PNWD--1977-HEDR-Vol.1

DE92 017950

RECOMMENDATIONS TO THE TECHNICAL STEERING PANEL REGARDING APPROACH FOR ESTIMATING INDIVIDUAL RADIATION DOSES RESULTING FROM RELEASES OF RADIONUCLIDES TO THE COLUMBIA RIVER

Volume 1: Recommendations

Hanford Environmental Dose
Reconstruction Project

B. A. Napier
A. J. Brothers

Approved:
D. B. Shipler, Manager

July 1992

Letter report for
the Technical Steering Panel
and the Centers for Disease Control
under Contract Number 18620

MASTER

Battelle
Pacific Northwest Laboratories
Richland, Washington 99352

July 10,1992

Battelle
Pacific Northwest Laboratories
Battelle Boulevard
P.O. Box 999
Richland, Washington 99352
Telephone (509) 375-4354

Mr. Michael E. Donnelly
Project Officer
Hanford Environmental Dose
Reconstruction Project
Public Health Service
Centers for Disease Control
2201 Sixth Avenue, Mail Stop RX-22
Seattle, Washington 98121

Dear Mr. Donnelly:

RECOMMENDATIONS FOR USE OF MONITORING DATA AND/OR MODELING FOR THE COLUMBIA RIVER PATHWAY

Ref. 1: Milestone 0204B, Recommendation on Modeling or Monitoring Approach for the River Pathway

Ref. 2: TSP Milestone, Decision on How Far Down the River to Extend the River Pathway Study

In support of the Technical Steering Panel (TSP) decision milestone regarding definition of additional work on the river pathway (Ref. 2), Battelle has formally evaluated the many alternatives and developed recommendations for your consideration (Ref 1). The process used to define and evaluate potential alternatives is called "Value of Information" analysis and provides a format for quantifying existing and anticipated information, values, and expected outcomes.

The results of the analysis and the recommendations are included in the enclosed report (Volume 1). A description and defense of the methodology is included in Volume 2 of the report to be provided under separate cover.

It turns out that the scopes of work and technical approaches for the river pathway contained in TSP approved FY 1992 and 1993 Task Plans are not very much different from the recommendations. Contents of the report will be discussed in the TSP QA and Technical Integration Subcommittee meeting on Thursday, July 16, 1992 in Astoria, Oregon.

Questions concerning this report should be addressed to me at the above phone number or Mr. B.A. Napier of my staff at (509) 375-3896.

Very truly yours,

Dillard B. Shipler, Manager
Hanford Environmental
Dose Reconstruction Project

DBS:smf

Enclosure

cc: RH Gray
MS Power
LE Sewell
JE Till

PREFACE

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

The Columbia River was a major pathway of transport for radionuclides from the Hanford Site. Many thousands of curies of various radionuclides were routinely released to the Columbia River from the eight once-through-cooled plutonium production reactors operating on the Site (Walters et al, 1992, p. 5.12). However, initial dose estimates (Napier 1991, pp. C.1-C.57; PNL 1991a, pp. 5.1-5.16; PNL 1991b, pp. C.1-C.7) indicated that the doses resulting from Columbia River releases were considerably smaller than those resulting from atmospheric releases, so work in the early portions of the HEDR Project was largely directed to the atmospheric pathway, with the study of the Columbia River pathway performed at a lower level of effort (Shipler 1991a, pp. C.1-C.3).

The dose reconstruction efforts are now scheduled to focus more directly on the Columbia River, pending a decision by the TSP on the extent and level of detail required (Shipler 1991a, p. 2). The TSP has established a decision framework that outlines the requirements for considering spatial and temporal domains of the project as a function of individual dose[a]. A review of available monitoring data has been recently completed (Walters et al. 1992), providing necessary background for decision making. This report builds on the information provided in Walters et al. and makes specific recommendations for follow-on work related to the Columbia River pathway. This report completes HEDR Milestone 0204B, as described in Shipler (1992, p. 3.4). Upon direction

---

(a) Shleien, B. 1992. Scoping Document for Determination of Temporal and Geographic Domains for the HEDR Project. Submitted to the Technical Steering Panel, Washington State Department of Ecology, Olympia, Washington, 1-800-545-5581. Hereafter referred to as Shleien (1992).

by the TSP, Battelle will prepare detailed plans for fiscal year 1993 to implement the TSP decision.

SUMMARY

At the direction of the Technical Steering Panel (TSP) of the Hanford Environmental Dose Reconstruction (HEDR) Project, Battelle staff have reviewed and analyzed available data regarding possible historical radiation doses to individuals resulting from radionuclide releases to the Columbia River. The objective of this review was to recommend to the TSP the spatial and temporal scope and level of effort on Columbia River work to most effectively extend work performed in Phase I of the project (PNL 1991a, PNL 1991b) to meet the project objectives.

A number of options were analyzed. Four stretches of the Columbia River and adjacent Pacific coastal waters were defined and investigated for four time periods. Radiation doses arising from ten potentially major exposure pathways were evaluated for each of the time/location combinations, and several alternative methods were defined for estimating the doses from each pathway. Preliminary cost estimates were also developed for implementing dose estimation activities for each of the possible combinations.

The number of combinations of the alternatives is obviously very large. A "value of information" (VOI) decision analysis tool was developed and applied to the problem of selecting a few "optimal" sets of alternatives to consider. This VOI analysis relies on both available data and the judgment of technical experts. Input data and the algorithms used are described.

A key consideration in the final selection of recommended activities was the TSP's guidance on the level of individual dose considered to be of sufficient interest to the project to require additional work (Shleien 1992). *Information recently compiled (Walters et al. 1992, Section 10) indicates that this dose level (100 mrem/year) is exceeded for a period covering about a decade for the Columbia River below Hanford for only those specific people who relied on the Columbia River fish for a large portion of their diet (e.g., those consuming roughly one pound per day or more).* This result implies that some additional effort, beyond that performed for Phase I, should be undertaken. The following recommendations are considered to be technically sufficient and cost effective to perform this recommended work.

The additional work recommended to the TSP is

- reconstruct (model), at a moderate level of effort (i.e., a one-dimensional, unsteady-flow, routing and decay calculation), radionuclide concentrations in Columbia River water in at least the 1950s and 1960s as far downriver as Astoria, Oregon

- reconstruct, at an intermediate level of effort (i.e, a model based on species-specific, seasonal bioaccumulation factors), radionuclide concentrations in several species of fish resident year-round in the river, as well as waterfowl and game birds for the same set of locations

- reconstruct (model), at a low level of effort (i.e., use of calculated uptake by the salmon while they are in the Pacific Ocean, modified with a simple bioaccumulation model while they are in the Columbia River), radionuclide concentrations in anadromous species (salmon and steelhead) returning to the river

- estimate, using monitoring data and temporal extrapolation, the concentration of radionuclides in Pacific coastal shellfish.

- reconstruct, using the concentrations derived for river water, fish, salmon, and shellfish, individual doses for people living in the vicinity of the Columbia River and adjacent coastal areas in the 1950s and 1960s.

The detailed rationale for these recommendations is provided in this volume (Volume 1). Details on the decision-analysis tools used to support these recommendations, and the numerical input to and output from those tools, are provided in Volume 2.

ACKNOWLEDGMENTS

The authors would like to acknowledge the contributions of numerous Battelle staff and reviewers. R. E. Rhoads provided the impetus for the Value of Information (VOI) analysis performed for this report. W. L. Templeton and J. K. Soldat provided valuable help with the definition and interpretation of much of the input to the VOI analysis. HEDR staff, W. H. Walters, R. L. Dirkes, and S. P. Gydesen provided inputs on consistency and feasibility of the various alternatives. A. H. McMakin and D. J. Hanley helped to get the report into a readable format.

CONTENTS

PREFACE iii

SUMMARY v

ACKNOWLEDGMENTS vii

1.0 INTRODUCTION 1.1

1.1 CONSTRAINTS ON THE DECISION PROCESS 1.1

1.2 AVAILABLE DATA SOURCES 1.2

1.3 APPLICATION OF "VALUE OF INFORMATION" ANALYSIS 1.3

1.4 APPLICATION OF DATA QUALITY OBJECTIVES TO THE RECOMMENDATIONS . . 1.3

1.5 REPORT PREVIEW 1.4

2.0 STRUCTURING OF THE ISSUE 2.1

2.1 POSSIBLE LOCATIONS 2.1

2.2 TIME PERIODS 2.2

2.3 EXPOSURE PATHWAYS 2.4

2.3.1 Directly Related to Water Concentration 2.4

2.3.2 Indirectly Related to Water Concentration 2.4

3.0 ALTERNATIVES CONSIDERED 3.1

3.1 ALTERNATIVES FOR CALCULATING RADIONUCLIDE CONCENTRATIONS IN WATER 3.1

3.1.1 Monitoring Data 3.1

3.1.2 Extrapolation 3.1

3.1.3 Low-Level Modeling 3.1

3.1.4 Moderate-Level Modeling 3.2

3.1.5 High-Level Modeling 3.2

3.1.6 Modeling Radionuclide Concentrations in Ocean Water 3.2

3.2 ALTERNATIVES FOR CALCULATING RADIONUCLIDE CONCENTRATIONS IN RESIDENT FISH 3.2

3.2.1 Monitoring Data 3.3

3.2.2 Extrapolation 3.3

3.3.3 Low-Level Modeling 3.3

3.3.4 Intermediate-Level Modeling 3.3

3.4 ALTERNATIVES FOR CALCULATING RADIONUCLIDE CONCENTRATIONS IN SALMON 3.4

3.4.1 Low-Level Modeling 3.4

3.4.2 High-Level Modeling 3.4

3.5 CONSTRAINTS ON ALTERNATIVES 3.5

4.0 ATTRIBUTES AND DATA APPROXIMATIONS 4.1

4.1 APPROXIMATIONS, EXPERT OPINION, AND PEER REVIEW 4.1

4.2 SOURCE TERMS 4.1

4.3 NUMBER OF PEOPLE POTENTIALLY EXPOSED 4.2

4.4 DOSE ESTIMATES 4.2

4.5 VARIANCE ESTIMATES 4.3

4.6 COST ESTIMATES 4.6

5.0 SUMMARY OF VOI RESULTS 5.1

5.1 COMPARISON ACROSS TIMES AND LOCATIONS 5.2

5.1.1 VOI-Cost Tradeoffs 5.3

5.1.2 Sensitivity of Results to Input Changes 5.3

5.2 CONCLUSIONS OF VOI ANALYSIS 5.4

6.0 RECOMMENDATIONS 6.1

6.1 RECOMMENDATION FOR EXPOSURE PATHWAYS TO CONSIDER 6.1

6.2 RECOMMENDATION FOR CALCULATING RADIONUCLIDE CONCENTRATIONS IN WATER 6.2

6.3 RECOMMENDATION FOR MODELING RADIONUCLIDE CONCENTRATIONS IN RESIDENT FISH 6.3

6.4 RECOMMENDATION FOR MODELING RADIONUCLIDE CONCENTRATIONS IN SALMON 6.4

6.5 RECOMMENDATION FOR MODELING RADIONUCLIDE CONCENTRATIONS IN SEAFOOD 6.4

6.6 ADDITIONAL JUSTIFICATIONS 6.5

6.7 SUMMARY OF RECOMMENDATIONS 6.5

7.0 REFERENCES 7.1

FIGURES

2.1 Columbia River Zones Used in Analysis 2.3

5.1 Summary of VOI Versus Cost for All Columbia River Locations 5.5

5.2 Summary of VOI Versus Cost for Pacific Coastal Areas 5.6

TABLES

3.1 Possible Combinations of Levels of Effort for Reconstructing Radionuclide Concentrations in Resident Fish and River Water . . . 3.6

3.2 Possible Combinations of Levels of Effort for Reconstructing Radionuclide Concentrations in Resident Fish, Salmon, and River Water at a Particular Time and Location 3.7

3.3 Possible Combinations of Levels of Effort for Reconstructing Radionuclide Concentrations in Resident Fish, Salmon, and River Water from Bonneville Dam to Columbia River Mouth 3.8

3.4 Possible Combinations of Levels of Effort for Reconstructing Radionuclide Concentrations in Resident Fish, Salmon, and Ocean Water for Coastal Areas 3.9

4.1 Geometric Standard Deviations Assigned to Individual Dose Estimates for the Richland Area in the 1960s 4.4

4.2 Factors Added to the Geometric Standard Deviation for the Richland Area to Account for Uncertainties in Other Areas 4.5

5.1 Dominant Options for Each Combination of Time and Location 5.7

5.2 Union and Intersection of Dominant Options Across Times 5.8

5.3 Union and Intersection of Dominant Options Across Locations 5.9

5.4 Dominant Options When VOI Analysis is Aggregated over Times, Locations, and Times and Locations 5.10

1.0 INTRODUCTION

The Hanford Environmental Dose Reconstruction (HEDR) Project was established to estimate the radiation doses people may have received from operations that began at the Hanford Site in 1944. The technical work is being conducted by Battelle staff at the Pacific Northwest Laboratory (PNL) under the direction of an independent Technical Steering Panel (TSP). The Columbia River received cooling water effluent from the eight Hanford once-through-cooled plutonium production reactors and was a major pathway for off-site releases of radionuclides. Preliminary estimates of radiation doses to reference individuals in the area of the Columbia River immediately downstream of Hanford for a short time period were reported in Phase I of the project in July 1990 (PNL 1991a; PNL 1991b).

The results of the Phase I investigations showed that radiation doses to most people living along the Columbia River were relatively low, and were much lower than the doses resulting from atmospheric releases in the mid-1940s (PNL 1991a, Section 5). However, the results did indicate that doses to individuals consuming large numbers of fresh fish caught from the river (i.e., more than 20 meals per year--from 10 to 40 kg/year) could have received effective doses approaching 0.1 rem per year.

The model used for the HEDR Phase I estimates was relatively simple (Napier 1991). In July 1992, the TSP is scheduled to make a decision regarding the overall simulation approach to take. In September 1992, the TSP will decide on the scope and level of effort required to meet the project objectives for the river pathway dosimetric analysis (Shipler 1991a). The TSP decisions will determine the activities to be performed in the next years of the HEDR Project to refine and extend the Phase I dose estimates. FY 1992 Task Plans for the project require Battelle to provide technical input and recommendations to the TSP for use in decision making (Shipler 1992, p. 3.4).

1.1 CONSTRAINTS ON THE DECISION PROCESS

A number of things must be considered in making recommendations on the scope and level of effort needed for ongoing river pathway work. Early work with various stakeholders in the HEDR Project revealed several key objectives: minimizing cost, maximizing the utility of the derived information, being as complete as possible, and minimizing the uncertainty of the results (Holmes 1991).

A key consideration in the final selection of recommended activities is the TSP's guidance on the level of individual dose considered to be of sufficient interest to the project to require dose estimation (Shleien 1992). The TSP guidance states that some efforts are warranted if individual doses could exceed the guidance dose level (for these circumstances, 100 mrem/year). The dose criterion was exceeded for a specific category of individuals. This report recommends ways of optimally performing the required efforts.

Native American tribes in the Northwest also have an interest in the potential doses resulting from the Columbia River pathways. Tribal members could have been among the most exposed because their unique cultural, demographic, and dietary characteristics place some of them in the category of individuals for whom the TSP dose guidelines were exceeded.

1.2 AVAILABLE DATA SOURCES

In addition to the HEDR Phase I information, recent HEDR efforts have provided information related to the Columbia River pathway. A literature review for the TSP by Walters et al. (1992) provides a comprehensive listing of sources of available data on concentrations of radionuclides in water, sediment, and biota. In this literature review, data were selected from several locations along the river for screening dose estimates. The dose estimates considered drinking water, fish, seafoods, and various other related pathways.

The work by Walters et al. strongly suggests that, for those people who relied on Columbia River fish for a large portion of their diet, the TSP's individual-dose guidance level was exceeded for about a decade for most of the Columbia River below Hanford. Therefore, additional efforts to reconstruct some pathways should be expended.

1.3 APPLICATION OF "VALUE OF INFORMATION" ANALYSIS

The public's interest in the project and the project's objectives imply that development of any recommendation is both a technical and nontechnical issue. In order to effectively address the various objectives on cost, feasibility, dose level, and uncertainty, a structured decision-analysis tool was developed. This tool is called a "value of information" (VOI) analysis. Issue structuring is an art for which it is not possible to specify an exact algorithm; the structure emerges as a result of extensive discussions with the decision maker and the other stakeholders. For the HEDR Project, there were numerous meetings with the public, the TSP, and HEDR managers and scientists. From these, a definition of the question being asked was developed, and a series of objectives was defined.

A major benefit of using a structured approach in decision analysis is that it forces definition of the various alternatives to resolve the issue. It also requires coherent assembly of the state of current knowledge about the problem and estimates of what might be gained through the use of each alternative. Finally, it provides logical input to the final recommendations.

1.4 APPLICATION OF DATA QUALITY OBJECTIVES TO THE RECOMMENDATIONS

The recommendations provided in this report are based on the opinions of the authors, project staff, and reviewers. The data used as inputs to the VOI model come both from published reports and estimates made by the authors and project staff. For the information taken from other HEDR reports, the data quality objectives applied to those reports are assumed. For the rough estimates used herein (provided in Appendix B, Volume 2), particularly for estimated doses and for probable levels of uncertainty (before and after implementation of the various alternatives), reasonable ranges were attempted and verified through internal review and consensus building. Some reviewers felt that certain cost estimates may have been underestimated, but the VOI results are largely invariant to monotonically increasing or decreasing costs, so no changes were made.

The primary data quality objective applicable to this work is one of completeness (Shipler 1992, p. 3.3). The results of Walters et al. (1992)

indicate that the consumption of drinking water, resident fish, salmon, and seafoods accounts for well over 95% of the dose to any individual that exceeds the TSP dose guideline. (Other pathways could contribute larger fractions to people not eating fish or seafood, but then the total dose would be well below the guideline.) This meets the stated data quality objective of 95% coverage.

The final recommendations are based on the professional opinions of the authors, project staff, and reviewers, and include intangible (and unquantifiable) policy and feasibility factors.

1.5 REPORT PREVIEW

Section 2.0 of this report discusses the options for selection of locations, time periods, and exposure pathways to be used as input to the VOI analysis. Section 3.0 describes the alternatives (levels of effort) considered for the various options--alternatives for calculating radionuclide concentrations in river water, resident fish, salmon, and seafood. Section 4.0 describes the input assumptions provided for the VOI model, and how data and expert judgments were used to reach consensus on these assumptions. Section 5.0 summarizes the VOI results, and Section 6.0 lists recommendations for selection of exposure pathways and levels of effort for future river pathway work.

Volume 2, which contains Appendixes A, B, and C, contains supporting information for the VOI model. Appendix A provides a detailed discussion of the VOI model and its application. Appendix B describes the numerical inputs to the VOI model used to support the HEDR recommendations. Appendix C gives the actual results of the VOI analysis.

2.0 STRUCTURING OF THE ISSUE

To provide a structure on which to base any recommendations, the possible doses to individuals from the river pathway were categorized as functions of time, location, and exposure pathway. Specific regions, periods, and pathways were defined.

2.1 POSSIBLE LOCATIONS

Part of calculating doses is defining the geographic area for which they must be calculated. This is largely a function of applicable exposure pathways for various locations, dilution and decay of radionuclides with increasing distance from the source, and information available from which to make estimates.

The Columbia River makes its way through several distinct ecological zones on its way to the Pacific Ocean. The area immediately downstream of Hanford is arid, and was largely sparsely populated during most of the Hanford Site's operating history. According to Walters et al. (1992), this zone has the best environmental monitoring database. The river passes through the Cascade Mountains via the Columbia Gorge, a zone where the precipitation increases but where the potential exposure pathways are reduced. Also, Walters et al. (1992) found that routine monitoring was largely confined to the upstream (McNary Dam) and downstream (Bonneville Dam) ends of this reach; thus some sort of extrapolation or modeling would be required for the stretch between these points. The tidally influenced estuary between Bonneville Dam and the river's mouth passes through a rainy and relatively populous zone. Very little monitoring data are available here. The coastal regions around the mouth of the Columbia have significantly different exposure pathways (e.g., no drinking water or irrigation but potential for consumption of oysters and other seafoods). Modeling of transport of radionuclides in the ocean would be significantly different than modeling transport in the river itself.

Because of these variations, dose estimates in Walters et al. (1992) were made for people at Richland, Washington; McNary Dam; Bonneville Dam;

Astoria, Oregon; and Willapa Bay, Washington. These locations are noted in Figure 2.1. For the analysis in this report, these locations were used to define four zones: 1) Hanford to McNary Dam, 2) McNary Dam to Bonneville Dam, 3) Bonneville Dam to the river's mouth, and 4) the Pacific coast. These are illustrated in Figure 2.1. These four locations are qualitatively different from each other with respect to the type of data available and the potential level of radiation dose that could have been received by the public.

2.2 TIME PERIODS

The HEDR Project is committed to evaluating doses to people over the entire period of Hanford operation, from 1944 to the present. However, different levels of detail may be required for different times, particularly if individual doses fall well below the TSP's guidance level (Shleien 1992, p.9). In setting the dose guidance level, the TSP evaluated three time periods: 1944-1951, 1952-1972, and 1973-present. These "windows of time" were largely justified because of the atmospheric releases, but also for reasons related to releases to the Columbia. For this analysis, however, the 1952-1972 period was felt to be too broad, because significant changes occurred in reactor operations over that time.

The operating history of the reactors (Ballinger and Hall 1991, Section 3.5) or the total gross beta activity released to the river by the reactors' operations (Walters et al. 1992, Figure 7.1), show a system that can be broken down into four periods, which were used for this analysis: 1) 1944-1954, 2) 1955-1961, 3) 1962-1972, and 4) 1972-present. The first time period represents the initial construction and low-power operation of the reactors. The second time period, 1955-1961, shows the ramped increase in power produced by the reactors in response to upgrading programs. Operating parameters varied widely during this period. The third time period, 1962-1971, shows the period of high-power operation and gradual shut-down of the reactors. Finally, the period 1972-present has no once-through-cooled reactor operations. An additional breaking point in 1957, to account for the introduction of radionuclide spectral-analysis capabilities, was considered but dismissed as unnecessary for this analysis.

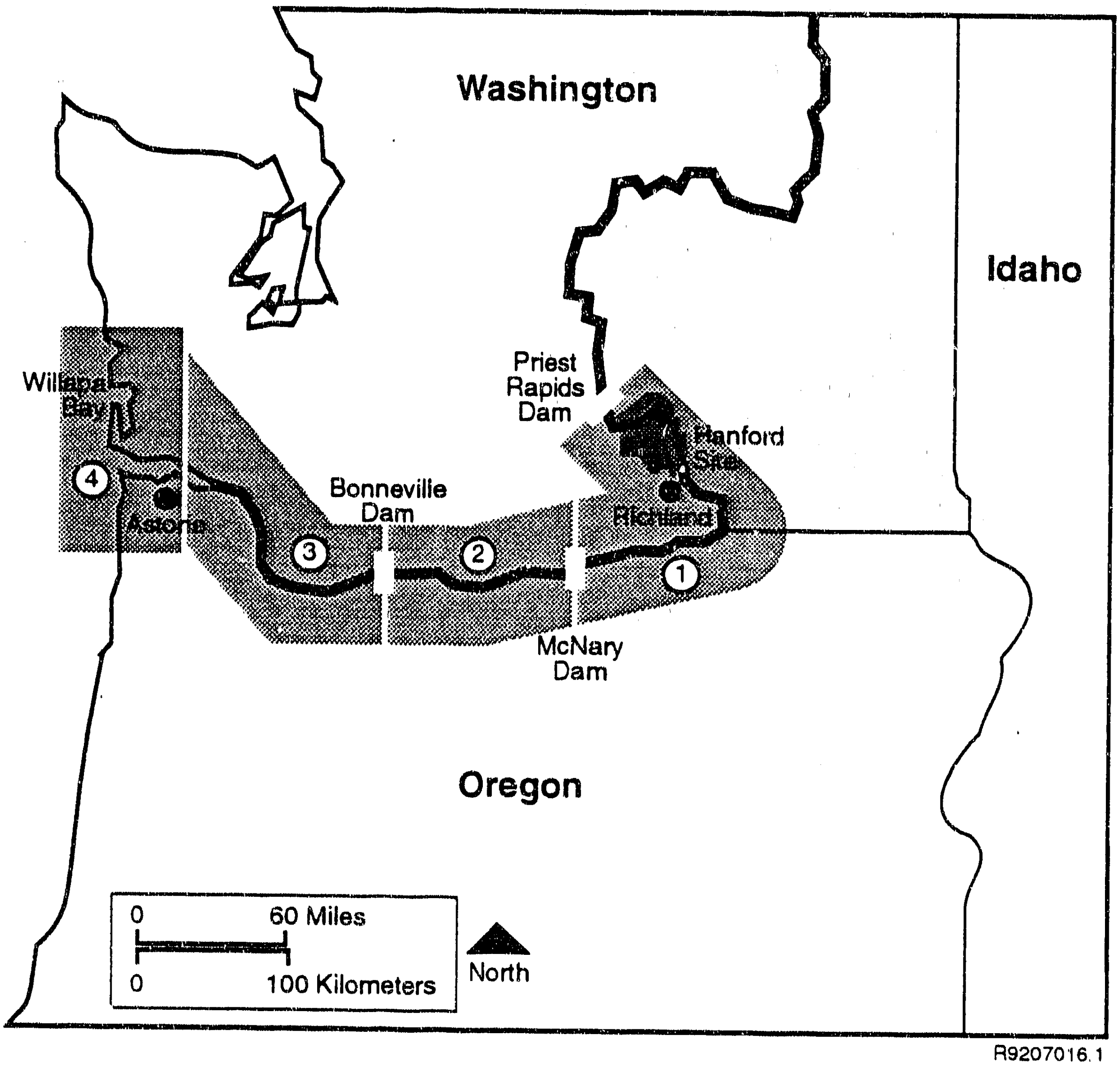

FIGURE 2.1. Columbia River Zones Used in Analysis

2.3 EXPOSURE PATHWAYS

Various pathways associated with the river have been identified by which the public could have been exposed to radiation. During the analysis, it was useful to partition these into pathways that are directly related to the concentration of radionuclides in river water and those that are indirectly (or integrally) related to river-water concentration.

2.3.1 Directly Related to Water Concentration

The radiation dose rate essentially relates directly to the instantaneous water concentration (the dose rate is directly proportional to the water concentration) for the following pathways:

- drinking untreated river water
- drinking treated river water (commercial supply)
- external exposure while boating
- external exposure while swimming
- external exposure while on the river/coastal shoreline
- external exposure to dock/dam/tugboat workers.

2.3.2 Indirectly Related to Water Concentration

The radiation exposure at any time is a function of the prior variations of the radionuclide concentrations in river water (the dose rate is determined by the current concentration and all those that have preceded it) for the these pathways:

- consuming irrigated food crops
- consuming resident fish
- consuming waterfowl and game birds
- consuming anadromous fish (salmon and steelhead)
- consuming shellfish.

The HEDR screening and Phase I results (Walters et al. 1992, Section 10; PNL 1991a, Section 5; PNL 1991b, Section 3) showed that the more fish eaten, the higher the dose. For this analysis, additional breakdowns for resident fish by typical consumption (0 to 20 meals per year, nominally 1 kg); large consumption (20 to 100 meals per year, nominally 40 kg); and maximum consumption (greater than 100 meals per year--up to 1 kg/day) are used from Walters et al. (1992). Similarly, for salmon, ranges of typical consumption (nominally 5 kg/year); large consumption (nominally 100 kg/year); and maximum consumption (up to 1 kg/day) are used (Walters et al. 1992, pp. 10.11-10.12).

Simple screening techniques (Baker and Soldat 1992) indicate that radionuclide uptake by waterfowl and other game birds living near the Columbia River could pose an additional pathway of exposure to people who hunt them. Radionuclide concentrations in waterfowl and upland game birds were routinely monitored over much of the reactor operating period (e.g., Wilson 1965, Appendix C; Healy et al. 1958, p. 314). The measurements indicate that ducks and birds could accumulate concentrations up to or exceeding those found in resident fish at the same locations, particularly those waterfowl feeding on algae and plants from the river. Reliable estimates of human consumption of wild birds are not available at this time, but because the measured concentrations of birds and resident fish were similar, this pathway has been included with the resident fish for the analysis in this report.

3.0 ALTERNATIVES CONSIDERED

Based on the locations and time periods defined in the preceding section, results for each of the exposure pathways could be calculated in a variety of ways ranging from simple to very complex. The simple methods may be quick, but the complex methods may have better accuracy or face validity. Because the pathways that are associated directly with river water concentration can be calculated easily once the water concentrations are known, the alternatives for those pathways essentially collapse into alternatives for calculating the water concentrations. This is true for all radionuclides of interest.

3.1 ALTERNATIVES FOR CALCULATING RADIONUCLIDE CONCENTRATIONS IN WATER

Five levels of effort were identified for calculating radionuclide concentrations in water: 1) use of monitoring data, 2) extrapolation based on monitoring data, 3) low-level modeling, 4) moderate-level modeling, and 5) high-level modeling. The alternatives are only identified points on a continuum of possible effort, but they are useful in helping guide discussion. Each level of effort is defined in the following sections.

3.1.1 Monitoring Data

This option involves use of only available monitoring data. It is restricted to those locations and times for which measurements are available. It is further restricted to using only reported radionuclides.

3.1.2 Extrapolation

This option is defined as use of all available monitoring data, as extended to intermediate times and places by temporal or spatial extrapolation and interpolation, filling data gaps as necessary. This extrapolation/ interpolation may use known effluent and river-flow information as auxiliary inputs.

3.1.3 Low-Level Modeling

Efforts for this option are envisioned as an extension of the procedure used in the HEDR Phase I calculations. Source terms (on approximately a monthly basis) would be assumed to be uniformly mixed and diluted in the total flow of the river over the period of interest. Simple decay corrections for transit time would be applied.

3.1.4 Moderate-Level Modeling

This option is a refinement of low-level modeling. It would use more detailed source-term data; the complete river hydrograph; simple one-dimensional, unsteady-flow, or reservoir-routing techniques; and other supporting data. Effects of sediment uptake and release would be investigated using a simplified empirical approach. This alternative is essentially what is described in the current HEDR task plans for FY 1993 (Shipler 1991b).

3.1.5 High-Level Modeling

The alternative here is to use the most detailed model possible. This is envisioned as an unsteady-flow model (probably multidimensional) with daily source-term input, and the effects of sediment transport are considered. (This alternative should be distinguished from the concept of minimum uncertainty, which ignores technological limitations and considers only the limitations in precision and accuracy resulting from random error.)

3.1.6 Modeling Radionuclide Concentrations in Ocean Water

The modeling alternatives described above apply only to the Columbia River. Totally different methods would need to be used if it were necessary to determine concentrations of Hanford-originated radionuclides in the Pacific Ocean. For this analysis, ocean-water modeling was limited to either a low-level effort or a high-level effort. These levels represent either a very limited effort or a large-scale attempt to simulate ocean transport. Because it is not anticipated that a large-scale effort would be needed, it was assumed that the overall effectiveness of such an effort would be minimal, and no credit was assumed for ocean-transport modeling in the subsequent analyses (although a major cost differential was included).

3.2 ALTERNATIVES FOR CALCULATING RADIONUCLIDE CONCENTRATIONS IN RESIDENT FISH

Four levels of effort were identified for calculating radionuclide concentrations in resident fish. Similar to the water-concentration estimates, these options are really points on a continuum of effort. The identified options are 1) use of monitoring data, 2) extrapolation of measurements, 3) low-level modeling, and 4) intermediate-level modeling. (Only two levels of modeling were defined, because a high-level model, perhaps using a dynamic food-web approach, was considered to be beyond the state of the art for this type of assessment.) Note that, for this analysis, "resident fish" in the Willapa Bay zone were considered to be oysters, and in other areas includes waterfowl.

3.2.1 Monitoring Data

This option involves using only available monitoring data. It is restricted to those locations, fish species, and times for which measurements are available. It is further restricted to using only reported radionuclides.

3.2.2 Extrapolation

This option is defined as use of all available monitoring data, as extended to intermediate times, places, and fish types by temporal, spatial, or inter-species extrapolation and interpolation, filling data gaps as necessary.

3.3.3 Low-Level Modeling

For the purposes of analysis, this was defined to be the use of water-to-fish bioaccumulation factors. A standardized set of bioaccumulation factors would be used as representative of "all fish" (perhaps weighted by the proportion usually found in the diet). This approach was used in the screening analysis performed for fish consumption doses in Walters et al. (1992, Section 10).

3.3.4 Intermediate-Level Modeling

A more detailed investigation of bioaccumulation is envisioned for this option. Sufficient data exist that specific distributions of bioaccumulation could be prepared as a function of species, location, and time of year. While some of this was done in the Phase I modeling (PNL 1991b), a great deal more could probably be accomplished, particularly for areas outside of the Hanford reach (that portion of the Columbia River nearest the Hanford Site analyzed in Phase I of the project).

3.4 ALTERNATIVES FOR CALCULATING RADIONUCLIDE CONCENTRATIONS IN SALMON

Little to no radionuclide monitoring data exist for salmon or other anadromous fish in the Columbia River, which limits the number of available options. Walters et al. (1992, p 4.9) found evidence that salmon returning to the Columbia River to spawn take up contamination while still in the Pacific Ocean. However, the salmon undergo radical metabolic and physiological changes upon entering the fresh water of the Columbia, which may cause changes in their radionuclide content and uptake. Because of the dearth of monitoring data, use of measurements or extrapolation is precluded. Only two levels of modeling, low and high, are postulated. An intermediate level of modeling could not be defined.

3.4.1 Low-Level Modeling

This is assumed to use a baseline concentration derived from monitoring data from the Pacific Ocean, augmented with a simple bioaccumulation factor while the fish are still in the ocean. Some investigations must be performed to provide justification for either maintaining the baseline value as the fish go upstream or for using some sort of bioaccumulation factor for short-lived materials that may transfer through the gills after the salmon enter the river.

3.4.2 High-Level Modeling

Efforts at this level are currently ill-defined. Possibilities include use of a dynamic limiting-nutrient model (one is potentially available through the HEDR contacts with Chernobyl scientists) or some other sort of biological assimilation model. While it is to be hoped that such modeling would result in better predictions, there is a question as to whether or not aggressive modeling could actually improve calculations. This option was intentionally given a fairly high cost factor, because it would probably require an extensive research effort.

3.5 CONSTRAINTS ON ALTERNATIVES

An option consists of a specified level of effort for each combination of time, location, and pathway. Theoretically, there are numerous possible options (for each of the 16 combinations of time and pathway there are two levels of effort for salmon, four for resident fish, and five for each of the other seven pathways). There are various substantive issues, however, that greatly constrain the number of viable options.

The levels of effort for the various water pathways are not independent. For a given time and location, the levels of effort for treated drinking water, irrigation, boating, swimming, and dock/dam workers depend directly upon the level of effort for the raw drinking water pathway. These dependent water pathways have simple relationships to the raw river water concentration, and the uncertainty of the dose estimates via these pathways depends upon the uncertainty of the estimated radionuclide concentration in the river water. Consequently, the level of effort for raw drinking water determines the level of modeling for these pathways, and their cost is marginal and the same regardless of the level of effort for raw river water. Thus, there is really only one decision for the water pathways--what level of effort to use for river-water concentrations; consequently, within a given pathway and location the number of possible options is reduced to forty.

A second issue that constrains the number of viable options is that fish models take river-water concentration as input. Consequently, it does not make sense to undertake an elaborate model for fish if the input data from the river model are so "noisy" that they overwhelm the precision of the high-level fish model. Thus, not all combinations of levels of effort for fish and water are viable. The possible combinations are shown in Table 3.1. Thus, low-level modeling for fish assumes at least extrapolation for water modeling, and high-level modeling for fish assumes at least low-level modeling of water.

Another consideration is that data availability further constrains the possible levels of effort. One limitation is that there are few or no monitoring (measurement) data available for salmon. So, if some level of effort is to be undertaken for salmon, then use of water monitoring data is not an

TABLE 3.1. Possible Combinations of Levels of Effort for Reconstructing Concentrations in Resident Fish and River Water

	Water				
Resident Fish	Measured Data	Extrapolation	Low-Level Modeling	Medium-Level Modeling	High-Level Modeling
Measured data	X	X	X	X	X
Extrapolation	X	X	X	X	X
Low-level modeling		X	X	X	X
Intermediate/ high-level modeling			X	X	X

option for determining water concentrations. This leads to a further reduction to 27 options for a particular time and location, as shown in Table 3.2.

For locations further downstream, there are additional data limitations that result in more constraints. For the stretch of river from Bonneville Dam to the mouth, fish-monitoring data are not available; consequently, there are only 20 possible options. These are shown in Table 3.3. For the Pacific coastal areas, only after 1962 are use of monitoring data or extrapolation possible options for resident fish--which are shellfish for this location. Thus, there are 8 options available prior to 1962 and 16 options available after 1962, as shown in Table 3.4.

There are also dependencies among the various locations for a particular time. A downstream model takes as its input the output from the upstream model. This suggests that downstream modeling should be in no greater detail than the upstream model that feeds information into it. Furthermore, once the effort is carried out for a particular location upstream (for a given time period), then the cost is marginal to extend the model further downstream.

There also may be time dependencies, which may become apparent as a result of implementing the selected alternatives; these were not considered further. Also, the period from 1972 to 1990 was not analyzed because the availability of monitoring data and contemporaneous dose estimates coupled

TABLE 3.2. Possible Combinations of Levels of Effort for Reconstructing Radionuclide Concentrations in Resident Fish, Salmon, and River Water at a Particular Time and Location

Salmon: Low-level modeling

	Water				
Resident Fish	Measured Data	Extrapolation	Low-Level Modeling	Medium-Level Modeling	High-Level Modeling
Measured data		X	X	X	X
Extrapolation		X	X	X	X
Low-level modeling		X	X	X	X
Intermediate/high-level modeling			X	X	X

Salmon: High-level modeling

	Water				
Resident Fish	Measured Data	Extrapolation	Low-Level Modeling	Medium-Level Modeling	High-Level Modeling
Measured data			X	X	X
Extrapolation			X	X	X
Low-level modeling			X	X	X
Intermediate-level modeling			X	X	X

TABLE 3.3. Possible Combinations of Levels of Effort for Reconstructing Radionuclide Concentrations in Resident Fish, Salmon, and River Water from Bonneville Dam to Columbia River Mouth

Salmon: Low-level modeling

Resident Fish	Water: Measured Data	Water: Extrapolation	Water: Low-Level Modeling	Water: Medium-Level Modeling	Water: High-Level Modeling
Measured data					
Extrapolation		X	X	X	X
Low-level modeling			X	X	X
Intermediate/high-level modeling			X	X	X

Salmon: High-level modeling

Resident Fish	Water: Measured Data	Water: Extrapolation	Water: Low-Level Modeling	Water: Medium-Level Modeling	Water: High-Level Modeling
Measured data					
Extrapolation			X	X	X
Low-level modeling			X	X	X
Intermediate-level modeling			X	X	X

TABLE 3.4. Possible Combinations of Levels of Effort for Reconstructing Radionuclide Concentrations in Resident Fish, Salmon, and Ocean Water for Coastal Areas

Salmon: Low-level modeling

Resident Fish	Water: Measured Data	Water: Extrapolation	Water: Low-Level Modeling	Water: Medium-Level Modeling	Water: High-Level Modeling
Measured data			(X)[a]		(X)
Extrapolation			(X)		(X)
Low-level modeling			X		X
Intermediate/high-level modeling			X		X

Salmon: High-level modeling

Resident Fish	Water: Measured Data	Water: Extrapolation	Water: Low-Level Modeling	Water: Medium-Level Modeling	Water: High-Level Modeling
Measured data			(X)		(X)
Extrapolation			(X)		(X)
Low-level modeling			X		X
Intermediate-level modeling			X		X

(a) (X) = Measurement and extrapolation are options for fish after 1962.

with the minimum of reactor activity led the authors to the conclusion that individual doses were very unlikely to exceed the TSP guidelines, and thus modeling was not necessary.

4.0 ATTRIBUTES AND DATA APPROXIMATIONS

For each combination of time, location, and pathway, the VOI model required estimates of the number of people exposed, the average dose, the minimum possible uncertainty, the percentage uncertainty reduction for each level of effort, and the estimated cost for that level of effort.

4.1 APPROXIMATIONS, EXPERT OPINION, AND PEER REVIEW

Some of the estimates required judgments based upon expert opinion. Judgments are an integral and necessary part of all decision modeling. For some of the inputs, objective data were available and were used whenever possible. Often objective data were available for baseline estimates at a particular time and/or place, which were then modified by judgment to fit the particular circumstances of other times or places prior to input.

The required judgments were provided by the authors and verified by other individuals with the appropriate knowledge who provided feedback, which led to modification and consensus on the estimates. Reviewers and others who contributed to the process of data approximation are acknowledged in the "Acknowledgments" section of this report. A short summary of the status of the opinion of the project staff on each set of input assumptions is provided in the following sections.

4.2 SOURCE TERMS

Preparation of a "Hanford history" is a defined product of the HEDR Source Terms Task (Shipler 1991c, p. 4.6). One portion of this is a comprehensive source term for reactor releases to the Columbia River. It is likely that this research will be undertaken, as a result of strong public interest, whether surface-water doses are calculated or not. Therefore, for this analysis, the availability of a detailed Columbia River source term has been assumed as a given. Costs and time for preparation of a Columbia River source term are not included in this analysis.

4.3 NUMBER OF PEOPLE POTENTIALLY EXPOSED

The values reported in Volume 2, Appendix B, are estimates based on discussions with staff of the HEDR Demography, Food Consumption, and Agriculture Task. The values, which are intended to be order-of-magnitude estimates at best, accommodate several realistic pathway assumptions:

- There is little commercial irrigation with Columbia River water below the Columbia Gorge.
- The Richland/Kennewick/Pasco area is the largest public drinking water withdrawal below Hanford. (There are a few small towns using Columbia water, but no major population centers.)
- No contaminated water is used for drinking at Willapa Bay.
- Populations and affected groups change with installation of the dams above Bonneville.

The estimates are consensus values among HEDR staff and reviewers.

4.4 DOSE ESTIMATES

Doses are the same as those reported in Walters et al. (1992) for the year 1964. The background calculations used in each are the same. The doses are based on monitored data in the mid-1960s. That report provided doses by aggregated pathway for five locations. The individual pathways were disaggregated for this analysis. The only difference is that the results for McNary and Bonneville were averaged for the McNary-Bonneville stretch. The individual pathway doses are given in Volume 2, Appendix B. Values for both the typical and maximally exposed individuals were used.

The detailed calculations in Walters et al. (1992) were only done for the years 1964-1966. For this analysis, only the 1964 values were used to represent the 1962-1971 period. These results were scaled by a factor of 0.5 for the 1955-1961 period, and by a factor of 0.1 for the 1944-1954 period. These scaling factors were developed as functions of reactor power and gross beta output, using the technique described in Walters et al. (1992).

The doses are considered to be representative of the time periods, but not necessarily accurate for any given person for any given year; the scaling was done to illustrate broad periods, not to accurately portray any one year. Because of temporal averaging, the scaling factors are possibly overestimates for most of the years of the 1944-1954 period, possibly underestimates for the years 1958-1961, and again overestimates for years after 1964. The scaling factors are a consensus opinion of the authors and internal reviewers as being reasonably descriptive of the broad time periods investigated.

4.5 VARIANCE ESTIMATES

The model requires as inputs both a prior variance--which represents the current uncertainty, and a prior estimate of a posterior variance--which is an estimate of what the uncertainty would be after implementing the various levels of effort. The variance being estimated is the one concerning the true value of the average dose. This may be very different than the variance of the population dose (which describes the variability across individuals in the population). There is probably no reason to believe that the variance of the population dose will decrease as a result of carrying out a particular alternative (there will still be a range of doses among individuals in the population), but there is reason to believe that the confidence interval around the estimate of the average dose will decrease as a result of further study (we will understand the distributions better). It is this confidence in the estimate that is being addressed when estimating the variance.

For the river pathway, variance estimates were obtained indirectly from estimates of the average dose and estimates of the upper 95th fractile. Again, it cannot be stressed too much that this is the upper 95% confidence interval of the authors' belief about the average value of the true dose. Assuming that the underlying belief distribution for the average dose is lognormally distributed, the variance is then calculated as

$$\mathrm{Var} = \{[\mathrm{Log}(95\text{th fractile}) - \mathrm{Log}(\mathrm{avg})]/1.645)^2 \qquad (4.1)$$

All uncertainty estimates are based on the mid-1960s calculations. The current uncertainties are based on the Phase I calculations for the Hanford reach segment of the river (Priest Rapids to McNary Dam), so the basic prior and posterior estimates are derived from that stretch, and extended over space and time away from that set. Most of the pathways are directly related to the concentration of radionuclides predicted in the river water. These are all dominated by the uncertainties in the water concentration. A few others have an "intermediate step," estimation of concentrations in fish, salmon, or food crops from irrigation. This adds to the water uncertainty. A "well-defined individual" is assumed in all cases, so that the uncertainties generated from lifestyle differences, etc., are compensated for. All dose distributions were assumed to be lognormally distributed. Therefore, uncertainty could be described in terms of a geometric standard deviation (GSD). The "algorithm" for assigning prior and posterior uncertainties is presented in Table 4.1. To extend these in space (i.e., to the other four locations for the 1960s), the values shown in Table 4.2 are added to all the Hanford GSD estimates. The negative addition (subtraction) for the salmon indicates that the best data are likely to be from the Pacific Ocean measurements, and estimations we make upstream will be less and less reliable the more radionuclides we encounter closer to Hanford sources.

TABLE 4.1. Geometric Standard Deviations Assigned to Individual Dose Estimates for the Richland Area in the 1960s

Prior Estimates	Geometric Standard Deviation
River Pathways	1.7 (factor of 3 at 95th percentile)
River + Irrigation	4.0 (factor of 16)
River + Fish	3.0 (factor of 9)
River + Salmon	5.0 (factor of 25)
Posterior Estimates	**Geometric Standard Deviation**
River Pathways	1.5 (factor of 2)
River + Irrigation	3.0 (factor of 9)
River + Fish	2.0 (factor of 4)
River + Salmon	3.5 (factor of 12)

TABLE 4.2. Factors Added to the Geometric Standard Deviation for the Richland Area to Account for Uncertainties in Other Areas

	McNary Dam to Bonneville Dam	Bonneville Dam to River Mouth	Coastal Areas
Prior estimates (all but salmon)	0.2	0.4	0.6
Posterior estimates (all but salmon)	0.1	0.2	0.3
Salmon (prior and posterior)	-0.1	-0.3	-0.3

To extend these estimates in time (to the 1950s and 1940s), the following are added to each location:

- 1950s: add 0.5 to all 1960s estimates of GSD
- 1940s: add 1.0 to all 1960s estimates of GSD (0.5 to the 1950s).

The logic here is that only gross beta data, rather than spectral data, are available for a part of the 1950s and all of the 1940s periods.

The estimates of uncertainty reduction by means of various investigation techniques are also the judgments of the authors and other Battelle staff. For monitoring and extrapolation, although these account for time and space gaps, there is relatively little improvement in the uncertainty. It was assumed that low-level modeling would not be particularly accurate below about McNary Dam, so the uncertainty reduction estimates for low-level modeling are about the same as for extrapolation from there on downstream. Moderate-level modeling is assumed to be "credible engineering" and to provide a reasonable improvement in the answers. High-level modeling, while possibly providing better estimates than the other techniques, for input to the VOI analysis was not allowed to get a 100% reduction in the uncertainty, but it was allowed to be better than moderate-level modeling. This is, potentially, a bias that makes modeling efforts look more accurate than they may actually be (particularly with fish and salmon).

4.6 COST ESTIMATES

Cost estimates are based mainly on current work-plan projections (Shipler 1991b, 1992). It was assumed that the current work plans are essentially equivalent to moderate-level water modeling with low-level fish and salmon modeling. Costs for the "monitoring" options are based on the cost projections for the HEDR Environmental Monitoring Data Task (Shipler 1991b, 1992). A further assumption was that the cost for low-level modeling would be essentially the same as that for extrapolation of monitoring data. Costs for collection of demographic and food consumption data are assumed to be about the same across the options, and are equal to the projected Demography, Food Consumption, and Agriculture Task expenses (Shipler 1991b, 1992).

The costs for many of the water-related pathways were lumped together; because doses via these pathways are all easy to derive once the water concentrations are known, they have low marginal costs. Also, the costs initially estimated were aggregate costs for the entire project using a particular option; these were then broken down for the individual time periods and river stretches. Use of a "cost" for a single option applied to a single river stretch or single time period is, therefore, not a true reflection of the actual cost if that option were independently selected. (Each option has development and startup costs that were pro-rated across the times and locations.)

There is a possibility that the estimated costs for high-level fish and salmon modeling may be underestimated, because those levels of effort are currently ill-defined. However, increases in cost should be roughly monotonic with increases in level of effort. Inaccuracies in the relative VOI/cost ratio for different combinations of alternatives would result only from relative cost differentials, rather than from absolute cost differentials. Therefore, the relative relationships between the various combinations of alternatives as a function of cost should remain about the same.

5.0 SUMMARY OF VOI RESULTS

An independent VOI analysis was carried out for the first three time periods at each of the four locations. Thus, VOI analyses were conducted for twelve combinations of time and location. Within each of these combinations, the VOI analysis was conducted for the applicable options. For each level of effort, the VOI was computed for each of the exposure pathways. These pathways consisted of the seven water pathways, resident fish consumption (at three consumption rates), and salmon consumption (also at three consumption rates). The total VOI for water at a given level of effort was found by summing (as defined in Appendix A in Volume 2) the VOIs for the seven water pathways. The total VOI for resident fish is the sum of the VOIs for the three levels of fish consumption, and the total VOI for salmon is the sum of the three VOIs for the three levels of salmon consumption. Next, the VOIs for each option were calculated. This is just the sum of the total VOI for water, the total VOI for resident fish, and the total VOI for salmon, each at their respective levels of effort. The final step in the analysis was to compare the VOIs for each of the options with their costs.

Details of the complete VOI assessment are provided in Volume 2 in Appendixes A, B, and C. Appendix A provides a discussion of the theory of value of information as applied to the HEDR application of selection of Columbia River dose-estimation methods. Appendix B provides all of the input information used in the numerical assessment of VOI. Appendix C provides all of the numerical results, with a discussion and graphical interpretations.

In Appendix C, and in the following discussion, the various options are discussed using a "shorthand" notation. All of the options consist of some combination of level of effort for determining radionuclide concentration in river water, resident fish, and salmon. For the various levels of effort, possibilities include use of extrapolation of monitoring data; low-level modeling; moderate-level modeling of water and intermediate-level modeling of fish; and high-level modeling. In the notation used, these are represented by triplets of the initials E, L, I, M, and H. Thus, for a time period and location of interest, a combination consisting of moderate-level modeling of river water, extrapolation of resident fish data, and low-level modeling of salmon would be represented as MEL. The ordering of the initials is always river/fish/salmon.

5.1 COMPARISON ACROSS TIMES AND LOCATIONS

One option is said to dominate another option if the first is better than the second for at least one of the dimensions being considered and is no worse than the second on all of the other options. A complete discussion of the concept of option dominance is provided in Volume 2, Appendix C.3.

Table 5.1 shows the results of applying the VOI analysis to all combinations of time and location. For each time and location, the set of nondominated options is listed in order from least to most costly. In almost every case, the least costly member of this set is LLL (low-level modeling of concentrations in river water/low-level modeling of fish/low-level modeling of salmon), and the most costly member of this set is HIH (high-level modeling of concentrations in river water/intermediate-level modeling of fish/high-level modeling of salmon). In one case (McNary Dam to Bonneville Dam, 1962-1971), ELL dominates LLL as the least-costly option. Also, LIH dominates HIH as the least costly option for the Pacific coastal areas across all time periods.

The nondominated options were further analyzed across locations for a given time period and across time periods for a given location. These analyses were of two types. One analysis consists of the identification of the intersections and unions of the nondominated options--i.e, what options different times or locations had in common (unions) and what were available for at least one time-location (intersections). The other analysis consisted of summing the VOIs either for a given location across time or for a given time across locations. The sets of nondominated options that resulted from these analyses are shown in Tables 5.1 through 5.4.

The sets of nondominated options for a given location across times are fairly similar. This can be seen from a comparative examination of Figures C.25-C.36 in Volume 2, and it is also apparent from a comparison of the cardinality of the set of intersections with the cardinality of the set of unions when these are taken across times for a given location. These sets are similar in size. In fact, for Bonneville Dam to the river's mouth, these sets are exactly the same, as shown in Table 5.2. On the other hand, a comparison across locations for a given time period shows that the nondominated sets have very little in common, as shown in Table 5.3. These considerations naturally lead to the summation of VOI across times for each location. The results of these summations were plotted against cost and are shown in Volume 2 in Figures C.37-C.40. The nondominated options for these sums are shown in Table 5.4. VOI was also summed across locations for each time period. These results are plotted against cost and are shown in Figures C.41-C.43 in Volume 2, and the set of nondominated options is shown in Table 5.4. Figure 5.1 shows the results of summing VOI over all times and all locations for the Columbia River, and the set of nondominated options is also shown in Table 5.4. Figure 5.2 provides the same information for the Pacific coastal regions.

5.1.1 VOI-Cost Tradeoffs

A choice among the nondominated options will reflect the decision maker's judgment as to the relative importance of cost and VOI. Such judgments require that the decision analyst provide the decision maker with information concerning the relationship between the inputs and the magnitude of VOI. This process can be helped with an understanding of the relationship between changes in the magnitude of the input variables and the corresponding changes in the magnitude of the VOI results. A detailed discussion of these relationships is given in Volume 2, Appendix C.

5.1.2 Sensitivity of Results to Input Changes

A sensitivity study was performed to investigate the sensitivity of the conclusions to variations of the input values. This study is described in Appendix C.5 of Volume 2. The results show that cardinal dominance was preserved throughout the range of parametric values. Ordinal dominance was also preserved, with a few minor exceptions.

5.2 CONCLUSIONS OF VOI ANALYSIS

Although HIH is a dominant option and provides the maximum VOI, it should probably be eliminated from consideration. An examination of any of the figures that plot VOI against cost shows that very little is gained by increasing the modeling of the river water from L to H; i.e., HIH is not much, if any, better than LIH, regardless of the time or location. So LIH marks the upper end of the options that make sense.

LLL is the dominant low-cost option for all time-locations except two; thus, LLL defines the lower end of the options. However, unless budget is an overriding consideration, LLL can be greatly improved upon for a moderate increase in cost. (This can be seen by an examination of Figures C.25-C.36 in Volume 2.) The logical choice for the next costly option is, for most time-locations, LIL (low modeling for water, intermediate modeling for resident fish, and low modeling for salmon), as seen, for example, in Figure C.25. In fact, Figure C.25 shows LIL to be in some sense the optimal choice, because further increases in effort gain little in the way of information value.

A major exception to LIL as optimal is for the stretch from McNary Dam to Bonneville Dam. Here the optimal choice is LLH, rather than LIL; i.e., for this location it makes more sense to spend the extra effort in high-level modeling of salmon rather than resident fish. This reflects the fact that it was on this stretch of the river that the majority of the salmon were caught. However, considering that the marginal cost of extending a level of modeling effort to other time-locations is relatively small once such a model is developed, it makes little sense to model LIL for some locations and LLH for others. The total VOI summed over all times and locations for the Columbia is shown in Figure 5.1. This figure shows LIL or LIH to be optimal choices representing a steady increase in value for increases in effort over all other options, while any further increase in effort yields very little increase in information value. For the coastal areas, LIH appears to be optimal.

No one method of analysis will unequivocally give the final answer to any decision issue. This particular application of VOI to the level-of-effort decision for the river pathway represents a novel approach, but one that has a firm foundation in the theory of decision making (see Appendix A in Volume 2).

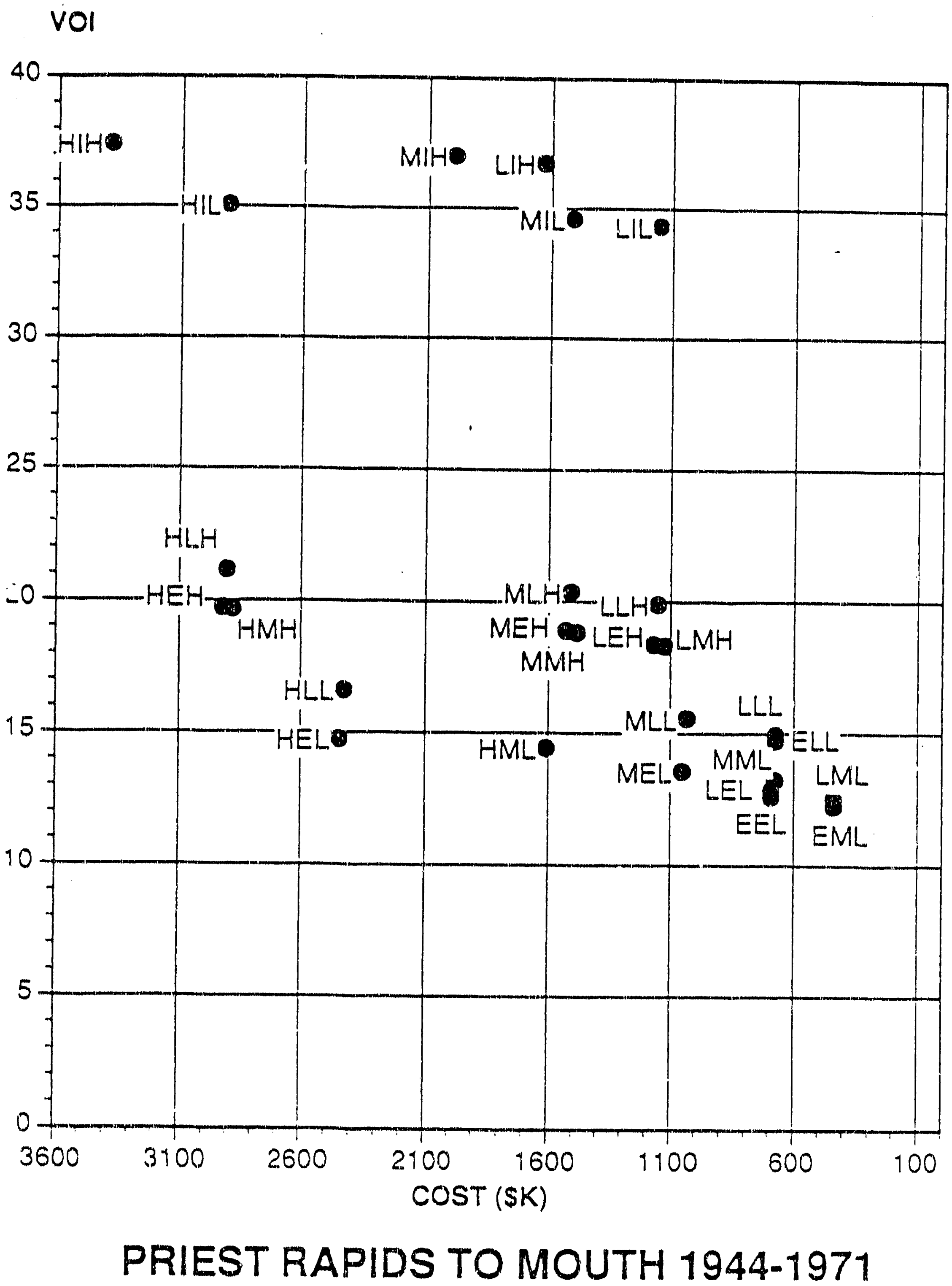

FIGURE 5.1. Summary of VOI Versus Cost for All Columbia River Locations

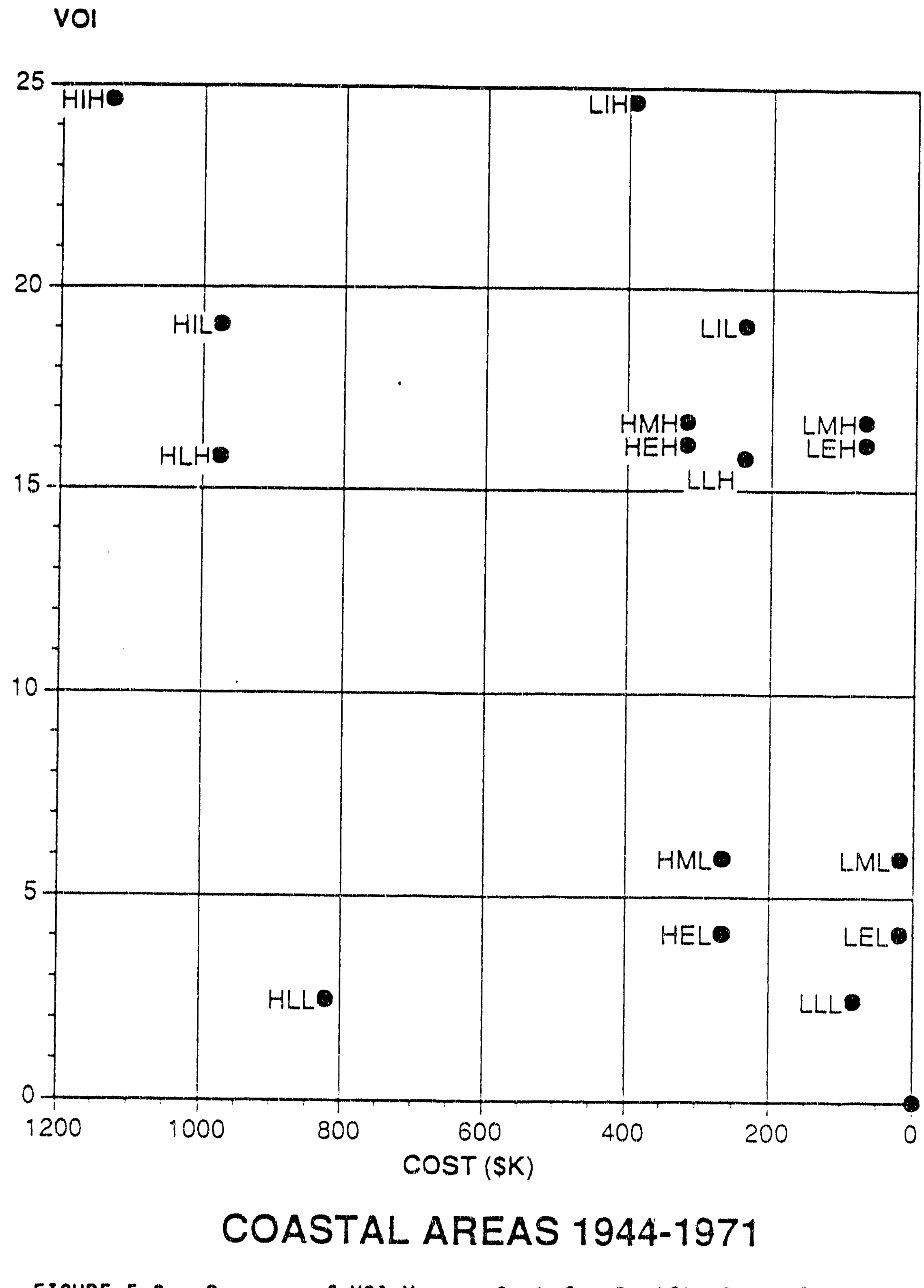

FIGURE 5.2. Summary of VOI Versus Cost for Pacific Coastal Areas

TABLE 5.1. Dominant Options for Each Combination of Time and Location

1944-1954

Priest Rapids to McNary Dam
LLL, LIL, LIH, MIH, HIH

McNary Dam to Bonneville Dam
LLL, LLH, LIH, MIH, HIH

Bonneville Dam to River Mouth
LLL, LIL, LIH, MIH, HIH

Coastal Areas
LLL, LIL, LIH

1955-1961

Priest Rapids to McNary Dam
LLL, LIL, MIL, MIH, HIL, HIH

McNary Dam to Bonneville Dam
LLL, LLH, LIH, MIH, HIH

Bonneville Dam to River Mouth
LLL, LIL, LIH, MIH, HIH

Coastal Areas
LLL, LIL, LIH

1962-1971

Priest Rapids to McNary Dam
LLL, LIL, MIL, MIH, HIL, HIH

McNary Dam to Bonneville Dam
ELL, LLH, LIH, MIH, HIH

Bonneville Dam to River Mouth
LLL, LIL, LIH, MIH, HIH

Coastal Areas
LML, LIL, LIH

TABLE 5.2. Union[a] and Intersection[b] of Dominant Options Across Times

Priest Rapids to McNary Dam--All Times

Union

LLL, LIL, LIH, MIL, HIL, HIH

Intersection

LLL, LLH, MIH, HIH

McNary Dam to Bonneville Dam--All Times

Union

LLL, LLH, LIH, MIL, MIH, HIH

Intersection

LLL, LIL, MIH, HIH

Bonneville Dam to River Mouth--All Times

Union

LLL, LLH, LIH, MIH, HIH

Intersection

LLL, LLH, LIH, MIH, HIH

Coastal Areas--All Times

Union

LML, LLL, LIL, LIH

Intersection

LIL, LIH

(a) Option is in union if it is the dominant option at least once.

(b) Option is in intersection if it is the dominant option every time.

TABLE 5.3. Union[a] and Intersection[b] of Dominant Options Across Locations

1944-1954--All Locations

Union

LLL, LLH, LIL, LIH, MIH, HIH

Intersection

LLL, LIH

1966-1961--All Locations

Union

LLL, LIL, LLH, LIH, MIL, MIH, HIL, HIH

Intersection

LLL, LIL, MIH, HIH

1962-1971--All Locations

Union

LLL, LIL, LLH, LIH, MIL, HIL, HIH

Intersection

LLL

(a) Option is in union if it is the dominant option at least once.

(b) Option is in intersection if it is the dominant option every time.

TABLE 5.4. Dominant Options When VOI Analysis is Aggregated over Times, Locations, and Times and Locations

All Times

- Priest Rapids to McNary Dam
  - LLL, LIL, MIL, MIH, HIL, HIH
- McNary Dam to Bonneville Dam
  - LLL, LLH, LIH, MIH, HIH
- Bonneville Dam to River Mouth
  - LLL, LIL, LIH, MIH, HIH
- Coastal Areas
  - LML, LMH, LIL, LIH, HIH

All Locations

- 1944-1954
  - LML, LIL, LIH, HIH
- 1955-1961
  - LML, LIL, LIH, HIH
- 1962-1971
  - LML, LIL, LIH, HIH

All Locations and All Times

- LML, (LMH), LIL, LIH, HIH

6.0 RECOMMENDATIONS

The VOI analysis conducted for the project provided a basis for understanding the implications of the various options for modeling radionuclide concentrations in the river and calculating the human doses resulting from exposure to them. The conclusions of the VOI analysis, described in Section 5.0, suggest that the combinations LIL or LIH are best supported by current information. However, as also noted in Section 5.0, considerations other than just cost and individual dose also need to be considered. Thus, the Battelle recommendations described in the following sections are based on technical as well as other considerations.

The recommendations to the TSP for continuing work fall in the areas of

- exposure pathways to consider
- level of effort for modeling the radionuclide concentrations in
  - the Columbia River
  - resident fish
  - salmon
  - seafoods.

6.1 RECOMMENDATION FOR EXPOSURE PATHWAYS TO CONSIDER

As a result of the modeling exercise described in Walters et al. (1992, Section 10), the importance of some exposure pathways over others is apparent in terms of dose. Dose from inhalation of material resuspended from shorelines or irrigated fields is extremely small (one-thousandth of a millirem). Radiation exposure to individuals from most external pathways (e.g., swimming, boating) is low (on the order of a few millirem). Of the same order of magnitude is exposure from irrigated crops. The small dose resulting from irrigation (and inhalation) is a consequence of the spectrum of radionuclides released to the river: few long-lived radionuclides that would build up in irrigated soil or food are present. The dominant pathways are ingestion of drinking water (for most people), ingestion of resident fish and salmon caught from the Columbia River, and ingestion of seafood from the Pacific coastal bays.

Dose resulting from swimming and boating is very simple to calculate once the water concentrations are known. Including these pathways for completeness is easy and would have minimal incremental cost. *Therefore, it is recommended that the swimming and boating pathways be included.* However, doses from irrigated foods would be much more difficult to include, because much additional data on quantities of irrigated food produced, the irrigated-food distribution network, and individual consumption would be needed. Such efforts could be as costly as past and current efforts to reconstruct the milk production and distribution system. The dose impact to any individual from irrigated foods is low. *Therefore, it is recommended that irrigated foods be omitted from the river pathway calculations.*

Because of its relative importance to most of the downriver population, drinking water (both treated and untreated) should be included. Because of the importance to groups depending on them for a substantial portion of their diet, resident fish and salmon in the Columbia River should be included. Waterfowl and game birds should be investigated at the same level of effort as the resident fish. Finally, some level of effort should be expended to fully characterize the potential for doses from oysters and other seafood along the Pacific coast of Washington and Oregon.

6.2 RECOMMENDATION FOR CALCULATING RADIONUCLIDE CONCENTRATIONS IN WATER

The conclusion from the VOI analysis was that low-level modeling of water concentrations, similar to that done for Phase I, would be adequate (see Figure 5.1, or Appendix C in Volume 2). However, a slight increase in the value of the information generated could be gained for a small additional cost by going to a moderate level of effort (see Figure 5.1). Because of the public interest in the surface-water pathway, the authors believe that continuing with the level of effort currently defined in the project task plans (Shipler 1991c, 1992) (which corresponds with the moderate-level modeling defined for the VOI analysis) is warranted. Public understanding and confidence would be enhanced by doing more than is minimally necessary for modeling radionuclide concentrations in river water. The results of the other pathways would also be more generally defensible if modeling were done at a moderate, rather than low, level of effort. Because source-term information will be available over the entire period of reactor operations, once a model is established, it is only a marginal incremental effort to use it for the entire time period.

Therefore, the recommendation to the TSP is for moderate-level modeling of radionuclide concentrations in Columbia River water concentrations for 1944-1972.

The VOI analysis considered only low-level and high-level modeling of radionuclide concentrations in Pacific coastal regions. Because the doses from seafoods beyond the river mouth are moderate to low (generally less than a few tens of millirem at most), only a low level of effort is recommended for this work. (See the recommendation for seafood, below.)

6.3 RECOMMENDATION FOR MODELING RADIONUCLIDE CONCENTRATIONS IN RESIDENT FISH

Walters et al. (1992) illustrate that the pathway with the potential for the largest doses to individuals is that of consumption of resident fish. On a pound-for-pound basis, the dose from waterfowl and game birds may be approximately equal to that for resident fish. It is likely that the total number of people with a potential for high doses from these pathways is small. The individuals most likely to fall into this group are members of minority groups using the fish or birds as a subsistence food source.

Both of the options discussed in Section 5.2 as providing the best value of information for a given expenditure include intermediate-level modeling of fish. The authors believe that a simple single-concentration-ratio model for fish (low-level modeling) is insufficient for the HEDR Project, for reasons of completeness, technical defensibility, and public acceptance, because bioaccumulation differs from time to time, location to location, and fish to fish. Characterization of radionuclide concentrations in wild birds would also need a model with somewhat more complexity than a simple ratio to water concentration.

Therefore, intermediate-level modeling of resident fish and waterfowl is recommended. This level is defined to consist of research leading to estimated distributions of bioaccumulation as a function of species, location, and time of year.

6.4 RECOMMENDATION FOR MODELING RADIONUCLIDE CONCENTRATIONS IN SALMON

Ideally, modeling of radionuclide uptake in salmon returning to the Columbia River would be done at the same level of detail as that for resident fish. Figure 5.1 illustrates about a 10% increase in value of information with high-level modeling over low-level modeling of salmon. However, this figure also indicates that the cost of going to high-level modeling is considerable (on the order of two to three person-years of additional effort). In addition, the authors described the high-level modeling of salmon as an option that was ill-defined (see Section 3.4.2). The authors are not comfortable recommending high-level modeling of salmon because of the potentially high cost, and because such a recommendation would, in essence, be a recommendation for a very large (and possibly unrewarding) research project.

The recommendation to the TSP is for low-level modeling of radionuclide concentrations in salmon.

6.5 RECOMMENDATION FOR MODELING RADIONUCLIDE CONCENTRATIONS IN SEAFOOD

Monitoring done along the Washington and Oregon coasts in the 1960s identified Hanford-originated radioactive zinc-65 and phosphorus-32 in seafoods, particularly commercially harvested oysters (Walters et al. 1992, Section 9). The dose results of Walters et al. (1992, Section 10) indicate that this pathway could add to the dose that people got from other pathways. There is also a small possibility that people relying on Willapa Bay oysters for a very large portion of a subsistence diet could have received a dose above the TSP dose guideline (Shleien 1992) for a period between the mid-1950s and mid-1960s. Therefore, this pathway needs to be included in the HEDR analysis.

Nevertheless, the highest doses are only marginally greater than the TSP guideline. Detailed study of the transport of radionuclides into the

Ocean and up to the commercial harvesting areas would be extremely complex and of a different nature than that proposed for the Columbia River. Any simulated concentrations of radionuclides in ocean water would also require a model to simulate uptake by seafood. As illustrated in Figure 5.2, the potential gain in value of information is quite small, while the potential cost is quite large, if detailed modeling of transport in the ocean is required. In originally setting up the potential alternatives, the emphasis on "water modeling" was probably misguided. Most of the effort would be better spent on direct analysis of the oyster data.

A reliance on monitoring data, enhanced with low-level modeling, is recommended to the TSP for determining radionuclide concentrations in Pacific coastal seafood.

6.6 ADDITIONAL JUSTIFICATIONS

The combined package of recommendations is believed by the authors and reviewers to represent a reasonable and consistent set of technical activities. The authors and reviewers believe that the activities fall within the scope of the current work plans, and also have a good potential for completion within the next year to year-and-a-half. Those pathways that have been included, and the level of effort associated with them, are directly related to the TSP's guidance on doses of interest to the project (Shleien 1992).

The final results should be scientifically defensible, while answering many of the public's questions about the impact of past Hanford activities on the Columbia River and to humans exposed via the river pathway.

6.7 SUMMARY OF RECOMMENDATIONS

The additional work recommended to the TSP is

- reconstruct (model), at a moderate level of effort (i.e., a one-dimensional, unsteady-flow, routing and decay calculation), radionuclide concentrations in Columbia River water in at least the 1950s and 1960s as far downriver as Astoria, Oregon

- reconstruct, at an intermediate level of effort (i.e, a model based on species-specific, seasonal bioaccumulation factors), radionuclide concentrations in several species of fish resident year-round in the river, as well as waterfowl and game birds, for the same set of locations

- reconstruct (model), at a low level of effort (i.e., use of calculated uptake by the salmon while they are in the Pacific Ocean, modified with a simple bioaccumulation model while they are in the Columbia River), radionuclide concentrations in anadromous species (salmon and steelhead) returning to the river

- estimate, using monitoring data and temporal extrapolation, the concentration of radionuclides in Pacific coastal shellfish

- reconstruct, using the concentrations derived for river water, fish, salmon, and shellfish, individual doses for people living in the vicinity of the Columbia River and adjacent coastal areas in the 1950s and 1960s.

7.0 REFERENCES

Baker, D. B., and J. K. Soldat. 1992. Methods for Estimating Doses to Organisms from Radioactive Materials Released into the Aquatic Environment. PNL-8150, Pacific Northwest Laboratory, Richland, Washington.

Ballinger, M. Y., and R. B. Hall. 1991. A History of Major Hanford Facilities and Processes Involving Radioactive Material. PNL-6964 HEDR, Pacific Northwest Laboratory, Richland, Washington.

Healy, J. W., B. V. Anderson, H. V. Clukey, and J. K. Soldat. 1958. "Radiation Exposure to People in the Environs of a Major Production Atomic Energy Plant," pp. 309-318. In Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, Waste Treatment, and Environmental Aspects of Atomic Energy. United Nations, Geneva.

Holmes, C. W. 1991. A Preliminary Examination of Audience-Related Communications Issues for the Hanford Environmental Dose Reconstruction Project. PNL-7321 HEDR, Pacific Northwest Laboratory, Richland, Washington.

Napier, B. A. 1991. Selection of Dominant Radionuclides for Phase I of the HEDR Project. PNL-7231 HEDR, Pacific Northwest Laboratory, Richland, Washington.

PNL. 1991a. Summary Report, Phase I of the HEDR Project. PNL-7410 HEDR Rev. 1, Pacific Northwest Laboratory, Richland, Washington.

PNL. 1991b. Columbia River Pathway Report, Phase I of the HEDR Project. PNL-7411 HEDR Rev. 1, Pacific Northwest Laboratory, Richland, Washington.

Shipler, D. B. 1991a. HEDR Project Summary Schedule. PNL-7685 HEDR, Pacific Northwest Laboratory, Richland, Washington.

Shipler, D. B. 1991b. FY 1993 Task Plans for the Hanford Environmental Dose Reconstruction Project. PNL-7760 HEDR, Pacific Northwest Laboratory, Richland, Washington.

Shipler, D. B. 1991c. FY 1994 Task Plans for the Hanford Environmental Dose Reconstruction Project. PNL-7759 HEDR, Pacific Northwest Laboratory, Richland, Washington.

Shipler, D. B. 1992. FY 1992 Revised Task Plans for the Hanford Environmental Dose Reconstruction Project. PNL-7757 HEDR, Rev. 1, Pacific Northwest Laboratory, Richland, Washington.

Walters, W. H., R. L. Dirkes, and B. A. Napier. 1992. Literature and Data Review for the Surface Water Pathway: Columbia River and Adjacent Coastal Areas. PNL-8083 HEDR, Pacific Northwest Laboratory, Richland, Washington.

Wilson, R. H. 1965. _Evaluation of Radiological Conditions in the Vicinity of Hanford for 1964_. BNWL-90, Pacific Northwest Laboratory, Richland, Washington.

DISTRIBUTION

No. of
Copies

OFFSITE

Technical Steering Panel

D. S. Barth
University of Nevada
4505 Maryland Parkway
Las Vegas, NV 89154

W. A. Bishop
2503 Wedgewood Court S.E.
Olympia, WA 98501

M. L. Blazek
Oregon Department of Energy
625 Marion Street N.E.
Salem, OR 97310

G. G. Caldwell
Director
Tulsa City-County Health Dept.
4616 East 15th Street
Tulsa, OK 74112

S. N. Davis
Dept. of Hydrology and
Water Resources
Building 11
University of Arizona
Tucson, AZ 85721

N. J. Germond
224 Iron Mountain Blvd.
Lake Oswego, OR 97034

P. C. Klingeman
Civil Engineering Dept.
Appejin Hall 202
Oregon State University
Corvallis, OR 97331-2302

No. of
Copies

K. J. Kopecky
Fred Hutchinson Cancer
Research Center
1124 Columbia Street
Seattle, WA 98104

P. D. McGavran
Dept. of Health and Welfare
450 W. State Street, 4th Floor
Boise, ID 83720-5450

R. L. Morrill
Dept. of Geography, DP-10
University of Washington
Seattle, WA 98195

A. H. Murphy
Dept. of Atmospheric Sciences
Oregon State University
Corvallis, OR 97331-2209

D. W. Price
Agricultural Economics
Hulbert Hall Room 211
Washington State University
Pullman, WA 99164-6210

M. A. Robkin
Radiological Sciences, SB-75
University of Washington
Seattle, WA 98195

G. S. Roessler
Route 1 Box 139H
Elysian, MN 56028

B. Shleien
2421 Homestead Drive
Silver Springs, MD 20902

No. of Copies	
	A. P. Slickpoo, Sr. 809 Nez Perce Lane P.O. Box 331 Kamiah, IH 83536
	J. E. Till Route 2 Box 122 Neeses, SC 29107
	D. E. Walker, Jr. P.O. Box 4147 Boulder, CO 80306

OTHER

2	DOE Office of Scientific and Technical Information Technical Information Center P.O. Box 62 Oak Ridge, TN 37830
	D. M. Beck, EM-521 Trevion 2 Building Department of Energy Washington, DC 20585-0002
	B. G. Brooks, EH-421 Room J-112 Department of Energy Germantown, MD 20545
18	K. CharLee Office of Nuclear Waste Mgmt. Department of Ecology 719 Sleater Kinney Road, S.E. Suite 200 Olympia, WA 98504
	M. R. Donnelly Public Health Service Centers for Disease Control 2201 6th Ave. Mail Stop RX-22 Seattle, WA 98121

No. of Copies	
	L. E. Sewell Centers for Disease Control 1600 Clifton Road Atlanta, GA 30333
	J. Thomas HEAL 1720 N. Ash Spokane, WA 99205

ONSITE

6	DOE Richland Field Office	
	R. F. Brich, TSD	A5-55
	Public Reading Room (5)	A1-65
36	Pacific Northwest Laboratory	
	J. M. Daer (5)	K1-25
	D. H. Denham	K6-15
	W. T. Farris	K3-54
	M. D. Freshley	K6-77
	R. O. Gilbert	K7-34
	W. A. Glass	K4-13
	S. P. Gydesen	P8-55
	G. L. Harvey	K1-77
	C. M. Heeb	K6-42
	T. A. Ikenberry	K3-54
	A. H. McMakin	K1-25
	B. A. Napier (10)	K3-54
	J. V. Ramsdell	K6-03
	D. B. Shipler	K1-25
	D. L. Stewart	K6-91
	W. L. Templeton	K1-30
	M. E. Thiede	K6-13
	W. H. Walters	K6-09
	G. L. Wilfert	K6-54
	Publishing Coordination	K1-06
	Records Center	K3-70
	Technical Library (2)	P8-55

END

DATE FILMED

9/9/92