Computational Model Design Specification for Phase I of the Hanford Environmental Dose Reconstruction Project

B. A. Napier

July 1991

Prepared for the Technical Steering Panel

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Printed in the United States of America

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Richland, Washington 99352

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This document has been reviewed
and approved by the Technical Steering Panel.

John E. Till, Chairman
Technical Steering Panel
Hanford Environmental
Dose Reconstruction Project

June 26, 1991
Date

PREFACE

15 In recent years, concern has been mounting about possible health effects to the public from over 40 years of operations at the Hanford Site. This concern prompted the Washington State Nuclear Waste Board and the Indian Health Service to request the Centers for Disease Control (CDC) to convene a Hanford Health Effects Review Panel to review and evaluate epidemiological and environmental data relevant to Hanford operations. In 1986, based on this review, the Panel recommended a study be initiated to reconstruct radiation doses potentially received by the public residing in the vicinity of Hanford, and a separate study of thyroid morbidity in the same population. The HEDR Project is the outgrowth of that recommendation; *the project is being managed and conducted by Battelle staff at the Pacific Northwest Laboratory under the direction of an independent Technical Steering Panel.*

The HEDR Project is divided into the following technical tasks. These tasks address each of the primary steps in the path from radioactive releases to dose estimates:

- Source Terms
- Environmental Transport
- Environmental Monitoring Data
- Demographics, Agriculture, and Food Habits
- Environmental Pathways and Dose Estimates.

The Source Terms Task will develop estimates of radioactive emissions from Hanford facilities since 1944. These estimates will be based on historical measurements and production information.

The Environmental Transport Task will reconstruct the probable movement of radioactive materials from the areas of release to populations. Movement via the atmosphere, surface water (Columbia River), and ground water will be studied.

The Environmental Monitoring Task will assemble, evaluate, and report historical monitoring data.

The Demographics, Agriculture, and Food Habits Task will develop the data needed to determine which population groups could have been affected by the releases. Population and demographic information will be developed for the general population within the study area. This information will also be developed for several special population groups including the Native American tribes in the study area, military personnel stationed at Hanford, Hanford construction workers, and migrant farm workers. The food and water consumption patterns and practices and sources of food and water must also be estimated.

Historical dairy farming practices and milk distribution systems will be studied because milk is a significant pathway for iodine-131 to enter the human body. Cows could have eaten vegetation contaminated with this radionuclide.

The Environmental Pathways and Dose Estimates Task will use the information produced by the other tasks to estimate the radiation doses people could have received from Hanford operations.

This report is the result of a collaboration of the Statistics Task and the Environmental Pathways and Dose Estimates Task. This report outlines the computations that will be needed to incorporate all of the data collected by the various tasks to produce radiation dose estimates. Preliminary models are defined and the structure and logic of the envisioned computer code are outlined.

FOREWORD

Appendix G is a record of TSP comments and Battelle's responses; the TSP has reviewed and approved these responses to their comments. Comment numbers appear in this report in the left margin next to the paragraph in which the corresponding comment was addressed. Changed text is shown in italics. In addition to responses to TSP comments, some text was changed to correct errors or to provide clarification.

SUMMARY

The objective of the Hanford Environmental Dose Reconstruction (HEDR) Project is to estimate the radiation dose that individuals could have received as a result of emissions from nuclear operations at Hanford since their inception in 1944. The purpose of this report is to outline the basic algorithm and necessary computer calculations to be used to calculate radiation doses to both specific and hypothetical individuals in the vicinity of Hanford. The system design requirements, those things that must be accomplished, are defined. The system design specifications, the techniques by which those requirements are met, are outlined. Included are the basic equations, logic diagrams, and preliminary definition of the nature of each input distribution.

ACKNOWLEDGMENTS

The author would like to acknowledge the efforts of D. L. Strenge in reviewing the basic approaches to the calculational scheme, and to J. W. Brothers, W. V. DeMier, and R. A. Burnett for practical advice on applications. A. M. Liebetrau and R. O. Gilbert provided information on incorporating statistical techniques in the computer code.

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1.0 INTRODUCTION

The objective of the Hanford Environmental Dose Reconstruction (HEDR) Project is to estimate the radiation dose that individuals could have received as a result of emissions from nuclear operations at Hanford since their inception in 1944.^(a) This report documents the algorithms that will be implemented for initial computer calculations.

In response to a directive from HEDR's Technical Steering Panel, the reconstruction of doses to offsite populations is being performed in a series of phases. The first phase is the development of basic techniques and proof of principle. The objective of Phase I is to demonstrate through calculation that adequate models and support data exist or can be developed to allow estimation of realistic doses to individuals from releases of radionuclides to the environment that occurred as long as 45 years ago. Later phases will expand the capabilities and refine the dose estimations. Much of the data being used in Phase I is preliminary or approximate and, therefore, the doses calculated must also be considered preliminary approximations. Within the constraints of Phase I, a computational methodology has been developed. This report documents the requirements that the resulting computer code must meet and outlines a method of meeting the requirements.

The work described in this report was conducted in accordance with the requirements of ANSI/ASME NQA-1 1986 Edition (ASME 1986), Quality Assurance Program Requirements for Nuclear Facilities, as interpreted by the Pacific Northwest Laboratory (PNL) Quality Assurance (QA) Program.

Development of the HEDR computer code(s) will be guided by the PNL QA program requirements, which are embodied in a series of Software Control Procedures (SCPs). There are seven applicable procedures, dealing with 1) determining and documenting software requirements (SCP-312), 2) final review and acceptance of codes and documentation (SCP-313), 3) software configuration management (SCP-314), 4) conversion testing, verification, and/or validation of software (SCP-315), 5) application control (SCP-316),

(a) The project is being managed and conducted by Battelle staff at the Pacific Northwest Laboratory under the direction of an independent Technical Steering Panel.

6) transfer of software, data, and documentation into and out of the project (SCP-317), and 7) control of databases (SCP-318).

Preparation of this document partially fulfills the requirements of SCP-312, which stipulates code design requirements, design specifications, data input and output, testing, and verification. Upon completion of the code, a Final Internal Development Review (FIDR) will be performed according to SCP-313, resulting in a documented review of the code for adequacy, applicability, and correctness. Following the FIDR, the code will be placed under configuration management, which controls methods of backup, storage, user access control, change requests, and updating. All applications of the code will be tracked and documented under the requirements of SCP-316.

All procedures used to support this report were written and controlled in accordance with PNL QA program requirements. Records that support the derivations in this report were created and stored in accordance with applicable HEDR Project record control requirements, including requirements on the generation of computer output, verification of computer codes, and review of all intermediate output.

Drafts of this document underwent internal independent technical review. Review comments were satisfactorily resolved, and there were no controversial resolutions to the comments.

2.0 SYSTEM DESIGN REQUIREMENTS

This section identifies the system design requirements needed to make the computer codes easy to use, compatible with current computer facilities, and well-suited to the calculational requirements of the project.

The goal of the project is the calculation of estimates of radiation dose, with associated variability and uncertainty, for both hypothetical Reference Individuals and actual Specific Individuals. For representative Reference Individuals, information is being developed on the basis of geographic location, age, lifestyle, ethnic group, and dietary habits. For Specific Individuals, additional information will be required on actual values for each of these data categories, along with definitions of the time frames of changes in each. It becomes immediately obvious that the number of variables and potential permutations is very large, and the level of detail is very fine, so a major undertaking is simply the control and explanation of this much information.

50 All final dose results are being provided in terms of a range of potential doses, with a distribution of expected values. The calculations incorporate the uncertainty caused by both natural variability and lack of knowledge of true values of parameters. *Uncertainty in the model structure is not included but will be addressed in future analyses.*

2.1 GENERAL COMPUTATIONAL APPROACH

1,16 Appropriate scales for spatial and temporal resolution have been
29,42 identified. A recent similar project that attempted to reconstruct doses for releases of radionuclides from the Department of Energy's (DOE's) Nevada Test Site used county-level grids, with specific locations sometimes superimposed (Dose Assessment Advisory Group 1987). For releases from the Hanford facilities, it was quickly determined that the county grid would be too coarse because atmospheric concentration and deposition could be shown to vary significantly within individual counties. A simple rectilinear grid, such as that used in most atmospheric dispersion models, was found to be too inflexible; that is, no grid could be devised that did not have such undesirable features as splitting major population centers. Demographic data are

mostly available from the U.S. Census Bureau, and census subdivisions were found to be essentially unchanged over most of the potential study period from initiation of Hanford operations in 1944 to the present. The census subdivisions were originally developed by the Census Bureau to create stable enumeration districts. Consideration was given in their development to trade and service areas, principal settlements, major land uses, and physiographic differences. Additionally, the census tracts tend to follow political boundaries such as township and range lines, which in much of the potential study area also tend to follow a fairly regular grid pattern. Each of these characteristics is favorable for use by the project with the added advantage of tending to follow a regular grid. Therefore, the census subdivision was selected as the basic unit of spatial area, with some minor modifications (usually combinations of very small adjacent subdivisions, although decomposition of large areas into smaller ones was also done). A map of the initial subdivisions selected for study is shown in Figure 2.1.

2 Selection of a unit of temporal measure proceeded in a manner similar to that for spatial resolution. The Hanford releases have for the most part been routine and continuous. Meteorological data used to describe the atmospheric transport of released radionuclides are available for 15-minute intervals for much of Hanford's history. Census data on locations and numbers of exposed individuals are available for every decade since 1944. For some time periods, data on releases from the Hanford facilities and monitoring of environmental contamination resulting from those releases are available from archived monthly reports. However, other information cannot be expected to be so well documented. Reference dietary data are available, at best, on a seasonal basis. For lifestyle surveys, also, it seems unreasonable to expect most people to remember habits and activities up to 45 years ago on anything more than a seasonal or monthly basis. Based on these considerations, therefore, the month was selected as the project's unit of temporal resolution.

For Phase I, the 10-county area shown in Figure 2.1 has been investigated. The years of initial interest have been 1944-1947 for the atmospheric releases and 1964-1966 for the surface water releases. These were

FIGURE 2.1. HEDR Census Divisions

selected to represent periods of relatively high release and, in the case of the surface water releases, comprehensive monitoring data.

2.2 COMPUTATIONAL FACILITIES, HARDWARE, AND DATABASES

The computer code shall be designed for implementation on the PNL Y-VAX in conjunction with the Sequent database system. The code shall be secondarily designed for in-house microVAX and other minicomputer systems. If it is necessary to improve data processing speeds, provision should be made for the code to run on the NAS-9060 LSIS (large-scale information system) Cray computer.

Input data will be generated in several of the technical tasks on the project. Each task will be responsible for maintaining its own separate database and transferring the documented results to the main HEDR database. The main HEDR database should be kept on a central PNL mainframe, such as the Sequent system in the Sigma V Building. A database management system, e.g., Oracle, should be considered for controlling and accessing this data.

Because of the large quantities of spatially related data that must be maintained and analyzed, provisions shall be made to adapt the calculated outputs to a Geographic Information System (GIS). Input and output data stored in a coherent form on the Sequent should facilitate transfer to a GIS.

2.3 CODE LANGUAGE

The computer code shall be written in standard ANSI FORTRAN-77 language. This choice will facilitate the communication and understanding of the code calculations, conversion to other computing systems, modifications to the code, and necessary updating.

2.4 CODING STANDARDS

Programming shall follow the guidelines of the following coding standard. This coding standard is intended to provide a concise, uniform, and complete form of documentation and quality control; to streamline review efforts; and to simplify software maintenance. All FORTRAN routines shall consist of three blocks:

1. Definition block (routine name, limitations and prerequisite, arguments, logical names and files used, routines used),
2. Implementation block (development information, modification history, algorithms, constants, parameter statements, common blocks, and variables), and
3. Code block (data statements and executable statements).

Where applicable, the programmer should

- localize system-dependent calls
- avoid dependency on internal word size
- place constants in an up-front parameter file
- put variables in common blocks
- use logical device names in front of file names
- hold to a limit of one routine per file.

2.5 DATA INPUT

The code will need to access the following types of information in arrays of data logically prepared as functions of spatial location and time period:

Source Terms

- 51,52 • source terms by radionuclide; *for Phase I, iodine-131 for the atmospheric release pathway and phosphorus-32, neptunium-239, chromium-51, sodium-24, manganese-56, zinc-65, arsenic-76, and copper-64 for the Columbia River pathway.*
- number of curies released for each month
 - associated low and high estimates for each nuclide and time period
 - atmospheric releases assigned to a single location mid-site for Phase I.

Transport

- atmospheric dispersion data in terms of time integrated air concentrations, curie-second/cubic meter per curie released at each location for each month

- best estimate and uncertainty descriptors given as the mean and standard deviation of the logarithm (base 10) of the time-integrated air concentration
- 17 • atmospheric deposition data in terms of monthly averaged deposition rates, $Ci[m^2\text{-sec}]$ per Ci released at each location for each month'
- cumulative atmospheric deposition data in terms of Ci/m^2 at the end of each month per curie released at each location for each month for the total time period
- best estimate values and an uncertainty descriptor - The transport model will perform this calculation on a single-month basis and the subsequent software models will aggregate the running total in order to allow the statistical portion of the calculation to proceed.
- river water concentrations in terms of curies/liter monthly average with an uncertainty descriptor for each river-adjacent location (approximately one for each river-adjacent census tract)
- sediment concentrations in terms of curies/square meter monthly average, if available (probably not available for Phase I) with an uncertainty descriptor for each river-adjacent location.

Monitoring Data

- measured vegetation concentrations in terms of curies/kilogram monthly average for each location - This requires prior averaging of data, which results in a distribution descriptor. This is likely to be a sparse matrix.
- measured fish concentrations in terms of curies/kilogram monthly average at each of the locations used above for water and sediment concentrations - This requires prior averaging of data, which results in a distribution descriptor. This has the potential to be a fairly sparse matrix.
- for later phases, measured air concentrations in terms of curies/cubic meter for each location for each month - This requires some averaging of data, which should result in a distribution descriptor. This is likely to be a sparse matrix.
- for later phases, measured animal product concentrations in terms of curies/kilogram or liter for each location for each month - This requires some averaging of data, which should result in a distribution descriptor. This is likely to be a sparse matrix.

Demography and Food Habits

- animal feeding practices (kilogram/day per animal for each feed type) by location and month - Five feed types will be used for Phase I. Associated uncertainty descriptors will be defined as high and low estimates.
- for later phases, feed distribution arrays (the fraction of feed consumed in one location that is produced in another location) by feed type and month - Associated uncertainty arrays, probably high and low estimates. This may be a sparse matrix. For Phase I, it will be assumed that all feeds are produced locally.
- milk accumulation arrays, the fraction of milk received at a distribution center (dairy) from each location - We anticipate about 20 dairies for Phase I. Associated uncertainty arrays, probably high and low estimates. This may be a sparse matrix.
- milk distribution arrays, the fraction of milk available to be consumed in each location from each distribution center - We anticipate about 20 dairies for Phase I. Associated uncertainty arrays, probably high and low estimates. This may be a sparse matrix.
- dietary consumption rates, in terms of kilograms/month for each food type, as a function of age, sex, lifestyle, and month. Associated distributions derived from the 1977 National Food Consumption Survey.

Environmental Pathways and Doses

- 56,57 • radiation dose factors in terms of rem or rad per curie (depending on pathway) ingested or inhaled, by age and sex - There will probably be only two age groups in Phase I, *infant and adult*. Uncertainty distributions parameterized as log-normal.

2.6 OUTPUT REQUIREMENTS

- 59 *Distributions of radiation dose will be calculated for various intakes of radionuclides, including uptake by the body, distribution and retention of the radionuclides in various organs, and information on the resulting dose in the various organs from radionuclide decay in other organs. Seven age groups, based on the resolution provided by available data (with the inclusion of fetal thyroid), will eventually be used for interpolation to specific ages. For Phase I, only the adult and infant categories are being investigated. Provisions for the age groups shown in Table 2.1 will be made in the code structure. Each age group is also subdivided into male and female, with the adult female further subdivided into pregnant and non-pregnant.*

TABLE 2.1. Age Groups Included in Code Structure

Age Group	Age	Nominal Body Mass
Prenatal	0 - 270 days	Variable
Newborn	About 0 days	3.4 kg
1 - 4 yr	1 yr	9.8 kg
5 - 9 yr	5 yr	19 kg
10 - 14 yr	10 yr	32 kg
15 - 20 yr	15 yr	55 kg (58 kg adult female)
Adult	20+ yr	70 kg (male)

Dosimetry for male and female children through about age 15 will be the same; the only potential variable would be uptake if there is a sex difference in food consumption. After age 15, the dosimetric calculations vary, as well. The number of people in the seven age groups will be provided for each of the major subpopulations defined below, subdivided by spatial location on the census subdivision grid.

58,59 Output doses for the atmospheric pathway shall be reported as absorbed dose in rad to the thyroid. For the Columbia River pathway, doses shall be reported as absorbed dose in rad to the organs bone, liver, and lower large intestine, and as effective dose equivalent in rem to the whole body. *Output will be given as dose distributions, not specific numbers.*

2.6.1 Population Groups

Population groups specifically identified in the HEDR Work Plan approved by the TSP include Native American tribes, Army personnel stationed at Hanford, unbadged Hanford construction workers, migrant workers, and the general population. The subcategories of population groups included in Table 2.2 are required. Those having a higher emphasis are needed for the Phase I study area in FY 1989-1990. Those having lower emphasis will be addressed in future work; however, this does not preclude some data collection when appropriate.

The groups of higher emphasis are being investigated for each of the census subdivisions within the Phase I 10-county study area. Each will be

TABLE 2.2. Population Groups Emphasized in Code

<u>Subpopulation</u>	<u>Emphasis</u>	<u>Additional Notes</u>
General population	Higher	Air and river releases
Native Americans	Higher	Air and river releases
Unbadged site workers	Lower	Air releases
On-site military	Lower	Air releases
Migrant workers	Lower	Air and river releases

further subdivided into the lifestyle categories, urban and rural. With the number of subpopulation categories, and the very limited occupation information available, a further breakdown probably could not be supported by the data at this time. Race has not been included as a discriminator for Phase I.

2.6.2 Food Types

The consumption of contaminated food was a major pathway of exposure for people who lived in the Hanford area during the years 1944-1947. A number of different general food types, which were identified as potentially important, are typically used in radiological evaluations and are available in the preliminary mathematical models being used for HEDR sensitivity studies and Phase I initial development. For each subpopulation/age/sex/lifestyle category, distributions of monthly consumption rates of the locally produced foods listed in Table 2.3 are required. Because of the similarity of the lists of general population and Native American foods, the same basic models will be used for each. All foods will be examined as both fresh and stored.

2.7 GRAPHICS

Although no graphics have been explicitly identified as necessary, a future need is expected for displaying numbers calculated by the computer code, for instance, a plot of air_concentration versus distance from the point of release. A mechanism shall be designed to retain output in files for later graphics applications.

TABLE 2.3. Local Foods Requiring Calculation of Monthly Consumption Rates for Population Categories

General Population

- Leafy vegetables
- Other (protected) vegetables and root vegetables
- Legumes (if they can be broken out of other vegetables)
- Grains (generally dried and stored)
- Orchard fruits, berries, melons
- Milk (subdivided into cow and goat, if possible)
- Eggs
- Beef, pork, lamb
- Poultry
- Fish
 - anadromous
 - piscivorous
 - benthic
- Any other aquatic biota

Native American

- Exposed produce (leafy vegetables, pine moss, etc.)
- Other vegetation (roots, bulbs, etc.)
- Legumes (if available)
- Grains and seeds
- Fruit, berries, melons, etc.
- Milk (subdivided, if possible)
- Eggs (chicken and others as applicable)
- Beef, pork, lamb, elk, deer, other native mammals
- Birds (including chicken, pheasant, partridge, quail, geese, etc.)
- Fish
 - anadromous
 - piscivorous
 - benthic
- Other aquatic biota (freshwater clams, any water plants, etc.)
- Miscellaneous other protein sources

2.8 DOCUMENTATION AND INSTRUCTIONS

Documentation shall be prepared during code development. Documentation shall include code algorithms as well as a user manual that is updated as changes are made. A record of changes made once the code is under configuration management shall be retained as project records.

2.9 ERROR MESSAGES

Error messages shall assist the user when improper input parameters or formats are used, or when illegal calculations are requested. All input

errors shall be identified by the input routines prior to main program execution. Messages shall identify the issuing subroutine and provide a concise definition of the error.

2.10 UPDATES AND REVISIONS

Notices of code updates and revised instructions shall be provided to known users. A list of potential users shall be maintained so that revisions and notices may be distributed as appropriate. This shall be performed by a designated code custodian.

2.11 SECURITY

The computer code and associated databases are to be considered sensitive. Security measures shall be implemented to protect the code from access by unauthorized users. A control mechanism with sign-off procedures shall be implemented to protect the software from unauthorized modifications. Needed changes shall be verified before modifications are permitted to the final versions.

3.0 SYSTEM DESIGN SPECIFICATIONS

The computer codes developed for Phase I of the HEDR Project are to be fully modular and stochastic (using Monte Carlo techniques). The codes will use distributions of input data and produce dose estimates in the form of distribution rather than simply producing deterministic (single-point) estimates.

A simplified project diagram for calculating doses from atmospheric releases is shown in Figure 3.1. Generic pathways are submersion in contaminated air, inhalation of contaminated air, exposure to surfaces contaminated from atmospheric deposition, consumption of contaminated food crops, and consumption of contaminated animal products. Animal products such as milk are complicated by the fact that the feed consumed by the animal may come from areas distant from the animal's location, and the milk itself may be shipped to accumulation centers and then redistributed.

A similar diagram has been prepared for surface water releases (Figure 3.2) and similar pathways are considered: immersion (swimming or boating) in contaminated water, drinking of contaminated water, consumption of fish and other aquatic foods, and consumption of foods contaminated via irrigation with contaminated water. The overall calculation of radiation dose will be the sum of parallel pathway calculations. Parameterization of each of the terms in the equation is described in this section.

The initial calculation of dominant radionuclides indicates no important decay chains that cannot be treated as either single radionuclides or pairs in equilibrium (Napier 1989). For the equilibrium pairs, the decay energies of the daughter can be effectively considered to be included in the energies of the parent. Therefore, calculation of radioactive decay in the HEDR Monte Carlo routines is greatly simplified. Decay can be explicitly written into each module as a simple exponential term.

GENERALIZED DATA FLOW; AIR

FIGURE 3.1. Project Steps Required for Calculating Doses from Atmospheric Releases of Radionuclides

GENERALIZED DATA FLOW: SURFACE WATER

FIGURE 3.2. Project Steps Required for Calculating Doses from Surface Water Releases of Radionuclides

3.1 ATMOSPHERIC RELEASE MODEL

The logic diagram of Figure 3.1 indicates "module breaks" for individual portions of the calculation. These represent individual portions of the computer code that can be run in a stochastic simulation (Monte Carlo analysis). There are three reasons for structuring the calculation with module breaks: the interdependence of information, the need to input data during calculations, and the use of the code in another ongoing Hanford study.

Because of the interconnected nature of the cow feed/milk distribution model, no doses can be calculated for individuals in a particular census subdivision without knowledge of the environmental conditions in many other locations. The calculation has been structured so that repetitive calculations are minimized, and information on the potential distributions of environmental parameters such as air concentration, vegetation concentration, or milk concentration can be saved and examined for each time period.

A second reason for the structure of the model is that it allows the input of either calculated or measured data at each step of the calculation. Where monitoring data are available, they will be relied on rather than on simulated data. However, since the monitoring is not complete over all times, locations, and pathways, the structure allows use of measurement data supported by calculations when necessary.

3,18 This structure also supports the calculation of doses to both reference
30,45 individuals and specific individuals. This is important because the dose reconstruction project supports a parallel project being conducted by the CDC, which is investigating potential thyroid morbidity caused by the early Hanford releases. Then a CDC contractor will be interviewing many individuals about their past lifestyle and dietary habits and attempting to correlate dose with thyroid disease. The HEDR computational model will be used for the calculation of doses for those interviewed by the CDC's contractor.

3.1.1 Module 1: Atmospheric Transport and Deposition

The proposed logic for Module 1 is illustrated in Figure 3.3. The objective of this module is to initiate calculations by providing

MODULE 1: ENVIRONMENTAL TRANSPORT

- Notes: 1) dotted line () indicates Monte Carlo routine
 2) "Select" means pick from distribution systematically
 3) "Store" means add to histogram array
 4) "Process" means convert stored histogram array into a mean + standard deviation or other distribution parameters and save as output.

FIGURE 3.3. Proposed Logic for Module 1: Environmental Transport

time-integrated air concentrations, deposition rates, and month-end concentrations of radionuclides on the ground for each of the census divisions and monthly increments. (See Appendix A for equations used in calculating these parameters.) The solid lines in Figure 3.3 represent the computer looping structure, i.e., the code routines which repeat the same type of calculations for each location, each month, and each radionuclide. The dashed line indicates that portion of the code that must operate in a Monte Carlo fashion, repetitively calculating multiple values of each output variable on the basis of randomly selected parameter values from the multiple input distributions. The inputs to this module are the source-term vectors and atmospheric dispersion, deposition rate, and month-end deposition arrays described in Section 2.5. The techniques for selecting realizations from these distributions for the Monte Carlo analysis are defined in a memo by A. Leibetrau (see Appendix B).

The definitions of the equations for calculating air concentration, deposition rate, and total month-end ground deposition are presented in Appendix A. Variables and units are also presented. The anticipated nature of each of the input distributions is presented in Table 3.1.

The output of Module 1 will essentially contain intermediate values for input to Module 2. Output shall be stored in the form of histograms of the Monte Carlo results. The use of histograms provides a convenient mechanism for storing arbitrary distribution shapes. Histograms should contain a minimum of 20 bins. A memo by A. Leibetrau defining the nature of storing and retrieving data from histograms is provided as Appendix C.

Source terms for Phase I will include only iodine-131. Allowance should be made in the code for expansion to additional radionuclides, as illustrated in Figure 3.3. Atmospheric transport results for Phase I will be the result of an interim model. In later phases, it may be found to be more convenient to combine source terms with dispersion modelling. The modular structure of the HEDR code should allow this with minimal disruption.

TABLE 3.1. Anticipated Parameter Distribution Types for Module 1

<u>Parameter Distribution</u>	<u>Type of Data Input</u>
X / Q'	Lognormal
$\dot{d} / Q'$	Lognormal
d / Q'	Lognormal
Q'	Triangular
μ_r	Constant
γ	Calculated Histogram
$\dot{d}$	Calculated Histogram
d	Calculated Histogram

3.1.2 Module 2: Vegetation Concentrations

19,33 The proposed logic of Module 2 is shown in Figure 3.4. The purpose of this module is to calculate or input concentrations of radionuclides on vegetation. The nomenclature of this figure is the same as that of Figure 3.3. (See Appendix B for documentation of algorithms for generating samples from selected probability distributions.) Input to this module may be either the histograms of deposition rate and total deposition from Module 1 or measured values of air concentration from the monitoring database. For Phase I, it may be assumed that no monitoring data will be available, but the coding should anticipate the possibility that it may become available in later phases. Vegetation types that must be considered are those for human consumption (leafy vegetables, other vegetables and tubers, fruits, and grains) and for animal consumption (grains, pasture grass, silage, and alfalfa hay). The grains for human and animal consumption may be considered to be the same. An additional category, sage-brush, will be added to allow direct comparison to monitoring measurements.

The equations to be used for Module 2 are presented and the parameters defined and units given in Appendix A. Additional detail on the interception/retention model is presented in a memo by B. A. Napier provided as Appendix D. These equations are derived from differential equations of the rate of increase and weathering of the various types of vegetation. They have been integrated over the monthly time increment to a quasi-steady-state formulation. Important parameters include time-dependent biomass, rates of

MODULE 2: VEGETATION CONCENTRATIONS

FIGURE 3.4. Proposed Logic for Module 2: Vegetation Concentrations

wash-off and weathering, and soil-to-plant concentration ratios. Provision should be made to incorporate periodic harvesting of certain types of vegetation by biomass reduction and concentration reduction. The anticipated distributions of the input parameters are provided in Table 3.2.

3.1.3 Module 3: Animal Product Concentrations

The proposed logic structure for Module 3 is given in Figure 3.5. The purpose of this module is to calculate concentrations of radionuclides in meat, milk, and eggs produced in each census division for each monthly increment. Input to this module is either calculated vegetation concentrations from Module 2 or measured vegetation concentrations from the monitoring database. Data structures for monitoring data should be established in formats similar to those for the calculated values. These may be used to supplement or replace the calculated values. Additional input shall include information on the diets of farm animals as a function of location and time, provided to the main database by the Demographics, Agriculture, and Food Habits Task. (In later phases, this will include feed transport between census divisions.)

The equations to be used in Module 3 are listed in Appendix A, with parameter definitions and units. Provision should be made for calculation of

TABLE 3.2. Anticipated Parameter Distribution Types for Module 2

<u>Parameter Distribution</u>	<u>Type of Data Input</u>
T_p	Constant for leafy vegetables, alfalfa, forage, ensilage, sagebrush
Y_m	Constant for each plant type and month
μ_w	Triangular
B_v	Triangular distributions of $\log(10) B$
P	Constant
C_m	Calculated histogram
K	Constant for each plant type

MODULE 3: ANIMAL PRODUCT CONCENTRATIONS

FIGURE 3.5. Proposed Logic for Module 3: Animal Product Concentrations

concentrations in meat, poultry, eggs, and milk. Milk may be assumed to be produced by cows or goats. Cows must be assumed to eat several types of diets. Each diet will be defined as a sum of fractional feed type intakes. The fraction of each feed type eaten by the various animals may be graphically represented, as illustrated in Figure 3.6. Currently, four feeding regimes are planned to be provided by the Demographics, Agriculture, and Food Habits Task.

Anticipated parameter distributions to be used as input to Module 3 are presented in Table 3.3.

FIGURE 3.6. A Food-Chain Model to Predict Radionuclide Ingestion (Whicker and Kirchner 1987)

TABLE 3.3. Anticipated Parameter Distribution Types for Module 3

<u>Parameter Distribution</u>	<u>Type of Data Input</u>
f_t	Triangular
Q_f	Triangular
FM_p	Log-normal
A_{m1}	Calculated histogram

The use of fractional intakes of various types of feed introduces a minor complication within the Monte Carlo routine for Module 3. Each of these fractions has its own distribution. The results of the selection process of the fractions must, however, sum to 1, which implies a correlation structure. The means of handling this implied correlation is described in a memo by B. A. Napier, provided as Appendix D. This approach may be used in subsequent modules, as well.

The output of this module may be used directly in Module 6 (meat, eggs, and milk from backyard cows) or as input to Module 4.

3.1.4 Modules 4 and 5: The Milk Accumulation/Distribution Model

Milk produced in the various census divisions may be combined or pooled at creameries (milk-bottling plants). The proposed logic structure for Module 4 for handling the calculations in concentration of brand-name milk is presented in Figure 3.7. Input to this module is the output of Module 3, along with extensive data on sources of milk for creameries, from the Demographics, Agriculture, and Food Habits Task. Output of this module is the concentration of milk from each creamery in the Phase I study area as a function of time. This may be used directly in Module 6, if the milk source is known by name, or as input to Module 5.

Calculation of doses to certain classes of individuals will require knowledge of the average concentration of all milk available in a census tract. Module 5 is the milk distribution module. The proposed logic structure for this module is given in Figure 3.8. This module requires as input the pooled milk concentrations of Module 4, and a milk distribution database that is conceptually the inverse of that used to collect milk in Module 4.

Equations and parameter definitions for Modules 4 and 5 are presented in Appendix A. The anticipated distribution types of the variables for Modules 4 and 5 are listed in Table 3.4.

MODULE 4: MILK ACCUMULATION (to Creamery)

FIGURE 3.7. Proposed Logic for Module 4: Milk Accumulation at Creameries

MODULE 5: MILK DISTRIBUTION (to stores at each location)

FIGURE 3.8. Proposed Logic for Module 5: Milk Distribution to Stores in Each Census Tract

TABLE 3.4. Anticipated Parameter Distribution Types
for Modules 4 and 5

<u>Parameter Distribution</u>	<u>Type of Data Input</u>
t1	Triangular
t2	Triangular
t3	Probably = t2
f_1^C	Triangular
F_1^G	Triangular
M0	Calculated histogram
M1	Calculated histogram
M2	Calculated histogram

3.1.5 Individual Exposure and Dose

Modules 1 through 5 establish the environmental concentrations of radionuclides in environmental media for all census subdivisions and months of interest. Module 6, however, introduces humans exposed to the radionuclides. Module 6 is designed for the calculation of doses to either "reference" or "specific" individuals. (Note that for Phase I, only input data for reference individuals will be available.) The proposed logic structure for Module 6 is shown in Figure 3.9. Inputs to this module are the outputs from all prior modules, plus an extensive database of generic consumption and exposure rates for each category of individual type (age, sex, and lifestyle) developed by the Demographics Task. For calculations to reference individuals, exposure conditions shall be selected stochastically from this database. For calculations to specific individuals, specific input values or distributions will be used, where known, and data from the generic database will be used for unspecified or unknown parameters.

Equations to be used for dose calculations are provided in the system design outline for Module 6 (Appendix A). These equations describe dose via inhalation and exposure to contaminated air, irradiation by contaminated surfaces and soils, and ingestion of local farm products. Note that, for this phase of the code development, the formulations imply that all foods other than milk are produced in the census tract in which they are consumed.

MODULE 6: INDIVIDUAL EXPOSURE & DOSE

[tied together because individual consumption rates & dose factors will be correlated by age/sex]

FIGURE 3.9. Proposed Logic for Module 6: Individual Exposure and Dose

For certain individuals, this practice will tend to overestimate the dose, while for others it may tend to underestimate. The magnitude of the error in estimation will be evaluated as the project progresses, and revised formulations (similar to the milk distribution model) may be used.

Because the results of Module 6 may be required to support projects other than HEDR (e.g., the CDC thyroid morbidity study), the input to Module 6 should be structured such that at a later time, a simple interactive driver may be developed for ease of use. This will simplify the calculation of large numbers of individual doses.

The dose calculations shown in Figure 3.9 do not fully reflect the number of calculations required. Doses must be provided for a number of internal organs, as must a weighted effective dose equivalent, which will require looping on the actual dose calculation once the radionuclide exposures are known. Thus, consideration must be given to convenient storage of multiple outputs.

The anticipated distributions of input and output parameters are listed in Table 3.5.

3.2 SURFACE WATER RELEASE MODEL

The HEDR Phase I dose model for surface water release is separate from the atmospheric release dose model. The surface water model is based much more on measured data than is the atmospheric model. However, its structure is modular (see Figure 3.2), in a fashion similar to that for the atmospheric release model.

39 Unlike data for the early atmospheric releases, detailed effluent data
22,31 are available for the releases from the operating production reactors during the period 1964-1966. In many instances, these data were available on a daily or weekly basis. This information was used directly as source term input to the surface water transport calculation without recourse to modeling. Thus, estimation of surface water concentration from Hanford releases in the mid-1960s was straightforward. A simple routing model was applied to the effluent data, accounting for dilution in the time-varying flow of the

TABLE 3.5. Anticipated Parameter Distribution Types for Module 6

<u>Parameter Distribution</u>	<u>Type of Data Input</u>
E1	Uniform
E2	Uniform
DF _S	Constant
DF _G	Constant
DF _{Ha} , DF _{Ia}	Lognormal
BR _a	Constant
K	Constant
D _{sm}	Calculated histogram
D _{Gm}	Calculated histogram
D _{Hm}	Calculated histogram
R ^V _{ma}	Triangular
R ^P _{ma}	Triangular
ff _{va}	Triangular
ff _{pa}	Triangular
ff _{ma}	Triangular
Month-of-Harvest	Fixed
Holdup Times	Constant
f ₀ , f ₁ , f ₂	Delta functions, Phase I Sum = 1.0 for specific
D _{Iv}	Calculated histogram
D _{Ip}	Calculated histogram
D _{Im}	Calculated histogram

river as well as decay for the various associated travel times of radionuclides to the locations of interest. The results of this model compare excellently to the measured values. The variability in the surface water estimates is derived from the upper and lower measured values found for each radionuclide at each sampling location and time. This database provides the input to the surface water dose model. With limited exceptions (e.g., *Fast Flux Test Facility* visitor's center), ground water at the Hanford Site is not now and has not been used for any purposes by members of the general offsite public. Based on current understanding, radionuclide sources within the

200 Area did not contribute significantly to concentrations in the Columbia River until the early 1970s. Because of the proximity of the 100 and 300 Areas to the river, operations in these areas may have contributed more radionuclides to the river via the groundwater pathway. These additions are accounted for in the monitoring data and, thus, add to the variability of the estimates for Phase I.

The various stretches of the river can be conveniently associated with the census divisions used in the atmospheric release dose model. This is because the census tracts tend to use geographical divisions, such as tributaries to the Columbia River, as dividing lines. A memo from B. A. Napier defining the stretches of the river in relation to the census divisions is provided as Appendix F.

3.2.1 Modular Approach

As described above, modeling is not required for surface water concentrations. However, the measured data include parameterization of uncertainty, which must be included in the subsequent steps of the calculation. This includes monitored data for fish caught in the Columbia River. Fish concentration data have also been extensively monitored, and calculations are necessary only for interpolation between measurements. The availability of fish concentration data is reflected in the logic diagram for Module 1 of the surface water code (see Figure 3.2). Fish concentrations are calculated only if such data are not available from the database. A bioaccumulation model is to be used.

Module 2 is used simply to account for the quantities of fish that were caught at various locations of the river and consumed. It is similar in concept to the milk distribution model described in Section 3.1.4, but the input is from a database from the Demographics, Agriculture, and Food Habits Task.

Module 3 accounts for the fact that drinking water is almost entirely processed prior to human consumption, and that processing can remove radionuclides found in the untreated river water. At this time, it has not been decided whether or not to include irrigated foods as an explicit exposure pathway, or whether it is of sufficiently minor importance that a simple

"transfer factor" approach may be adequate. Additional sensitivity studies with simpler models will be performed before the final structure is determined.

Module 4 parallels Module 6 of the atmospheric release model. Calculations are required for both reference and specific individuals. The age groups, lifestyles, and dose factors are the same as those defined for the atmospheric release model.

3.2.2 Models and Parameters

The equations to be used in the surface water model are listed with Module 6 in Appendix A. The structure is similar to the more complex model described for atmospheric releases, but the equations are generally much simpler. The anticipated parameter distributions are listed in Table 3.6.

TABLE 3.6. Anticipated Parameter Distributions for the Surface Water Release Model

<u>Parameter Distribution</u>	<u>Type of Data Input</u>
W_{m1}	Triangular
B^{Tm}	Triangular
$CF1_{mst}$	Calculated histogram
f^L_{st}	Triangular
$CF2_{mst}$	Calculated histogram
DWCF	Uniform
tw	Triangular
DW_{m1}	Calculated histogram
DF_{Ia}	Lognormal
R^F_{amT}	Triangular
R^W_{am1}	Triangular
E3	Uniform
E4	Uniform
DF_w	Constant
$DFISH, a, 1$	Calculated histogram
$DWATER, a, 1$	Calculated histogram
$DSWIM, a, 1$	Calculated histogram
$D_{BOAT}, a, 1$	Calculated histogram

4.0 REFERENCES

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APPENDIX A

EQUATIONS FOR SYSTEM DESIGN MODULES

Module 1

EQUATIONS FOR CALCULATION OF

- AIR CONCENTRATION - x_m
- AVERAGE DEPOSITION RATE - $\bar{d}_m$
- END-OF-MONTH SOIL CONCENTRATION - d_m
(for each location)

$$x_m = \left[x/Q'_m \right] \cdot Q'_m$$

$$\bar{d}_m = Q'_m \cdot \left[\bar{d}/Q'_m \right]$$

$$d_m = Q'_m \cdot \left[d/Q'_m \right] + d_{m-1} e^{-\lambda_r t}$$

$$Q'_m = \text{Ci/month}$$

$$x/Q'_m = \text{Ci-sec/m}^3 \text{ per Ci/month}$$

$$\bar{d}/Q'_m = \text{Ci/m}^2\text{-sec per Ci/month}$$

$$d/Q'_m = \text{Ci/m}^2 \text{ per Ci/month at end of month}$$

$$x_m = \text{time-integrated air concentration, Ci-sec/m}^3*$$

$$\bar{d}_m = \text{average deposition rate, Ci/m}^2\text{-sec}$$

$$d_m = \text{month end soil concentration, Ci/m}^2*$$

$$t = 1 \text{ month}$$

$$10.23 \quad \lambda_r = \text{radiological decay constant, month}^{-1}$$

* Alternatively from Monitoring Data

Module 2

EQUATIONS FOR CALCULATION OF

•VEGETATION CONCENTRATION

(at production, for each location l & vegetation type T)

$$C_{leaf,m} = T_p \left[\frac{d_m r_m}{Y_m} \left(\frac{1 - e^{-(\lambda r + \lambda w)t}}{\lambda r + \lambda w} \right) \right] + \frac{C_{m-1} e^{-(\lambda r + \lambda w)t}}{Y_m/Y_{m-1}}$$

$$C_{root,m} = \frac{d_m B_v}{P}$$

$$C_m = C_{leaf,m} + C_{root,m}$$

$$r_m = 1 - e^{-kY_m}; \text{ interception fraction}$$

$k = \text{function of plant type}$

Y_m = Biomass for month m for this plant type, kg/m^2
 from a file (need to account for harvesting)
 (will be function of growing season: function of location)

$\lambda r, \lambda w$ = radiological & weathering decay constants, day^{-1}

t = number of days in current month

P = soil surface density ~ 240 kg/m^2

B_v = concentration ratio for plant type

10 d_m = month end soil concentration, Ci/m^2

Note: if plant cut or harvested in month $m-1$, then $C_{m-1}/(Y_m/Y_{m-1})$ term should go to zero.

48 T_p = leaf-to-edible-part translocation; $T_p = 1.0$ for pasture & leafy vegetation, alfalfa, ensilage, sagebrush

* C_m alternatively from monitoring data

Module 3

EQUATION FOR CALCULATION OF ANIMAL PRODUCT CONCENTRATIONS (AT PRODUCTION FOR EACH LOCATION AND MONTH)

For each nuclide r and each animal product:
For each location l and month m , compute:

$$A_{ml} = \sum_{j=1}^m \sum_{k=1}^L \sum_{t=1}^T f_{jkt}^{ml} \cdot QF_t^{ml} \cdot C_{jkt} \cdot FM \cdot e^{-\lambda_r (m-j)}$$

$\uparrow$ $\uparrow$ $\uparrow$
 Over all months prior to and including current month m Over all locations that supply feed to location l Over all feed types

m = current month (when feed was eaten by animal)

l = current location (where feed was eaten by animal)

L = total number of locations (census divisions) in study area

T = total number of feed types

j = month in which feed was harvested

k = location where feed was grown and harvested

A_{ml} = nuclide concentration in animal product produced at location l during month m (Ci/L milk or Ci/kg meat and eggs). Calculated histogram.

f_{jkt}^{ml} = fraction of feed of type t eaten by animal at location l during month m that was harvested at location k during month j (from feed source/transport data). The sum of these fractions over all j and k for a given feed type t for the current location l and month m must equal 1.0. Triangular distribution.

QF_t^{ml} = quantity of feed of type t that animal at location l eats during month m (kg/day dry weight). This is from the data on distribution of feeding regimes to census divisions (Ward/Darwin/Beck). Triangular distribution.

C_{jkt} = radionuclide concentration (Ci/kg) in feed of type t harvested in month j at location k (from Module 2). Calculated histogram.

FM = intake-to-product transfer factor, days/L milk or days/kg meat or eggs. Triangular distribution.

λ_r = radioactive decay constant for nuclide r (months⁻¹).
= 0.693/(half-life _{r}). Constant.

$(m-j)$ = decay correction time for feeds not consumed fresh (months).

Modules 4 & 5

24, 25

EQUATIONS FOR CALCULATION OF

•MILK CONCENTRATION AT CONSUMPTION
(for each month m and location l)

1) Backyard Cow:

$$M_{ml} = A_{ml} e^{-\lambda_r th_1}$$

2) Specific Creamery:

$$MA_{cm} = \sum_{l=1}^L f_l^C A_{ml}$$

$$M1_{cm} = MA_{cm} e^{-\lambda_r th_2}$$

3) Grocery Milk at location l :

$$M2_{ml} = \sum_{c=1}^C F_c^l MA_{cm} e^{-\lambda_r th_3}$$

M_{ml} = Ci/L from family cow at consumption in location l

MA_{cm} = Ci/L at specific creamery C at accumulation (no decay)

$M1_{cm}$ = Ci/L from specific creamery C at consumption

$M2_{ml}$ = Ci/L from groceries at location l at consumption

λ_r = radiological decay constant, day^{-1}

th_1 = generic holdup, milking-to-consumption; family cow

th_2 = generic holdup, milking-to-consumption; creamery

th_3 = generic holdup, milking-to-consumption; grocery

f_l^C = fraction of milk at creamery C from source location l

F_c^l = fraction of milk at groceries in location l from creamery C

A_{ml} = milk concentration at production, Ci/L, at location l for
month m

Module 6

EQUATIONS FOR CALCULATION OF

- SUBMERSION DOSE
- GROUNDSHINE DOSE
- INHALATION DOSE

- 1) Air submersion doses, by month at location 1 for lifestyle or specific

$$D_{sm} = x_{m1} \cdot E1 \cdot DF_s \cdot K$$

10, 26

x_{m1} = air concentration at location 1 and month m , Ci/m^3

$E1$ = exposure time, hr/month for lifestyle or specific

DF_s = submersion dose rate factor, rem/hr per Ci/m^3

K = constant unit conversion, mo/sec

- 2) Groundshine doses, by month at location 1 for lifestyle or specific

$$D_{Gm} = d_{m1} \cdot E2 \cdot DF_G$$

10, 26

d_{m1} = end-of-month soil concentration at location 1 and month m , Ci/m^2

$E2$ = exposure time, hr/month

DF_G = groundshine dose rate factor, rem/hr per Ci/m^2

- 3) Inhalation doses, by month at location 1 for lifestyle or specific

$$D_{Hm} = x_{m1} \cdot E1 \cdot [DF_{Ha} \cdot BR_a] \cdot K$$

DF_{Ha} = inhalation dose factor, rem/Ci by age group a

BR_a = breathing rate for age group a , m^3/hr

Module 6 (contd)

EQUATIONS FOR CALCULATION OF

• INGESTION DOSE

- 1) Vegetables, for each vegetable type, age group, lifestyle, location

$$D_{iv} = DF_{1a} R_{ma}^V [ff_{vm} C_{m1} + (1 - ff_{vm}) C_{H1} e^{-\lambda r(H-m)}]$$

- 2) Meat and eggs, for each age group, lifestyle, location

$$D_{IP} = DF_{1a} R_{ma}^P [ff_{pm} A_{m1} + (1 - ff_{pm}) A_{m-h,1} e^{-\lambda r(h-m)}]$$

- 3) Milk

$$D_{IM} = DF_{1a} R_{ma}^M [ff_{Mm} \{MO_m \cdot f_0 + M1 \cdot f_1 + M2 \cdot f_2\} + (1 - ff_{Mm}) \{MO_{M-H} \cdot f_0 + M1_{M-H} \cdot f_1 + M2_{M-H} \cdot f_2\}]$$

$R_{a,m}$ = ingestion rate, kg/month, for each age group
(also probably lifestyle)

ff_v, ff_p, ff_m = fresh fraction

$DF_{1,a}$ = dose factor, rem/Ci, by age group

f_0, f_1, f_2 = fractions of milk for each source (probably delta function)

C_{m1} = vegetation concentration at location 1 and month m, Ci/kg

C_{H1} = vegetation concentration at location 1 and harvest month m, Ci/kg

λr = radiological decay constant, month⁻¹

$(m-H)$ = time between harvest data and consumption, months

A_{m1} = animal product concentration at month m and location 1, Ci/kg

MO = Ci/L from family cow

$M1$ = Ci/L from specific creamery at consumption

$M2$ = Ci/L from grocery at location

SURFACE WATER CODE MODULES

EQUATIONS FOR CALCULATION OF

- FISH CONCENTRATION
- DRINKING WATER CONSUMPTION

- 27 Module 1) At catch, if not using measured values, for each "river stretch" s, for each month m, for each fish type T

$$CF1_{msT} = W_{ms} \cdot B_{Tm}$$

W_{ms} = water concentration at river location s for month m, Ci/L

B_{Tm} = bioaccumulation factor for fish type T for month m

Module 2) At consumption

24, 25

$$CF2_{m|T} = \sum_{l=1}^s f_{st}^l \cdot CF1_{mst}$$

28

f_{st}^l = fraction of fish of type T consumed at location l caught at river stretch s (this is the "fish transport model")

Module 3) Drinking water

$$DW_{ms} = W_{ms} \cdot DWCF \cdot e^{-\lambda_r t_w}$$

DWCF = drinking water cleanup factor, fraction removed by treatment facilities

t_w = time in drinking water distribution system, day

30

λ_r = radiological decay constant, day^{-1}

Surface Water Code, Module 4

- FISH CONSUMPTION DOSE
- DRINKING WATER DOSE
- SWIMMING/BOATING DOSES

24, 25 FISH CONSUMPTION, by age group, lifestyle, etc., at location 1

$$D_{\text{Fish},a,l} = \sum_{T=1}^T R_{amT}^F \cdot CF2_{msT} \cdot DF_{Ia}$$

10 R_{amT}^F = fish consumption rate for age group a, month m, type T

$CF2_{msT}$ = concentration in fish type T at month m, river stretch s

DF_{Ia} = ingestion dose factor for age group a, rem/Ci

DRINKING WATER, by age group

10 $D_{\text{water},a,l} = R_{ams}^W \cdot DF_{Ia} \cdot DW_{ms}$

R_{ams}^W = water consumption rate

DW_{ms} = drinking water contamination at month m, river stretch s, Ci/L

SWIMMING

$$D_{\text{swim},a,s} = E3_{mA} \cdot W_{ms} \cdot DF_w$$

$E3_m$ = exposure time, hr/month spent swimming, a function of age and lifestyle

DF_w = swimming dose factor rem/hr per Ci/L

BOATING

$$D_{\text{boat},a,s} = E4_{ma} \cdot W_{ms} \cdot DF_w/2$$

$E4_{ma}$ = exposure time boating, hr/month, a function of age and lifestyle

APPENDIX B

TECHNIQUES FOR SELECTING REALIZATIONS
FROM ARBITRARY DISTRIBUTIONS

ALGORITHMS FOR THE GENERATION OF SAMPLES
FROM SELECTED PROBABILITY DISTRIBUTIONS

by

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January 15, 1990

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1.0 SUMMARY AND INTRODUCTION

The purpose of this report is to document algorithms for generating samples from the probability distributions that are being, or may be, used in the calculation of dose estimates and uncertainties. Algorithms are presented for generating realizations of random variables with the following distributions:

- $U(a,b)$ -- a uniform distribution over the interval (a,b) , $a < b$
- $LU(\alpha,\beta)$ -- a loguniform distribution over the interval (α,β) , $\alpha < \beta$
- $T(a,b,c)$ -- a triangular distribution over the interval (a,c) with mode at b , $a \leq b \leq c$
- $N(\mu,\sigma^2)$ -- a normal (Gaussian) distribution with mean μ and variance σ^2
- $LN(\theta,\tau^2)$ -- a lognormal distribution with mean θ and variance τ^2 .

Each algorithm requires the generation of random numbers or values from a $U(0,1)$ distribution. It is anticipated that (pseudo) random numbers will be generated using currently available system routines. Because random numbers are crucial to the generation of realizations from any distribution, an alternative algorithm is presented in Section 4.0 for generating (pseudo) random numbers in case the system random number generator proves unacceptable for some reason.

2.0 GENERAL METHODS FOR UNIVARIATE DISTRIBUTIONS

A fundamental method that theoretically works for any univariate distribution is the Inversion Method. This method, which requires the inversion of the cumulative distribution function (cdf), is based on the following theorem of probability (see Mood, Graybill, and Boes 1974, p. 202):

If X is a random variable with cumulative distribution function F , then the random variable U , defined by $U = F(X)$, has a uniform distribution over the interval $(0,1)$.

In practice, realizations are obtained by generating a pseudo-random number u (a realization of a $U(0,1)$ random variable), setting this number equal to U in the above theorem, and solving for X . For each realization u , this procedure yields the realization $x = F^{-1}(u)$ of the random variable X . The Inversion Method is shown schematically in Figure 1. The utility of the

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FIGURE 1. The Inversion Method of Generating Realizations from the Cumulative Distribution Function F : x is the realization that corresponds to the random number u .

Inversion Method is limited by the difficulty of obtaining F^{-1} ; consequently, alternative methods are preferable for many distributions whose cdfs are difficult to invert. The Inversion Method is used to generate realizations from uniform and triangular distributions.

Technical Note: If F is not continuous, then there exist values of u for which $F^{-1}(u)$ is not well defined. In this case, x should be taken as the largest value to x_0 such that $F(x) \leq u$, i.e.,
$$x_0 = \sup x F(x) \leq u.$$

A second method for generating realizations of specified distributions is by means of transformations. If Y is obtained by transformation from the variable X , say $Y = g(X)$, then realizations of Y can be obtained by applying the transformation g to realizations of X . Transformations are used to generate loguniform variates from uniform variates and lognormal variates from normal variates. Transformations may also be used to generate $U(a,b)$ variates from $U(0,1)$ variates and $N(\mu, \sigma^2)$ variates from $N(0,1)$ variates.

In addition to the two general methods identified above, special methods exist that are efficient for specific distributions. The Box-Muller algorithm given in Section 3.4 is a special method for the generation of standard normal variables [e.g., $N(0,1)$ variables].

The algorithms obtained by applying the methods in this section to the distributions listed in Section 1.0 are given in Section 3.0. A good overview of methods for generation of realizations from univariate distributions is given in Chapter 2 of Johnson (1987); a more extensive discussion is found in Chapter 5 of Bratley, Fox, and Schrage (1983).

3.0 ALGORITHMS FOR SELECTED DISTRIBUTIONS

3.1 The Uniform Distribution

The Inversion Method is used to obtain $U(a,b)$ variates from pseudo-random variates. If X has a $U(a,b)$ distribution, then the cdf of X is

$$F_U(x) = \begin{cases} 0, & x \leq a \\ (x - a)/(b - a), & a \leq x \leq b \\ 1, & x \geq b \end{cases}$$

In the interval $a < x < b$, $F_U(x) = (x - a)/(b - a)$, so F_U^{-1} is given by

$$x = F_U(x) (b - a) + a$$

Therefore, we obtain the following algorithm for generating a realization x from a $U(a,b)$ distribution.

Algorithm

Step 1. Generate a pseudo-random number u from the $U(0,1)$ distribution.

Step 2. Compute $x = u (b - a) + a$.

References

Iman and Shortencarier (1984, p. 18)
Mood, Graybill, and Boes (1974, p. 105)
Any standard statistics textbook.

3.2 The Loguniform Distribution

Log uniform variates are obtained by transforming uniform variates. By definition, the random variable Y has a loguniform distribution over the interval (α, β) , $\alpha < \beta$, $\alpha > 0$, $\beta > 0$, if, and only if, the random variable $X = \ln Y$ has a uniform distribution over the interval (a,b) , where $a = \ln \alpha$ and $b = \ln \beta$. From this definition, it follows that

$$F_U(x) = (x - \ln \alpha)/(\ln \beta - \ln \alpha)$$

or

$$x = F_U(x)(\ln \beta - \ln \alpha) + \ln \alpha$$

for $\ln \alpha \leq x \leq \ln \beta$. Therefore, we obtain the following algorithm for generating a realization x from a $LU(\alpha, \beta)$ distribution.

Algorithm

Step 1. Generate a pseudo-random number u from a $U(0,1)$ distribution.

Step 2. Compute $y = \exp [u (\ln \beta - \ln \alpha) + \ln \alpha]$.

Reference

Iman and Shortencarier (1984, p. 19)

3.3 The Triangular Distribution

The Inversion Method is used to obtain realizations from a triangular distribution. If X has a triangular distribution over the interval (a,c) with mode b , then the cdf of X is

$$F_T(x) = \begin{cases} 0, & x \leq a \\ (x - a)^2 / [(c - a)(b - a)], & a \leq x \leq b \\ \frac{b - a}{c - a} - \frac{(x + b - 2c)(x - b)}{(c - a)(c - b)}, & b \leq x \leq c \\ 1, & x \geq c \end{cases}$$

Note that at $x = b$, $F_T(x) = F_T(b) = (b - a)/(c - a)$. Inverting $F_T(x)$ yields the following algorithm for generating a realization x from a triangular distribution with parameters a , b , and c , $a \leq b \leq c$.

Algorithm

Step 1. Generate a pseudo-random number u from a $U(0,1)$ distribution.

Step 2. If $u \leq (b - a)/(c - a)$

Set $u = F_T(x) = (x - a)^2 / [(c - a)(b - a)]$

Compute $x = a + [u(c - a)(b - a)]^{1/2}$

Step 3. Otherwise,

$$\text{Set } u = F_T(x) = \frac{b-a}{c-a} - \frac{(x+b-2c)(x-b)}{(c-a)(c-b)}$$

$$\text{Compute: } x = c - [(b-c)^2 + (b-a)(c-b) - u(c-a)(c-b)]^{1/2}$$

References

Iman and Shortencarier (1984, p. 20)
Johnson and Kotz (1970)

3.4 The Normal Distribution

The inverse of the cdf of a normally distributed random variable X cannot be expressed in closed form, so the inversion method is not the method of choice for generating normal variates. The method used to generate normal variates, which is due to Box and Muller (1958), involves transformation of a pair of pseudo-random numbers to obtain a pair of standard normal variates. These are further transformed to obtain a pair of realizations from a normal distribution with mean μ and variance σ^2 .

The Box-Muller algorithm is an efficient method for generating simple random samples of normal variates, but it may not be as efficient for Latin Hypercube Sampling, which involves partitioning the range of the simulated variables. To generate normal variates using Latin Hypercube Sampling, it is desirable to use an algorithm that generates specified percentage points of a normal distribution. The algorithm cited below, due to Beasley and Springer (1977), is used for this purpose.

The Box-Muller Algorithm

Step 1. Generate independent pseudo-random numbers u_1 and u_2 from the $U(0,1)$ distribution.

Step 2. Compute $g_1 = (-2 \ln u_1)^{1/2} \cos(2\pi u_2)$
 $g_2 = (-2 \ln u_1)^{1/2} \sin(2\pi u_2)$

Step 3. Compute $x_1 = \sigma g_1 + \mu$
 $x_2 = \sigma g_2 + \mu$

The quantities x_1 and x_2 are independent realizations from a normal distribution with mean μ and variance σ^2 .

Step 4. (optional) If

$$y_1 = g_1$$

$$y_2 = \rho g_1 + (1-\rho^2)^{1/2} g_2$$

are computed for some ρ , $-1 \leq \rho \leq 1$, then y_1 and y_2 are realizations from a standard bivariate ($\mu_1 = 0$, $\mu_2 = 0$, $\sigma_1^2 = 1$, $\sigma_2^2 = 1$) normal distribution with correlation coefficient ρ .

References

Box and Muller (1958)
Abramowitz and Stegun (1970, p. 953)
Johnson (1987, p. 29)

Algorithm for Computing Percentage Points of the Normal Distribution

Algorithm AS III, due to Beasley and Springer (1977), is used to calculate percentage points of the normal distribution in connection with Latin Hypercube Sampling methods. The algorithm is fast, numerically accurate, and portable without modification. FORTRAN code for implementing Algorithm AS III is given in the reference cited.

3.5 The Lognormal Distribution

Log normal variates are obtained by transferring normal variates. By definition, the random variable Y has a lognormal distribution with mean Θ and variance τ^2 if, and only if, the random variable $X = \ln Y$ has a normal distribution with mean μ and variance σ^2 , where

$$\mu = \ln \left[\Theta^2 / \sqrt{\Theta^2 + \tau^2} \right] \quad \text{and} \quad \sigma^2 = \ln \left[(\Theta^2 + \tau^2) / \Theta^2 \right] \quad (1)$$

This definition yields the following algorithm for generating a realization y from a lognormal distribution with mean Θ and variance τ^2 .

Algorithm

Step 1. Generate a realization x from a normal distribution with mean μ and variance σ^2 , where μ and σ^2 are computed using Equation (1) above. (See algorithms in Section 3.4 for generating normal realizations.)

Step 2. Compute $y = \exp(x)$. Then y is a realization from a lognormal distribution with mean Θ and variance τ^2 .

References

Iman and Shortencarier (1984 p. 17)
Crow and Shimizu (1988)

4.0 THE GENERATION OF PSEUDO-RANDOM NUMBERS

Each algorithm in Section 3.0 requires the generation of values from a $U(0,1)$ distribution. It is anticipated that the pseudo-random number generator available on the PNL VAX network will prove adequate for HEDR Project dose calculations and related uncertainty analyses. In case the system generator proves inadequate for some reason, and for the sake of completeness, a pseudo-random number generator is given here. The selected generator is due to Wichmann and Hill (1982) and produces $U(0,1)$ realizations by combining the results of three multiplicative congruential generators. The algorithm is short, reasonably fast, statistically sound, and machine independent. A FORTRAN implementation is given below. On machines that use only 23 bits for representation of the fractional part of a real number, it is possible for this algorithm to produce exact zeros because of rounding error; see McLeod (1985) for a discussion of this problem and possible modifications. An extensive discussion of uniform random number generators, including the algorithm presented here, is found in Chapter 6 of Bratley, Fox, and Schrage (1983).

Algorithm AS 183 (Wichmann and Hill)

```
REAL FUNCTION RANDOM(L)
C
C   ALGORITHM AS 183  APPL. STATIST. (1982) VOL.31, P.188
C
C   RETURNS A PSEUDO-RANDOM NUMBER RECTANGULARLY DISTRIBUTED
C   BETWEEN 0 AND 1.
C
C   IX, IY AND IZ SHOULD BE SET TO INTEGER VALUES BETWEEN
C   1 AND 30000 BEFORE FIRST ENTRY.
C
C   INTEGER ARITHMETIC UP TO 30323 IS REQUIRED.
C
COMMON /RAND/ IX, IY, IZ
IX = 171 * MOD(IX, 177) - 2 * (IX / 177)
IY = 172 * MOD(IY, 176) - 35 * (IY / 176)
IZ = 170 * MOD(IZ, 178) - 63 * (IZ / 178)
C
IF (IX .LT. 0) IX = IX + 30269
IF (IY .LT. 0) IY = IY + 30307
IF (IZ .LT. 0) IZ = IZ + 30323
C
C   IF INTEGER ARITHMETIC UP TO 5212632 IS AVAILABLE,
C   THE PRECEDING 6 STATEMENTS MAY BE REPLACED BY
C
C   IX = MOD(171 * IX, 30269)
C   IY = MOD(172 * IY, 30307)
C   IZ = MOD(170 * IZ, 30323)
C
C   ON SOME MACHINES, THIS MAY SLIGHTLY INCREASE
C   THE SPEED. THE RESULTS WILL BE IDENTICAL.
C
RANDOM = AMOD(FLOAT(IX) / 30269.0 + FLOAT(IY) / 30307.0 +
S      FLOAT(IZ) / 30323.0, 1.0)
RETURN
END
```

5.0 REFERENCES

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APPENDIX C

METHODS OF STORING AND RETRIEVING DATA FROM HISTOGRAMS

Date June 26, 1989

To JT Caplinger

From AM Liebetrau

Subject Algorithm for Input of and Generation of
Realizations from Cumulative Distribution
Functions

BS Dennis
RO Gilbert
HA Haerer
BA Napier
B Sagar
File/LB

The estimation of dose estimate uncertainties will involve simulating realizations of probability distributions. The distributions may be theoretical (i.e., expressed in a functional form) or empirical (estimated from real data or generated by simulation from a hypothetical distribution). The distributions may be used to describe the distribution of input parameters to the dose model or the variability of submodel output variable(s).

The following algorithm can be used to approximate a given distribution function regardless of whether it is theoretical or empirical. The notation used in Eq. (1) below is illustrated in the attached figure.

Step (a): Divide the range of the distribution into k intervals. For Phase I calculations, a maximum of $k = 20$ intervals will be used.

Step (b): The interval boundaries (denoted by x 's) and the cumulative probabilities (denoted by h 's) associated with the right-hand endpoints of the k intervals are:

$$(x_0, h_0 = 0), (x_1, h_1), (x_2, h_2), \dots, (x_{k-1}, h_{k-1}), (x_k, h_k = 1) \quad (1)$$

Where x_0 is the minimum value of the variable and x_k is the maximum value.

The intervals defined by Eq. (1) defined a k -segment piecewise linear approximation to the actual input distribution. A maximum of $k = 20$ intervals will be used for Phase I calculation. A smaller value of k may be used in cases where an adequate approximation to the actual input distribution does not require 20 intervals. Note that when the distribution is expressed in cumulative form, both the x 's and the h 's are nondecreasing sequences of numbers. It is convenient to choose the representation in Eq. (1) so that either the x 's or the h 's are equally spaced. For the Phase I study, we will use equal spacing of the x 's.

After a distribution such as that in Step (b) has been assigned to a particular input variable, then realization of the variable may be generated from the assigned distribution as follows:

Step 1: Generate a pseudo-random number, from the uniform distribution over the interval $(0,1)$. Denote the value of this number by h , where $0 < h < 1$.

JT Caplinger
June 26, 1989
Page 2

Step 2: Determine the index i , $i = 1, 2, \dots, k$, such that $h_{i-1} < h < h_i$.

Step 3: Compute $x = x_{i-1} + \frac{h - h_{i-1}}{h_i - h_{i-1}} (x_i - x_{i-1})$ (2)

The quantity x obtained by (2) is the realization of a random variable x whose cdf is given by (1). Steps 1-3 can be repeated, as necessary, to generate the desired number of realizations from the given distribution.

AML/slc

APPENDIX D

HANDLING ATMOSPHERIC DEPOSITION AND INTERCEPTION BY VEGETATION

Date April 26, 1989

To Distribution

From Bruce Napier *Bruce*

Subject Recommendation for Treating Radionuclide
Deposition and Interception on Vegetation
on Phase 1

DA Cataldo	JK Soldat
DM Beck	JV Ramsdell
CL Bruneau	RE Rhoads
JM Callaway	JG Stephan
MD Freshley	DL Streng
RO Gilbert	WH Walters
SP Gydesen	RK Woodruff
HA Haerer	Project Office
LG Morgan	File/LB

INTRODUCTION

Evaluation of the atmospheric transport and deposition of radionuclides on soil and vegetation is one of the major undertakings of the HEDR project. The initial sensitivity studies, as mentioned in the September 1988 Workplan to the TSP, performed by Dennis Streng and Bruce Napier for the iodine air-cow-milk pathway, indicated that the parameterization of deposition and vegetation uptake was one of the most important to the final result. In addition, the demarcation between the Environmental Transport Task and the Environmental Pathways and Dose Estimates Task comes at the point of deposition. Van Ramsdell and I have had many discussions on the appropriate method of doing this and have reached a working agreement.

Deposition and interception have been widely studied. They seem to be correlated with atmospheric conditions (such as wind speed, turbulence), type of surface (measured in terms of a "friction velocity" or a "surface roughness"), as well as with type and state of vegetation. Most studies have attempted to lump many parameters into a "deposition velocity" (e.g., Heinemann and Vogt 1980). Often, the deposition velocity also includes the interception fraction (i.e., v_g is deposition onto grass rather than onto the soil).

DISCUSSION

The original Hanford model for deposition/interception incorporated a "deposition velocity" term with a constant interception fraction (Soldat and Harr 1971). Combined with a feed-to-milk transfer factor, this model provided a fairly accurate prediction of milk concentrations for the Hanford environment. Recent results of the Biospheric Model Validation Study (BIOMOVs), presented at the VII Workshop in Tokai, Japan, November 7-10, 1988, but yet unpublished, indicate that this formulation tends to underpredict the concentrations on the grass, but to overpredict the transfer from grass to milk, and therefore the final answer is in the right range. The observation of underprediction of deposition/interception is repeated by Pinder, McLeod, and Adriano (1989). The current Hanford model (Napier et al. 1988) uses a variable interception fraction that is a function of vegetation biomass. The interception fraction is based on the model of Chamberlain (1970). It generally results in a higher value of interception than the older constant fraction. The Chamberlain model is an empirical fit to a large amount of data, relating to both iodine and particulate radionuclides.

Chamberlain's approach is a filtration model of the form $r = 1 - e^{-\mu B}$, where r is the interception fraction, μ is an empirical constant, and B is the biomass. The constant μ and the variable B are usually defined to be in terms of dry biomass.

I performed a review of current modeling approaches to the problem of deposition/interception. Sehmel (1984) provides an extensive overview of deposition velocities, but does not differentiate between deposition on soils and surfaces and on vegetation (which is important because deposition velocities onto vegetation may incorporate an interception fraction implicitly). The IAEA Safety Series 57 (1982) suggests that for forage, the quotient of the interception fraction and the dry weight of the biomass be held a constant, and for food crops that the interception fraction be held at a constant value of 0.20. Use of a constant value of the quotient was investigated by the Nevada dose reconstruction and used in the Nevada "Sheep Study." Holding the quotient of interception to biomass, a constant is equivalent to using a series expansion of the Chamberlain model truncated at the first term - it gives roughly equivalent results for low biomass. The IAEA position is a restatement of the recommendations given in several Oak Ridge National Laboratory documents (e.g., Hoffman and Baes 1979, Miller et al. 1980). The newer ORNL code TERRA (Baes et al. 1985) uses the Chamberlain formulation for interception by hay and pasture grasses, and an ad hoc variant with the same mathematical form for other vegetation. The British code FOOD-MARC (Linsley, Simmonds, and Haywood 1982) uses a constant interception fraction approach. The German code ECOSYS (Prohl, Friedland, and Paretzke 1985) uses the Chamberlain formulation, in particular for iodine. The PATHWAY model used by the ORERP study (Whicker and Kirchner 1987) uses the Chamberlain interception fraction model. The most recent literature on the topic by Pinder (Pinder, Ciravolo, and Bowling 1988; Pinder, McLeod, and Adriano 1989) also recommend the Chamberlain formulation, with very minor revisions to the empirical constants. It appears that, over the past decade, most researchers have determined that the Chamberlain filtration approach provides the most adequate method of predicting the interception fraction.

Recently declassified Hanford information from early 1946 indicates that the concentrations of radioiodine measured on vegetation from Hanford releases varies from species to species by about a factor of eight (all measurements were done on the basis of activity per unit mass as collected - i.e., without drying). One-gram samples were spread on a surface and counted. Dry grass and weeds were found to be more active (per unit mass as collected) than live vegetation. Reproducibility of these measurements was said to be about plus or minus 30% (Healy 1946). This indicates to me that if these had been normalized to dry weight, the variability would have been less. A model using the interception fraction described by Chamberlain and corrected for the moisture content of the vegetation as a function of time of year would give a variability the same as seen in these original Hanford measurements. (Chamberlain (1970) also reports a variable weathering half-time, one that is longer in the winter. This seems also to be supported in the Hanford measurements.)

CONCLUSIONS

We propose to use a two-part description of deposition and interception. The total flux of radioactive material out of the passing atmospheric puff is needed by Van Ramsdell in the atmospheric dispersion model to maintain a mass balance and properly account for plume depletion. Van proposes to use a model that accounts for atmospheric conditions and radionuclide properties (particulate vs. noble gas vs. iodine) to provide the net wet and dry flux out of the plume. I propose to use the Chamberlain filtration model to account for interception of this flux on the vegetation. This two-part approach will allow convenient data transfer between the tasks. The approach is essentially the same as that used for data transfer in the ORERP project.

The model for interception fraction will be made variable as a function of plant biomass and moisture content, which means it will be a function of crop type and time of year. This model should explain most of the variability seen in the historical environmental measurements.

Additional sensitivity studies will be possible once this system becomes operational. This will allow us to investigate whether wind-tunnel experiments with iodine-131 or field experiments with iodine-129 from PUREX will add appreciable data to our study in the next fiscal year.

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BAN:cs

APPENDIX E

HANDLING CORRELATIONS IN COMPLEMENTARY FRACTIONS

Date August 18, 1989

To Distribution

From Bruce Napier

Subject Handling Correlations in Complementary Fractions

JW Brothers
RO Gilbert
HA Haerer
AM Liebetrau
B Sagar
DL Streng
Project Office
File/LB

INTRODUCTION

In several of the calculations to be performed for the HEDR Phase 1 analyses, a series of fractions must be selected from input distributions. Each of these fractions has its own distribution. The results of the selection process of the fractions must, however, sum to one, which implies a correlation structure. A technique is needed to handle the correlations between the various fractions.

DISCUSSION

Several options are available. We could use a simple rule to adjust the randomly drawn fractions, or we could draw the fractions from a multivariate distribution with an assumed correlation structure.

In general, the fractions are being generated via expert opinion. There is considerable uncertainty about many of them. No information is currently available on correlations between the constituent parts of the sum desired, other than that it is constrained to add to unity. The structure of the proposed computer implementation also does not lend itself to incorporating large correlation matrices.

The question of how to handle these correlations was discussed by Bruce Napier, Al Liebetrau, Dick Gilbert, and Budhi Sagar at a meeting on July 31, 1989.

CONCLUSIONS

It was concluded that for Phase 1, at least, a simple adjustment rule would be adequate, given the lack of strong information on correlations. The various fractions should be drawn independently from their distributions, and then the sum of the results should be used to normalize each value so that the total then adds to one.

BAN:cs

APPENDIX F

CORRESPONDENCE BETWEEN COLUMBIA RIVER LOCATION
AND HEDR CENSUS SUBDIVISION

Date August 17, 1989

To DM Beck

From BA Napier *[Signature]*

Subject Correspondence Between Columbia River Location and HEDR Census Subdivision Grid Points

HA Haerer
TM Poston
MC Richmond
Project Office
File/LB

INTRODUCTION

Much of the Phase 1 effort has gone into defining parameters to use for the atmospheric dispersion portions of the HEDR calculations. Proportionally less effort has been expended on the surface water pathways. However, definition of the various locations of potential exposure to the river or to river-related products (water, fish, irrigated foods) is also necessary.

DISCUSSION

Ted Poston, who was asked to accumulate and evaluate data on radionuclide concentrations of fish in the Columbia River for 1964-1966, devised a convention for collecting data based on sampling locations. These areas are (memo, T. M. Poston to Distribution, June 12, 1989, "Location of Fish Sampling Sites"):

<u>Site</u>	<u>Approximate River Mile</u>
Priest Rapids	390
Hanford	365
Coyote Rapids	383
Ringold	354
Richland	345
Island View	335
Burbank	322
McNary	294

The first three of these locations are inside of the Hanford Site, and thus of minimal importance for public exposure considerations. The others, however, are stretches of the river for which public access is available.

CONCLUSIONS

I have compared Ted's river stretches to our HEDR census subdivisions on the map. There is a very convenient correspondence for the publicly available locations, as follows:

<u>Site</u>	<u>HEDR Census Subdivision</u>
Ringold	FR4
Richland	BE7, FR5
Island View	BE3, FR3
Burbank	WA3, BE4
McNary	BE8, UM4

DM Beck
August 17, 1989
Page 2

Note that each stretch of the river touches two subdivisions, one on either side, if some minor overlaps are ignored. (The Benton County side of the Ringold stretch is still Hanford Site). Given the inexact nature of the selections, this would seem to be reasonable.

These divisions should be used for the transport, demography, and dose calculations required for Phase 1.

BAN:cs

APPENDIX G

SUMMARY OF TSP COMMENTS AND BATTELLE RESPONSES

SUMMARY OF TSP COMMENTS AND BATTELLE RESPONSES

Document Number PNL-7274 HEDRDocument Title Computational Model Design Specification for Phase I of the Hanford Environmental Dose Reconstruction Project

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
1.	J. Stohr	Page 2.1, last para, line 7	Correct atmos-pheric.	Corrected.
2.	JS	Page 2.2, para. 2, line 8	Change release to releases.	Corrected.
3.	JS	Page 3.4, para. 4, line 5	Correct The to Then, interview-ing.	Corrected.
4.	JS		Will the final computational code be designed to run on an IBM-compatible PC?	No. The computer system design requirements for the Phase I model are given in Section 2.2. Those for future model development will be determined in separate publications. It is unlikely that any major HEDR codes will be adaptable to personal computers.
5.	JS	Page 3.9, sec. 3.1.3	When will actual vegetation concentrations be used versus calculated? Criteria should be established and printed for this selection process. Why shouldn't actual measurements receive priority here when they will in the river pathway?	NA - At the time of the preparation of these design specifications, the intent was to allow the use of actual monitoring data if available. However, it has become apparent that there is insufficient terrestrial monitoring data for this to be practicable -
NA = No action.				

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
6.	JS	Page 3.19, sec. 3.2	Acknowledge that the model does not account for channels in the river or the non-homogenous distribution of materials in the horizontal or vertical directions.	monitoring data will, at best, be useful for model validation. Future code development efforts will deal mostly with calculated values. NA - The Phase I model inputs were either directly monitored water concentrations or simple modeled results. The monitored data do account for the details requested. The simpler routing model results do not.
7.	JS	Appendices A and D	Has resuspension of materials been addressed?	NA - The techniques described in Appendix D are applicable to deposition from either initial atmospheric contamination or resuspended soil. However, the simple models of Appendix A do not, at this time, account for resuspension. Resuspension will be addressed in future development efforts.
8.	M.A. Robkin	Page 2.11, sec. 2.11	How are "unauthorized users" defined?	NA - The code security described deals with the HEDR Project master copy of the code and databases. Copies of the code are, of course,
NA = No action.				

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
9.	Genevieve S. Roessler		Overall, this report seems like it was put together in a hurry. It is necessary to do a lot of cross referencing to understand tables and modules.	<p>available. The master copy is protected from changes by anyone but the official code custodian.</p> <p>NA - The <u>primary</u> audience defined for this document was the computer programmers who prepared the actual computer code from the conceptual model described in this report. It is unfortunate that the typical reader must perform considerable cross-referencing, but the document layout is reasonable for the primary purpose. Because no future code development will be based on this document, major rewriting/editing is not felt to be a prudent expenditure. Completed code listings can be made available to those interested in the ultimate workings of the code.</p>
10.	GSR	Appendix A	Terms are not all defined under each module. Each module should be able to stand alone. Explain terms that come from another module.	See response to comment 9. Some additional definitions have been added to make Appendix A more complete.
NA = No action.				

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
11.	GSR		After reading this and other reports and realizing that a huge amount of uncertainty will be inherent in the numbers, I have some concern about the results that will be released in Phase I.	NA
12.	GSR		Will the pre-existing conditions of hypo- or hyperactive thyroidism be considered as an input variable for specific individuals' dose calculations?	NA - Out of the scope of this project.
13.	GSR		Eventually, it will be necessary to be able to calculate doses to different stages (ages) in the prenatal category.	NA - Will be considered in future work.
14.	GSR		What data are being used to calculate transfer of radionuclides across the placenta and to the newborn from breast milk?	NA - Will be considered in future work.
15.	GSR	Page iii, para. 1	Paragraph should include comment about the TSP as on page 1.1, footnote (a).	Information was added.
16.	GSR	Page 2.1, para. 4, line 7	atmos-pheric, take out hyphen	Corrected.
17.	GSR	Page 2.6, para. 2, line 2	Why not use symbols for curie, etc.? Also, change "curies/meter squared/second" to "Ci/m ² .sec." Change throughout document.	Change was made.
NA = No action.				

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18.	GSR	Page 3.4, para. 4, line 5	interview-ing, take out hyphen	Corrected.
19.	GSR	Page 3.7, para. 1	Refer to Appendix B, which explains what this is all about.	Added reference to Appendix B.
20.	GSR	Page 3.9	Move Table 3.2 up to the top of the page where it is referred to.	NA - Battelle style is to place figures and tables at the top or bottom of a page, following their callouts.
21.	GSR	Page 3.17, para. 1, line 2	Concern about underestimation. What were the practices for selling food products other than milk outside the area?	NA - future work.
22.	GSR	Page 3.19, para. 1, line 1	Concentra-tions, take out hyphen	Corrected.
23.	GSR	Page A.1	Define λ_r .	See response to comment 10. λ_r is the radiological decay constant, in units of inverse month.
24.	GSR	Page A.2	Symbol for location not consistent throughout modules.	Location symbols are now consistent.
25.	GSR	Page A.4	Location is "L" here. Use the same symbols in all modules.	Location symbols are now consistent.
NA = No action.				

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
26.	GSR	Page A.5	Define all terms so that the module can stand by itself.	See response to comment 10.
27.	GSR	Page A.7	We all know who Ted is, but I don't think he should be given first-name ownership of the "River stretches" here.	References to Ted were removed from the module.
28.	GSR	Page A.7	Under 2), second definition use f not L.	Change was made.
29.	Glyn G. Caldwell	Page 2.1, para. 4, line 7	Inappropriately hyphenated word.	Corrected.
30.	GGC	Page 3.4, para. 4, line 5	Inappropriately hyphenated word.	Corrected.
31.	GGC	Page 3.19, line 1	Inappropriately hyphenated word.	Corrected.
32.	GGC	Page 3.4, para. 3, lines 3-4	Monitoring data must be used to verify/calculate the code whenever monitoring data are available.	NA - They will be used whenever appropriate.
33.	GGC	Page 3.7, para. 3.1.2(1), line 11	I assume tubers (potatoes, carrots, turnips, etc.) are included as "other vegetables."	As indicated in Table 2.3, tubers and other "root vegetables" are included. The word "tubers" has been added here.
NA = No action.				

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34.	GGC	Page 3.7, para. 3.1.2(2), lines 7-8	Are data available for these parameters? Have they been shown to the TSP Demography Subcommittee?	NA - During future work, all parameter values will be documented and approved by the TSP.
35.	GGC	Page 3.11, lines 2-3	Has or will such provision be made? When? How? By whom?	NA - Other agricultural models will be developed as needed and approved by the TSP.
36.	GGC	Page 3.15, para. 3.1.5(1), lines 1-3	I do not see where drinking water has been included in Modules 1 through 5. Where is it included?	NA - Drinking water is included in a separate model, the Surface Water Model described following Module 6 of the Air Pathway Model.
37.	GGC	Page 3.15, para. 3.1.5(2), lines 4-6	Can we determine which foods are totally irrelevant and exclude them from further consideration?	NA - As described in the remainder of the paragraph, this is a Phase I assumption with the underlying rationale that the milk pathway should generally result in larger doses, even considering this overestimate. The results to date have shown that the additional pathways do, in fact, contribute potentially significant doses, and they are being considered as such in later models.
NA = No action.				

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
38.	GGC	Page 3.15, para. 3.1.5(2), lines 5-6	Not true, "all foods other than milk" are not produced in census track of consumption. See prior comment.	See response to comment 37.
39.	GGC	Page 3.18, lines 6-7	Identify acronym FFTF upon first use.	Acronym was spelled out in text.
40.	GGC	Page 3.19, para. 5, lines 1-3	Module 3 is for Animal Product Concentrations and does not mention drinking water.	NA - The "module 3" referred to here is the third module of the Surface Water Model described in Section 3.2, not of the Air Pathway Model. This has been clarified in the headings of Appendix A.
41.	John E. Till		We must make certain our QA is especially good on this model and that we have hand-verified the calculations.	NA - All modeling and code development will follow Battelle QA procedures.
42.	JET	Page 2.1, para. 4, line 7	"atmospheric"	Corrected.
43.	JET	Page 2.5, Section 2.5, bullet 2	We should refine the temporal distribution further than on a monthly basis, provided the met data and the source term data justify it. Is the model set up to handle this?	NA - Temporal considerations are being evaluated based on dose needs and available data. The model will be modified as needed to accommodate final decisions.
NA = No action.				

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44.	JET	Page 2.8, Table 2.1	Add "Nominal <u>Body</u> Mass" and center the column.	Column heading was changed. The column is aligned according to Battelle style.
45.	JET	Page 3.4, para. 4, line 5	"The a CDC . . ." No sense here.	Corrected.
46.	JET	Page 3.11, para. 1	Last sentence: We must be certain that we can add many more feeding regimes in addition to our four. Also, we should consider "ramping" up onto the regimes since few farmers suddenly change the diet of animals.	NA - The feeding regime module will be evaluated and modified to meet information available.
47.	JET	Appendix A, Module 1	Again, t = 1 month. Can we readily change this to a shorter period?	NA - Will be evaluated.
48.	JET	Appendix A, Module 2	Tp = <u>leaf</u> -to-edible-part.	Corrected.
49.	B. Shleien	Page 1.1, para. 2, line 8	Redundant	NA - "expand the capabilities" refers to model capabilities. "Refine the dose estimates" <u>evolves</u> from the improved model. They are not the same thing.
NA = No action.				

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50.	BS	Page 2.1, para. 3, last line	Another uncertainty not included is the modeling uncertainty itself. I assume that the lack of knowledge refers to the completeness of the data.	True. A clarifying sentence has been added.
51.	BS	Sec. 2.5, bullet 1	Indicate specific radionuclides to be investigated.	A list has been added.
52.	BS	Sec. 2.5, bullet 2	More detail on uncertainties in source term.	See response to comment 51. This issue will be addressed further in future work.
53.	BS		Monitoring Data: Indicate that vegetation data will be used as a check on modeling deposition results.	NA - The intent of this section is to inform the programmers to the requirement to deal with this type of information. The intent is to use the monitored vegetation data in validation of the calculated values. The approach to this effort is described in the evolving HEDR Project Plan.
54.	BS		For river model, will calculated results and measured results be cross checked in situations where both exist?	NA - The intent of this section is to inform the programmers to the requirement to deal with this type of information. The information was indeed checked between calculated and monitored results. A description of this activity was
NA = No action.				

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55.	BS		Monitoring Data section lacks information on uncertainties.	provided by M.C. Richmond and W.H. Walters (1990), in <u>Estimates of Columbia River Radionuclide Concentrations: Data for Phase I Calculations</u> , PNL-7248 HEDR. NA - The intent of this section is to inform the project programmers that certain types of data will become available. At the time it was written, the actual form of the incorporation of uncertainties was unknown. These data will become available in later stages of the project.
56.	BS		Environmental Pathways and Dose: Which two age groups? I assume infant and adult; if so, indicate.	Correct. This information has been added on page 2.7. The initial intent was to make the Phase I model general enough to handle up to seven age groups, but to run the code for Phase I with only two groups to demonstrate the capability. The code was, in fact, written to access dietary and other information for several groups, but for Phase I reporting, dose results for only two age
NA = No action.				

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
57.	BS	Sec. 2.6	Age group statement at odds with 2.6 OUTPUT PARAMETERS, which indicates seven age groups as output.	groups were prepared (see Draft Air Pathway Report, PNL-7412 HEDR). See response to comment 56.
58.	BS		Note type of dose parameters to be used in output. Suggest thyroid dose for air pathway, and specific organ dose, effective dose equivalent, and annual committed dose equivalent for river pathway.	A paragraph has been added to Section 2.6.
59.	BS		Note that output will be in terms of a "dose distribution" rather than specific numbers.	Text modified on pages 2.7 and 2.8.
NA = No	action.			

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