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HEDR Modeling Approach

Hanford Environmental Dose
Reconstruction Project

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Letter report for the Technical Steering Panel
and the Centers for Disease Control and Prevention
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Preface

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

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

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

The purpose of the HEDR Project is to estimate the radiation dose that individuals could have received as a result of radionuclide emissions since 1944 from the Hanford Site. This report details the methods used for scoping studies and estimating final radiation doses to real and representative individuals who lived in the vicinity of the Hanford Site. The report is a revision of Shipler and Napier (1992).

Summary

This report is a revision of the previous Hanford Environmental Dose Reconstruction (HEDR) Project modeling approach report (Shipler and Napier 1992). This revised report describes the methods used in performing scoping studies and estimating final radiation doses to real and representative individuals who lived in the vicinity of the Hanford Site. The scoping studies and dose estimates pertain to various environmental pathways during various periods of time. The original report discussed the concepts under consideration in 1991. The methods for estimating dose have been refined as understanding of existing data, the scope of pathways, and the magnitudes of dose estimates were evaluated through scoping studies.

Scope

The dose reconstruction methods described herein are those approved by the Technical Steering Panel (TSP) and used by Battelle to estimate final doses for representative individuals. These methods are also used to estimate doses to real individuals included in the Hanford Thyroid Disease Study (HTDS). The report considers the major environmental transport pathways: atmospheric, Columbia River, and ground water. Time periods are defined based on the availability of historical measurements, confidence in analytical techniques and results, and the magnitude of doses that individuals might have received. The modeling sequence chosen for each pathway depends on the level of sophistication deemed appropriate for the particular pathway and time period being considered.

Technical Approach

The HEDR Project dose reconstruction is based on varying levels of effort and detail depending on the types of activities engaged in by individuals, the time periods during which such activities took place, and the adequacy of the recorded data. Not all pathways and time domains require the same level of detail. Thus, the staff of the HEDR Project, under the technical direction of the TSP, adopted a set of methods and parameter values based on the pertinent facts and circumstances, both historical and technical. Uncertainty and sensitivity analyses were performed for all major results. A validation process was used to compare model estimated values with historical measurements.

Results

As a result of existing information and scoping studies, more detailed reconstruction and, consequently, more effort were expended on the earlier rather than the later periods of Hanford Site operations. Also, more effort was expended on the air pathway rather than the river or ground-water pathways.

The varying levels of dose reconstruction effort are shown in Table S-1. Table S-1 depicts the HEDR modeling methods that were selected to estimate dose for the various pathway and time periods. For example, for the mid-1940s the air pathway modeling sequence requires a very fine temporal resolution because the largest releases of radionuclides to the air occurred during that period. Progressively less detailed modeling efforts were used for the middle and later periods of Hanford Site operation because 1) lower releases of radioactive materials occurred, 2) sufficient original data were not always available, 3) more technically defensible dose estimates were available in existing literature by the middle period (1952-1972), 4) published dose estimates were increasingly reliable during the later period (1973-1992), 5) the last of the eight single-pass reactors was shut down by January 1971, and 6) the last of the reprocessing plants was shut down by 1973.

Table S.1. Report Sections Defining the HEDR Dose Estimating Methods

METHOD	2.0* Major Offsite Air Pathways					3.0* Major Offsite River Pathways			4.0* Scoping Studies-Air Pathways		5.0* Scoping Studies-River Pathways		6.0* Offsite Ground-Water Pathways		7.0* HTDS Offsite Pathways	
	Iodine-131			Key Nuclides												
	1944-1949	1950-1951	1952-1972	1944-1972	1973-1992	1944-1949	1950-1971	1972-1992	1944-1972	1973-1992	1944-1971	1972-1992	1944-1972	1973-1992	1944-1949	1950-1957
STRM-hourly	2.1														7.1	
Hand Calculations-monthly		2.5	2.9	2.11												7.5
RATCHET-daily	2.2	2.6													7.2	7.6
DESCARTES-monthly	2.3	2.7													7.3	7.7
CIDER-annually	2.4	2.8													7.4	7.8
STRRM-monthly						3.1	3.1									
CHARIMA-monthly							3.2									
CRD-annually							3.3									
Air Dose Spread Sheets-monthly/ annually			2.10	2.12					4.1							
River Dose Spread Sheets-monthly											5.1					
Monitoring Data-daily/monthly							3.4		4.2		5.2		6.1			
Hand Calculations-annually						3.5							6.2			
Hanford Annual Reports					2.13			3.6		4.3		5.3		6.3		

Definitions:
STRM - Source Term Release Model (air) (Heeb 1993)
RATCHET - Regional Atmospheric Transport Code for Hanford Emissions Tracking (Ramsdell et al. 1994)
DESCARTES - Dynamic EStimates of Concentrations and Accumulated Radionuclides in Terrestrial EnvironmentS (Ikenberry et al. 1992)
CIDER - Calculation of Individual Doses from Environmental Radionuclides (Ikenberry et al. 1992)
STRRM - Source Term River Release Model (Heeb and Bates 1994)
CHARIMA - CHArriage des RIvieres MAillees (Walters et al. 1994)
CRD - Columbia River Dosimetry (Farris et al. 1994b)
* Report section numbers

Contents

Tables

1.0 Introduction

The purpose of this letter report is to describe the methods used by the Hanford Environmental Dose Reconstruction (HEDR) Project for estimating radiation doses to real and representative individuals living in the vicinity of the Hanford Site from 1944 through 1992. Each of the major environmental transport pathways (atmospheric, surface water, and ground water) is addressed. For each of the transport pathways, a different sequence of modeling methods was selected depending on the available data, confidence in analytical techniques and results, and the level of sophistication deemed appropriate. This discussion is an elaboration on the assumptions initially presented in the Hanford Environmental Dose Reconstruction (HEDR) Project Summary Schedule, April 1991;[a] the Technical Steering Panel (TSP) work plan, September 1991;[b] the original of this document, July 1992 (Shipler and Napier 1992); the original air and river computer software requirement specifications, December 1992 and May 1993, respectively (Appendixes A and B of this document),[c] and the refinements in the fiscal year (FY) 1992, FY 1993, and FY 1994 Task Plans (Shipler 1993a, 1993b).

The magnitude of radionuclide releases to air over time decreased radically from the mid-1940s to the present. In addition, the availability of reliable historical measurements and technically defensible dosimetric projections increased from the mid-1940s to the present. Therefore, more detailed reconstruction of air pathways was performed on the earlier times than on the later periods. Likewise, the larger releases to the river occurred during the late-1950s through the mid-1960s. A brief summary of the approach is provided in Table 1 for the atmospheric pathways and in Table 2 for the river pathways. Each of the items indicated by letter in Tables 1 and 2 is described in the following paragraphs.

The largest releases of radionuclides to the air occurred in the mid-1940s (Heeb 1993). To properly account for the transport and deposition of these radioactive materials and to properly propagate the uncertainties in the release estimates and meteorological conditions, an hourly temporal resolution was used (Table 1, Item A). This fine resolution was used because the timing of release and wind patterns had a profound influence on the deposition of the radionuclides. Other parts of the dose calculation were based on different time scales. It is unreasonable to require individuals to recreate their life histories on an hourly basis. It is also unnecessary because the individual daily variations are averaged over the entire exposure period. Therefore, the dose calculations performed by staff of the Environmental Pathways and Dose Estimates Task for this period were based essentially on seasonal variations but used the Source Terms Task and Environmental Transport Task input concentrations and depositions on a daily basis for computational accuracy and to properly propagate the uncertainties throughout the calculations (Table 1, Item A).

(a) Letter (HEDR Project Document No. 4910012), "Project Summary Schedule," from D. B. Shipler (BNW) to J. E. Till (TSP), April 3, 1991.

(b) Memorandum (HEDR Project Document No. 0991003), "Work Plan Proposal," from J. E. Till (TSP) to the Technical Steering Panel members and Battelle, Pacific Northwest Laboratories, August 1, 1991.

(c) The air and river computer software requirements specifications have been updated and included in this report in the format of the originally published documents.

Table 1. Calculational Resolution as a Function of Time for the Atmospheric Pathways

Time Period	1944-1951	1952-1972	1973-1992
Temporal Resolution			
Hourly/Daily	A		
Monthly		B	
Annual			C
Spatial Resolution			
Offsite 9.7-km x 9.7-km grid	D	E	
Offsite 29-km x 29-km grid	F	G	
General Area			H
Agricultural Resolution			
High (grid)	I		
Low (area average)		J	K

Table 2. Calculational Resolution as a Function of Time for the Columbia River Pathways

Time Period	1944-1971	1972-1992
Temporal Resolution		
Monthly	L	
Annually		M
Spatial Resolution		
Selected Sections	N	
Tri-Cities		O

During the middle years of Hanford operations, 1952-1972, the releases to air were much lower than during the carly period and were also essentially continuous. Because of the destruction of some of the original data, the difficulties in obtaining complete records from multiple operating contractors, and the availability of technically defensible contemporaneous dose estimates, the HEDR Project used monthly values for the source terms for 1952-1972. This resulted in less need for detailed information from the transport and dose portions of the models (Table 1, Item B).

The shut-down of the last of the eight single-pass reactors in 1971 and the last of the reprocessing plants in 1972 resulted in a large reduction in releases and in doses. These reductions, coupled with the availability of reliable dose estimates for the last period (1973-1992), justified increasing the temporal resolution from monthly to annually for this period (Table 1, Item C).

To make the best use of the early source term and transport temporal resolution, a fine grid of receptor locations was established. Beyond the Hanford Site boundaries (offsite), a 9.7-kilometer by 9.7-kilometer (6-mile by 6-mile) grid was used for areas closer to the Hanford Site (Table 1, Item D). For more distant areas, a larger 29-kilometer by 29-kilometer (18-mile by 18-mile) grid was used (Table 1, Item F). For the period of intermediate releases, these same scales were used (Table 1, Items E and G). In the period after 1972, doses were very small and use of such a fine grid was determined to be excessive, so the general approach of a site boundary exposure was taken (Table 1, Item H). A site boundary exposure is the term used for the estimation of doses to a hypothetical, maximally exposed individual at the boundary of the Hanford Site. This is the estimate reported in the Hanford Site annual reports and summarized in Farris et al. (1994a, 1994b).

A major consideration in estimating doses is the source and amount of food eaten by people. To best use the information developed by the source terms and transport activities, a high resolution, 9.7-kilometer by 9.7-kilometer (6-mile by 6-mile) transport grid was used for the counties closest to the Hanford Site for the early period in conjunction with detailed information on the milk and vegetable distribution system (Table 1, Item I). For the middle and later periods, when doses to the most exposed group were relatively small, estimates were made assuming local production of all foods; e.g., food distribution systems were not implemented (Table 1, Items J and K).

The magnitudes of doses resulting from transport of radioactive materials in the Columbia River do not follow the same temporal pattern as those from the air, and in general the peak doses via this pathway are lower than the peak doses from the air pathway. Though the reactors operated from 1944 to 1971, the period of peak power operations and, therefore, the highest releases were 1956-1965. Because downstream integrated concentrations of radionuclides are not as dependent on release rate as are atmospheric concentrations, a monthly time resolution was determined to be appropriate for the operating period of the reactors (Table 2, Item L). Following the shut-down of the single-pass reactors, an annual scale was used (Table 2, Item M).

Doses for the Columbia River were estimated for individuals at Richland for 1944-1949 and at twelve selected segments (including Richland) along the river's length and for coastal areas for 1950-1971 (Table 2, Item N). Once the single-pass reactors were shut down, the highest doses were those of residents closest to the Hanford Site. These doses were bounded in the Hanford Site annual reports for residents of the Tri-Cities of Richland, Kennewick, and Pasco, Washington (Table 2, Item O).

The modeling methods used for each of the pathway/time combinations, including the ground-water pathways, are presented in Table S.1. The approaches presented in that table constitute the "tools" that were used for estimating individual doses. Each of the "tools" is further described in the sections below.

The approach used in the models was in part dictated by the desire to directly incorporate uncertainty analyses in the calculations. The uncertainty analysis approach described in Simpson and Ramsdell (1993) was used to perform all the calculations.

2.0 Major Offsite Air Pathways

Pathways of exposure considered in this category are those of inhalation, air submersion, and ingestion of milk, meat, eggs, poultry, leafy vegetables, other vegetables, fruits, and grains, as currently included in the HEDR computer codes DESCARTES and CIDER (Snyder et al. 1994). Real individuals are all those living within the study area during this period. Software requirements specifications for air pathways computer codes are detailed in Appendix A. Section numbers of the report refer to the numbers in Table S.1. Doses from the radionuclide iodine-131 were given special attention because iodine-131 was the major contributor to dose from the air pathway (Napier 1992). Those doses are described separately below.

2.1 Iodine-131 Source Term Estimates, 1944-1949

Detailed hourly release estimates of iodine-131 were prepared using the Source Term Release Model (STRM) by staff of the Source Terms Task (Heeb 1993; Heeb 1994). The derivation of these estimates was based on the operating histories of individual reactors and on records of individual batches of fuel processed through the chemical separations plants. This was done so that the uncertainty of the amount released and the time it was released could be coupled with the uncertainty of the atmospheric transport model. The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for every reported value.

2.2 Iodine-131 Atmospheric Transport, 1944-1949

Daily integrated values of air concentration and deposition for each of the grid locations was prepared by Atmospheric Transport Subtask staff using the HEDR gaussian-puff/lagrangian-trajectory model RATCHET (Ramsdell et al. 1994). The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for every reported value.

2.3 Iodine-131 Environmental Accumulation, 1944-1949

Daily values of concentrations of radionuclides in soil, vegetation, and animal products were estimated for each grid location by staff of the Environmental Pathways and Dose Estimates Task using the HEDR environmental model DESCARTES (Ikenberry et al. 1992; Farris et al. 1994a). This estimate required the input of a considerable amount of data, which was prepared by staff of the Demography, Food Consumption and Agriculture Task, regarding the consumption of food (Anderson et al. 1993) and agricultural production and distribution systems (Deonigi et al. 1993; Marsh et al. 1992) in existence during the period 1944-1949. The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for every reported value.

2.4 Iodine-131 Representative Individual Dose Estimates, 1944-1949

Staff of the Environmental Pathways and Dose Estimates Task estimated representative individual radiation doses using the CIDER computer code (Ikenberry et al. 1992; Farris et al. 1994a). Doses fo. .epresentative individuals are reported on the basis of a full year's exposure. These doses were calculated as a sum of daily exposures from all sources. The individual's movements about the study area are accounted for, as well as her or his probable sources and quantities of food. The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for every reported value.

The validation process was used to compare HEDR model estimated values with historical measurements (Napier et al. 1994). Parameter values selected and approved by the TSP are documented and controlled (Snyder et al. 1994).

2.5 Iodine-131 Source Term Estimates, 1950-1951

Staff of the Source Terms Task provided monthly release estimates of iodine-131 for this time period (Heeb 1994). These estimates were based on the records of individual batches of fuel processed through the chemical separations plants (Heeb 1994). The degree of uncertainty in the results was estimated by using an analytic propagation of error method to estimate a 95 percent confidence interval.

2.6 Iodine-131 Atmospheric Transport, 1950-1951

Monthly average source term and subsequent monthly average calculations were used for iodine-131 for the years 1950-1951. Atmospheric concentrations and depositions were estimated for 1950-1951 using the monthly values computed by the RATCHET code (Ramsdell et al. 1994) for the 1946-1949 time period. Surrogate data sets were generated by selecting the RATCHET output for an appropriate month, for example, one of the RATCHET March output files if March values were required. The RATCHET output values were then adjusted to account for the differences in the amount of iodine-131 released in the month for which the RATCHET calculations were made and in the month being simulated. This process produced surrogate time-integrated air concentration and deposition data sets that had a wide but realistic uncertainty. Use of the surrogate data approach was required because no wind data were available for the Hanford Meteorological Station or Pasco, Washington for 1950-1952.

2.7 Iodine-131 Environmental Accumulation, 1950-1951

Daily values of concentrations of radionuclides in soil, vegetation, and animal products were estimated for each grid location by staff of the Environmental Pathways and Dose Estimates Task using the HEDR environmental model DESCARTES (Ikenberry et al. 1992; Farris et al. 1994a) and the same procedure as that used for 1944-1949. The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for every reported value.

2.8 Iodine-131 Representative Individual Dose Estimates, 1950-1951

Staff of the Environmental Pathways and Dose Estimates Task estimated representative individual radiation doses using the CIDER code (Ikenberry et al. 1992; Farris et al. 1994a) and the same procedure as that used 1944-1949. The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for every reported value.

2.9 Iodine-131 Source Term Estimates, 1952-1972

Staff of the Source Terms Task provided monthly release estimates of iodine-131 for this time period (Heeb 1994). These estimates were based on the operating histories of individual reactors and on records of individual batches of fuel processed through the chemical separations plants (Heeb 1994). The procedure is the same as that used for the 1950-1951 period. The degree of uncertainty in the results was estimated by using an analytic propagation of error method to estimate a 95 percent confidence interval.

2.10 Iodine-131 Atmospheric Transport, Environmental Accumulation, and Dose Estimates, 1952-1972

Atmospheric transport and deposition, environmental accumulation, and doses were calculated using a deterministic spread sheet (Napier 1992; Farris et al. 1994a). Grid-to-grid transport of food products was not simulated, but dose estimates allowed for age dependence and other monthly variations. Calculations were performed only for selected locations. The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for selected cases and by assigning the uncertainty range to all other cases by analogy.

2.11 Key Radionuclide Source Terms, 1944-1972

Staff of the Source Terms Task provided cumulative monthly release estimates of strontium-90, ruthenium-103, ruthenium-106, iodine-131, cerium-144, and plutonium-239 for this time period (Heeb 1994). These estimates were based on the operating histories of individual reactors and on records of individual batches of fuel processed through the chemical separations plants (Heeb 1994). The iodine-131 results were calculated as the sum of the hourly releases for the years 1944-1949. The degree of uncertainty in the results was estimated by using an analytic propagation of error method to estimate a 95 percent confidence interval.

2.12 Key Radionuclide Atmospheric Transport, Environmental Accumulation, and Dose Estimates, 1952-1972

The estimation of atmospheric transport and deposition and the estimation of environmental accumulation and doses were calculated using a deterministic spread sheet (Napier 1992; Farris et al.

1994a). Grid-to-grid transport of food products was not simulated, but dose estimates allowed for age-dependence and other monthly variations. Calculations were performed only for selected locations. The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for selected cases and by assigning the uncertainty range to all other cases by analogy.

2.13 Key Radionuclide Dose Estimates Beyond 1972

With the shut-down of the last of the single-pass Hanford production reactors in January 1971 and the last of their reprocessing plants in November 1972, the major source terms at Hanford ended. Individual doses beyond 1972 were not estimated. For completeness, estimates of individual doses reported in Hanford Site annual reports are summarized and provided in the air dose report (Farris et al. 1994a). These published doses are relatively low and were estimated using quality data and defensible calculational methods. The Source Terms Task staff provided additional information for the period 1973-1992, but this information was prepared only for project completeness and the public record. It is not being used formally for dose estimates. No range of uncertainty was estimated for this result.

3.0 Major Offsite Columbia River Pathways

Pathways of exposure from contaminated Columbia River water were direct consumption, swimming, boating, shoreline exposures, consumption of resident and anadromous fish, and consumption of shellfish. The people exposed were individuals using river water for domestic and recreation purposes, Native Americans and other individuals consuming fish and shellfish from the river. Software requirements specifications for the Columbia River pathways computer codes are given in Appendix B. Section numbers of this report refer to designations in Table S.1.

3.1 Source Term Estimates, 1944-1971

Staff of the Source Terms Task prepared detailed monthly release estimates for five radionuclides: sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239 (Heeb and Bates 1994). Information on additional radionuclides and gross beta were also provided for completeness but were not used in the estimation of dose.[a] The derivation of these estimates was based on individual reactor operating histories and historical measurements of reactor effluents. Historical summary data are available for either daily or monthly releases. The source terms for chromium-51 and scandium-46 were also prepared for use in the validation process of the river transport model. Only the chromium-51 values were used. Scandium-46 was omitted from the validation efforts because of lack of measured data. The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for every reported value.

3.2 Columbia River Transport, 1950-1971

River-water concentrations of radionuclides from 1950 through 1971 were estimated for twelve sections of the Columbia River on a monthly average basis by staff of the Surface-Water Transport Subtask. Detailed estimates of radionuclide concentrations prior to 1950 were not made. The model employed was the CHARIMA code (Holly et al. 1993) developed by the Iowa Institute of Hydraulic Research at the University of Iowa and enhanced by Washington State University (WSU-CHARIMA) to account for radioactive decay (Walters et al. 1994). WSU-CHARIMA is a one-dimensional, unsteady flow model that accounts for the river hydrograph and travel times to the various locations with and without dams. Because calculation of the time-integrated concentration of radionuclides in river water is less dependent on variations in release rate than is the calculation of atmospheric concentration, the monthly average was used throughout the period of reactor operations. The peak concentrations of radionuclides in the river occurred in the late-1950s to mid-1960s. The validation process was used to compare model estimated values with historical measurements (Walters et al. 1992; Thiede et al. 1994). The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for selected cases and by assigning the uncertainty range to all other cases by analogy.

(a) Letter (HEDR Project Document No. 07930232), "Key Radionuclides for River Pathway," from J. E. Till (TSP) to D. B. Shipler (BNW), April 12, 1993.

3.3 Environmental Accumulation and Representative Individual Dose Estimates, 1950-1971

Staff of the Environmental Pathways and Dose Estimates Task used the Columbia River Dosimetry (CRD) computer code (Napier 1992; Farris et al. 1994b) to estimate monthly concentrations of radionuclides in Columbia River water, treated drinking water, fish, and other media affected by the Columbia River for selected locations. For the radionuclides of interest in fish, bioaccumulation factors were developed for categories of resident and anadromous fish by season and location (Thiede et al. 1994). Doses for representative individuals for 1950 through 1971 are reported on the basis of a full year's exposure. These annual doses were estimated as a sum of monthly exposures from all sources. The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for selected cases and by assigning the uncertainty range to all other cases by analogy.

The validation process was used to compare model estimated values with historical measurements (Napier et al. 1994). Parameter values selected and approved by the TSP are documented and controlled (Snyder et al. 1994).

3.4 Use of Environmental Measurements in Dose Estimates, 1950-1971

An extensive database is available of measurements made of various radionuclides at various times and at various locations of various media associated with the river (Denham et al. 1993; Hanf et al. 1992; Thiede et al. 1994; Walters et al. 1992). While insufficient to allow estimation of doses at all times and places of interest, these historical measurements were useful in preparing bioaccumulation factors, regression equations, and for comparison with the model-estimated values. In the case of shellfish, historical measurements were used directly to estimate doses to individuals. For Columbia River salmon, approaches incorporating both historical measurements and bioaccumulation factors were used to bound the possible range of doses. These doses were summed and reported with other individual doses.

3.5 Columbia River Transport, Environmental/Accumulation, and Representative Individual Dose Estimates, 1944-1949

Representative individual doses for a maximally exposed individual in Richland, 1944-1949, were prepared for completeness using hand calculations. The calculations were based on the ratio of annual source terms from the 1950-1971 period to the source terms of the 1944-1949 period and on the 1950-1971 estimated doses. No range of uncertainty was estimated for these results.

3.6 Columbia River Transport, Environmental Accumulation, and Representative Individual Dose Estimates, 1972-1992

For the period following shut-down of the single-pass reactors, doses from the Columbia River pathway fall well below the TSP designated levels of interest. These doses reported in Hanford Site annual reports were summed and reported with other doses for completeness in Napier (1993) and Farris et al. (1994b). The 1972-1992 doses from the Columbia River pathway were relatively low and were estimated using quality data and defensible calculational methods. No range of uncertainty was estimated for these results.

4.0 Scoping Studies for Air Pathways

Scoping studies of all major and some minor pathways of exposure were conducted using spreadsheets (Napier 1992). Assessment calculations were performed to determine the relevance of each pathway to potential doses and the basis for a pathway's inclusion in more detailed and complex computer codes. For some low-dose pathways, spreadsheets were the only method of estimating doses. If it was determined that any given pathway had the potential to add more than 5 percent to the total annual dose for any individual at a time when the dose exceeded the TSP guidelines (Shipler and Napier 1992), the pathway was added to the main computer models. Being added to the main model does not necessarily imply full implementation in DESCARTES or CIDER. Some simple pathways were included as post-processed additions to individual doses, particularly if the number of people potentially exposed was known to be small. Software requirements specifications for air pathways computer codes are given in Appendix A.

4.1 Source Terms, Atmospheric Transport, Environmental Accumulation, and Representative Individual Dose Estimates, 1944-1972

Monthly or annual release estimates were developed from historical and HEDR literature by staff of the Technical Integration and Source Terms Tasks (Napier 1992). The detail needed for the estimates was a function of the pathway, time period, and level of dose being assessed. If monthly or annual average source terms were used, subsequent estimates were also based on a monthly or annual average calculation. Atmospheric transport was estimated for selected grid nodes using representative results of the RATCHET program reduced to monthly or annual average air concentration, normalized to a unit release rate ($\bar{\chi}/Q'$). A spreadsheet formulation of environmental transport and accumulation was used to estimate environmental concentrations in designated media. Doses were estimated using standard dose conversion factors that allow for age and sex dependence. The spreadsheets employ data for each of the separate locations. The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for selected cases and by assigning the uncertainty range to all other cases by analogy.

4.2 Use of Environmental Measurements in Dose Estimates, 1944-1972

An extensive database is available of measurements made of various radionuclides at various times and locations, and of various media associated with the terrestrial environment (Denham and Mart 1993; Denham et al. 1993; Duncan 1994; Hanf et al. 1993; Hanf and Thiede 1994; and Mart et al. 1993). While insufficient to allow estimation of doses at all times and places of interest, these data were useful in verifying other dose estimating methods. In some cases, historical measurements were used directly to estimate doses to individuals. These doses are summed and reported with other individual doses in Farris et al. (1994a).

4.3 Evaluation of Individual Doses, 1973-1992

Estimates of doses for individuals living near the Hanford Site are available in annual reports for this period (Farris et al. 1994a). These dose estimates are for the current major pathways. Scoping studies were used to show that exposure pathways not addressed in the annual reports did not contribute a significant fraction of the dose already reported (Napier 1992). Annual report results are summarized and reported with other pathways results in Farris et al. (1994a). The 1973-1992 doses from the atmosphere pathway were relatively low and were estimated using quality data and defensible calculational methods. No range of uncertainty was estimated for this result.

5.0 Scoping Studies for Columbia River Pathways

Scoping studies of all major and some minor pathways of exposure from the Columbia River were conducted using spreadsheets (Napier 1993). Assessment calculations were performed to determine the relevance of each pathway to potential doses and the basis for a pathway's inclusion in more detailed and complex computer codes. For some low-dose pathways, spreadsheets were the only method of estimating doses. If it was determined that any given pathway had the potential to add more than 5 percent to the total annual dose for any individual at a time when the dose exceeded the TSP guidelines (Shipler and Napier 1992), the pathway was added to the main computer models. Software requirements specifications for river pathways computer codes are given in Appendix B. Section numbers in this report refer to designations in Table S.1.

5.1 Source Terms, Columbia River Transport, Environmental Accumulation, and Representative Individual Dose Estimates, 1944-1972

Monthly release estimates were developed from historical and HEDR literature by staff of the Technical Integration and Source Terms Tasks (Napier 1993). The use of monthly average source terms requires that the subsequent estimates also be based on a monthly average approach. River transport and dilution were estimated for selected locations using simple dilution and decay calculations. A spreadsheet formulation of environmental transport and accumulation was used to estimate environmental concentrations in designated media. Doses were estimated using standard dose conversion factors that allow for age and sex dependence. The spreadsheets employ data for only a single location for a given time period. The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for selected cases and by assigning the uncertainty range to all other cases by analogy.

5.2 Use of Environmental Measurements in Dose Estimates, 1944-1971

An extensive environmental database is available of measurements made of various radionuclides at various times and locations, and of various media associated with the Columbia River (Hanf et al. 1992; Denham et al. 1993; Walters et al. 1992; Thiede et al. 1994). While insufficient in themselves to allow estimation of doses for all times and places of interest, these data were used where possible to estimate concentrations in media affected by the Columbia River. For shellfish in the Columbia River and adjacent bays and estuaries, the measured concentrations were the only method used to estimate doses. For Columbia River salmon, approaches incorporating both historical measurements and bioaccumulation factors were used to bound the possible range of doses. These doses were summed and reported with other individual doses in Farris et al. (1994b).

5.3 River Transport, Environmental Accumulation, and Individual Dose Estimates, 1972-1992

For the period following shut-down of the reactors, dose rates from the Columbia River pathway fell well below the TSP designated levels of interest (Soldat et al. 1986). This has been verified using results from scoping studies and historical measurements (Napier 1993). Estimates of doses provided in the Hanford Site annual reports are summarized and reported with other dose estimates for completeness (Farris et al. 1994b). No range of uncertainty was estimated for this result.

6.0 Offsite Ground-Water Pathways

Outside of the Hanford Site boundaries, the pathways of exposure to ground water are essentially the same as those described for surface water in Section 5.0. Exposed individuals are also the same. On the Hanford Site, the pathways of exposure include wells, springs, and seeps. The potential for human exposure was reduced because access to ground water was controlled. No range of uncertainty was estimated for this result.

6.1 Ground-Water Transport and Environmental Accumulation, 1944-1972

A description of measurements of various radionuclides at various times and at various locations associated with ground water is available in Freshley and Thorne (1992). This description includes measurements of radionuclides associated with ground-water discharge to the Columbia River, as well as those contributed directly from the reactors and chemical processing plants. These data were sufficient to support estimates of doses at times and places of interest in determining that ground-water pathways contributed very little to historical doses of individuals living in the Hanford Site area and, therefore, even less to those living off the Hanford Site.

6.2 Representative Individual Dose Estimates, 1944-1972

Dose estimates for selected pathways were made by simple hand calculations documented in Freshley and Thorne (1992). Extrapolation was used to cover the time period.

6.3 Transport, Environmental Accumulation, and Individual Dose Estimates Beyond 1972

For this period, dose rates from ground-water pathways can be found in Hanford Site annual reports referenced in Freshley and Thorne (1992).

7.0 Estimates for the Hanford Thyroid Disease Study

Exposure pathways considered in this category are inhalation, air submersion, and ingestion of milk, meat, eggs, poultry, leafy vegetables, other vegetables, fruits, and grains. These pathways are currently included in the HEDR codes DESCARTES and CIDER (Farris et al. 1994a). Real individuals are those identified by the Fred Hutchinson Cancer Research Center as living within the study area during 1944-1957. Iodine-131 is the radionuclide of interest for this study. Estimated doses are absorbed dose for thyroid and effective dose equivalent.

7.1 Iodine-131 Source Term Estimates, 1944-1949

Staff of the Source Terms Task (Heeb 1994) prepared detailed hourly release estimates of iodine-131 using the Source Term Release Model (STRM). Inputs are the same as those used for representative individuals (Section 2.1). The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for every reported value.

7.2 Iodine-131 Atmospheric Transport, 1944-1949

Staff from the Atmospheric Transport Subtask prepared daily integrated values of air concentration and deposition for each of the grid locations using the HEDR Gaussian-puff/Lagrangian-trajectory model RATCHET (Ramsdell et al. 1994). Inputs are the same as those used for representative individuals (Section 2.2). The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for every reported value.

7.3 Iodine-131 Environmental Accumulation, 1944-1949

Daily radionuclide concentrations in soil, vegetation, and animal products were estimated for each grid location by staff of the Environmental Pathways and Dose Estimates Task using the HEDR environmental model DESCARTES (Farris et al. 1994a). This estimate was based on a considerable amount of data, which were prepared by staff of the Demography, Food Consumption and Agriculture Task. The data denote food consumption (Anderson et al. 1993) and agricultural production and distribution systems (Marsh et al. 1993; Deonigi et al. 1993) in existence during the period 1944-1949. Inputs are the same as those used for representative individuals (Section 2.3). This information is being used to estimate concentrations in those foods reported by real individuals and as default values when real individuals could not recall their specific food consumption types or rates. The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for every reported value.

7.4 Iodine-131 Real Individual Dose Estimates, 1944-1949

Staff of the Environmental Pathways and Dose Estimates Task estimated specific individual radiation doses using the CIDER code (Farris et al. 1994a). Doses for representative individuals are reported on the basis of a full year's exposure. Doses for real individuals are based on the actual time spent in the study area. These doses are calculated as a sum of daily exposures from all sources. The individual's movements about the study area are accounted for, as well as his or her probable sources and quantities of food, as defined by the Hanford Thyroid Disease Study. The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for every reported value.

The validation process was used to compare model-estimated values with historical measurements (Napier et al. 1994). Parameter values selected and approved by the TSP are documented and controlled (Snyder et al. 1994).

7.5 Iodine-131 Source Term Estimates, 1950-1957

Staff of the Source Terms Task provided monthly release estimates of iodine-131 for this time period (Heeb 1994). These estimates were based on the operating histories of individual reactors and on records of individual batches of fuel processed through the chemical separations plants (Heeb 1994). This is the same information used for representative individuals (Sections 2.5 and 2.9). The degree of uncertainty in the results was estimated by using an analytic propagation of error method to estimate a 95 percent confidence interval.

7.6 Iodine-131 Atmospheric Transport, 1950-1957

Monthly average source term and subsequent monthly average calculations were used for iodine-131 for the years 1950-1951. Atmospheric concentrations and depositions were estimated for 1950-1951 using the monthly values computed by the RATCHET code (Ramsdell et al. 1994) for the 1946-1949 time period. Surrogate data sets were generated by selecting the RATCHET output for an appropriate month, for example, one of the RATCHET March output files if March values were required. The RATCHET output values were then adjusted to account for the differences in the amount of iodine-131 released in the month for which the RATCHET calculations were made and in the month being simulated. This process produced surrogate time-integrated air concentration and deposition data sets that had a wide but realistic uncertainty. Use of the surrogate data approach was required because no wind data were available for the Hanford Meteorological Station or Pasco, Washington for 1950-1952. The approach is an extension of that used for representative individuals (Section 2.6).

7.7 Iodine-131 Environmental Accumulation, 1950-1957

Daily radionuclide concentrations in soil, vegetation, and animal products were estimated for each grid location by staff of the Environmental Pathways and Dose Estimates Task using the HEDR environmental model DESCARTES (Farris et al. 1994a) and the same procedure as that used for 1944-1949. Data for distribution of commercial milk and vegetables were obtained only for 1944 through 1951. After this time, the 1951 data are used (Marsh et al. 1993; Deonigi et al. 1993). The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for every reported value.

7.8 Iodine-131 Real Individual Dose Estimates, 1950-1957

Staff of the Environmental Pathways and Dose Estimates Task estimated representative individual radiation doses using the CIDER code (Farris et al. 1994a) and the same procedure as that used for 1944-1949. Results were transmitted to Fred Hutchinson Cancer Research Center as a single file, incorporating the 1944-1949 and 1950-1957 periods as appropriate for each individual. The degree of uncertainty in the results was estimated by varying the input parameters and repeating the calculations 100 times for every reported value.

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Appendix A

Software Requirements Specification for HEDR Air Pathway Codes

Software Requirements Specification

for

THE HANFORD ENVIRONMENTAL DOSE RECONSTRUCTION PROJECT AIR PATHWAY ENVIRONMENTAL ACCUMULATION AND DOSE CODES

Version 2.3
January 17, 1994

Concur: ______________________
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Concur: ______________________
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This specification covers software and quality assurance requirements for the software that will compute environmental accumulation and doses associated with the air release pathway. This requirements specification supersedes all previously documented software requirements.

Contents

1.0 General Requirements

1.1 The software shall calculate environmental accumulations and doses from atmospheric releases and transport of radionuclides from Hanford site operations as modeled by the Source Term Release Model (STRM) and by the Regional Atmospheric Transport Code for Hanford Emission Tracking (RATCHET).

1.2 The software shall be capable of reporting environmental accumulation estimates and dose estimates separately.

1.3 The software shall be capable of operating on data for the time period from 1944 through 1957 inclusive.

2.0 Quality Assurance Requirements

2.1 The software development and design shall be subject to the quality assurance (QA) requirements in the HEDR QA plan (QAP #OHE-003, dated 7/21/92) and the PNL Software Control Procedures (SCP's) in PNL-MA-70.

2.2 The software shall log information such as names and versions of files used, data identification labels, and version of the software to provide complete traceability of the output.

2.3 The software shall produce the same output for separate runs using identical inputs.

2.4 The software shall be documented with the following items:

a. software development plan (SDP)
b. software design document (SDD)
c. interface requirements specification (IRS)
d. data dictionary (DD)
e. configuration management plan (CMP)
f. user's guide (UG)
g. module development folders (MDF)
h. software requirements specification (SRS)
i. software test plan (STP)
j. software test results (STR)

Requirements for the contents of each document shall be identified in the SDP. All documents are technical resources for the purposes of code design, implementation, testing and operation.

2.5 The software shall be subjected to the following HEDR internal reviews:

a. software design review
b. code walkthrough
c. final internal development review
d. independent testing review
e. operational readiness review

Requirements for each review shall be identified in the SDP.

3.0 Host System Requirements

3.1 The software shall operate on the HEDR Sun 690 platform.

3.2 The following three operating environments shall be supported:

a. development and/or maintenance
b. test and/or verification
c. production

The operating environments do not have to function simultaneously.

4.0 General User Interface Requirements

4.1 The software shall provide a procedure to allow operation by a trained nondeveloper through the use of script or text control files.

5.0 Data Size Requirements

5.1 The software shall support calculations for one radionuclide, ^{131}I.

5.2 The software shall be designed to support future expansion with up to 15 plant media and up to 15 animal media. Implementation of future expansion may require code modifications.

5.3 The software shall support using up to 100 realizations of air concentration and deposition data through the environmental accumulation and dose estimates. A single realization of the code consists of all values input or calculated for each active mode for each operational time step.

5.4 The software shall be capable of operating on a spatial grid containing up to 1102 nodes.

6.0 Mathematical Models

6.1 The software calculations shall implement the functionality of equations DES-1 through DES-18 and CID-1 through CID-5 as documented in

> "Parameters used in the Environmental Pathways (DESCARTES) and Radiological Dose (CIDER) Modules of the Hanford Environmental Dose Reconstruction Integrated Codes (HEDRIC) for Air Pathway". S.F. Snyder, W.T. Farris, B.A. Napier, T.A. Ikenberry, and R.O. Gilbert. PNWD-2023 HEDR, September 1992.

6.2 The software shall support only simple exponential decay of radionuclides.

6.3 The software shall provide the capability to generate random numbers from the following statistical distributions:

a. uniform
b. piecewise uniform
c. loguniform (base 10 and base e)
d. normal
e. lognormal (base 10 and base e)
f. triangular
g. discrete uniform
h. constant

Generation of values from the normal and lognormal distributions will be truncated at the tail probabilities of 0.01 and 0.99.

6.4 The software shall provide the capability to generate all random numbers using a stratified sampling technique.

6.5 Addition or deletion of a media or pathway shall not change the selection of stochastic parameters for other media or pathways.

6.6 The environmental accumulation software shall use the Euler method for solution of all differential equations.

6.7 The software shall support the stochastic parameter definitions and sampling frequencies defined in Section 6.0 and Table A-1 of:

> "Parameters used in the Environmental Pathways (DESCARTES) and Radiological Dose (CIDER) Modules of the Hanford Environmental Dose Reconstruction Integrated Codes (HEDRIC) for Air Pathway". S.F. Snyder, W.T. Farris, B.A. Napier, T.A. Ikenberry, and R.O. Gilbert. PNWD-2023 HEDR, dated September 1992.

7.0 Environmental Accumulation Data Interface Requirements

7.1 The environmental accumulation software shall receive air transport information from the RATCHET code as documented in

> "Regional Atmospheric Transport Code for Hanford Emission Tracking (RATCHET)", J.V. Ramsdell, Jr. and K.W. Burk, PNL-8003 HEDR, dated February 1992.

7.2 The software shall implement milk information as presented in:

> "Milk Cow Feed Intake and Milk Production Estimates for Phase I", D.M. Beck, R.F. Darwin, A.R. Erickson, and R.L. Eckert, PNL-7227 HEDR, April 1992.

and

> "Milk Production and Distribution in Low-Dose Counties for Hanford Thyroid Disease Study", PNL-8153, June 1992.

7.3 Assignment of commercial milk values for requirement 7.2 for nodes outside of the region where milk production and distribution information is available shall be handled by treating it as milk generated from cows on feeding regime 1, using a herd cow transfer factor.

7.4 The software shall implement a fresh leafy vegetable distribution network as presented in

> "Commercial Production and Distribution of Fresh Fruits and Vegetables: A Scoping Study on the Importance of Produce Pathways to Dose", T.L. March, D.M. Anderson, W.T. Farris, T.A. Ikenberry, B.A. Napier, and G.L. Wilfert, PNL-2022, September 1992.

7.5 Assignment of commercial leafy vegetable values for requirement 7.4 for nodes outside of the region where leafy vegetable production and distribution information is available shall be handled by using the value for locally produced leafy vegetables.

7.6 Physical locations shall be specified by node.

7.7 The software shall use a creamery identifier to distinguish creamery milk information.

7.8 Animal feeding regimes shall include consumption of contaminated water. The algorithm for intake on any given day shall be implemented as the product of a water consumption amount, a dilution factor in the stock tank, and the deposition of nuclide for that same day. The consumption amounts and dilution factor shall be treated as random quantities.

7.9 Animal feeding regimes shall include intake from fallout on foods that have already been harvested. The algorithm for intake on any given day shall be implemented as a transfer factor times the deposition of nuclide for that same day. The transfer factor shall be treated as a random quantity.

7.10 The environmental accumulation code shall be able to model up to 175 creameries. Up to 4 cow feeding regimes can be used in the computation of radionuclide concentrations in milk at each creamery. A feeding regime definition applies to the entire modeling domain.

7.11 The calculation of the radionuclide concentration in grocery milk at each node shall be implemented as a linear combination of: i) milk concentrations from a specified set of creameries, ii) milk concentration from an unknown creamery, and iii) milk concentrations from sources outside the HEDR modeling domain. Milk concentrations from an unknown creamery shall be handled by treating it as milk generated from cows on commercial feeding regime 1, using a herd cow transfer factor (referenced to the output grocery milk node). Milk from outside the modeling domain shall be assigned a zero concentration.

8.0 Environmental Accumulation Control Requirements

8.1 The environmental accumulation software shall allow user selection of the set of nodes where environmental accumulation calculations shall be performed.

8.2 The environmental accumulation software shall allow the user to process one or more plant and/or animal media independently.

8.3 The environmental accumulation software shall allow the user to select start and stop times for each run.

8.4 The environmental accumulation software shall allow the user to select the number of realizations (NREAL) to process. The maximum number of realizations allowed is the minimum of 100 (see requirement 5.4) and the number of iterations output by RATCHET. If more realizations exist in the input file from RATCHET than are desired, the first NREAL realizations in the data file will be processed.

8.5 The environmental accumulation software shall allow the user to change commercial leafy vegetable production information on an annual time step.

8.6 The environmental accumulation software shall allow the user to change commercial milk production and distribution information on an annual time step.

8.7 The environmental software shall allow the user to change the definition of an animal diet on an annual time step. The definition of an animal diet covers consumption patterns for an entire calendar year.

9.0 Environmental Accumulation General Requirements

9.1 The environmental accumulation software shall be able to accept information from RATCHET in daily time steps.

9.2 The environmental accumulation software shall provide an environmental accumulation database to the dose code at user selectable intervals: daily, weekly, or monthly.

9.3 A minimum radiation dose threshold shall be implemented with respect to environmental media to restrict data passed to the dose software to significant levels. The algorithm for this calculation is given in the July 1, 1993, memo by Bruce Napier on "Use of Threshold Values in CIDER".

9.4 The environmental accumulation model shall implement an algorithm that uses meteorological-based data from 1944-1949 from RATCHET and source terms from STRM to calculate daily concentration and deposition values in the 1950-1957 time period. Details of the algorithm are given in the January 6, 1994, memo by Paul Eslinger on "Changed Requirements for DESCARTES and CIDER".

10.0 Environmental Accumulation Data Transfer Requirements

10.1 The environmental accumulation software shall be able to report, in human-readable form or electronic media, the radionuclide concentrations in the following media for selected nodes and time steps:

Plant Media

a. inner leafy vegetables - local
b. outer leafy vegetables - local
c. inner leafy vegetables - commercial
d. outer leafy vegetables - commercial
e. other vegetables
f. inner fruit
g. outer fruit
h. grain
i. alfalfa hay
j. pasture
k. grass hay
l. silage
m. sagebrush

Animal Media

a. backyard goat milk
b. grocery cow milk
c. deleted pathway - (the rural versus urban grocery milk distinction has been removed)
d. creamery cow milk
e. cow feeding regime 1 milk (individual cow and herd cow)
f. cow feeding regime 2 milk (individual cow and herd cow)
g. cow feeding regime 3 milk (individual cow and herd cow)
h. cow feeding regime 4 milk (individual cow and herd cow)
i. eggs
j. beef/meat
k. poultry

Other Media

a. air concentration
b. air deposition
c. upper soil layer
d. soil root zone

10.2 The environmental accumulation software shall produce a data set for use by the dose code that contains the following media:

Plant Media

a. inner leafy vegetables - local
b. outer leafy vegetables - local
c. inner leafy vegetables - commercial
d. outer leafy vegetables - commercial
e. other vegetables
f. inner fruit
g. outer fruit
h. grain

Animal Media
a. backyard goat milk
b. grocery cow milk
c. creamery cow milk
d. cow milk - first feeding regime
e. cow milk - second feeding regime
f. cow milk - third feeding regime
g. cow milk - fourth feeding regime
h. eggs
i. beef/meat
j. poultry

Other Media
a. air concentration
b. air deposition
c. upper soil layer
d. soil root zone

11.0 Dose Model Requirements

11.1 The software shall be able to calculate doses for both reference and real individuals.

11.2 The dose software shall operate internally on a daily time step, even when the environmental data is passed on a weekly or monthly time step.

11.3 The dose software shall be able to calculate prenatal doses for infants. Prenatal doses are based on the diet and lifestyle of the mother. The transfer function of the mother's intake to the infant's dose is represented by dose factors in units of rad to infant per curie of maternal intake. The algorithm is given in the May 3, 1993, memo by Bruce Napier on "Prenatal/Nursing Dose Implementation".

11.4 The dose software shall be able to calculate doses for nursing infants. Doses for nursing infants are based on the diet, location and lifestyle of both the mother and the child. The infant's dose is a function of infant's intake plus a transfer parameter multiplied by the mother's intake. The infant and mother are required to live at the same node.

11.5 The dose software shall allow a combination of five types of fresh cows milk and a combination of five types of stored cows milk to be included in a diet at any single time step.

11.6 The dose software shall utilize environmental concentration values from the node where an individual lives. An individual can only live at one node for a given time step.

11.7 The dose software calculations shall account for holdup times (decay) from the previous year's harvest in both fresh and stored food media.

11.8 The dose software shall allow consumption of leafy vegetables to be treated as a linear combination of consumption of locally and commercially produced leafy vegetables. The default consumption mode is to use only locally produced leafy vegetables.

11.9 The dose software shall allow an individual to supply milk concentrations for consumption where the concentrations came from a custom cow feeding regime. Only date information (no location information) will be associated with the custom milk concentrations upon entry to the dose code. The milk concentrations must have been computed to match the residence history of the individual.

(Per agreement with the TSP, the module to calculate custom milk concentrations using the outputs of the environmental accumulation code was not written.) If written, the module must support: i) custom cow diets that consist of some combination of the separate cow foods utilized in the environmental accumulation code (see the plant media in requirement 10.1), and ii) the ability of an individual to move between different locations in a single run.

11.10 Data size limitations: A maximum of 1000 diet specifications can be used in a single run. A maximum of 1000 cases can be specified in a single run. A maximum of 20 creameries can be identified in all diet specifications in a single run. A maximum of 15 categories can be identified for data that change with age. A maximum of 200 creameries can be accessed for milk concentrations. A maximum of 5 milk types are allowed in a single run.

12.0 Dose Control Requirements

12.1 The dose software shall allow the user to select a start date and end date.

12.2 The dose software shall support "map" data generation for reference individuals and a user specified set of nodes.

12.3 A user specified diet shall be implemented as an override of a reference diet by food category. The user specified diet may contain combinations only of the Plant Media (a-h) and Animal Media (a-k) given in requirement 10.1.

12.4 The dose software shall allow the user to supply a diet that may change with time.

12.5 The dose software shall allow the living location of an individual to change with time.

12.6 The dose software shall allow real individuals to exit and reenter the study area.

12.7 Changes to an individuals' diet, living location, and lifestyle may be allowed to occur at a frequency no more rapid than the internal time step at which the dose software is running.

12.8 The dose software shall be capable of operating in a multiple run mode. The multiple run mode will allow the sequential calculation of doses to multiple individuals at different locations with different diets and lifestyles.

12.9 Reference diet information shall be handled as specified consumption rates by food category for a specified year, with associated multiplicative factors that adjust the consumption rates to apply to other years.

12.10 Time-dependent variables (i.e., dose factors, breathing rates, food consumption) can change on time intervals that are different for each variable.

13.0 Dose Reporting Requirements

13.1 The dose software shall be able to report doses on an annual basis.

13.2 Requirement eliminated.

13.3 The dose software shall be able to report cumulative doses over the entire time period selected.

13.4 The dose software shall be able to report doses to the thyroid and effective dose for the following pathways based on operator selection:

a. external
b. inhalation
c. beef/meat ingestion
d. leafy vegetable ingestion
e. other vegetable ingestion
f. fruit ingestion
g. grain ingestion
h. poultry ingestion
i. eggs ingestion
j. milk ingestion
k. total over all pathways.

The doses shall be output for the entire set of realizations.

14.0 Computation Time Requirements

14.1 The environmental software shall be capable of producing a full environmental accumulation database on a dedicated machine for use by the dose code (1 radionuclide, all media, 1102 nodes, years 1944 through 1957) in 15 days wall clock time. This timing requirement applies to all processing of air data after it is output by the RATCHET code.

14.2 The dose software shall be able to calculate and output data for a "map" run of 1102 nodes on a dedicated machine for a single year and a single radionuclide with an elapsed wall-clock time of no more than 532 minutes (30 seconds average per node). The output of this production run is the dose to a representative individual at each node for one organ, all pathways, and 100 realizations.

Appendix B

Software Requirements Specification for HEDR Columbia River Pathway Codes

Software Requirements Specification

for

THE HANFORD ENVIRONMENTAL DOSE RECONSTRUCTION PROJECT COLUMBIA RIVER PATHWAY: SOURCE TERM, RIVER TRANSPORT, ENVIRONMENTAL ACCUMULATION AND DOSE MODELS

Version 2.0
March 25, 1994

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This specification covers software and quality assurance requirements for the software that will compute source term, river transport, environmental accumulation and doses associated with the Columbia River pathway. This requirements specification supersedes all previously documented requirements for the Columbia River pathway.

Contents

1.0 General Requirements

All software shall allow for the semi-automated transfer of data from one module to the next. No manual manipulation of data shall be required.

2.0 Quality Assurance Requirements

2.1 The software development and design shall be subject to the quality assurance (QA) requirements in the Hanford Environmental Dose Reconstruction (HEDR) Project QA plan (QAP #OHE-003, Rev. 7, dated 11/9/93) and the Battelle, Pacific Northwest Laboratories (BNW) Software Control Procedures (SCP) in PNL-MA-70.

2.2 Any software and/or data acquired from other sources shall be formally tested and accepted according to BNW Software Control Procedures (SCP) in PNL-MA-70.

2.3 The software shall log names and versions of files used, data identification labels, version of the software, and any other information needed to provide complete traceability of the output.

2.4 The software generated by HEDR Project staff shall be documented with the following items:

a. Software requirements specification (SRS)
b. Configuration management plan (CMP)
c. Software test plan (STP)
d. Software test results (STR)
e. Users' guide (UG)

2.5 The software generated by HEDR Project staff shall be subjected to the following HEDR internal reviews:

a. Software design review
b. Code walk-through
c. Final internal development review
d. Independent testing review
e. Operational readiness review

3.0 Source Term Module

3.1 The software shall operate on the HEDR Sun 690 platform.

3.2 The software shall provide a procedure to allow operation by a trained non-developer through the use of script or text-control files.

3.3 The software shall support stochastic calculations for gross beta, sodium-24, phosphorus-32, scandium-46, chromium-51, manganese-56, zinc-65, gallium-72, arsenic-76, yttrium-90, iodine--131, and neptunium-239.

3.4 The source term data should be in units of curies (Ci) per month discharged from each reactor area retention basin as the discharge enters the Columbia River.

3.5 Source term data shall be calculated monthly for the period September 1944 through January 1971 inclusive, for a total of 317 months.

3.6 Source term data shall be provided to the river transport code for seven radionuclides: sodium-24, phosphorus-32, scandium-46, chromium-51, zinc-65, arsenic-76, and neptunium-239. Data shall be provided for the months January 1950 through January 1971 for a total of 253 months. The data shall be in the form of monthly average discharges for each of the eight single-pass reactors.

3.7 For the purpose of estimating uncertainty, 100 realizations of the source term model predictions (curies/month) for each month, reactor, and radionuclide shall be obtained using Monte Carlo simulation methods.

3.8 The source term discharge data for each realization shall be transferred as eight files, one for each reactor, containing the monthly data for each of the seven radionuclides. The format shall be as follows with one record per line:

Record	Field	Description
1	1	Jan 1950
	2	sodium-24 discharge (Ci)
	3	phosphorus-32 discharge (Ci)
	4	scandium-46 discharge (Ci)
	5	chromium-51 discharge (Ci)
	6	zinc-65 discharge (Ci)
	7	arsenic-76 discharge (Ci)
	8	neptunium-239 discharge (Ci)
2	1	Feb 1950
253	8	neptunium-239 discharge (Ci)

3.9 The data shall be in a human-readable format (ASCII).

3.10 The software shall provide the capability to generate random numbers from the following statistical distributions:

a. Uniform
b. Piecewise uniform
c. Discrete uniform
d. Loguniform (base 10 and base e)
e. Normal
f. Lognormal (base 10 and base e)
g. Triangular
h. Constant

Generation of values from the normal and lognormal distributions shall be truncated at the tail probabilities of 0.01 and 0.99.

3.11 The software shall provide the capability to generate all random numbers using a stratified sampling technique.

4.0 River Transport Module

4.1 The software calculations shall implement the CHARIMA (CHAffiage des Rivieres MAillees) computer model as documented in:

> Holly, F. M., Jr., J. C. Yang, P. Schwarz, J. Schaefer, S. H. Hsu, and R. Einhellig. 1993. Numerical Simulation of Unsteady Water and Sediment Movement in Multiple Connected Networks of Mobile-Bed Channels. IIHR Report No. 343, Iowa Institute of Hydraulic Research, University of Iowa, Iowa City, Iowa.

Modifications to the software are acceptable, and the modified code should be clearly identified.

4.2 The software shall operate on a Hewlett Packard Model 9000/730 workstation.

4.3 The software shall provide a procedure to allow operation by a trained non-developer through the use of script or text-control files.

4.4 The software shall be capable of calculating average cross-section concentrations of sodium-24, phosphorus-32, scandium-46, chromium-51, zinc-65, arsenic-76, and neptunium-239 in Columbia River water.

4.5 The software shall be designed to produce monthly average concentrations in cross sections of Columbia River water. The cross sections shall be representative of each of 12 river segments for each radionuclide. The segment names and approximate locations are as follows:

a. Ringold (from below reactor areas to north of Richland)
b. Richland (from north of Richland to above the Yakima River)
c. Kennewick/Pasco (from below the Yakima River to above the Snake River)
d. Snake/Walla Walla Rivers (from below the Snake River to near McNary Dam)
e. Umatilla/Boardman (from near McNary Dam to near Arlington, Oregon)
f. Arlington (Arlington, Oregon, vicinity)
g. John Day Dam/Biggs (from below Arlington, Oregon, to near Biggs, Oregon)
h. Deschutes River (Deschutes River mouth vicinity)
i. The Dalles/Celilo (Dalles/Celilo vicinity)
j. Klickitat River (Klickitat River mouth vicinity)
k. White Salmon/Cascade Locks (from White Salmon River to Bonneville Dam)
l. Lower River (from below Bonneville Dam to Columbia River mouth)

4.6 The software shall accept data from the source term module (see requirement 3.8 above). These data shall be in units of curies (Ci) per month for each radionuclide discharged from the retention basin of each reactor as the discharge enters the Columbia River.

4.7 The software shall produce monthly arithmetic average concentrations of Columbia River water for the specified months, locations, and radionuclides. The concentrations are to be the average cross-section concentrations including sediment corrections but not plume corrections.

4.8 Plume-correction factors shall be estimated for three locations. The correction factors are the average shoreline concentrations relative to the average river water cross-section concentrations. An ASCII file with the correction factors by month (253 months) for each location shall be provided for dose calculations. The factors are to be estimated at the following locations:

a. East shoreline at Ringold
b. West shoreline at Richland pumping station
c. North shoreline at Pasco pumping station

4.9 The CHARIMA model shall operate in a deterministic mode meaning the parameters of the model shall be considered to be known with certainty. The rationale for this approach shall be demonstrated by evaluating the uncertainty of CHARIMA model output using limited Monte Carlo computer simulations or by using a limited set of possible combinations of parameter values.

4.10 The CHARIMA model shall be run for the median result of the 100 realizations of the source term produced by the source term model.

5.0 Environmental Accumulation Data

5.1 Bioconcentration factors shall be produced that are dependent upon radionuclide, season, and species of organism. The bioconcentration factors shall be used to estimate the radionuclide concentration in the edible meat of a particular organism based on the modelled average concentrations of cross sections of Columbia River water including sediment effects. Data specific to the Columbia River for water and organisms shall be used to develop the factors. If no differentiation in bioconcentration factors by species and/or season is noted in the available data, then bioconcentration factors that are applicable to more than one season or species shall be prepared. If no data are available for the Columbia River, the literature values shall be used. A minimum of 5 (radionuclide dependent, species and season independent) and a maximum of 100 (radionuclide, species, season dependent) bioconcentration factors shall be prepared. Factors shall be prepared for the following organisms:

a. Omnivores (e.g., bullhead, carp, catfish, sturgeon, suckers, whitefish)
b. First order predators (e.g., bluegill, crappie, perch)
c. Second order predators (e.g., bass, trout)
d. Waterfowl (harvested species only)

The bioconcentration factors shall be provided for five radionuclides: sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239. The bioconcentration factors are to be dependent on season where applicable data exist. The following five seasons are to be considered:

a. Winter (Jan/Feb/Mar)
b. Spring (Apr/May)
c. Summer (Jun/Jul/Aug)
d. Early fall (Sep/Oct)
e. Late fall (Nov/Dec)

5.2 The bioconcentration factors provided for dose calculations are to be the median values as derived from the available data. The expected range and distribution for each bioconcentration factor shall be provided but not used in the deterministic dose calculations. The range and distributions shall be used in uncertainty analyses (see requirement 6.3).

5.3 Radionuclide-dependent water-treatment factors are to be prepared for the five individual radionuclides. These factors are the ratio of the average concentration in municipally treated drinking water to the average river water cross-section concentrations. These factors shall be developed for the time period of concern, 1950 to 1971, but will not be time or location dependent. These factors shall be used to estimate realistic drinking-water concentrations from the average river water cross-section concentrations including plume effects.

5.4 Factors shall be prepared that account for the probability that any given waterfowl became contaminated from the Columbia River. The probability factor shall be location-dependent only and shall be multiplied by the location-dependent average water cross-section concentration and by the waterfowl bioconcentration factor to estimate the concentration of each radionuclide in the edible portions of birds taken by hunters. The probability factor shall be developed using regional environmental monitoring data collected in the 1960s.

5.5 Annual average media concentrations shall be estimated using available source term and environmental monitoring data. Factors that relate the annual average radionuclide discharge from all reactors for a given radionuclide to the measured media concentrations shall be developed. Ratios of annual average media concentrations to annual radionuclide discharges shall be estimated for the following media and radionuclides:

a. Columbia River anadromous fish (zinc-65, phosphorus-32)
b. Willapa Bay oysters (zinc-65)

The factors shall have the units of pCi/kg (edible media) per Ci/year for each media and radionuclide. The Willapa Bay oyster factor shall be developed using monitoring data for clams, oysters, and crabs sampled from Willapa Bay.

6.0 Environmental Accumulation and Dose Module

6.1 The software shall operate on an IBM compatible personal computer.

6.2 The software shall run in a deterministic mode only.

6.3 In addition to the deterministic dose calculations, uncertainty analyses shall be done with an automated tool (computer software) such as Crystal Ball® or other suitable software.

6.4 The software shall be in the form of a spreadsheet or other simple programming language.

6.5 The software shall support deterministic environmental accumulation and dose calculations for five radionuclides: sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239.

6.6 The software shall be designed to produce intermediate data that include average radionuclide concentrations in key environmental media for each month and location.

6.7 The software shall not implement a production and/or distribution network for any media.

6.8 Physical locations shall be specified by river segment. Up to 12 river segments shall be supported. Doses from consumption of media from two other locations shall be supported. These other media/location pairs are oysters from Willapa Bay and anadromous fish caught at any location in the Columbia River.

6.9 The environmental accumulation software shall be able to accept information from CHARIMA in monthly time steps.

6.10 The environmental accumulation software shall provide an environmental accumulation database to the dose code for monthly intervals. Environmental accumulation estimates shall be made for the following media for each river segment, month and radionuclide:

a. Omnivores (e.g., bullhead, carp, catfish, sturgeon, suckers, whitefish)
b. First order predators (e.g., bluegill, crappie, perch)
c. Second order predators (e.g., bass, trout)
d. Waterfowl (harvested species only)
e. Untreated river water
f. Treated river water

6.11 Annual average media concentrations shall be used in the dose calculations for the following media types and radionuclides:

a. Columbia River anadromous fish (zinc-65, phosphorus-32)
b. Willapa Bay oysters (zinc-65)

The concentrations shall be developed using the procedure described in requirement 5.5 above.

6.12 The software shall be able to calculate doses for reference individuals.

6.13 The dose software shall function internally on a monthly time step.

6.14 The dose software shall utilize environmental concentration values from each river segment. Each dose calculation shall be based on an individual's consumption of water, fish, and waterfowl from only one primary location.

6.15 The dose software calculations shall account for holdup times (decay between collection and consumption). The estimated dose for any month shall include the consumption of all fish caught that month including fish that have been held for more than one month.

6.16 The dose software shall calculate doses to all river segments in a batch mode.

6.17 The dose software shall calculate doses for all months in a batch mode.

6.18 The dose software shall allow the selection of exposure and consumption rates by month of the year for the following media:

a. Columbia River use (hours/month)
b. Untreated drinking water (l/month)
c. Treated drinking water (l/month)
d. Resident fish (omnivore) ingestion (kg/month)
e. Resident fish (1st predator) ingestion (kg/month)
f. Resident fish (2nd predator) ingestion (kg/month)
g. Waterfowl ingestion (kg/month)
h. Willapa Bay oyster ingestion (kg/month)
i. Columbia River anadromous fish (salmon/steelhead) ingestion (kg/month)

6.19 The dose software shall have the ability to report doses on a monthly and annual basis.

6.20 The dose software shall have the ability to report cumulative doses over a specified time period.

6.21 The dose software shall be able to report doses to the red bone marrow, lower large intestine and effective dose for the following pathways:

a. External
b. Drinking water ingestion
c. Resident fish ingestion
d. Oyster ingestion
e. Anadromous fish (salmon/steelhead) ingestion
f. Waterfowl ingestion
g. Total overall pathways

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