat Milk. CONF-8410157--4, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- 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." Conf-710818-2, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
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^{131}I TF_{milk_goat}

Stevens, W., J.E. Till, D.C. Duncan, J.L. Lyon, R.A. Kerber, S. Preston-Martin, S.L. Simon, M.L. Rallison, and R.D. Lloyd. 1992. Assessment of Leukemia and Thyroid Disease in Relation to Fallout in Utah. Prepared for the National Cancer Institute, Bethesda, Maryland, by the University of Utah, Salt Lake City, Utah.

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 1 liter of the pooled milk.

Units: Ci_{milk_herd}/L per Ci_{intake}/d = d/L

Value(s): mean   1.2E-2
                 minimum   7.3E-3
                 maximum   1.6E-2

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 TF values for cow milk. Milk obtained from cows that consumed radioiodine will contain a fraction of that radioiodine intake.

The iodine-131 inhalation intake of cows was not 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 from pasture. 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 TF of radioiodine to cow's 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 have been 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 measured in individual cows are listed in the following table. 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 the d/L units used in the HEDR code.

<u>Transfer Factor, d/L</u>	<u>Reference</u>
approx. 7E-3 (single)	Garner et al. (1960)
approx. 8E-3 (single)	Comar et al. (1967)
approx. 1E-2 (single)	Lengemann (1963)
approx. 3E-3 (single)	Auraldsson et al. (1971)
approx. 3E-3 (single)	Bretthauer et al. (1972)
approx. 2.9E-2 (single) approx. 3.4E-2	Garner and Jones (1960)
approx. 1.1E-2	Lengemann and Comar (1964)
approx. 5.0E-3 to 1.7E-2	Lengemann (1965)
approx. 4.5E-2 to 6.1E-2	Douglas et al. (1971)
approx. 2.2E-2 to 6E-3	Mason et al. (1971)
3.5E-3	Hawley et al. (1964)
1.4E-3 to 7.6E-3	Black et al. (1971)
1.0E-3 to 1.3E-2	
1.0E-3 to 2.9E-3	
3.5E-3 to 8.8E-2	
8.3E-4 to 2.2E-2	
4.7E-3 to 2.2E-2	

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 TF_{milk_herd} central value was calculated by assuming the herd was a collection of individual cows whose TF values are described by the HEDR TF_{milk_ind} definition.

The distribution of $\text{TF}_{\text{milk\_herd}}$ was determined by assuming a herd size of 25. The random selection of 25 individual cow TF values ($\text{TF}_{\text{milk\_ind}}$) would be averaged and plotted. This selection and averaging procedure continued until a normal distribution emerged from the summation of the many lognormal values for an individual cow.

The consideration of milk from a collection of cows will narrow the variance on the TF value according to the central limit theorem (Remington and Schork 1985). The standard deviation of the $\text{TF}_{\text{milk\_ind}}$ 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 $\text{TF}_{\text{milk\_herd}}$ is, therefore, 0.002. Minimum and maximum $\text{TF}_{\text{milk\_herd}}$ values were calculated as the 1st and 99th percentile values, respectively. The DESCARTES code uses a normal distribution with a mean of 0.012 and a sigma of 0.002.

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.
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- Bretthauer, E.W., A.L. Mullen, and A.A. Moghissi. 1972. "Milk Transfer Comparisons of Different Chemical Forms of Radioiodine." Health Physics 22(3):257-260.

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- 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(1):55-59.

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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, 2nd ed. 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):881-898.

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 1 liter of milk.

Units: $\text{Ci}_{\text{milk\_ind}}/\text{L}$ per $\text{Ci}_{\text{intake}}/\text{d} = \text{d}/\text{L}$

Value(s): median   9.2E-3
                 minimum   1.6E-3
                 maximum   5.2E-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 TF values. Milk obtained from cows that consumed radioiodine will contain a fraction of that radioiodine intake.

The iodine-131 inhalation intake of cows was not 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 from pasture consumption. 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 have been 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 the d/L units used in the HEDR code.

<u>Transfer Factor, d/L</u>	<u>Reference</u>
approx. 7E-3 (single)	Garner et al. (1960)
approx. 8E-3 (single)	Comar et al. (1967)
approx. 1E-2 (single)	Lengemann (1963)
approx. 3E-3 (single)	Auraldsson et al. (1971)
approx. 3E-3 (single)	Bretthauer et al. (1972)
approx. 2.9E-2 (single)	Garner and Jones (1960)
approx. 3.4E-2	
approx. 1.1E-2	Lengemann and Comar (1964)
approx. 5.0E-3 to 1.7E-2	Lengemann (1965)
approx. 4.5E-2 to 6.1E-2	Douglas et al. (1971)
approx. 6E-3 to 2.2E-2	Mason et al. (1971)
3.5E-3	Hawley et al. (1964)
1.4E-3 to 7.6E-3	Black et al. (1971)
1.0E-3 to 1.3E-2	"
1.0E-3 to 2.9E-3	"
3.5E-3 to 8.8E-2	"
8.3E-4 to 2.2E-2	"
4.7E-3 to 2.2E-2	"
0.01	Michon and Jeanmaire (1963)
2.0E-3 to 1.8E-2	Bertilsson et al. (1988)

The lognormal distribution for the milk TF was selected as a result of evidence provided by Hoffman and Baes (1979). A geometric standard deviation of 2.1 was assumed from the values listed above. Minimum and maximum values were calculated as the 1st and 99th percentile values, respectively. The

DESCARTES code input values are for a lognormal (base e) distribution using a log_e(median) of -4.68855 and a sigma of 0.74157.

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- 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.

Michon, G., and L. Jeanmaire. 1963. Study of the Contamination of Livestock During Periods of Radioactive Fall-Out. HW-TR-73, Translation by E.R. Appleby, June 1964. General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Silva, J. 1985. "Effects of Iodine and Iodine-Containing Compounds on Thyroid Function." Medical Clinics of North America 69(5):881-898.

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: $\text{Ci}_{\text{chicken}}/\text{kg}$ per $\text{Ci}_{\text{intake}}/\text{d} = \text{d}/\text{kg}(\text{wet})$

Value(s):   minimum   4.0E-3
                  maximum   9.4E-2

Distribution: uniform

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

Ennis et al. (1988) specifically addressed the question of chicken meat TFs. 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 translocation of iodine-131 to eggs. Okonski et al. suggested that TFs to egg albumen would be indicative of $\text{TF}_{\text{poultry}}$ values. Their research reported an average albumen TF of 1 percent of the daily intake per 100 grams (1E-1 d/kg) with a standard deviation of ± 30 percent.

The NRC Regulatory Guide 1.109 (NRC 1977) recommends a value of $2.9\text{E-}3$ d/kg for use for all meat products. Zach (1980) uses a poultry TF value of $4\text{E-}3$ 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.

References:

- Ennis, M.E., Jr., 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(2):167-170.
- Okonski, J., F.W. Lengemann, and C.L. Comar. 1961. "Incorporation of Iodine-131 into Chicken Eggs." Health Physics 6(1/2):27-31.
- NRC - U.S. Nuclear Regulatory Commission. 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, 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, Pinawa, Canada.

th_p

Parameter: Holdup time

Reference equations: CID-4

CID-5

Dependencies: crop or animal product, month of consumption

CID-8

Equation symbol: th_p

Frequency of selection: realization

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

Units: d

Value(s):	Food Type	Minimum	Maximum
	Leafy vegetables, ^(a) other vegetables, fruit, grain	0.0	7.0
	Backyard cow or goat milk	0.0	2.0
	Commercial cow milk	1.0	4.0
	Stored milk products	14.0	60.0
	Beef	7.0	21.0
	Poultry	2.0	10.0
	Eggs	0	21.0

(a) 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 holdup times in order that a conservative amount of radiologic decay would result.

th_p

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 of 30 days used in the Phase I code.

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

<u>Vegetation Type</u>	<u>Fresh Harvest Months</u>
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 holdup 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.

th_p

Reference:

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 HEDR, Pacific Northwest Laboratory, Richland, Washington.

V_d

Parameter: Deposition velocity of resuspended material

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: $[\mu\text{Ci}/\text{m}^2 \text{ per } (\mu\text{Ci}\cdot\text{s})/\text{m}^3] \times (\text{s}/\text{d}) = \text{m}/\text{d}$

Value(s): minimum 86.4 m/d
maximum 2.59E3 m/d

Distribution: uniform

Technical basis: The local deposition velocity reflects the rate at which airborne soil particles will accumulate on the vegetative surfaces. This process is one of three that accumulate radionuclides on vegetative surfaces (the others being deposition from the passing plume and rainsplash). 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.

<u>Particle Diameter (μm)</u>	<u>Value (cm/s)</u>	<u>Reference</u>
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 (not μm)	0.004 and 0.008	"
< 1	0.03 to 0.03	"
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-centimeter 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/cm³) 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 cm/s (Sehmel 1980) and 1.0 to 2.4 cm/s (Hoffman 1977).

The minimum and maximum deposition velocities were chosen to represent the range of values provided by Sehmel (1980) and Hoffman (1977), 0.1 cm/s (86.4 m/d) and 3.0 cm/s (2.59E3 m/d). No information is available on the distribution of deposition velocity values. 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(11):519-550.
- Fisher, H.L. 1966. Deposition Velocities of Aerosols and Vapors on Pasture Grass. URCL-14702, University of California, Lawrence Radiation Laboratory, Livermore, California.
- Gifford, F.A. 1962. "Surface Deposition of Airborne Material." Nuclear Safety 3(4):76-80.
- 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(5):437-441.
- Sehmel, G.A. 1980. "Particle and Gas Dry Deposition: A Review." Atmospheric Environment 14(9):983-1011.
- Whicker, F.W., and V. Schultz. 1982. Radioecology: Nuclear Energy and the Environment. CRC Press, Boca Raton, Florida.

7.0 COLUMBIA RIVER PATHWAY PARAMETER DESCRIPTIONS

Descriptions of individual parameters used in the CRD code are found in this section. The material in this section was not included in the first publication of this document (Snyder et al. 1992). As with the air pathway parameters, each river pathway parameter is presented alphabetically with Greek symbols before the Arabic.

7.1 TECHNICAL APPROACH

There are pronounced differences in the technical approach used in the development of the CRD parameters and those used for the air pathway parameters. The magnitude of the radiation dose which individuals received from Columbia River pathways was significantly smaller than that of the air pathway. Therefore, considerable effort and energy was spent investigating accurate and precise values for air pathway parameters. Less effort was spent investigating most river pathway parameters. The decreased effort does not imply less accurate numbers. It does, however, imply more uncertainty in the value selected for a number of the parameters.

Several approaches were taken to define river pathway parameter values. Dose factors were developed in a manner similar to that of the air pathway, although only adult dose factors are reported. Bioconcentration values for Columbia River biota were developed after the compilation of historical Hanford monitoring data. This effort was necessary due to the scarcity of information in the scientific literature and the uniqueness of nutrient supply and transport specific to individual river systems. Water concentrations and plume correction factors were developed by the Surface-Water Transport Subtask. The remainder of the parameters were investigated by the review of past Hanford annual environmental reports. These parameters pertained to local demographic characteristics and water treatment systems.

Each parameter discussion is organized in a uniform format, similar to that of the air pathway parameters. Because CRD parameters are deterministic (single-value) rather than stochastic, the page format was modified to reflect this change.

Although the CRD models are deterministic, uncertainty and sensitivity analyses were performed for two types of representative individuals at two locations (Farris et al. 1994). Uncertainty distributions were required for these analyses. Distributions for bioconcentration factors were developed concurrently with the central estimates from Hanford historical measurements (Thiede et al. 1994). Distributions for dose conversion factors and some of the other parameters were determined subjectively through self-assessment. Distributions not reported elsewhere (e.g., Thiede et al. 1994) are given in this report.

Three "representative individuals" were specifically modeled for the CRD code results. The intake and usage factors for each representative individual are summarized at the beginning of the parameter descriptions. Rather than develop separate descriptions for each individual parameter, the values are summarized together to facilitate comparisons among individuals.

The headings used for the remainder of the CRD parameter description pages are defined as follows:

Parameter: Brief, descriptive name for the parameter.

Dependencies: Other model parameters or conditions upon which the value of the parameter being discussed depends.

Reference equations: CRD reference equations that use the parameter (see Section 2.2.1).

Equation symbol: Generic form of the parameter. Parameter subscripts are those used in the CRD reference equations (see Section 2.2.1). The subscript of the parameter being discussed may differ. Parameter discussions address specific cases of the generic form.

Definition: Definition of the parameter as it is used in CRD.

Units: Units for the parameter values.

Values: Values used for the parameter in CRD. Scientific notation is often used (e.g., 2E-7 is equivalent to 2×10^{-7}).

Technical basis: Summary of the method used to generate the parameter value(s).

References: List of references cited in the technical basis section.

7.2 REFERENCES

Farris, W.T., B.A. Napier, J.C. Simpson, S.F. Snyder, and D.B. Shipler. 1994. Columbia River Dosimetry Report, 1944-1992. PNWD-2227 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Snyder, S.F., W.T. Farris, B.A. Napier, T.A. Ikenberry, and R.O. Gilbert. 1992. 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. PNWD-2023 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Thiede, M.E., D.J. Bates, E.I. Mart, and R.W. Hanf. 1994. A Guide to Environmental Monitoring, 1945-1972. PNWD-2226 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

7.3 CRD PARAMETERS

<u>Parameter Symbol</u>	<u>Parameter Description</u>
various	Representative individual assumptions
λ_j	Radiological decay constants
$BCF_{b,j}$	Waterfowl bioconcentration factors
$BCF_{fw\ i,j}$	Freshwater fish bioconcentration factors
$DF_{ing,j,o}$	Ingestion dose factors
$DF_{sub,j,o}$	Submersion dose factors
f_{w2}	Treated water retention fraction
P_{act}	Resident duck probability
x	HEDR river segments

Parameter: Representative individual assumptions

Reference equations: see below

Equation symbol: see below

Dependencies: month

Definition: Intake, usage, and holdup time assumptions for CRD code average and representative individuals.

Units and values: See tables.

Technical basis: The CRD code requires ingestion rates and usage factors for each pathway evaluated. The behaviors of all individuals exposed to Columbia River pathways vary. The pathways considered are: human ingestion of fresh-water fish (omnivorous, predator1, and predator2 types), salmon, shellfish, waterfowl, and Columbia River water, and two external exposure pathways (i.e., fishing or boating and swimming).

Reference values were defined for each representative individual's usage and intake rates for each pathway. The usage and intake values vary by month. Holdup times, the time between removal from the river and consumption, must also be defined for the reference individual because of the short half-life of most of the radionuclides evaluated. The assumed holdup times are tabulated below.

Although these assumptions are not statistically rigorous, they are believed to be reasonable. Assumptions are based on values used in historical estimates of intake rates in the region as reported in Hanford Site annual environmental reports from 1958 to 1970 (references summarized in Soldat et al. 1986), current "average individual" model assumptions, and the authors' judgment.

Only the holdup times used for dose estimates for representative individuals were varied in the uncertainty/sensitivity analyses because these times could also apply to any real individual.

<u>Parameter</u>	<u>Equation Symbol</u>	<u>Reference Equation</u>
Ingestion of:		
freshwater fish, 1	$R_{fw\ 1}$	CRD-4
salmon	R_{sal}	CRD-11
shellfish	R_{shell}	CRD-10
waterfowl	R_b	CRD-5
Drinking water intake		
treated water	R_{w2}	CRD-7
untreated water	R_{w1}	CRD-6
Fishing or boating duration	E_x	CRD-8
Swimming duration	E_x	CRD-9
Holdup times	th_p	CRD-4,5,6,7,10,11

Food Type	Holdup Time	Range	Distribution
Columbia River	omnivores-7	1-14-60	triangular
freshwater fish	predators-2	1-2-14	triangular
Salmon	15	1-2-14	triangular
Shellfish	7	1-2-14	triangular
Waterfowl	7	1-2-14	triangular
Treated water	1	0.5-1.0-3.0	triangular
Untreated water	0	0.0	constant

Maximum Reference Individual Parameters

Parameter	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
CRD food ingestion (kg wet)													
omnivorous fish	3.0	2.0	0.2	0.2	0.0	0.0	0.0	0.2	1.1	2.0	2.0	3.0	13.7
predator1 fish	0.3	1.2	2.8	2.8	3.0	3.0	3.0	2.8	2.0	1.2	1.2	0.3	23.6
predator2 fish	0	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.1	0.1	0	2.3
salmon	-	-	-	-	-	-	-	-	-	-	-	-	2.5
shellfish	-	-	-	-	-	-	-	-	-	-	-	-	0.45
Waterfowl ingestion (kg wet)	5	5	0	0	0	0	0	0	0	0	5	5	20
Drinking water intake (L)													
treated	61	61	61	61	61	61	61	61	61	61	61	61	732
untreated	0	0	0	1	1	1	1	1	1	1	1	0	8
Boating or fishing (h)	42	42	42	42	42	42	42	42	42	42	42	42	504
Swimming (h)	0	0	0	0	5	5	5	10	10	5	0	0	40

Typical Reference Individual Parameters

Parameter	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
CRD food ingestion (kg wet)													
omnivorous fish	-	-	-	-	-	-	-	-	-	-	-	-	0
predator1 fish	-	-	-	-	-	-	-	-	-	-	-	-	0
predator2 fish	-	-	-	-	-	-	-	-	-	-	-	-	0
salmon	-	-	-	-	-	-	-	-	-	-	-	-	2.0
shellfish	-	-	-	-	-	-	-	-	-	-	-	-	0.45
Waterfowl ingestion (kg wet)	-	-	-	-	-	-	-	-	-	-	-	-	0
Drinking water intake (L)													
treated	37	37	37	37	37	37	37	37	37	37	37	37	444
untreated													0
Boating or fishing (h)	0	0	0	0	5	5	5	5	5	0	0	0	25
Swimming (h)	0	0	0	0	0	3	3	3	3	0	0	0	12

Occupational Reference Individual Parameters

Parameter	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
CRD food ingestion (kg wet)													0
omnivorous fish	-	-	-	-	-	-	-	-	-	-	-	-	0
predator1 fish	-	-	-	-	-	-	-	-	-	-	-	-	0
predator2 fish	-	-	-	-	-	-	-	-	-	-	-	-	0
salmon	-	-	-	-	-	-	-	-	-	-	-	-	0
shellfish	-	-	-	-	-	-	-	-	-	-	-	-	0
Waterfowl ingestion (kg wet)	-	-	-	-	-	-	-	-	-	-	-	-	0
Drinking water intake (L)													
treated	0	0	0	0	0	0	0	0	0	0	0	0	0
untreated	61	61	61	61	61	61	61	61	61	61	61	61	732
Boating or fishing (h)	240	240	240	240	240	240	240	240	240	240	240	240	2880
Swimming (h)	0	0	0	0	2	2	5	5	2	0	0	0	18

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Reference:

Soldat, J.K., K.R. Price, and W.D. McCormack. 1986. Offsite Radiation Doses Summarized from Hanford Environmental Monitoring Reports for the Years 1957-1984. PNL-5795, Pacific Northwest Laboratory, Richland, Washington.

λ_j

Parameter: Radiological decay constant

Reference equation: CRD-4
CRD-5
CRD-6
CRD-7

Dependencies: radionuclide

Equation symbol: λ_j

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

Units: d^{-1}

Value(s):	<u>Radionuclide</u>	<u>λ</u>
	Sodium-24	1.10756
	Phosphorus-32	0.04854
	Zinc-65	0.00284
	Arsenic-76	0.63253
	Neptunium-239	0.29496

Technical Basis: The rate at which a radionuclide 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 convert to a more stable (less excited) state. The process of radioactive decay occurs as a decreasing exponential function over time. The decay constant is determined by the decay law:

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

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

The values indicated have been confirmed by a number of scientists (e.g., Lederer and Shirley 1978).

References:

Lederer, C.M., and V.S. Shirley, eds. 1978. Table of Isotopes, 7th ed. John Wiley and Sons, New York.

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

BCF_{b,j}

Parameter: Resident waterfowl bioconcentration factors

Reference equation: CRD-3

Dependencies: radionuclide

Equation symbol: BCF_{b,j}

Definition: The ratio of activity in a unit mass of waterfowl muscle relative to the activity in a unit volume of Columbia River water.

Units: L/kg(wet)

Value(s):	<u>Radionuclide</u>	<u>BCF</u>
	Phosphorus-32	290
	Zinc-65	45

Technical basis: The bioconcentration factors (BCFs) for waterfowl were derived from historical Hanford monitoring data and modeled Columbia River water radionuclide concentrations (Thiede et al. 1994). The historical data were derived from the radionuclide levels in the heads and muscle tissue of puddle ducks (mallard, gadwall, pintail, shovelers, widgeon, and woodduck) captured in the vicinity of Hanford. The radionuclides measured in these fowl were phosphorus-32 and zinc-65. The other radionuclides of interest in the HEDRIC river pathway (i.e., sodium-24, arsenic-76, and neptunium-239) were not measured in the waterfowl and are considered to be at insignificant levels. The indicated BCFs are the median values. BCF values are the same for all river segment locations. Changing radionuclide concentrations in the Columbia River water at various river locations generate variable waterfowl muscle concentrations at those separate locations. The full distributions defined in Thiede et al. (1994) were used in the uncertainty/sensitivity analyses.

BCF_{b,j}

Reference:

Thiede, M.E., D.J. Bates, E.I. Mart, and R.W. Hanf. 1994. A Guide to Environmental Monitoring Data, 1945-1972. PNWD-2226 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

$$BCF_{fw\ i,j}$$

Parameter: Freshwater fish bioconcentration factor

Reference equation: CRD-2

Dependencies: radionuclide (all), season and trophic level (some)

Equation symbol: $BCF_{fw\ i,j}$

Definition: The ratio of activity in a unit mass of Columbia River freshwater fish muscle relative to the activity in a unit volume of Columbia River water.

Units: $pCi_{fish}/kg_{fish}(wet)$ per $pCi_{water}/L = L/kg(wet)$

Value(s):

	<u>Season</u>	<u>Omnivore</u>	<u>Predator1</u>	<u>Predator2</u>
Sodium-24	cool	8.0	2.0	2.0
	warm	8.0	2.0	2.0
Phosphorus-32	cool	420	76	76
	warm	1500	979	979
Zinc-65	cool	132	97	67
	warm	217	252	105
Arsenic-76	cool	244	244	244
	warm	244	244	244
Neptunium-239	cool	21	21	21
	warm	21	21	21

Technical basis: Historical Hanford monitoring data and model estimates were used to develop the bioconcentration factors for Columbia River freshwater fish populations. A detailed description of the methodology used to develop the $BCF_{fw\ i,j}$ values is found in Thiede et al. (1994). This technical basis section summarizes the work of that report.

The freshwater fish in the Columbia River were divided into three trophic levels for evaluation: omnivore, predator1, and predator2. The

trophic levels indicate the generalized food types upon which the adult fish feed. Omnivores feed primarily on the biota on the bottom of the river. First-order predators (predator1) consume aquatic insects and invertebrates, and second-order predators (predator2) consume small fish and larger aquatic invertebrates. The trophic levels and the fish types included in each category are as follows:

<u>Trophic Level</u>	<u>Fish Types</u>
Omnivore	Bullhead, catfish, suckers, whitefish, chiselmouth, chub, minnows, shiners, sturgeon
Predator1	Perch, crappie, pumpkinseed, bluegill
Predator2	Bass, trout, squawfish

The use of bioconcentration factors permits the calculation of radionuclide concentration in fish muscle when measurement data are lacking. Historical environmental monitoring activities of the Columbia River radionuclide concentrations include that of water and fish. Unfortunately, the times and locations of water and fish sampling do not coincide in many cases. Therefore, radionuclide concentrations in the water were modelled over all time periods for which fish monitoring data were evaluated by HEDR staff (Walters et al. 1994). This permitted the calculation of bioconcentration factors specific to the Columbia River for all fish samples.

The resulting BCFs were then statistically evaluated to determine the BCFs appropriate for each radionuclide, trophic level, and season. The two seasons considered were the "cool" season (December through May) and the "warm" season (June through November). Then, further statistical evaluations were performed to determine the significance of the difference between the BCFs calculated for each trophic level and season. In the cases where there

was no significant difference, the trophic levels and seasons were collapsed to include all trophic levels or seasons. Median BCF values are tabulated above. The full distributions defined by Thiede et al. (1994) were used in the uncertainty/sensitivity analyses.

References:

- Thiede, M.E., D.J. Bates, E.I. Mart, and R.W. Hanf. 1994. A Guide to Environmental Monitoring Data, 1945-1972. PNWD-2226 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
- Walters, W.H., M.C. Richmond, and B.G. Gilmore. 1994. Reconstruction of Radionuclide Concentrations in the Columbia River from Hanford, Washington to Portland, Oregon, January 1950-January 1971. PNWD-2225 HEDR, Battelle, Pacific Northwest Laboratory, Richland, Washington.

DF_{ing,j,o}

Parameter: Ingestion dose factor

Reference equations: CRD-4

Dependencies: radionuclide, organ

CRD-5

CRD-6

CRD-7

CRD-10

CRD-11

Equation symbol: DF_{ing,j,o}

Definition: The dose to organ o from a unit intake of radionuclide j.

Units: mrem/pCi_{ingested}

Values:

<u>Radionuclide</u>	<u>Lower Large Intestine</u>	<u>Red Bone Marrow</u>	<u>EDE</u>
Sodium-24	1.3E-6	1.4E-6	1.4E-6
Phosphorus-32	2.7E-5	3.0E-5	7.7E-6
Zinc-65	1.9E-5	1.7E-5	1.4E-5
Arsenic-76	4.4E-5	4.4E-7	4.8E-6
Neptunium-239	3.2E-5	1.7E-7	2.9E-6

Technical basis: When an individual ingests a radioactive element, it follows the same metabolic pathway as its stable counterpart until it radiologically decays. For example, phosphorus-32 will follow the same metabolic pathway as a stable phosphorus atom (phosphorus-31) until the phosphorus-32 decays.

The dose factors (DFs) listed here are from a U.S. Department of Energy reference document (DOE 1988) and a U.S. Environmental Protection Agency (EPA) reference document (Eckerman et al. 1988). Internal dose factors were generated by using International Commission on Radiological Protection (ICRP) dosimetric models. Organ doses are 50-year committed dose equivalents and the EDE is the 50-year committed effective dose equivalent. The ICRP models were based on Reference Man (ICRP 1975). The dose factors for neptunium-239 or arsenic-76 in the red bone marrow were considered below the chosen threshold

cut-off point of the ICRP upon which DOE (1988) DFs were based and, so, were obtained from EPA (Eckerman et al. 1988).

All radionuclides, except for zinc-65, deposit over 90 percent of their 50-year committed dose within the first year of intake. Zinc-65 doses are contributed over a longer time period because of its longer radiological and biological half-life.

Uncertainty distributions for all ingestion dose factors were assumed to be lognormal for the uncertainty/sensitivity analyses. The central values given above were assumed to be means with geometric standard deviations shown in the table. The distributions were truncated at the 1 and 99 percentiles.

<u>Radionuclide</u>	<u>Lower Large Intestine</u>	<u>Red Bone Marrow</u>	<u>EDE</u>
Sodium-24	1.3	1.3	1.3
Phosphorus-32	1.3	1.8	1.5
Zinc-65	1.3	1.8	1.5
Arsenic-76	1.3	1.5	1.3
Neptunium-239	1.3	1.5	1.3

References:

- DOE - U.S. Department of Energy. 1988. Internal Dose Conversion Factors for Calculation of Dose to the Public. DOE/EH-0071, U.S. Department of Energy, Assistant Secretary for Environment, Safety, and Health, Washington, D.C.
- Eckerman, K.F., A.B. Wolbarst, and A.C.B. Richardson. 1988. Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion. EPA-520/1-88-020, Federal Guidance Report No. 11, U.S. Environmental Protection Agency, Washington, D.C.
- ICRP - International Commission on Radiological Protection. 1975. Report of the Task Group on Reference Man. Publication 23, Pergamon Press, New York.

DF_{sub,j,o}

Parameter: Submersion dose rate factor

Reference equations: CRD-8
CRD-9

Dependencies: radionuclide, organ

Equation symbol: DF_{sub,j,o}

Definition: External dose factor to organ o from radionuclide j from exposure to activity in Columbia River water.

Units: mrem/h per pCi/L

Values:

<u>Radionuclide</u>	<u>Lower Large Intestine</u>	<u>Red Bone Marrow</u>	<u>EDE</u>
Sodium-24	4.9E-6	5.3E-6	5.9E-6
Phosphorus-32	0	0	0
Zinc-65	6.1E-7	6.7E-7	7.5E-7
Arsenic-76	4.3E-7	4.9E-7	5.5E-7
Neptunium-239	1.5E-7	1.6E-7	2.2E-7

Technical basis: When an individual is in water that contains radionuclides, the individual may be exposed to the decay energy of those radionuclides and receive a dose. Different radionuclides emit different amounts of energy during their decay. Therefore, the dose factors differ for each radionuclide.

Dose factors were taken from a current U.S. Department of Energy reference document (DOE 1988). These dose factors were generated by assuming submersion in an infinite, uniformly contaminated water medium. Exposure of standard man, an adult, was assumed.

Phosphorus-32 is a pure beta-emitter. This beta, with an average energy of 0.7 MeV (ICRP 1983), does not produce a significant dose. The other radionuclides are energetic emitters of beta and gamma radiation.

Sparse research and modeling has investigated the dose rate factors associated with dose rates to an individual above the water (e.g., in a

fishing boat). Numerous uncertainties and scenario-specific factors prevent the definition of uniform dose factors for an individual located along the shoreline of a radioactively contaminated river. The uncertainties include such topics as the build-up of radionuclides over time in the shoreline sediments, the accumulation of radionuclides in shoreline microbes and algae, and the changing shoreline elevation. As a default, scientists use a value equivalent to half (i.e., 0.5) the submersion dose rate factor to approximate the boating DF. Equation CRD-8, external dose (nonsubmersion) to organ o from the Columbia River, uses this default assumption.

For the uncertainty/sensitivity analyses, each submission dose rate factor was assumed to be lognormally distributed with a geometric standard deviation of 1.2. The central values were assumed to be means of the distribution. The distributions were truncated at the 1 and 99 percentiles.

References:

- DOE - U.S. Department of Energy. 1988. External Dose-Rate Conversion Factors for Calculation of Dose to the Public. DOE/EH-0070, U.S. Department of Energy, Assistant Secretary for Environment, Safety, and Health, Washington, D.C.
- ICRP - International Commission on Radiological Protection. 1983. Radionuclide Transformations, Energy and Intensity of Emissions. ICRP Publication 38, Pergamon Press, Oxford.

f_{w2}

Parameter: Treated water retention fraction

Reference equation: CRD-7

Dependencies: radionuclide

Equation symbol: f_{w2}

Definition: The fraction of the radionuclide present in Columbia River water that is present in drinking water after water treatment.

Units: none

Values:	<u>Radionuclide</u>	<u>Retention Fraction</u>
	Sodium-24	0.90
	Phosphorus-32	0.38
	Zinc-65	0.39
	Arsenic-76	0.50
	Neptunium-239	0.67

Technical basis: A limited number of communities along the Columbia River use the river as a water source for personal consumption. Richland, Pasco, and Kennewick, Washington, are the greatest consumers of the river water. Both the untreated and treated water in Pasco and Richland had been monitored extensively in the 1960s and 1970s because they were known to be a potentially important exposure pathway.

Water treatment can reduce the concentrations of radionuclides in the water consumed. The radionuclide levels in Richland and Pasco were significantly reduced as a result of the flocculation-filtration treatment systems of these two cities. The level of reduction varied according to radionuclide. The retention fractions listed above were derived from measurements of the Richland and Pasco water (Denham and Soldat 1975).

Kennewick has a different water treatment system, consisting of Rainey well collectors (infiltration pipes) laid in the riverbank. Less activity should result from this system. However, the same retention fractions will be

used for Kennewick as were determined for the Richland and Pasco treatment plants. It is believed that conservative doses (i.e., overestimates of dose) for the Kennewick population will result because the radioactivity in the Kennewick raw water is much less than that of Richland and Pasco. The lower radioactivity in Kennewick results from the confluence of the Yakima River and the Columbia River a short distance from the Kennewick intake point.

The retention fractions derived from the Richland and Pasco treatment plant samples will be used for all HEDR river segment locations where an individual indicates that they drank treated water originally drawn from the Columbia River.

For the uncertainty/sensitivity analyses, the treated water retention fractions were assumed to have triangular distributions. The ranges of the distribution were based on monitoring results reported in the Hanford annual reports of the mid-1960s. The ranges given in the table are the same as used in PNL (1991).

<u>Radionuclide</u>	<u>Minimum</u>	<u>Central Value</u>	<u>Maximum</u>
Sodium-24	0.4	0.7	0.9
Phosphorus-32	0.2	0.4	0.7
Zinc-65	0.2	0.4	0.6
Arsenic-76	0.2	0.5	0.7
Neptunium-234	0.5	0.7	0.9

References:

- Denham, D.H., and J.K. Soldat. 1975. "A Study of Selected Parameters Affecting the Radiation Dose from Radionuclides in Drinking Water Downstream of the Hanford Project." Health Physics 28(2):139-144.
- PNL - Pacific Northwest Laboratory. 1991. Columbia River Pathway Report: Phase I of the Hanford Environmental Dose Reconstruction Project. PNL-7411 HEDR Rev. 1, Pacific Northwest Laboratory, Richland, Washington.

P_{act}

Parameter: Probability of bagging a year-round resident waterfowl

Reference equation: CRD-3

Equation symbol: P_{act}

Dependencies: none

Definition: Conceptually, the probability that a bagged waterfowl was a year-round resident of the Columbia River.

Units: none

Value: 1.0

Technical basis: The CRD code includes this parameter to account for the probability that a waterfowl bagged near the Columbia River was a year-round resident of the river. Year-round resident fowl accumulate Columbia River water radionuclides to greater levels than do waterfowl who merely migrate through the area. If an explicitly derived P_{act} were to be used, then only data for resident waterfowl would have been used to derive the waterfowl bioconcentration factors ($BCF_{b,j}$). Because a clear distinction between resident and migratory ducks was not possible, the final determination of $BCF_{b,j}$ parameter values of Equation CRD-3 considered historic monitoring data for both resident and migratory ducks. Thereby, the P_{act} parameter is implicitly incorporated into the $BCF_{b,j}$ values. As a result, the P_{act} value is defined to be unity (1.0) in the final CRD code runs. This parameter is discussed here for completeness because it remains in the CRD model equations.

The abundant waterfowl in the Columbia Basin made the hunting of waterfowl and upland game birds a widely practiced activity. Some waterfowl are year-round residents, but these numbers are greatly diluted with nonresident waterfowl during fall and spring migrations. The dilution factor has been estimated at 200:1 to 1000:1 (Junkins et al. 1960). It has been found that ducks must remain resident on the river for several weeks before phosphorus-32 and zinc-65 concentrations in their flesh approach that of resident whitefish

(Foster and Soldat 1966). The probability of shooting a resident duck is, therefore, an important issue.

The assumed P_{act} was subjectively derived from the scant information available and is likely somewhat conservative. It was assumed that the fraction of waterfowl that are year-round residents does not change over the entire length of the river. This information, derived from Hanford-region information, which included both waterfowl and gamebirds, is summarized below.

The extent of hunting in the immediate vicinity of the Hanford Site during the 1940s and 1950s is unclear. The 1959 annual environmental report (Junkins et al. 1960) stated that the "Ringold vicinity is the first downstream area accessible to the public...some waterfowl are harvested here by local hunters." The first explicit note of any hunting restrictions is indicated in the 1960 annual environmental report (Nelson 1961): "Hunting for waterfowl is not permitted within the Hanford Reservation nor within one-quarter mile of the Columbia River in this part of the state." The only exception was that hunting was permitted on the McNary Wildlife Refuge at the mouth of the Snake River.

During 1960, approximately 40 percent of 600 ducks bagged in the local area contained "detectable" activity. Less than 15 percent of the samples contained phosphorus-32 levels similar to whitefish (Nelson 1961).

An extensive duck study was conducted in 1961. Samples of 3400 ducks bagged in Washington, Idaho, Oregon, and California were collected and evaluated for phosphorus-32 content (Nelson 1962). It was found that 7.7 percent of the ducks sampled contained detectable phosphorus-32; i.e., greater than $5E-5$ $\mu\text{Ci/g}$ wet weight, and that 0.4 percent of the ducks contained more than $5E-4$ $\mu\text{Ci/g}$ wet weight.

Similar, but less extensive duck studies were conducted in the years following. Of 102 ducks bagged in Washington and Oregon during the 1962 hunting season, 5.9 percent contained detectable; i.e., greater than $5E-5$ $\mu\text{Ci/g}$ wet weight phosphorus-32 activity (Wilson 1963). Samples from 299 ducks bagged by Washington hunters during the 1963 hunting season netted 7.4 percent containing detectable phosphorus-32 activity (Wilson 1964). The report of the 1963 hunting season survey was the first to specifically indicate that it was duck flesh that was sampled. The material sampled in the previous surveys is uncertain.

No information about fowl hunting between 1963 and 1966 was located. No information about offsite fowl radionuclide content for radionuclides other than phosphorus-32 was located before the 1967 reports. Surveys in 1967 found that birds, presumed to be primarily pheasants, collected beyond approximately 5 kilometers from the Columbia River in the Ringold and McNary region, contained "little" if any radioactivity (Woolridge 1969). Woolridge (1969) also indicated that approximately 30 percent of the gamebird meals consumed by local hunters were shot within 5 kilometers of the Columbia River between Ringold and McNary. Had the $\text{BCF}_{b,j}$ parameter not implicitly included the P_{act} concept, the P_{act} of choice would be 0.12.

References:

- Foster, R.F., and J.K. Soldat. 1966. "Evaluation of the Exposure Resulting from the Disposal of Radioactive Wastes into the Columbia River." In Disposal of Radioactive Wastes into Seas, Oceans, and Surface Waters, pp. 683-695. International Atomic Energy Agency, Vienna, Austria.
- Junkins, R.L., E.C. Watson, I.C. Nelson, and R.C. Henle. 1960. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1959. HW-64371, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

- Nelson, I.C. ed. 1961. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1960. HW-68435, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.
- Nelson, I.C., ed. 1962. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1961. HW-71999, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.
- Wilson, R.H., ed. 1963. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1962. HW-76526, General Electric Company, Hanford Atomic Products Operations, Richland, Washington.
- Wilson, R.H., ed. 1964. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1963. HW-80991, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.
- Woolridge, C.B., ed. 1969. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1967. BNWL-983, Battelle Northwest Laboratory, Richland, Washington.

x

Parameter: River segment

Reference equation: CRD-1 to CRD-9

Dependencies: none

Equation symbol: x

Definition: The Columbia River segments considered for CRD dose estimation.

Units: none

Value(s): Integer values from 1 to 12

Comment: River pathway doses were calculated for 12 river segments downstream of the Hanford reactors (see Figure 7.1). Each segment is identified by a unique integer label, as follows:

<u>Segment</u>	<u>Name</u>
1	Ringold
2	Richland
3	Kennewick/Pasco
4	Snake/Walla Walla Rivers
5	Umatilla/Boardman
6	Arlington
7	John Day Dam/Biggs
8	Deschutes River
9	The Dalles/Celilo
10	Klickitat River
11	While Salmon/Cascade Locks
12	Lower River

7.30

o Location of Computed Water Concentrations

S9403005.1

FIGURE 7.1. Columbia River Study Segments

APPENDIX A

ATMOSPHERIC PATHWAY PARAMETER SUMMARY

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

Parameter	Units	Distribution	Central Value	Minimum	Maximum	Dependencies	Frequency of Selection
α	$\text{m}^2/\text{kg(dry)}$	uniform		1.0	4.0	none	realization
$^{131}\text{I } \lambda_{\text{leach}}$	d^{-1}	uniform		4E-6	5E-3	radionuclide	realization
$^{131}\text{I } \lambda_{\text{perc}}$	d^{-1}	uniform		0.14	0.91375	radionuclide	realization
$^{131}\text{I } \lambda_{\text{rad}}$	d^{-1}	none	0.08625			radionuclide	N/A
$^{131}\text{I } \lambda_{\text{splash}}$	d^{-1}	none	0			none	N/A
λ_{weath}	d^{-1}	triangular	0.0495	0.0347	0.0866	none	realization
p_{rz}	$\text{kg(wet)}/\text{m}^2$	uniform		186	230	none	realization
p_{usl}	$\text{kg(wet)}/\text{m}^2$	uniform		1.10	1.45	none	realization
B_{max}	$\text{kg(dry)}/\text{m}^2$	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} leafy veg other veg fruit grain pasture grass hay alfalfa silage sagebrush	kg(dry)/m ²	none	0.01 0.01 0.27 0.01 0.04 0.03 0.01 0.01 0.008			vegetation type	N/A
BR 0 to 6 mo 6 mo to 2 yr 2 yr to 7 yr 7 yr to 12 yr 12 yr to 17 yr 17+ yr	m ³ /d	triangular	1.62 5.14 8.71 15.3 17.7 22.0	0.5 1.7 2.9 5.1 5.9 7.3	4.9 15.4 26.1 45.9 53.9 66.0	age	daily
¹³¹ I CR per Ci/kg _{vegetation} (dry) per Ci/kg _{soil} (wet)	Ci/kg _{vegetation} (dry) per Ci/kg _{soil} (wet)	loguniform		0.01	0.25	radionuclide	realization
¹³¹ I DF _{imm} rem _{EDE} /d per Ci/m ³	rad _{thyroid} /d per Ci/m ³ rem _{EDE} /d per Ci/m ³	uniform		2.8E+3 2.6E+3	1.1E+4 1.0E+4	radionuclide	realization
¹³¹ I DF _{ing} 3 mo 1 yr 5 yr 10 yr 15 yr adult-male female 3 mo 1 yr 5 yr 10 yr 15 yr adult-male female	rad _{thyroid} /Ci _{ingested} rem _{EDE} /Ci _{ingested}	lognormal	1.4E+7 1.3E+7 7.8E+6 4.1E+6 2.5E+6 1.4E+6 1.7E+6 4.1E+5 4.1E+5 2.3E+5 1.2E+5 7.8E+4 4.8E+4 5.8E+4	2.2E+6 2.0E+6 1.2E+6 6.4E+5 3.9E+5 2.2E+5 2.7E+5 6.4E+4 6.4E+4 3.6E+4 1.9E+4 1.2E+4 7.5E+3 9.1E+3	5.5E+7 5.1E+7 3.1E+7 1.6E+7 9.9E+6 5.5E+6 6.7E+6 1.6E+6 1.6E+6 9.1E+5 4.7E+5 3.1E+5 1.9E+5 2.3E+5	age, sex, radionuclide	realization

TABLE A.1. (contd)

Parameter	Units	Distribution	Central Value	Minimum	Maximum	Dependencies	Frequency of Selection
^{131}I DF _{inh} 3 mo 1 yr 5 yr 10 yr 15 yr adult-male female	rad _{thyroid} /Ci inhaled	lognormal	8.5E+6 8.1E+6 4.8E+6 2.4E+6 1.5E+6 1.0E+6 1.2E+6	1.3E+6 1.3E+6 7.5E+5 3.8E+5 2.3E+5 1.6E+5 1.9E+5	3.3E+7 3.2E+7 1.9E+7 9.5E+6 5.9E+6 3.9E+6 4.7E+6	age, sex, radionuclide	realization
3 mo 1 yr 5 yr 10 yr 15 yr adult-male female	rem _{EDE} /Ci inhaled		2.5E+5 2.5E+5 1.4E+5 7.4E+4 4.8E+4 3.0E+4 3.6E+4	3.9E+4 3.9E+4 2.2E+4 1.2E+4 7.5E+3 4.7E+3 5.6E+3	9.9E+5 9.9E+5 5.5E+5 2.9E+5 1.9E+5 1.2E+5 1.4E+5		
^{131}I DF _{nurs}	rad _{thyroid,baby} /Ci intake, mother rem _{EDE,baby} /Ci intake, mother	lognormal	2.4E+6 7.0E+4	3.3E+5 9.4E+3	1.0E+7 3.0E+5	radionuclide	realization
^{131}I DF _{pre}	rad _{thyroid,fetus} /Ci intake, mother	triangular	2.3E+6	1.1E+6	4.6E+6	radionuclide	realization
^{131}I DF _{rz}	rem/d per Ci/m ²	uniform		49	88	radionuclide	realization
^{131}I DF _{usl}	rad _{thyroid} /d per Ci/m ² rem _{EDE} /d per Ci/m ²	uniform		84 77	120 110	radionuclide	realization
f _d leafy veg other veg fruit grain	none	uniform		0.05 0.04 0.13 0.85	0.09 0.26 0.35 1.00	vegetation type	realization
FS _{chicken}	kg(wet)/d	uniform		6.0E-5	1.2E-2	none	realization
FS _{cow} all pasture half pasture no pasture	kg(wet)/d	triangular	0.5 1.0 2.0	0.25 0.50 1.0	1.0 1.5 4.0	time on pasture	realization

TABLE A.1. (contd)

Parameter	Units	Distribution	Central Value	Minimum	Maximum	Dependencies	Frequency of Selection
f_{time}	none	triangular				age, lifestyle, sex, season	realization
3 mo - 2 yr			0.0	0.0	0.13		
winter			0.04	0.0	0.17		
spring			0.13	0.0	0.29		
summer			0.04	0.0	0.17		
fall							
2 - 17 yr			male female				
urban			0.10 0.05	0.04	0.13		
winter			0.13 0.08	0.04	0.17		
spring			0.35 0.22	0.08	0.38		
summer			0.13 0.08	0.04	0.17		
fall							
rural			0.13 0.08	0.04	0.17		
winter			0.21 0.17	0.04	0.23		
spring			0.34 0.32	0.13	0.50		
summer			0.21 0.08	0.04	0.23		
fall							
> 17 yr							
urban			0.05 0.07	0.0	0.17		
winter			0.18 0.29	0.0	0.31		
spring			0.22 0.29	0.04	0.41		
summer			0.10 0.15	0.0	0.31		
fall							
rural			0.33 0.21	0.04	0.37		
winter			0.44 0.36	0.04	0.50		
spring			0.47 0.29	0.06	0.50		
summer			0.34 0.21	0.04	0.37		
fall							
^{131}I f_{trans}	none	loguniform		0.01	0.2	radionuclide	realization
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				

TABLE A.1. (contd)

Parameter	Units	Distribution	Central Value	Minimum	Maximum	Dependencies	Frequency of Selection
k_s leafy veg other veg fruit grain pasture grass hay alfalfa silage sagebrush	d^{-1}	none	0.07 0.08 0.07 0.08 0.09 0.09 0.15 0.09 0.09			vegetation type	N/A
^{131}I L_{proc} leafy veg, fruit	none	uniform		0.15	0.75	vegetation type, radionuclide	realization
ML	kg(dry)/m ³	lognormal	7E-8	1.4E-8	3.5E-7	none	realization
R_{10}	none	uniform		0.35	1.0	none	daily
S	m ⁻¹	triangular	1.0	0.2	1.6	none	realization
^{131}I $Sh1$	none	uniform		0.05	0.93	radionuclide	realization
^{131}I TF_{beef}	d/kg(wet)	uniform		0.004	0.054	radionuclide	realization
^{131}I TF_{eggs}	d/kg(wet)	uniform		1.5	6.0	radionuclide	realization
^{131}I TF_{milk_goat}	d/L	lognormal	0.27	0.04	1.15	radionuclide	realization
^{131}I TF_{milk_herd}	d/L	normal	1.20E-2	7.30E-3	1.66E-2	radionuclide	realization
^{131}I TF_{milk_ind}	d/L	lognormal	9.2E-3	1.6E-3	5.2E-2	radionuclide	realization
^{131}I $TF_{poultry}$	d/kg(wet)	uniform		4.0E-3	9.4E-2	radionuclide	realization

TABLE A.1. (contd)

Parameter	Units	Distribution	Central Value	Minimum	Maximum	Dependencies	Frequency of Selection
th _p * leafy veg, other veg, fruit, grain backyard cow or goat milk commercial cow milk stored milk products beef poultry eggs	d	uniform		0 0 1 14 7 2 0	7 2 4 60 21 10 21	crop or animal product, month of consumption	realization
v _d	m/d	uniform		8.64E+1	2.59E+3	none	realization
* During fresh harvest months.							

APPENDIX B

COLUMBIA RIVER PATHWAY PARAMETER SUMMARY

TABLE B.1. CRD Code Parameter Summary

Parameter	Units	Value	Dependencies
λ_j sodium-24 phosphorous-32 zinc-65 arsenic-76 neptunium-239	d ⁻¹	1.10756 0.04854 0.00284 0.63253 0.29496	radionuclide
BCF _{b,j} phosphorous-32 zinc-65	L/kg(wet)	290 45	radionuclide

TABLE B.1. (contd)

Parameter	Units	Value	Dependencies
BCF _{fw 1,j}	L/kg(wet)		radionuclide, trophic level, season
sodium-24 omnivore (cool and warm seasons)		8.0	
pred1, pred2 (cool and warm seasons)		2.0	
phosphorous-32 omnivore		420	
cool		1500	
warm			
pred1, pred2			
cool		76	
warm		979	
zinc-65 omnivore			
cool		132	
warm		217	
pred1			
cool		97	
warm		252	
pred2			
cool		67	
warm		105	
arsenic-76 omnivore, pred1, pred2		244	
neptunium-239 omnivore, pred1, pred2		21	

TABLE B.1. (contd)

Parameter	Units	Value	Dependencies
DF _{ing,j,o}	mrem/pCi _{ingested}		radionuclide, organ
LL intestine			
sodium-24		1.3E-6	
phosphorous-32		2.7E-5	
zinc-65		1.9E-5	
arsenic-76		4.4E-5	
neptunium-239		3.2E-5	
red marrow			
sodium-24		1.4E-6	
phosphorous-32		3.0E-5	
zinc-65		1.7E-5	
arsenic-76		4.4E-7	
neptunium-239		1.7E-7	
wholebody EDE			
sodium-24		1.4E-6	
phosphorous-32		7.7E-6	
zinc-65		1.4E-5	
arsenic-76		4.8E-6	
neptunium-239		2.9E-6	

TABLE B.1. (contd)

Parameter	Units	Value	Dependencies
DF _{sub,j,o}	mrem/h per pCi/L		radionuclide, organ
LL intestine			
sodium-24		4.9E-6	
phosphorous-32		0	
zinc-65		6.1E-7	
arsenic-76		4.3E-7	
neptunium-239		1.5E-7	
red marrow			
sodium-24		5.3E-6	
phosphorous-32		0	
zinc-65		6.7E-7	
arsenic-76		4.9E-7	
neptunium-239		1.6E-7	
wholebody EDE			
sodium-24		5.9E-6	
phosphorous-32		0	
zinc-65		7.5E-7	
arsenic-76		5.5E-7	
neptunium-239		2.2E-7	
f _{w2}	none		radionuclide
sodium-24		0.90	
phosphorous-32		0.38	
zinc-65		0.39	
arsenic-76		0.50	
neptunium-239		0.67	
P _{act}	none	1.0	none

APPENDIX C

SUMMARY OF TECHNICAL STEERING PANEL COMMENTS AND
BATTELLE, PACIFIC NORTHWEST LABORATORIES RESPONSES

APPENDIX C
SUMMARY OF TECHNICAL STEERING PANEL COMMENTS AND
BATTELLE, PACIFIC NORTHWEST LABORATORIES RESPONSES

Document Number: PNWD-2023 HEDR

Document Title: "Parameters used in the Environmental Pathways and Radiological Dose Modules (DESCARTES, CIDER, and CRD Codes) of the Hanford Environmental Dose Reconstruction Integrated Codes (HEDRIC)"

C.1

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
1	D. Walker	Full Report	I defer to the judgement of the Quality Assurance and Environmental Transport Subcommittees in evaluating this report. Questions I have raised have been answered satisfactorily both by Allan Murphy and Del Barth.	NA
2	W. Bishop	Full Report	No comment.	NA
3	S. Davis	Full Report	No comment.	NA
4	M. Robkin	General Comment	I found this report to be an excellent summary of the parameters used in pathway analysis. It will be a very useful reference for work outside of HEDR as well. I have only a few comments and questions.	NA
5	J. Till	General Comment	I have a fundamental problem with the selection of range of values for specific parameters. The problem lies in the origin of values, experimental or calculated. For example, is it acceptable to review the literature for a range of experimentally derived values such as α (empirical foliar interception constant). I CR	The literature was reviewed to define parameter values applicable to this region, as much as possible. The work directive was to review literature values with as little raw data manipulation as warranted.
6	M. L. Blazek	General Comment	No specific comments. We should be apprised of the identity, expertise, and opinions of peer reviewers of this document.	See acknowledgments section.

NA = No action.

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
7	G. Roessler	General Comment	It is important to document the DESCARTES and CIDER equations; however, I am not familiar enough with them to check their accuracy. I think it is important for someone on the TSP (Till?) or for someone like Ward Whicker to check them. The report mentions "two outside experts". Who are they, how were they selected and what are their credentials? What was their evaluation of this part of the project?	This report documents the parameter values used in DESCARTES, CIDER, and now CRD. It is not intended to justify or explain the model algorithms. See Ikenberry et al. (1992) See acknowledgments section.
8	B. Shleien	General Comment	Output requirements to the TSP need to be included. That is: Maps for 25 representative individuals for I-131 over 10 (19) counties. Initial output should be part of the dose code requirements.	The purpose of this report is to document parameter values. The maps are in the atmospheric pathway report (Farris et al. 1994).
9	B. Shleien	Sec. 1, Page 3, Para. 3	HEDRIC appears from out of nowhere. I assume that it is the HEDR code used in Phase I. Define, perhaps on page 1, where Phase I is mentioned.	It is now defined in the Preface.
10	G. Roessler	Sec. 2.3.3.	Variable Symbols and Definitions: Why not use negative exponents consistently?	Document reviewed and variables and symbols standardized.
11	B. Shleien	Sec. 2, Page 3	Daily human dietary intake appears too fine a "cut." Most of us cannot remember what we ate yesterday, much less what we ate each day years ago. Perhaps you mean the quantity and types of food eaten daily. Not clear.	The human diet intake rates are only summarily described in this document. The brief discussion was slightly expanded to include the food categories defined for the air pathway model. See Section 2.1.2.
12	M. Robkin	Sec. 2, Page 5	The expression (equation DES-3) for B^{max} can be written as $B^{\text{max}} = B_{\text{max}} / [1 - ((k_s/k_g)(1 - B_{\text{min}}/B_{\text{max}}))]$. For B^{max} to remain positive, the denominator must be between 0 and 1 so that B^{max} is always larger than B_{max}. Since B_{max} is defined as the maximum potential biomass, it is not clear what is the physical meaning of an adjusted biomass that is even larger.	NA - Equation DES-3 was borrowed from the Whicker and Kirchner (1987) PATHWAY model. The use of B^{max} preserves the continuity in B versus time.
13		DES-5	What is the physical meaning of this equation. f_{trans} lies between 0 and 1 so that λ_{trans} lies between λ_{weath} and infinity. The lower limit is physically possible, but as f_{trans} increases, the meaning of λ_{trans} seems to get lost. Is f_{trans} restricted in value?	This equation is used to define λ_{trans} to account for the fact that weathering occurs over time and the activity removed by weathering is unavailable for translocation.

NA = No action.

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
14	S. Shleien	Sec. 2, Pages 5-14	Presentation of data with no explanation of the underlying processes is inappropriate. No one has the familiarity with this large a group of equations to make any sense of the underlying processes they represent.	See response to comment number 7.
15	M. Robkin	Sec. 2, Page 8, DES-16	Why isn't this indexed on v, the particular plant. Presumably the holdup time for a stored feed crop can be different from one crop to another.	This equation accounts for the different stored feed crops in the calculation of the animal-feed radionuclide concentration calculation. The animals consume varying quantities of each feed type as defined by their feeding regime.
16		DES-18	fgroc is defined as fraction of milk not as a general animal product. Which is it?	Equation DES-18 title was changed to indicate that only milk concentrations are evaluated with this equation.
17	M. Robkin	Sec. 2, Page 11	In definition of <i>pusl</i> delete "from"	Document revised.
18	B. Shleien	Sec. 3, Page 1	Well, HEDRIC is defined and I was wrong about it being from Phase I. I think. Now we have STRM. Where did it come from? What is it?	HEDRIC is now defined in the Preface. STRM is one of the four codes of the HEDRIC air pathway, as indicated in the Preface.
19	B. Shleien	Sec. 3, Page 1, Para. 1	Highlights uncertainties and especially that on over-sophisticated computer program is questionable. How much does it gain us given the large number of other uncertainties?	It is important to understand the parameters that go into the model in order to better understand the model output.
20	B. Shleien	Sec. 3, Page 3	Probability Density Function of a Parameter. What is a real-valued function? The entire exercise depends on understanding what it is, but it is nowhere defined.	Document revised. See definition of PDF in Section 3.1.1.
21	B. Shleien	Sec. 3, 3.2.3	<u>Calibrated Assessment.</u> Identification and calibration of the assessor's assessment depends on the calibration.	NA
22	B. Shleien	Sec. 3, Page 8 Para 1.	It is difficult to believe that HEDR rejected the use of a method because it was too expensive. Furthermore, the statement implies that the best method was ignored because of cost.	NA - Funding was provided for the approach used. Expert elicitation was not funded.
23	B. Shleien	Sec. 3, Page 8	HEDR uses prudent judgment, I hope. Why go on for pages trying to explain that it is your choice? Battelle was hired, I thought, because it was judged to be the expert. Cannot it be said that prudent judgement based on training and experience and on extensive search of the literature was used to establish the pdf?	Battelle is considered by some to have a conflict of interest. Credibility must be demonstrated.

NA = No action.

Comment Number	Commenter	Page. Paragraph	Comment Summary	Resolution
24	B. Shleien	Sec. 3, Page 12	"see parameter 1". Where? What? I cannot believe that any of the parameters being discussed would vary daily. They would vary seasonally, at best, for agricultural products. For diets and migratory factors a time step function would be appropriate.	Parameter "1" is the location of interest. The short half-life of iodine-131 and its variable, daily source term, makes it necessary to vary some parameters daily.
25	G. Roessler	Sec. 4.0	Data Quality Objectives: Correct terms are finally used here and are used consistently.	NA
26	B. Shleien	Sec. 4, Page 1	Three of the four QA objectives also depend on judgment and peer review.	The quality of the parameters in this document are based on judgment and peer review.
27	M. Robkin	Sec. 6, Page 2, Line 11	Is I- more reactive than I2?	Yes.
28	G. Roessler	Parameter Descriptions	It is nice to have them all documented; however, I have the same comment as in my general description. I think it is important for some expert to check the values.	TSP review of key parameters has been performed.

C.4

NA = No action.

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
29	B. Shleien	Parameter Descriptions	1. Percolation rate discussion should precede soil leaching rate discussion. 2. Is "distribution" the same as pdf? Does not pdf need to be discussed here? Looks like they are the same. 3. Does "none" as a description of distribution mean a "uniform" pdf? I think it does. 4. I assume the age dependent breathing rate is a triangular distribution for each age group? Between age groups it is more likely stepwise or perhaps a different function. 5. Is the effect of exercise on age-dependent breathing rate considered? I think it is. Discuss/mention. 6. None of the <u>dose factors</u> consider latest Keith Ekerman work. They should since they are recent and relate to ICRP 51, 60 recommendations. Contact Ekerman or check Health Physics and Radiological Health Handbook, Revised Edition. B. Shleien, ed.	The parameters are listed alphabetically. Distribution and pdf are the same. A uniform and "none" distribution are different. A parameter with a uniform distribution may have any value within the defined range, each value being equally probable. A parameter with no distribution ("none") can only exist as one discrete value. Document revised. See parameter BR in Section 6.0. The effect of exercise is addressed in the uncertainty defined for the BR parameter. Age-dependent dose factors were the required input for the CIDER code. ICRP 56 provides these for the ingestion pathway. Phipps et al. (1991) (see DFinh) provided these for the inhalation pathway.

NA = No action.

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
			7.** <u>I cannot believe</u> that you will employ inhalation dose factor based on a 1 micron AMAD <u>exclusively</u>. What about particle size considerations? ICRP 56 gives values for 0.1, 1 and 10 micron AMADs. <u>Particle size is important</u>. Do I misunderstand, I hope I do? <u>Without some particle size characterization</u>, and its inclusion into the dose model we have spent millions on computer codes, statistical uncertainty, but left out basic essential health physics practice. Although inhalation is not an important pathway, it needs to be addressed correctly. (** I expect a personal individual response to me [B. Shleien] on this matter.) 8. Particle size is as important a parameter as is mass loading in characterizing airborne radioiodine. Appears not to be discussed. Is it part of RACHET?	ICRP 56 uses only an assumed 1-μm AMAD for its calculations (ICRP 56, p.8) because the new ICRP lung model was not published at the time of ICRP 56 publication. It is assumed that the uncertainty of the DFinh incorporates any variability resulting from changing particle size. There are no assumptions regarding particle size in DESCARTES. RACHET assumes a 1-μm particle size. Actual particle size was never measured and is not known. B. Shleien (TSP) was called to discuss this matter.
30	M. Robkin	FSchicken, Page 1, Para. 2, Line 4	Sentence states that digestion occurs in the gizzard of a chicken. Isn't the gizzard only used to grind the food with the first digestion in the stomach? Shouldn't "in the gizzard" be deleted?	Digestion is both a mechanical and chemical process. The gizzard mechanically grinds food, so the stomach and intestines can chemically digest it.
31	B. Shleien	2.0	Quality Assurance Requirements: No requirement is listed for external review. The TSP need to be sure that an external and/or CDC review of the code(s) takes place.	NA - See response to comment number 28. Also the TSP and public have been briefed on the results of the peer review of the DESCARTES and CIDER codes.
32	B. Shleien	4.0	General User Interface Requirements: Software needs to be in form and procedure in place to turn code over to CDC and ensure that it is usable.	The HEDRIC software deliverables to the CDC are controlled under configuration management.
33	B. Shleien	6.2	Only simple exponential decay supported. How will weathering, washoff, and resuspension be handled?	Equations DES-8 and DES-9 explicitly account for weathering, which includes wash-off and resuspension.
34	B. Shleien	7.3	Does this mean that only one feeding regime will be accommodated? If so, it is too restrictive. 10.1 notes 4 feeding regimes.	Eight feeding regimes are supported.
35	B. Shleien	14.2	Two organ doses? Thyroid and effective dose, I assume. Effective dose is not an organ dose.	The current revision has incorporated DFs for the thyroid (rad units) and effective dose equivalent (rem units).

NA = No action.

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
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Farris, W. T., B. A. Napier, T. A. Ikenberry, J. C. Simpson, and D. B. Shipler. 1994. <u>Atmospheric Pathway Dosimetry Report, 1944-1992</u> . PNWD-2228 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.				
ICRP - International Commission on Radiological Protection. 1990. <u>Age - Dependent Doses to Members of the Public from Intake of Radionuclides: Part 1</u> . Publication 56, Pergamon Press, New York.				
Phipps, A. W., G. M. Kendall, J. W. Stather, and T. P. Fell. 1991. <u>Committed Equivalent Doses and Committed Effective Doses from Intakes of Radionuclides</u> . NRPB-R245, National Radiological Protection Board, Chilton, Didcot, Oxon, United Kingdom.				
Whicker, F. W., and T. B. Kirchner. 1987. "PATHWAY: A Dynamic Food-Chain Model to Predict Radionuclide Ingestion after Fallout Deposition." <u>Health Physics</u> 52:717-737.				

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