



VOLUME II - PART B  
DOSE RECONSTRUCTION FEASIBILITY STUDY

TASKS 3& 4

Identification of Important  
Environmental Pathways for Materials Released  
from Oak Ridge Reservation

Prepared by  
ChemRisk®  
A Division of McLaren/Hart

for the  
Tennessee Department of Health and the  
Oak Ridge Health Agreement Steering Panel



# OAK RIDGE HEALTH STUDIES PHASE I REPORT

## Volume II - Part B - Dose Reconstruction Feasibility Study

Tasks 3 & 4: Identification of Important Environmental Pathways for  
Materials Released from the Oak Ridge Reservation

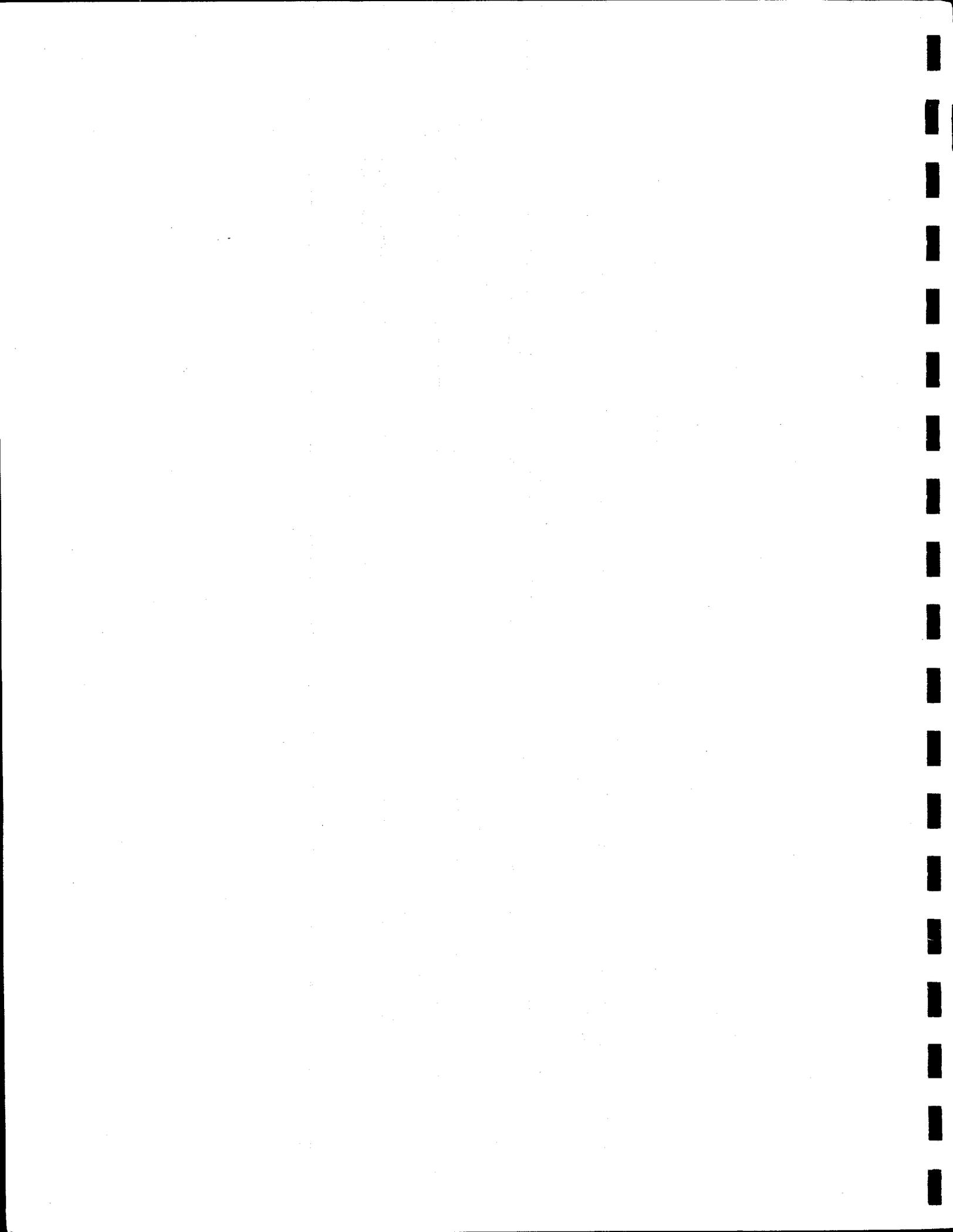
Prepared by:

ChemRisk  
A Division of McLaren/Hart  
Environmental Engineering Corporation

for

The Oak Ridge Health Agreement Steering Panel and  
The Tennessee Department of Health  
Division of Environmental Epidemiology  
C1-130 Cordell Hull Building  
Nashville, Tennessee 37247-4913

SEPTEMBER 1993



*This document was prepared as a team effort by the following ChemRisk employees:*

**Project Manager:**

Stephen R. Ripple, Chief Health Scientist

**Administrative Support:**

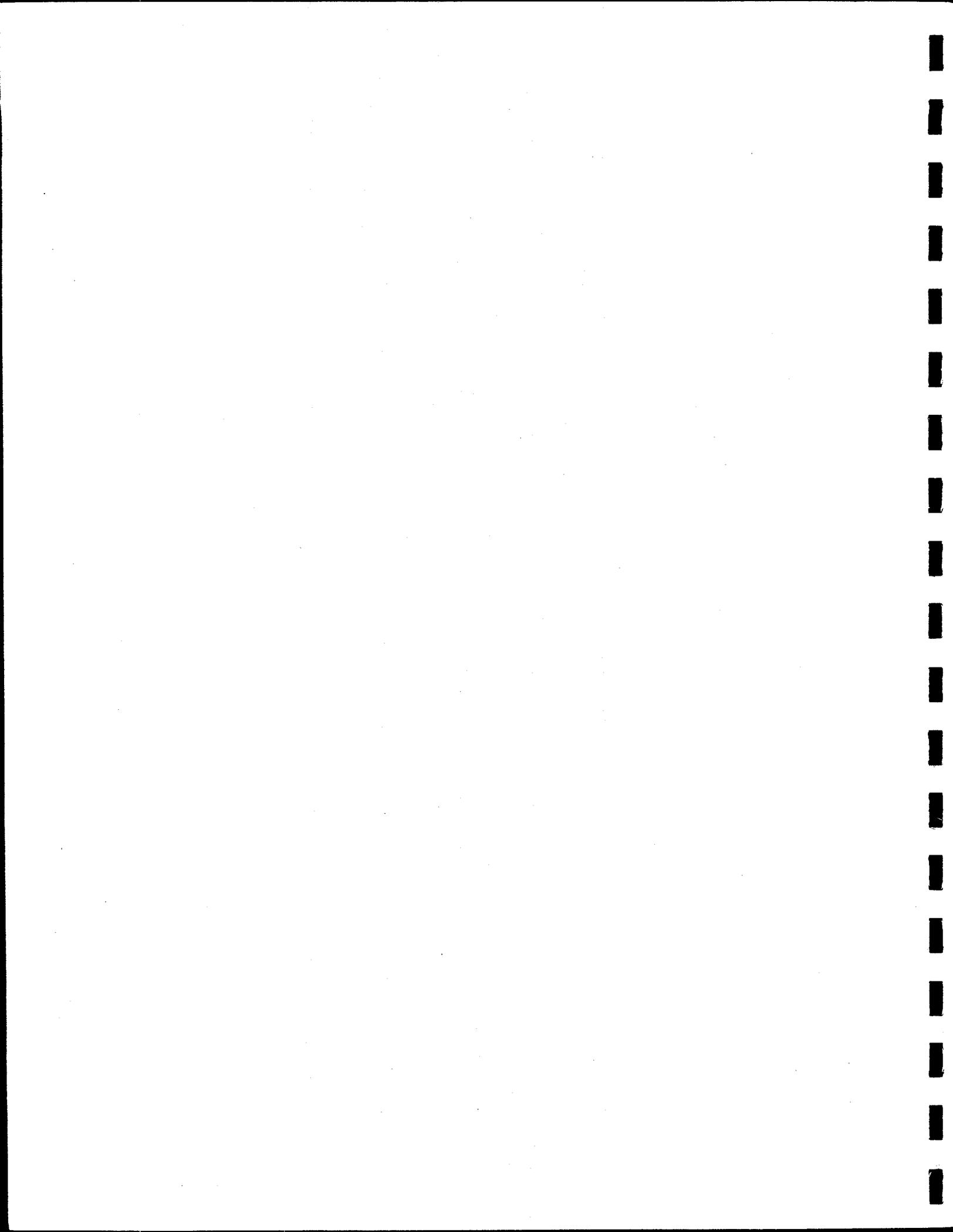
Angélica Perea, Secretary

**Principal Authors:**

Gregory P. Brorby, Senior Health Scientist

Gretchen M. Bruce, Associate Health Scientist

Thomas E. Widner, Principal Environmental Scientist



## CONTENTS OF THE OAK RIDGE HEALTH STUDIES PHASE I REPORT

**Volume I** summarizes the activities of the Oak Ridge Health Agreement Steering Panel, other than the Dose Reconstruction Feasibility Study, during Phase I of the Oak Ridge Health Studies. It includes four major topics:

- **Executive Summary of the Oak Ridge Health Studies Phase I Report**
- **Health Studies Background and Overview**
- **Phase I Goals**
- **Conclusions and Recommendations for Phase I**

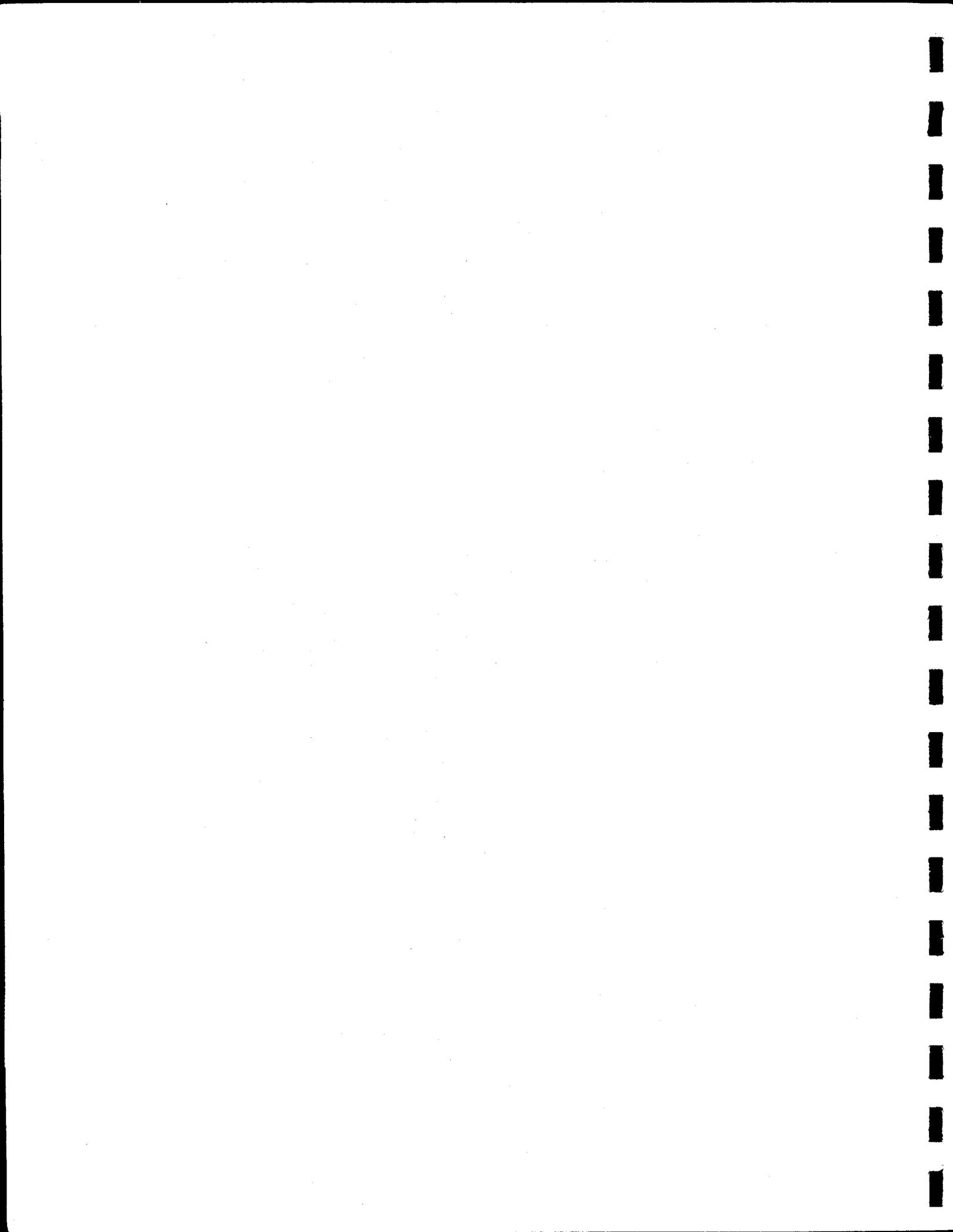
**Volume II** documents the study (referred to as the Dose Reconstruction Feasibility Study) to find out if enough data exist to estimate historical doses of chemicals and radionuclides to the public living around the Reservation. It is comprised of four parts:

- **Part A** addressing project Tasks 1 and 2 to identify the historical operations and emissions at each of the complexes and characterize the availability of environmental sampling and research data

- **Part B** addressing Tasks 3 and 4 to identify important environmental exposure pathways and contaminants released from the Reservation

- **Part C** addressing Task 5 to identify information regarding historical locations and activities of off-site populations that could potentially be affected by releases from the Reservation

- **Part D** addressing Task 6 to identify the hazards associated with substances used at the reservation



## TABLE OF CONTENTS

|  |      |
|--|------|
| VOLUME SUMMARY .....   | VS-1 |
| 1.0 INTRODUCTION .....   | 1    |
| 1.1 Contaminants Released from the Oak Ridge Reservation .....               | 1    |
| 1.2 Complete Exposure Pathways .....   | 1    |
| 1.3 Comparison Within an Environmental Medium .....                          | 2    |
| 1.4 Comparison Between Environmental Media .....                             | 2    |
| 2.0 CONTAMINANTS RELEASED FROM THE OAK RIDGE RESERVATION ...                 | 2    |
| 3.0 COMPLETE EXPOSURE PATHWAYS .....   | 6    |
| 3.1 Complete Air Pathways .....  | 8    |
| 3.2 Complete Surface Water Pathways .....                                    | 11   |
| 3.3 Complete Soil/Sediment Pathways .....                                    | 13   |
| 3.4 Groundwater Pathways .....   | 14   |
| 3.5 Mother's Milk .....  | 15   |
| 3.6 Summary—Exposure Pathway Selection .....                                 | 15   |
| 4.0 COMPARISON WITHIN AN ENVIRONMENTAL MEDIUM .....                          | 18   |
| 4.1 Air Pathway Comparisons .....  | 23   |
| 4.2 Surface Water Pathway Comparisons .....                                  | 32   |
| 4.3 Soil and Sediment Pathway Comparisons .....                              | 32   |
| 5.0 COMPARISON BETWEEN ENVIRONMENTAL MEDIA .....                             | 32   |
| 5.1 Airborne Releases .....  | 37   |
| 5.1.1 Air Source-Term Estimates for X-10 .....                               | 37   |
| 5.1.2 Air Source-Term Estimates for K-25 .....                               | 44   |
| 5.1.3 Air Source-Term Estimates for Y-12 .....                               | 46   |
| 5.1.4 Air Dispersion Modeling .....  | 48   |
| 5.2 Contaminant Concentrations in Surface Water, Soil/Sediment, and Fish ... | 52   |
| 5.3 Results of Comparisons Between Environmental Media .....                 | 53   |
| 5.3.1 X-10 Pathway Comparisons .....   | 53   |
| 5.3.2 K-25 Pathway Comparisons .....   | 65   |
| 5.3.3 Y-12 Pathway Comparisons .....   | 65   |
| 5.3.4 Summary of Comparisons Between Environmental Media .....               | 65   |
| 5.4 Relative Importance of Releases from the Oak Ridge Reservation .....     | 68   |

**TABLE OF CONTENTS**  
(Continued)

|     |                   |    |
|-----|-------------------|----|
| 6.0 | CONCLUSIONS ..... | 73 |
| 7.0 | REFERENCES .....  | 75 |

**LIST OF APPENDICES**

|            |   |
|------------|---|
| APPENDIX A | TRITIUM EXPOSURE MODELING   |
| APPENDIX B | EXPOSURE PATHWAY EQUATIONS  |
| APPENDIX C | EXPOSURE PARAMETERS   |
| APPENDIX D | WITHIN-MEDIUM COMPARISON SUMMARY SHEETS   |
| APPENDIX E | SOURCE TERM ESTIMATES FOR X-10  |
| APPENDIX F | SOURCE TERM ESTIMATES FOR K-25  |
| APPENDIX G | SOURCE TERM ESTIMATES FOR Y-12  |
| APPENDIX H | ENVIRONMENTAL MONITORING DATA FROM SURFACE WATER<br>BODIES ASSEMBLED FOR PATHWAY EVALUATION |
| APPENDIX I | BETWEEN-MEDIA COMPARISON SUMMARY SHEETS   |

**LIST OF FIGURES**

| Figure   | Page |
|--|------|
| 3-1 Elements of a Complete Exposure Pathway .....  | 6    |
| 4-1 Evaluation of Relative Importance of Exposure Pathways for Protactinium-233<br>in Soil ..... | 29   |
| 5-1 Location of Nearest Residents to the Three Oak Ridge Plants .....                            | 51   |

**LIST OF TABLES**

| Table  | Page |
|--|------|
| VS-1 Highest Priority Operations/Contaminants for Further Study Based<br>on Quantitative Screening .....   | VS-2 |
| VS-2 Contaminants that Could Not Be Quantitatively Evaluated for Any<br>Medium as Part of Phase I of the Health Studies .....                            | VS-3 |
| 2-1 Contaminants Released from the Oak Ridge Reservation for Which Additional<br>Investigation May be Required Based on Project Tasks 1 & 2 Review ..... | 3    |
| 2-2 Contaminants to be Evaluated in Tasks 3 & 4 .....  | 5    |
| 2-3 Contaminants Used in Relatively Small Quantities or Not Believed to be<br>Associated with Significant Off-Site Releases .....                        | 7    |

**LIST OF TABLES**  
(Continued)

| Table   | Page |
|---|------|
| 3-1 Complete Exposure Pathways Associated With the Air Medium . . . . .   | 9    |
| 3-2 Criteria for Respirable Dust . . . . .  | 10   |
| 3-3 Complete Exposure Pathways Associated With the Surface Water Medium . . . . .   | 12   |
| 3-4 Complete Exposure Pathways Associated With the Soil/Sediment Medium . . . . .   | 14   |
| 3-5 Complete Exposure Pathways for Contaminants Released from the Oak<br>Ridge Reservation . . . . .  | 16   |
| 4-1 Physical Constants for Contaminants Released from the Oak Ridge Reservation . .   | 20   |
| 4-2 Toxicity Criteria for Chemicals Released from the Oak Ridge Reservation . . . . .   | 22   |
| 4-3 Committed Effective Dose Equivalent Factors for Inhaled and Ingested<br>Radionuclides . . . . .   | 24   |
| 4-4 Effective Dose Equivalent Rate Factors for External Exposure to Radionuclides . .   | 26   |
| 4-5 Comparison of Complete Exposure Pathways Within the Air Medium . . . . .  | 30   |
| 4-6 Comparison of Complete Exposure Pathways Within the Surface Water Medium .  | 33   |
| 4-7 Comparison of Complete Exposure Pathways Within the Soil/Sediment Medium .  | 35   |
| 5-1 Predicted Maximum Average Annual Air Concentrations Off-Site for<br>Screening Evaluation of Contaminants Released from X-10 . . . . .   | 39   |
| 5-2 Predicted Maximum Average Annual Air Concentrations Off-Site for<br>Screening Evaluation of Contaminants Released from K-25 . . . . .   | 45   |
| 5-3 Predicted Maximum Average Annual Air Concentrations Off-Site for<br>Screening Evaluation of Contaminants Released from Y-12 . . . . .   | 47   |
| 5-4 Air Dispersion Model Input Parameters . . . . .   | 49   |
| 5-5 Maximum Contaminant Concentrations Measured in Water, Sediment, and Fish<br>at or Just Downstream of the Confluence of the Clinch River with White Oak<br>Creek (CRM 20.8) Assumed to Result from Contaminants Released from X-10 . . | 54   |
| 5-6 Maximum Contaminant Concentrations Measured in Water, Sediment, and Fish<br>in the Clinch River at or Just Downstream of Its Confluence with Poplar<br>Creek (CRM 12.0) Assumed to Result from Contaminants Released from K-25 . .    | 58   |
| 5-7 Maximum Contaminant Concentrations Measured in East Fork Poplar Creek<br>Water, Sediment or Floodplain Soil, and Fish at or Near East Fork Poplar<br>Creek Mile 13.5 Assumed to Result From Contaminants Released from Y-12 . . .     | 61   |
| 5-8 Relative Importance of Exposures to Contaminants in Environmental Media<br>Based on Highest Identified Concentrations—X-10 Releases . . . . .   | 64   |
| 5-9 Relative Importance of Exposures to Contaminants in Environmental Media<br>Based on Highest Identified Concentrations—K-25 Releases . . . . .   | 66   |
| 5-10 Relative Importance of Exposures to Contaminants in Environmental Media<br>Based on Highest Identified Concentrations—Y-12 Releases . . . . .  | 67   |
| 5-11 Preliminary Ranking of Potential Hazards . . . . .   | 69   |
| 6-1 Highest Priority Operations/Materials for Further Study Based on<br>Quantitative Screening . . . . .  | 74   |
| 6-2 Contaminants that Could Not Be Quantitatively Evaluated for Any Medium as<br>Part of Phase I of the Health Studies . . . . .  | 74   |

## ACRONYMS, INITIALISMS, AND ABBREVIATIONS

---

|       |   |
|-------|---|
| ACGIH | American Conference of Governmental Industrial Hygienists   |
| ATSDR | Agency for Toxic Substances and Disease Registry  |
| Bq    | Becquerel   |
| CRM   | Clinch River Mile   |
| CY    | Calendar Year   |
| EFPC  | East Fork Poplar Creek  |
| HEAST | Health Effects Assessment Summary Tables  |
| ICRP  | International Commission on Radiological Protection   |
| IRIS  | Integrated Risk Information System  |
| ISC   | Industrial Source Complex   |
| K-25  | Code name for the site of the Oak Ridge Gaseous Diffusion Plant   |
| MMES  | Martin Marietta Energy Systems, Inc.  |
| NCRP  | National Council on Radiation Protection and Measurements   |
| NRC   | National Research Council   |
| ORNL  | Oak Ridge National Laboratory   |
| ORR   | Oak Ridge Reservation   |
| PAHs  | Polycyclic Aromatic Hydrocarbons  |
| PCBs  | Polychlorinated Biphenyls   |
| PCM   | Poplar Creek Mile   |
| RaLa  | Radioactive Lanthanum   |
| RfD   | Reference Dose  |
| RFP   | Request for Proposal  |
| SF    | Slope Factor  |
| Sv    | Sievert   |
| TSCA  | Toxic Substance Control Act   |
| TVA   | Tennessee Valley Authority  |
| UCC   | Union Carbide Corporation   |
| USAEC | United States Atomic Energy Commission  |
| USDOE | United States Department of Energy  |
| USEPA | United States Environmental Protection Agency   |
| USNRC | United States Nuclear Regulatory Commission   |
| X-10  | Code name for the site of the Oak Ridge plutonium production plant (now the site of the Oak Ridge National Laboratory)    |
| Y-12  | Code name for the site of the Oak Ridge electromagnetic enrichment plant (Now the site of the Y-12 nuclear weapons plant) |

## VOLUME SUMMARY

The purpose of the Phase I Health Studies of the Oak Ridge Reservation (ORR) is to provide a wide-ranging review of past facility operations in order to 1) identify ORR activities that resulted in the release of contaminants that could have impacted the health of off-site individuals and 2) determine the need and/or feasibility of performing more detailed investigations. Previous project tasks have focussed on the review of documents related to the history of operations and contaminant releases. The product of these efforts is a report documenting the history of facility operations and the availability of information related to contaminant releases in the form of a Project Tasks 1 & 2 Final Report (ChemRisk, 1993a). In view of the 50-year history of operations and the complex nature of the activities at the three main ORR facilities, this initial review, although in many respects only a summary-level overview of activities, presents a large volume of data and information. In addition, the Tasks 1 & 2 report identifies a number of activities at the facilities that had a high potential for release of substantial quantities of contaminants to the environment. Based on this qualitative determination, these activities were recommended as the potential focus of any future detailed health studies. The availability of information for further study of these activities was also characterized in this earlier report.

In structuring the scope of the Phase I studies, there was a desire to attempt a quantitative evaluation of the identified releases to further aid in the focussing of any future phases of the health studies. Project Tasks 3 & 4, which are the subject of this report, are designed to offer a first attempt at such a quantitative evaluation. In essence, these tasks are designed to provide an initial, very rough evaluation of the large quantity of information and data identified in Tasks 1 & 2 with regards to the potential for the contaminant releases to cause harm to the public's health. The data and information from Tasks 1 & 2 have not been thoroughly evaluated or independently verified, as would be done in any subsequent, more lengthy and detailed studies. As such, any conclusions reached in Tasks 3 & 4 are subject to revision due to errors in the readily available data or information or future identification of additional data and information. The analyses presented in this report should be viewed as one approach to setting some initial priorities for the detailed study of an enormously complex issue.

As mentioned earlier, historical facility processes and activities which were identified in Project Tasks 1 & 2 as likely being associated with the release of substantial quantities of contaminants to the environment were recommended as broad areas for potential further study. This report provides analyses that attempt to identify the exposure pathways and environmental media (e.g., air, surface water, soil) likely to be most highly associated with public exposure to contaminants in the environment, and should therefore be the initial focus of additional efforts. In addition, where some data or information are available to permit further quantitative evaluation as part of this feasibility study, the potential relative health hazard associated with identified contaminant releases has also been evaluated. This quantitative evaluation provides a screening-type estimate

of the relative hazard posed by measured or estimated quantities of contaminants in areas outside ORR boundaries. This evaluation was only performed when appropriate data or information were readily available. Consequently, some of the facility activities and contaminants suggested as the potential focus of further study in Tasks 1 & 2 could not be quantitatively evaluated in this report. The highest priorities that emerged from the quantitative analysis are summarized in Table VS-1. Those focus areas that could not be formally evaluated quantitatively for any environmental medium as part of this feasibility study are listed in Table VS-2. A complete ranking of all of the contaminants for which there was sufficient information for evaluation is provided in the report.

**TABLE VS-1**  
**HIGHEST PRIORITY OPERATIONS/CONTAMINANTS**  
**FOR FURTHER STUDY BASED ON QUANTITATIVE SCREENING**

| Facility  | Operation                                   | Years of Operation | Contaminant(s)            |
|-----------|---|--------------------|---------------------------|
| X-10      | Radioactive Lanthanum (RaLa) Processing     | 1944-1956          | Iodine-131, -133          |
| X-10      | Various Chemical Separation Programs        | Late 1943 - 1960s  | Cesium-137                |
| Y-12      | Lithium Separation and Enrichment Operation | 1955-1963          | Mercury                   |
| K-25/Y-12 | Transformers/Machining                      | Indeterminate      | Polychlorinated Biphenyls |

It should be noted that in some cases very limited information, often in only a single environmental medium, was available to perform the quantitative evaluation. In addition, the data that were available came from a variety of sources of differing quality or conservatism. The lack of information in one or more media or inconsistent levels of conservatism may have resulted in an incorrect placement in the hazard ranking. For these and other reasons, the results presented in this report should be considered preliminary and subject to change as more information becomes available. Keeping these limitations in mind, the priorities identified using this quantitative screening evaluation can be used in conjunction with information developed in Tasks 1 & 2 and input received from the public regarding their concerns to focus any subsequent Health Studies work.

TABLE VS-2

CONTAMINANTS THAT COULD NOT BE QUANTITATIVELY EVALUATED  
FOR ANY MEDIUM AS PART OF PHASE I OF THE HEALTH STUDIES

| Facility  | Operation   | Contaminant(s)           |
|-----------|---|--------------------------|
| K-25/Y-12 | Cooling towers  | Chromium(VI)             |
| K-25/Y-12 | Waste disposal ponds  | Neptunium-237            |
| X-10/Y-12 | Plutonium separation at X-10 (plutonium-240, -241 only)/feed material from Savannah River Plant at Y-12 | Plutonium-239, -240, 241 |
| Y-12      | Lithium deuteride production  | Tritium                  |
| Y-12      | Coal Ash Piles  | Arsenic                  |

*This page intentionally left blank.*

## 1.0 INTRODUCTION

A primary objective of this Tasks 3 & 4 report is to identify the important environmental pathways through which off-site populations could have been exposed to contaminants released from the Oak Ridge Reservation (ORR). This report relies upon information collected in three other project tasks. Task 1 describes the historical operations at the ORR and identifies activities that have likely been associated with significant off-site releases of important contaminants, while Task 2 focusses on identification and description of environmental monitoring and research data that are available to support dose reconstruction efforts. The results from Tasks 1 & 2 are presented in a combined final draft report (ChemRisk, 1993a), and provide the basis for identification of the contaminants evaluated in Tasks 3 & 4. Task 5 involves the identification of available information on historical populations and land uses within approximately 10 miles of each of the three plant sites on the ORR (ChemRisk, 1993b).

The existence of an exposure pathway is determined by a number of factors. These include environmental conditions (e.g., location of surface water and/or groundwater, prevailing wind direction), potential for a contaminant to move from one medium (e.g., soil, water, air) to another, and the life-styles and activities of the exposed population (e.g., gardening, water recreation). The combinations of media, transport mechanisms, and routes of contact create many possible environmental pathways; however, not all environmental pathways are necessarily complete. In addition, not all complete pathways make a significant contribution to the total potential health risk experienced by an off-site population. The combined objective of Project Tasks 3 & 4 and this report is to identify those complete exposure pathways that warrant detailed dose reconstruction efforts.

### 1.1 Contaminants Released from the Oak Ridge Reservation

In the Tasks 1 & 2 report, contaminants that were handled in large quantities and/or in a manner such that there was a high probability that the contaminant was released to the environment, or whose releases were documented, were identified for each of the ORR plant areas. Some of the contaminants identified in the Tasks 1 & 2 report are not believed to have contributed significantly to the total health hazard posed by the site. The basis for this conclusion is described in this report.

### 1.2 Complete Exposure Pathways

Complete exposure pathways, i.e., pathways for which a source of contaminant release, an environmental medium that will transport the contaminant to a point of exposure, and a route of exposure or entry to the body are all present, are identified for each of the important contaminants released by the various ORR facilities to the air, surface waters, and soil or

sediment. Exposure pathways associated with releases of contaminants to groundwater are not believed to have been complete in the past, and the basis for this conclusion is described in this report. The identified complete exposure pathways are reviewed further to determine, where possible, their potential relative importance to the total dose received by off-site individuals.

### 1.3 Comparison Within an Environmental Medium

There are many ways through which an individual can be exposed to a contaminant released to a single environmental medium. The relative importance of these pathways to the total dose of the contaminant can be identified by comparing the health risks to an individual based on a unit concentration of the contaminant in that medium. This comparison is based on exposure assumptions appropriate for an adult, since the additional complexity associated with taking into account various age groups is not warranted as part of this feasibility study. The results of this comparison are used to identify the relative importance of exposure pathways in each relevant environmental medium (i.e., air, surface water, and soil/sediment).

### 1.4 Comparison Between Environmental Media

Even though one pathway may be identified as the most important for a particular contaminant in a particular medium (e.g., direct inhalation of the contaminant in air), the associated health risk may be insignificant compared with the risk associated with exposures to the contaminant in another medium (e.g., direct ingestion of the contaminant in surface water). A comparison between media is used, where possible, to focus future dose reconstruction efforts. This type of comparison requires actual contaminant concentrations in different media; however, at this stage of the project, this information could not be obtained for a number of the contaminants included in the evaluation. This report does, however, present preliminary estimates of contaminant concentrations in the relevant environmental media for many of the contaminants of concern.

## 2.0 CONTAMINANTS RELEASED FROM THE OAK RIDGE RESERVATION

Project Tasks 1 & 2 provided an initial review of the historical operations and releases at the ORR. Because the missions differed between each of the complexes, i.e., X-10, K-25, and Y-12, and over time, historical operations and releases for each complex were addressed separately. The Tasks 1 & 2 report ended with a discussion of available environmental data that are not necessarily associated with the plants individually. Based on the investigations conducted as part of Tasks 1 & 2, a preliminary list of contaminants released from each of the plants for which additional investigation may be warranted has been compiled (Table 2-1). These contaminants are separated into four general groups of contaminants: radionuclides, nonradioactive metals, acids/bases and organics. The fact that no nonradioactive metals or

TABLE 2-1

CONTAMINANTS RELEASED FROM THE OAK RIDGE RESERVATION FOR WHICH  
ADDITIONAL INVESTIGATION MAY BE REQUIRED BASED ON PROJECT  
TASKS 1 & 2 REVIEW

| X-10  | K-25   | Y-12   |
|---|--|--|
| <b>RADIONUCLIDES</b>  |  |  |
| Argon-41<br>Barium-140<br>Cerium-144<br>Cesium-137<br>Cobalt-60<br>Iodine-129, -131, -133<br>Krypton-85<br>Lanthanum-140<br>Niobium-95<br>Plutonium-238, -239, -240, -241<br>Protactinium-233<br>Ruthenium-103<br>Ruthenium-106<br>Strontium-89, -90<br>Tritium<br>Uranium-234, -235, -238<br>Xenon-133<br>Zirconium-95 | Neptunium-237<br>Plutonium-239<br>Technetium-99<br>Uranium-234, -235, -238   | Neptunium-237<br>Plutonium-238, -239, -240, -241<br>Technetium-99<br>Thorium-232<br>Tritium<br>Uranium-234, -235, -238                                 |
| <b>NONRADIOACTIVE METALS</b>  |  |  |
| None Initially Identified   | Beryllium<br>Chromium, trivalent and hexavalent<br>Nickel  | Arsenic<br>Beryllium<br>Chromium, trivalent and hexavalent<br>Lead<br>Mercury  |
| <b>ACIDS/BASES</b>  |  |  |
| Hydrochloric acid<br>Hydrogen peroxide<br>Nitric acid<br>Sodium hydroxide<br>Sulfuric acid  | Acetic Acid<br>Chlorine trifluoride<br>Fluorine and fluorine compounds<br>Hydrofluoric acid<br>Nitric acid<br>Potassium hydroxide<br>Sulfuric acid | Ammonium hydroxide<br>Fluorine and various fluorides<br>Hydrofluoric acid<br>Nitric acid<br>Phosgene   |
| <b>ORGANICS</b>   |  |  |
| None Initially Identified   | Carbon tetrachloride<br>Freons<br>Methylene chloride<br>Polychlorinated biphenyls<br>1,1,1-Trichloroethane<br>Trichloroethylene                    | Carbon tetrachloride<br>Freons<br>Methylene chloride<br>Polychlorinated biphenyls<br>Tetrachloroethylene<br>1,1,1-Trichloroethane<br>Trichloroethylene |

organics are identified for the X-10 site is not meant to imply that these types of contaminants were not used or potentially released to the environment, only that they do not appear to be significant compared to the identified radionuclides and acids/bases. Of the approximate 50 contaminants listed in the table, only a portion may be important with regard to historical exposures to off-site individuals. The contaminants evaluated in this report are shown in Table 2-2. Those contaminants shown in Table 2-1 that are not evaluated further in this report are discussed below.

#### Acids/Bases

Eleven of the identified compounds are classified as either acids or bases. The primary health effect of these compounds is commonly associated with acute exposure, producing some type of irritation. Acids and bases released to the environment (especially to water) are likely to rapidly dissociate, reacting with organic material present in the environment. As such, acids and bases are not generally associated with chronic, long-term health effects and are not evaluated further in this report.

#### Freons

A group of compounds, collectively known as chlorofluorocarbons (i.e., Freons), was used at multiple locations at each of the plant sites as coolants and/or solvents. As a class of compounds, exposure to freons results in little to no toxicity, even at high concentrations. As such, this class of compounds is not expected to have contributed to historical off-site health effects and is not evaluated further in Phase I.

#### Other Contaminants Not Evaluated in Phase I

Three contaminants, a group of compounds known as polyaromatic hydrocarbons (PAHs), asbestos, and unspecified pesticides, were identified in the Request for Proposal (RFP) for this project as being potential contaminants of concern for the three plant sites. Based on the results of Tasks 1 & 2, it was determined that the only source of PAHs would be combustion products associated with the TSCA incinerator and the coal gasification/coal liquification research. The TSCA incinerator represents a carefully controlled and monitored process, and the coal gasification/liquification was not production-related. Therefore, it is expected that only small quantities of PAHs would have been available for release to the environment from these activities. Any asbestos present at the ORR is likely associated with old insulation and building materials, and primarily represents a potential safety hazard to on-site workers. Any off-site releases of asbestos are not expected to be significant when compared to other contaminants released from the ORR. Pesticides have likely been used throughout the history of the Reservation for pest control. Chlordane, an organochlorine insecticide, is being studied as part

TABLE 2-2

CONTAMINANTS TO BE EVALUATED IN TASKS 3 & 4

| Radionuclides  | Nonradioactive Metals   | Organics   |
|--|---|--|
| <p>Argon-41<br/>Barium-140<br/>Cerium-144<br/>Cesium-137<br/>Cobalt-60<br/>Iodine-129, -131, -133<br/>Krypton-85<br/>Lanthanum-140<br/>Neptunium-237<br/>Niobium-95<br/>Plutonium-238, -239, -240, -241<br/>Protactinium-233<br/>Ruthenium-103<br/>Ruthenium-106<br/>Strontium-89, -90<br/>Technetium-99<br/>Thorium-232<br/>Tritium<br/>Uranium-234, -235, 238<br/>Xenon-133<br/>Zirconium-95</p> | <p>Arsenic<br/>Beryllium<br/>Chromium, trivalent and hexavalent<br/>Lead<br/>Mercury<br/>Nickel</p> | <p>Carbon tetrachloride<br/>Methylene chloride<br/>Polychlorinated biphenyls<br/>Tetrachloroethylene<br/>1,1,1-Trichloroethane<br/>Trichloroethylene</p> |

of the remedial investigation of the Clinch River/Watts Reservoir System. Information regarding the use or potential release of chlordane and other pesticides was not found during Task 1 & 2; however, any off-site releases are not expected to be significant when compared to other contaminants released from the ORR.

The contaminants listed in Table 2-1 represent only a subset of those investigated during Tasks 1 & 2. A variety of other contaminants that were used in relatively small quantities or in processes that are not believed to be associated with significant off-site releases were identified in the Tasks 1 & 2 report. These contaminants and the plant site and/or operation with which they were associated are listed in Table 2-3. In all cases, the information that has been gathered as part of this feasibility study suggests that these contaminants do not warrant further evaluation in Phase I.

### 3.0 COMPLETE EXPOSURE PATHWAYS

For a radionuclide or chemical used by the ORR to have posed a health hazard to off-site individuals, each of the following elements must have existed (Figure 3-1):

- A contaminant source that released the contaminant into the environment,
- A transport medium that carried the contaminant off-site to a location where exposure took place, and
- An exposure route through which the contaminant or nuclear radiations from the contaminant entered an individual's body to produce adverse health effects.

**FIGURE 3-1: ELEMENTS OF A COMPLETE EXPOSURE PATHWAY**

When any one of these three elements is missing, the pathway is incomplete. However, it is important to note that certain radionuclides that emit gamma or beta radiation can cause adverse health effects without entering the body, although these radionuclides need to be sufficiently close to the individual to produce external radiation exposure. An incomplete exposure pathway will not pose a health hazard to off-site individuals. It should be noted that complete exposure pathways are defined in a slightly different manner by different regulatory agencies (USEPA, 1989a; ATSDR, 1993). Although they may be broken down into more than three components, all of the definitions contain the essential elements listed above.

TABLE 2-3

CONTAMINANTS USED IN RELATIVELY SMALL QUANTITIES  
OR NOT BELIEVED TO BE ASSOCIATED WITH SIGNIFICANT OFF-SITE RELEASES

| Material                        | Operation/Use   |
|---------------------------------|---|
| <b>Radionuclides</b>            |   |
| Americium-241                   | X-10 Metal Recovery; Curium Recovery Facility                                   |
| Californium-252                 | X-10 High Flux Isotope Reactor; Isotope Production, Neutron Activation Products |
| Carbon-14                       | X-10 Isotope Production; Neutron Activation Products                            |
| Cobalt-57                       | X-10 Isotope Production; Cyclotron Products                                     |
| Cesium-134                      | Known Disposal by Hydrofracture   |
| Curium-242, -243, -244          | X-10 Isotope Production; Neutron Activation Products                            |
| Europium-152, -154, -155        | X-10 Isotope Production; Neutron Activation Products                            |
| Phosphorus-32                   | X-10 Isotope Production; Neutron Activation Products                            |
| Selenium-75                     | X-10 Isotope Production; Neutron Activation Products                            |
| Uranium-233                     | X-10 Thorium Processing   |
| Berkelium, Einsteinium, Fermium | X-10 High Flux Isotope Reactor; Isotope Production; Neutron Activation Products |
| <b>Nonradioactive Metals</b>    |   |
| Lithium                         | Y-12 Lithium Separation and Enrichment  |
| <b>Organics</b>                 |   |
| Benzene                         | K-25 Laboratory Use   |
| Chloroform                      | K-25 Laboratory Use   |

The complete environmental exposure pathways for the contaminants released from the ORR are identified for air, surface water, soil/sediment, and groundwater in the following sections. Information specific to the ORR is used in the evaluation. It should be noted that complete pathways are identified for this project solely on a retrospective basis. The likelihood of exposure pathways being complete in the future is not considered.

The approaches to the evaluation of environmental transport and exposure for tritium differ from the other contaminants released from the ORR. When released into the environment, tritium (in the form of tritiated water or hydrogen gas) is completely mixed with stable hydrogen in nature. Therefore, specific exposure pathways are not identified for tritium. A conventional method for estimating doses from tritium, the specific activity method, assumes an equilibrium between tritium concentrations in the atmosphere, water, food, and body tissues (Till, 1983). The National Council on Radiation Protection and Measurements (NCRP, 1979) proposed a variation of the specific activity method that can be used when the tritium concentrations in air, water, and food products are known or can be estimated. These methods are described in Appendix A, and are used later in this report to calculate screening-level risk estimates associated with the release of tritium from the ORR. Based on a comment received on the Draft Tasks 3 & 4 report, a comparative analysis using the exposure model developed for the other contaminants of concern is included in the appendix.

### 3.1 Complete Air Pathways

Complete exposure pathways for contaminants released into the atmosphere are identified in this section based on the criteria listed in Figure 3-1.

#### *Contaminant Source*

As described in the Final Tasks 1 & 2 report (ChemRisk, 1993a), routine operations and several accidents or incidents at the ORR have resulted in the release of a variety of contaminants to the atmosphere. During the early years of the plants' operations, airborne effluents were largely unfiltered and released directly to the atmosphere. Large quantities of particulates, vapors and gases were released during this period. Although most airborne effluents emitted from the three plant sites were filtered beginning in the late 1940s and early 1950s, some particulates were emitted continually to the atmosphere even when the filtering systems were working as intended. Large quantities of highly volatile solvents have reportedly been used at the ORR. In some cases, the majority of these solvents evaporated into the air and were ultimately released in the ventilation exhaust.

**Transport Medium**

Routine operations and accidents resulted in the release to the atmosphere of radioactive gases, radioactive and nonradioactive metals, and organic compounds. All but one of the organics identified in Table 2-2 (i.e., polychlorinated biphenyls) are volatile solvents. They are released to the air as vapors and are likely to stay in the atmosphere and be transported great distances by the wind. Similarly, some of the other contaminants, including argon-41, krypton-85, xenon-133, and some chemical forms of radioiodine and mercury, are released as gases or vapors and will also be dispersed over long distances in the atmosphere. The remaining radioactive contaminants and nonradioactive metals are nonvolatile and are released to the atmosphere as particulates. Particulates released before any filtration systems were installed likely consisted of a wide range of different particle sizes. Particles at the lower end of the range were likely transported significant distances away from the ORR, while the larger particles would have deposited within relatively short distances from the plant sites. Particulates released after filtration systems were installed were likely composed predominantly of extremely small particles that can be transported long distances by the wind before settling.

**Exposure Routes**

Table 3-1 presents the complete exposure routes associated with airborne releases from the ORR. The rationale for selecting these routes for one or more of the contaminants released from the ORR is detailed below.

**TABLE 3-1**  
**COMPLETE EXPOSURE PATHWAYS ASSOCIATED WITH THE AIR MEDIUM**

|   |
|---|
| Air to Humans (Inhalation)                                    |
| Air to Humans (Immersion) (Radionuclides Only)                |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              |
| Air to Vegetation to Humans (Ingestion)                       |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   |

Vapors, gases, and particulates released from the ORR are likely to have reached off-site locations. For vapors and gases, direct inhalation exposure is a complete pathway. Whether inhalation is a complete pathway for the particulates depends on the size of the particulates.

According to the American Conference of Governmental Industrial Hygienists (ACGIH) and the U.S. Atomic Energy Commission (USAEC), respirable particulates have aerodynamic diameters less than 10  $\mu\text{m}$ . Table 3-2 shows the relationship between particle size and percent of particles considered respirable (Hinds, 1982).

TABLE 3-2  
CRITERIA FOR RESPIRABLE DUST

| Aerodynamic Diameter ( $\mu\text{m}$ ) | Percent Respirable USAEC | Percent Passing Selector ACGIH* |
|--|--------------------------|---------------------------------|
| <2                                     | 100                      | 90                              |
| 2.5                                    | 75                       | 75                              |
| 3.5                                    | 50                       | 50                              |
| 5.0                                    | 25                       | 25                              |
| 10                                     | 0                        | 0                               |

Source: Hinds, 1982

\*The term "selector" refers to a component of a respirable mass sampling apparatus. The selector is a device that separates particles in an air stream that are various size fractions.

Nonvolatile contaminants released from the ORR during routine operations after filtration systems had been installed were likely to have been predominantly submicron-sized (i.e., < 1  $\mu\text{m}$ ) particles. Additionally, some of the particles released before the filtration systems were installed and from several accidents or incidents are believed to have been in the respirable size range. Inhalation exposure is therefore considered a complete pathway for the nonvolatile contaminants released from the ORR.

In addition to direct inhalation, individuals may be exposed to certain airborne radionuclides by immersion. Immersion exposure occurs when the atmosphere around an individual contains beta or gamma emitting radionuclides. All of the radionuclides released from the ORR emit beta, X, or gamma radiation. As such, immersion is considered a complete pathway for these contaminants.

Airborne contaminants can be inhaled by farm animals or wild game and reach humans through the food chain. Additionally, contaminants deposited on fruits or vegetables can be taken up by humans through ingestion and contaminants deposited on pasture can be taken up by grazing cattle or wild game, and subsequently by humans through meat and/or milk ingestion. Based on information collected in the Final Task 5 report (ChemRisk, 1993b), vegetables, beef cattle, and dairy cattle were raised in the vicinity of the ORR in the past. Therefore, indirect exposures

to contaminants through the ingestion of vegetables, beef, and milk are all considered complete pathways. Exposure pathways related to deer and other wild game are not specifically evaluated in this assessment. Any exposures as the result of ingestion of these animals would be expected to be lower than those estimated for beef ingestion due to lower rates of intake of wild game by humans.

### 3.2 Complete Surface Water Pathways

Complete exposure pathways for contaminants released to surface waters are identified in this section based on the criteria listed in Figure 3-1.

#### *Contaminant Source*

As described in the Final Tasks 1 & 2 report (ChemRisk, 1993a), waste water generated by the three plant sites was released into several holding ponds and/or waterways. For example, at X-10, several concrete (gunite) tanks were used initially to contain wastes generated by the plant. As the mission of X-10 expanded, the volume of waste exceeded the capacity of the concrete tanks and wastes were released directly to White Oak Creek. A dam was built across White Oak Creek to aid in the retention of radionuclides released from the plant. Waste water from K-25 was released to the Poplar Creek Embayment, while waste water from Y-12 was released to a series of holding ponds that drained into East Fork Poplar Creek and/or Bear Creek. White Oak Creek, Poplar Creek Embayment, East Fork Poplar Creek and Bear Creek are all tributaries to the Clinch River, which subsequently drains into the Tennessee River. Contaminants released from the ORR could have also reached the Clinch and Tennessee Rivers as a result of deposition of airborne contaminants on these watersheds.

#### *Transport Medium*

Dissolved gases, volatile and nonvolatile organics, and nonvolatile metals were released into surface waters around the ORR. Dissolved or entrained gases and volatile organics will readily evaporate from holding ponds and surface waters, and are unlikely to be transported off-site in surface waters to any significant extent (Dilling et al., 1975). In contrast, nonvolatile contaminants have low solubility in water and tend to adsorb to soil and sediments. These contaminants are much more likely to be transported as suspended particles than as dissolved ions. Exposure pathways associated with surface water are not considered to be complete for the gases and volatile organics released from the ORR, but surface water is considered a medium of transport for the nonvolatile contaminants.

### Exposure Routes

The complete exposure routes associated with waterborne releases from the ORR are presented in Table 3-3. The rationale for selecting these routes for one or more of the contaminants released from the ORR is detailed below.

TABLE 3-3  
COMPLETE EXPOSURE PATHWAYS ASSOCIATED  
WITH THE SURFACE WATER MEDIUM

|  |
|--|
| Water to Humans (Ingestion)                                    |
| Water to Livestock/Game (Beef) to Humans (Ingestion)           |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)             |
| Water to Humans (Recreational—Immersion) (Radionuclides Only)  |
| Water to Humans (Recreational—Dermal Contact) (Chemicals Only) |
| Water to Fish to Humans (Ingestion)                            |

As described in the Final Task 5 report (ChemRisk, 1993b), surface water was withdrawn during the 1980s at several locations on the Clinch and Tennessee Rivers, and from other surface water bodies in the vicinity or downstream of the ORR. Specific information on surface water withdrawal was not identified before 1980; however, it is anticipated that surface water was also withdrawn in the preceding years. Surface water has been withdrawn for both domestic and industrial uses, including use as drinking water. In some cases, surface water withdrawals represented the sole water source, including drinking water, for several surrounding communities. Very little surface water has been used for irrigation.

Complete pathways associated with domestic use of surface water include direct ingestion of water and indirect exposure via migration of contaminants through the food chain. Beef and milk could have become contaminated as a result of ingestion of surface water by cattle. Since essentially no irrigation occurred in the vicinity of the ORR, movement through the food chain via pasture and vegetation is not considered to be complete. The Clinch and Tennessee Rivers and two nearby reservoirs also serve as major recreational areas for boating and fishing. As such, direct exposure via immersion (radionuclides) or dermal contact (chemicals) during recreational activities and indirect exposure via ingestion of fish are also considered to be complete pathways.

### 3.3 Complete Soil/Sediment Pathways

Complete exposure pathways for contaminants released to soil and sediment are identified in this section based on the criteria listed in Figure 3-1.

#### *Contaminant Source*

Soil and sediment at off-site locations can become contaminated through contact with contaminants in liquid effluents from the plant or by deposition of airborne contaminants. Contaminated soil particles on-site can also be entrained by surface water or the wind and carried off-site. Nonvolatile contaminants deposited or released to soil may remain and accumulate in surface soil for a long period of time. Alternatively, volatile contaminants and dissolved gases do not remain in surface soil, but evaporate into the atmosphere or infiltrate to deep soils or groundwater. Surface soil and sediment therefore are not considered important environmental media for exposure to volatile contaminants.

#### *Transport Medium*

As stated above, deposited contaminants can be re-entrained by strong winds and dispersed through the air. This transport mechanism is known as resuspension and is enhanced by the occurrence of small soil particles, low humidity, high wind speed, mechanical disturbance, and an exposed ground surface. In addition, surface soils and sediments can be entrained by surface water runoff and carried away from the source. This latter transport mechanism may be particularly relevant to several waste disposal pits and holding ponds at the ORR. Soil is therefore considered to be a transport medium for nonvolatile contaminants.

#### *Exposure Routes*

The complete exposure routes associated with the soil/sediment medium are presented in Table 3-4. The rationale for selecting these routes for one or more of the contaminants released from the ORR is detailed below.

Contaminants in surface soils, including sediment, can be taken up by humans through inhalation following resuspension, ingestion, and dermal contact. Additionally, humans may be exposed to certain radionuclides in surface soil or sediment through immersion following resuspension or ground exposure. Similar to immersion, ground exposure occurs when an individual is exposed to beta or gamma radiation emitted from radionuclides deposited on the ground surface or from gamma-emitting radionuclides incorporated into soil or sediments. Inhalation or immersion following resuspension, ingestion, dermal contact and ground exposure are therefore considered complete pathways for soil and sediment at ORR.

**TABLE 3-4**  
**COMPLETE EXPOSURE PATHWAYS ASSOCIATED WITH THE SOIL/SEDIMENT MEDIUM**

|   |
|---|
| Soil/Sediment to Air to Humans (Inhalation)                             |
| Soil/Sediment to Air to Humans (Immersion) (Radionuclides Only)         |
| Soil/Sediment to Humans (Ingestion)                                     |
| Soil/Sediment to Humans (Dermal Contact) (Chemicals Only)               |
| Soil/Sediment to Humans (Ground Exposure) (Radionuclides Only)          |
| Soil/Sediment to Livestock/Game (Beef) to Humans (Ingestion)            |
| Soil/Sediment to Dairy Cattle (Milk) to Humans (Ingestion)              |
| Soil/Sediment to Vegetation to Humans (Ingestion)                       |
| Soil/Sediment to Pasture to Livestock/Game (Beef) to Humans (Ingestion) |
| Soil/Sediment to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   |

Besides direct exposures, contaminants in soil or sediment that has been dredged and used as fill material can migrate through the food chain and reach humans. Beef and milk can be contaminated in two ways:

- Contaminants in soil can be absorbed by pasture grasses through their root systems or be deposited onto pasture grasses following resuspension and then ingested by grazing cattle, or
- Contaminants in soil can be taken up by cattle through soil ingestion.

Vegetables and food crops grown on contaminated soil can also be contaminated via root absorption or deposition. Since vegetables, beef cattle and dairy cattle were raised in the vicinity of the ORR in the past, these indirect pathways are considered complete for nonvolatile contaminants released from the ORR.

### 3.4 Groundwater Pathways

The potential for existence of complete exposure pathways for contaminants released to groundwater is discussed in this section based on the criteria listed in Figure 3-1.

### ***Contaminant Source***

Groundwater can be contaminated through the percolation of liquid effluent discharged to soil or holding ponds and leaching of buried waste. Groundwater contamination has been documented on the ORR site (MMES, 1990).

### ***Transport Medium***

The information located to date on the historical location of drinking water wells in the urban portion of Oak Ridge and around the perimeter of the ORR is incomplete at this time. However, it is our current understanding that no public groundwater wells have been impacted by contaminated groundwater from the facility (Kornegay, 1993). Based on the hydrogeology of the ORR area, groundwater beneath the plant sites is generally believed to be connected to area streams and rivers within relatively short distances, and the extent to which groundwater contamination would be of concern for off-site exposures is associated with its potential to transport contaminants to surface waters that lead to transport off-site (Boyle et al., 1982; Sherwood and Borders, 1987; Moore, 1989; HSW, 1991; Tucci, 1992). For these reasons, exposure pathways associated directly with groundwater are considered to have been incomplete in the past and are not evaluated further in this report.

### **3.5 Mother's Milk**

Exposure to contaminants through mother's milk is a unique pathway, since contaminants can reach breast milk through any of the pathways discussed in the previous sections. This pathway is considered complete at the ORR, since it is likely that some women in the area breast-fed their children. However, this pathway is not included in the comparisons within a particular medium or between media conducted in this report. As discussed in the following sections, these comparisons are based on exposure assumptions appropriate for an adult. The additional complexity associated with taking into account various age groups, including infants, is not warranted as part of this feasibility study. The potential importance of the mother's milk pathway is more appropriately evaluated as part of any future health studies.

### **3.6 Summary—Exposure Pathway Selection**

Complete exposure pathways at the ORR were identified in this section. Potential pathways that lack one or more of the elements of a complete pathway for the contaminants released from the ORR are not considered further in this report. Exposure pathways considered to be complete are listed in Table 3-5 and are evaluated further in the following sections.

**TABLE 3-5**  
**COMPLETE EXPOSURE PATHWAYS FOR CONTAMINANTS RELEASED**  
**FROM THE OAK RIDGE RESERVATION**

| AIR MEDIUM: | Pathway   | Contaminants                                   |
|-------------|---|--|
|             | Air to Humans (Inhalation)                                    | Radionuclides, Nonradioactive metals, Organics |
|             | Air to Humans (Immersion)                                     | Radionuclides                                  |
|             | Air to Livestock/Game (Beef) to Humans (Ingestion)            | Radionuclides, Nonradioactive metals, Organics |
|             | Air to Dairy Cattle (Milk) to Humans (Ingestion)              | Radionuclides, Nonradioactive metals, Organics |
|             | Air to Vegetation to Humans (Ingestion)                       | Radionuclides, Nonradioactive metals, Organics |
|             | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | Radionuclides, Nonradioactive metals, Organics |
|             | Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | Radionuclides, Nonradioactive metals, Organics |

| SURFACE WATER MEDIUM: | Pathway  | Contaminants   |
|-----------------------|--|--|
|                       | Water to Humans (Ingestion)                          | Radionuclides, except argon-41, krypton-85, and xenon-133; Nonradioactive metals; PCBs |
|                       | Water to Livestock/Game (Beef) to Humans (Ingestion) | Radionuclides, except argon-41, krypton-85, and xenon-133; Nonradioactive metals; PCBs |
|                       | Water to Dairy Cattle (Milk) to Humans (Ingestion)   | Radionuclides, except argon-41, krypton-85, and xenon-133; Nonradioactive metals; PCBs |
|                       | Water to Fish to Humans (Ingestion)                  | Radionuclides, except argon-41, krypton-85, and xenon-133; Nonradioactive metals; PCBs |
|                       | Water to Humans (Recreational-Immersion)             | Radionuclides  |
|                       | Water to Humans (Recreational-Dermal Contact)        | Nonradioactive Metals, PCBs  |

TABLE 3-5  
 COMPLETE EXPOSURE PATHWAYS FOR CONTAMINANTS RELEASED  
 FROM THE OAK RIDGE RESERVATION

| SOIL/SEDIMENT MEDIUM:   | Pathway | Contaminants  |
|---|---------|---|
| Soil/Sediment to Air to Humans (Inhalation)                             |         | Radionuclides, except argon-41, krypton-85 and xenon-133; Nonradioactive metals; PCBs |
| Soil/Sediment to Air to Humans (Immersion)                              |         | Radionuclides   |
| Soil/Sediment to Humans (Ingestion)                                     |         | Radionuclides, except argon-41, krypton-85 and xenon-133; Nonradioactive metals; PCBs |
| Soil/Sediment to Livestock/Game (Beef) to Humans (Ingestion)            |         | Radionuclides, except argon-41, krypton-85 and xenon-133; Nonradioactive metals; PCBs |
| Soil/Sediment to Dairy Cattle (Milk) to Humans (Ingestion)              |         | Radionuclides, except argon-41, krypton-85 and xenon-133; Nonradioactive metals; PCBs |
| Soil/Sediment to Vegetation to Humans (Ingestion)                       |         | Radionuclides, except argon-41, krypton-85 and xenon-133; Nonradioactive metals; PCBs |
| Soil/Sediment to Pasture to Livestock/Game (Beef) to Humans (Ingestion) |         | Radionuclides, except argon-41, krypton-85 and xenon-133; Nonradioactive metals; PCBs |
| Soil/Sediment to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   |         | Radionuclides, except argon-41, krypton-85 and xenon-133; Nonradioactive metals; PCBs |
| Soil/Sediment to Humans (Dermal Contact)                                |         | Nonradioactive Metals, PCBs   |
| Soil/Sediment to Humans (Ground Exposure)                               |         | Radionuclides   |

#### 4.0 COMPARISON WITHIN AN ENVIRONMENTAL MEDIUM

A fairly large number of complete exposure pathways were identified in the preceding section. However, not all of these pathways will contribute significantly to the total potential health risk experienced by an off-site individual. Within each environmental medium, one or two exposure pathways are likely to dominate over the doses received from other pathways. The objective of this comparison is to identify the important pathway(s) for each contaminant in air, surface water, and soil/sediment.

The potential health hazards associated with exposure to a chemical or radionuclide are related to the magnitude of intake. For a radionuclide, intake can be estimated using the following equation:

$$I = C \times U \times FD$$

where:

- I = Intake of a radionuclide received through an exposure pathway (pCi).
- C = Concentration of a radionuclide at the exposure point (pCi/m<sup>3</sup>, pCi/L, or pCi/kg).
- U = Intake rate [breathing rate (m<sup>3</sup>/day), drinking rate (L/day), or ingestion rate (kg/day)]. This factor does not apply to immersion or ground exposure.
- FD = Exposure frequency and duration [i.e., how long and how often exposure occurs (days/year × years)].

Similar equations have been developed by regulatory agencies for exposure to radionuclides (USEPA, 1979; NCRP, 1991) and chemicals (USEPA, 1989a).

Exposure pathway equations that can be used to calculate chemical and radionuclide intakes for all of the identified complete exposure pathways are presented in Appendix B. These equations are consistent with those that have been developed by the aforementioned regulatory agencies. It should be noted that the determination of radionuclide intake as a result of immersion or ground exposure is not appropriate, since exposure occurs without the contaminant being taken up by the body. As such, the equations in Appendix B for these pathways are in terms of a radiation dose, which is described in more detail below. It should also be noted that the equations presented in Appendix B do not take into account radioactive decay of radionuclides

between the time of release from the ORR and the time of human intake. This omission likely affects only iodine-131 (half-life of 8.05 days) and iodine-133 (half-life of 20.3 hours). A more detailed discussion of the potential impacts on the screening calculations is provided in Section 5.4.

Ideally, many of the required inputs in the exposure equations (e.g., biomass yield, annual precipitation rate, inhalation rate or milk ingestion rate) should be based on site-specific or population-specific values. However, the identification and use of such detailed information is beyond the scope of this feasibility study. For the purpose of this assessment, estimates based primarily on the scientific literature are used. It is important to note that we have attempted to select the literature values in a consistent manner so that the identification of dominant pathways is unbiased. For the purpose of this evaluation, typical or "best-estimate" values for an adult are used. The exposure parameters are summarized in Appendix C.

A number of contaminant-specific parameters are required to estimate exposure or hazard. For example, the transfer of a contaminant present in soil or water to vegetation is dependent upon several physical characteristics (e.g., solubility, binding strength to organic material, chemical form). Parameters that describe the movement of contaminants into vegetation, pasture, meat, milk, and fish are presented in Table 4-1 for each of the contaminants released from the ORR. In addition, the permeability constant, which describes the movement of a contaminant across the skin, is also presented for the contaminants for which dermal contact is a complete pathway.

For each of the contaminants released from the ORR, the intake associated with each applicable pathway in each applicable medium is estimated for a unit contaminant concentration (e.g., 1 pCi/m<sup>3</sup> for a radionuclide in air, 1 µg/L for a chemical in water) using the exposure equations and exposure parameters presented in Appendices B and C and Table 4-1. However, the relative importance of each pathway within a particular medium cannot be determined by comparing the calculated intakes, because a contaminant may be more or less hazardous to an exposed individual depending on the route of intake. As such, some estimate of hazard or risk must be incorporated to evaluate relative importance.

For chemicals, cancer risk or hazard is determined by using the calculated intakes and the toxicity criteria of the contaminants. Slope factors (SFs) and reference doses (RfDs) established by the USEPA are used as toxicity criteria for carcinogens and noncarcinogens, respectively (see Table 4-2). A SF, which is expressed in units of (mg/kg-day)<sup>-1</sup>, is defined as the 95 percent upper confidence limit of the probability of a carcinogenic response per unit daily intake of a chemical over a lifetime. An RfD, which is expressed in units of mg/kg-day, delineates a dose of a chemical that is not expected to cause adverse health effects over a lifetime of daily exposure. Estimated cancer risks (i.e., intake multiplied by the SF) or hazard indices (i.e.,

TABLE 4-1

PHYSICAL CONSTANTS FOR CONTAMINANTS RELEASED  
FROM THE OAK RIDGE RESERVATION

| Material             | $B_{(veg)}$<br>(unitless) | $B_{(pasture)}$<br>(unitless) | $F_m$<br>(day/L)        | $F_r$<br>(day/kg)       | BCF<br>(pCi/kg)/(pCi/L)<br>or<br>(mg/kg)/(mg/L) | PC<br>(cm/hr) |
|----------------------|---------------------------|-------------------------------|-------------------------|-------------------------|---|---------------|
| <b>RADIONUCLIDES</b> |                           |                               |                         |                         |   |               |
| Argon-41             | 0.0 <sup>a</sup>          | 0.0 <sup>a</sup>              | 0.0 <sup>a</sup>        | 0.0 <sup>a</sup>        | 1.0 <sup>b</sup>                                | NA            |
| Cerium-144           | $8.4 \times 10^{-04c}$    | $9.0 \times 10^{-03c}$        | $6.0 \times 10^{-05c}$  | $7.5 \times 10^{-04ac}$ | $1.25 \times 10^{+02d}$                         | NA            |
| Cesium-137           | $2.6 \times 10^{-02c}$    | $1.4 \times 10^{-01c}$        | $7.1 \times 10^{-03c}$  | $2.0 \times 10^{-02ac}$ | $5.6 \times 10^{+03d}$                          | NA            |
| Cobalt-60            | $2.0 \times 10^{-02a}$    | $3.0 \times 10^{-03c}$        | $2.9 \times 10^{-03c}$  | $9.7 \times 10^{+03c}$  | $1.25 \times 10^{+02d}$                         | NA            |
| Iodine-129           | $3.4 \times 10^{-02c}$    | $1.8 \times 10^{-01c}$        | $9.9 \times 10^{-03c}$  | $7.2 \times 10^{+03c}$  | $4.4 \times 10^{+01d}$                          | NA            |
| Iodine-131           | $3.4 \times 10^{-02c}$    | $1.8 \times 10^{-01c}$        | $9.9 \times 10^{-03c}$  | $7.2 \times 10^{+03c}$  | $4.4 \times 10^{+01d}$                          | NA            |
| Iodine-133           | $3.4 \times 10^{-02c}$    | $1.8 \times 10^{-01c}$        | $9.9 \times 10^{-03c}$  | $7.2 \times 10^{+03c}$  | $4.4 \times 10^{+01d}$                          | NA            |
| Krypton-85           | 0.0 <sup>a</sup>          | 0.0 <sup>a</sup>              | 0.0 <sup>a</sup>        | 0.0 <sup>a</sup>        | 1.0 <sup>b</sup>                                | NA            |
| Lanthanum-140        | $1.7 \times 10^{-03a}$    | $1.0 \times 10^{-02a}$        | $2.0 \times 10^{-05a}$  | $3.0 \times 10^{+04a}$  | $2.5 \times 10^{+01j}$                          | NA            |
| Neptunium-237        | $1.0 \times 10^{-01a}$    | $4.3 \times 10^{-03a}$        | $5.0 \times 10^{-06a}$  | $5.5 \times 10^{+05a}$  | $1.0 \times 10^{+04b}$                          | NA            |
| Niobium-95           | $2.0 \times 10^{-02a}$    | $2.1 \times 10^{-03a}$        | $2.0 \times 10^{-02a}$  | $2.5 \times 10^{-01ac}$ | $3.0 \times 10^{+04b}$                          | NA            |
| Plutonium-238        | $4.5 \times 10^{-04a}$    | $9.0 \times 10^{-04c}$        | $1.0 \times 10^{-07ac}$ | $1.0 \times 10^{+06c}$  | 8.0 <sup>d</sup>                                | NA            |
| Plutonium-239/240    | $4.5 \times 10^{-04a}$    | $9.0 \times 10^{-04c}$        | $1.0 \times 10^{-07ac}$ | $1.0 \times 10^{+06c}$  | 8.0 <sup>d</sup>                                | NA            |
| Plutonium-241        | $4.5 \times 10^{-04a}$    | $9.0 \times 10^{-04c}$        | $1.0 \times 10^{-07ac}$ | $1.0 \times 10^{+06c}$  | 8.0 <sup>d</sup>                                | NA            |
| Protactinium-233     | $2.5 \times 10^{-03a}$    | $1.1 \times 10^{-04a}$        | $5.0 \times 10^{-06a}$  | $1.0 \times 10^{+05a}$  | $1.0 \times 10^{+01b}$                          | NA            |
| Ruthenium-103        | $1.3 \times 10^{-02c}$    | $9.0 \times 10^{-02c}$        | $3.3 \times 10^{-06c}$  | $2.0 \times 10^{-03ac}$ | $1.9 \times 10^{+01d}$                          | NA            |
| Ruthenium-106        | $1.3 \times 10^{-02c}$    | $9.0 \times 10^{-02c}$        | $3.3 \times 10^{-06c}$  | $2.0 \times 10^{-03ac}$ | $1.9 \times 10^{+01d}$                          | NA            |
| Strontium-89         | $1.1 \times 10^{-01c}$    | $1.1 \times 10^{-01a}$        | $1.4 \times 10^{-03c}$  | $3.0 \times 10^{-04ac}$ | $2.8 \times 10^{+01d}$                          | NA            |
| Strontium-90         | $1.1 \times 10^{-01c}$    | $7.2 \times 10^{-01c}$        | $1.4 \times 10^{-03c}$  | $3.0 \times 10^{-04ac}$ | $2.8 \times 10^{+01d}$                          | NA            |
| Technetium-99        | $6.4 \times 10^{-01a}$    | 9.5 <sup>a</sup>              | $1.0 \times 10^{-02a}$  | $8.5 \times 10^{+03a}$  | $7.8 \times 10^{+01d}$                          | NA            |
| Thorium-232          | $8.5 \times 10^{-04a}$    | $3.6 \times 10^{-05a}$        | $5.0 \times 10^{-06a}$  | $6.0 \times 10^{-06a}$  | $8.0 \times 10^{+01d}$                          | NA            |
| Uranium-234/235      | $8.5 \times 10^{-03a}$    | $1.7 \times 10^{-03a}$        | $3.7 \times 10^{-04c}$  | $2.0 \times 10^{-04a}$  | 7.5 <sup>d</sup>                                | NA            |
| Uranium-238          | $8.5 \times 10^{-03a}$    | $1.7 \times 10^{-03a}$        | $3.7 \times 10^{-04c}$  | $2.0 \times 10^{-04a}$  | 7.5 <sup>d</sup>                                | NA            |

TABLE 4-1

PHYSICAL CONSTANTS FOR CONTAMINANTS RELEASED FROM THE OAK RIDGE RESERVATION

| Material                     | B <sub>(veg)</sub><br>(unitless) | B <sub>(pasture)</sub><br>(unitless) | F <sub>m</sub><br>(day/L)   | F <sub>r</sub><br>(day/kg)  | BCF<br>(pCi/kg)/(pCi/L)<br>or<br>(mg/kg)/(mg/L) | PC<br>(cm/hr)              |
|------------------------------|----------------------------------|--------------------------------------|-----------------------------|-----------------------------|---|----------------------------|
| Xenon-133                    | 0.0 <sup>a</sup>                 | 0.0 <sup>a</sup>                     | 0.0 <sup>a</sup>            | 0.0 <sup>a</sup>            | 1.0 <sup>b</sup>                                | NA                         |
| Zirconium-95                 | 2.0 x 10 <sup>-03 a</sup>        | 2.1 x 10 <sup>-04 a</sup>            | 3.0 x 10 <sup>-05 a,c</sup> | 5.5 x 10 <sup>-03 a</sup>   | 2.6 <sup>d</sup>                                | NA                         |
| <b>NONRADIOACTIVE METALS</b> |                                  |                                      |                             |                             |   |                            |
| Arsenic                      | 4.0 x 10 <sup>-03 c</sup>        | 4.0 x 10 <sup>-02 a</sup>            | 6.2 x 10 <sup>05 e</sup>    | 2.0 x 10 <sup>-03 e</sup>   | 4.4 x 10 <sup>+01 f</sup>                       | 4.6 x 10 <sup>-04 g</sup>  |
| Beryllium                    | 1.0 x 10 <sup>-03 c</sup>        | 1.0 x 10 <sup>-02 a</sup>            | 9.1 x 10 <sup>-07 c,e</sup> | 1.0 x 10 <sup>-03 e</sup>   | 1.9 x 10 <sup>+01 f</sup>                       | 1.03 x 10 <sup>-03 g</sup> |
| Chromium (III)               | 8.0 x 10 <sup>-04 c</sup>        | 7.5 x 10 <sup>-03 a</sup>            | 1.1 x 10 <sup>03 c</sup>    | 9.2 x 10 <sup>-03 c,e</sup> | 1.6 x 10 <sup>+01 f</sup>                       | 6.01 x 10 <sup>-04 g</sup> |
| Chromium (VI)                | 8.0 x 10 <sup>-04 c</sup>        | 7.5 x 10 <sup>-03 a</sup>            | 1.1 x 10 <sup>05 c</sup>    | 9.2 x 10 <sup>-03 c,e</sup> | 1.6 x 10 <sup>+01 f</sup>                       | 6.01 x 10 <sup>-04 g</sup> |
| Lead                         | 5.0 x 10 <sup>-03 c</sup>        | 4.5 x 10 <sup>-02 a</sup>            | 2.6 x 10 <sup>04 c,e</sup>  | 4.0 x 10 <sup>-04 e</sup>   | 4.9 x 10 <sup>+01 f</sup>                       | 7.98 x 10 <sup>-05 g</sup> |
| Mercury                      | 9.0 x 10 <sup>-02 e</sup>        | 9.0 x 10 <sup>-01 a</sup>            | 4.7 x 10 <sup>06 c</sup>    | 2.7 x 10 <sup>-02 e</sup>   | 5.5 x 10 <sup>+03 f</sup>                       | 8.78 x 10 <sup>-05 g</sup> |
| Nickel                       | 6.0 x 10 <sup>-03 e</sup>        | 6.0 x 10 <sup>-02 a</sup>            | 1.0 x 10 <sup>03 c,e</sup>  | 2.0 x 10 <sup>-03 c,e</sup> | 4.7 x 10 <sup>+01 f</sup>                       | 5.6 x 10 <sup>-04 g</sup>  |
| <b>ORGANIC</b>               |                                  |                                      |                             |                             |   |                            |
| Carbon Tetrachloride         | NA                               | NA                                   | 3.5 x 10 <sup>-06 h</sup>   | 1.1 x 10 <sup>05 h</sup>    | 1.9 x 10 <sup>+01 f</sup>                       | NA                         |
| Methylene Chloride           | NA                               | NA                                   | 1.4 x 10 <sup>-07 h</sup>   | 4.5 x 10 <sup>-07 h</sup>   | NA  | NA                         |
| Polychlorinated Biphenyls    | 2.8 x 10 <sup>-03 i</sup>        | 2.8 x 10 <sup>-03 i</sup>            | 1.0 x 10 <sup>-02 e</sup>   | 5.0 x 10 <sup>-02 e</sup>   | 1.0 x 10 <sup>+05 f</sup>                       | 1.1 x 10 <sup>-02 g</sup>  |
| Tetrachloroethylene          | NA                               | NA                                   | 3.2 x 10 <sup>-06 h</sup>   | 1.0 x 10 <sup>-05 h</sup>   | 1.1 x 10 <sup>+01 f</sup>                       | NA                         |
| 1,1,1-Trichloroethane        | NA                               | NA                                   | 2.5 x 10 <sup>-06 d</sup>   | 7.9 x 10 <sup>-06 d</sup>   | 5.6 <sup>f</sup>                                | NA                         |
| Trichloroethylene            | NA                               | NA                                   | 1.9 x 10 <sup>-06 d</sup>   | 6.0 x 10 <sup>-06 d</sup>   | 1.06 x 10 <sup>+01 f</sup>                      | NA                         |

a USEPA, 1989b  
 b Chapman et al., 1968  
 c Ng, 1982  
 d Peterson, 1983  
 e Clement, 1988  
 f USEPA, 1986  
 g USEPA, 1991  
 h McKone and Daniels, 1991  
 i HDR, 1988  
 j USNRC, 1977

NA = Not Applicable (e.g., not a complete pathway)  
 B<sub>(veg)</sub> = Concentration ratio for the transfer of a contaminant from dry soil to leafy vegetables (wet weight)  
 B<sub>(pasture)</sub> = Concentration ratio for the transfer of a contaminant from dry soil to pasture (dry weight)  
 F<sub>m</sub> = Biotransfer factor from cattle intake to milk concentration  
 F<sub>r</sub> = Biotransfer factor from cattle intake to meat concentration  
 BCF = Bioconcentration factor for fish  
 PC = Skin permeability constant

TABLE 4-2

**TOXICITY CRITERIA FOR CHEMICALS RELEASED  
FROM THE OAK RIDGE RESERVATION**

| Material                     | Inhalation SF<br>(mg/kg-day) <sup>-1</sup> | Oral SF<br>(mg/kg-day) <sup>-1</sup> | Inhalation RfD<br>(mg/kg-day) | Oral RfD<br>(mg/kg-day) |
|------------------------------|--|--------------------------------------|-------------------------------|-------------------------|
| <b>NONRADIOACTIVE METALS</b> |  |                                      |                               |                         |
| Arsenic                      | 50   | 1.75 <sup>b</sup>                    | ND                            | 0.0003 <sup>a</sup>     |
| Beryllium                    | 8.4 <sup>a</sup>                           | 4.3 <sup>a</sup>                     | ND <sup>a</sup>               | 0.0050                  |
| Chromium(III)                | NA   | ND <sup>a</sup>                      | ND <sup>a</sup>               | 1.0                     |
| Chromium(VI)                 | 4.2  | NA                                   | ND <sup>a</sup>               | 0.0050                  |
| Lead                         | NA   | ND <sup>a</sup>                      | ND <sup>a</sup>               | 0.0014                  |
| Mercury                      | ND <sup>a</sup>                            | ND <sup>a</sup>                      | 0.00030                       | 0.0030                  |
| Nickel                       | ND <sup>a</sup>                            | ND <sup>a</sup>                      | ND <sup>a</sup>               | 0.020                   |
| <b>ORGANICS</b>              |  |                                      |                               |                         |
| Carbon Tetrachloride         | 0.053                                      | 0.13                                 | ND <sup>a</sup>               | 0.00070                 |
| Methylene Chloride           | 0.0017                                     | 0.0075                               | ND <sup>a</sup>               | 0.060                   |
| Polychlorinated<br>Biphenyls | NA   | 7.7 <sup>a</sup>                     | ND <sup>a</sup>               | ND <sup>a</sup>         |
| Tetrachloroethylene          | 0.0020                                     | ND <sup>a</sup>                      | ND <sup>a</sup>               | 0.010                   |
| 1,1,1-Trichloroethane        | ND <sup>d</sup>                            | ND <sup>a</sup>                      | 0.30                          | ND <sup>a</sup>         |
| Trichloroethylene            | 0.0060                                     | ND <sup>a</sup>                      | ND <sup>a</sup>               | ND <sup>a</sup>         |

NA = Not Applicable  
 ND = Not Determined  
 SF = Slope Factor  
 RfD = Reference Dose

a IRIS, 1993  
 b HEAST, 1991  
 c USEPA, 1986  
 d HEAST, 1992

intake divided by the RfD) have been identified for each of the chemicals released from the ORR.

For radionuclides, only an estimate of dose needs to be made to compare exposures to a single radionuclide through multiple pathways. Radiation dose is equal to the intake multiplied by the dose coefficient. Dose coefficients, which were previously referred to as dose conversion factors, are route-specific parameters for estimating dose for exposure to a radionuclide through a specified pathway (see Tables 4-3 and 4-4). Radiation dose can be estimated for a particular organ (equivalent dose) or for the whole body (effective dose). In either case, they are expressed in sieverts (Sv), although historically radiation doses were more commonly expressed in rem. One sievert is equal to 100 rem. For the purpose of this evaluation, radiation dose is expressed in terms of effective dose. Although not necessary to evaluate the relative importance of various exposure pathways, effective dose can be converted to an estimate of cancer risk by multiplying it by a whole body risk factor. The magnitude of this factor has been and continues to be debated within the scientific community. Values ranging from 4% to 8% per sievert have been recommended (NRC, 1990; ICRP, 1990a). For the purpose of this assessment, a whole body risk factor of 7.3% per Sv recommended by the International Commission on Radiological Protection (ICRP) was used in the between-media evaluation presented in Section 5.0.

For each contaminant, the relative importance of the complete exposure pathways within each environmental medium can be determined from the hypothetical health hazards (i.e., cancer risks, hazard indices, or radionuclide doses) described above. The calculation spreadsheets used to determine the hypothetical health hazards have been compiled in a separate document (ChemRisk, 1993c). Once calculated, the estimated health hazards are ranked, and the highest value is the "benchmark" to which all other pathways are compared. The ratio of each individual health hazard to the benchmark value is then calculated. A graphical representation of this comparison is shown for protactinium-233 in soil/sediment in Figure 4-1. For the purpose of this assessment, all pathways for which the calculated health hazard is greater than or equal to 1% of the most important pathway are the subject of further evaluation in this report. The results of these comparisons for each environmental medium are summarized below.

#### 4.1 Air Pathway Comparisons

Table 4-5 presents the results of the evaluation of the relative importance of complete pathways within the air medium. The squares indicate the most important pathway for each contaminant, and the check marks indicate the other pathways for which the calculated health hazard is greater than 1% of the most important pathway. The cancer risks, hazard indices, and radiation doses used to create this table are presented in Appendix D. As shown in the table, the direct inhalation pathway contributes to the hazard for nearly all contaminants, but in many cases does not represent the most important pathway. On the other hand, the air to livestock/game or dairy

TABLE 4-3

**COMMITTED EFFECTIVE DOSE EQUIVALENT FACTORS  
FOR INHALED AND INGESTED RADIONUCLIDES<sup>a</sup>**

| Nuclide                    | Adult Inhalation Committed Effective Dose Equivalent Factors (Sv/Bq inhaled) <sup>b</sup> | Adult Ingestion Committed Effective Dose Equivalent Factors (Sv/Bq ingested) |
|----------------------------|---|--|
| Argon-41                   | NA  | NA   |
| Barium-140                 | $9.7 \times 10^{-10}$ D   | $2.3 \times 10^{-9}$   |
| Cerium-144 <sup>c</sup>    | $1.0 \times 10^{-7}$ Y  | $5.8 \times 10^{-9}$   |
| Cesium-137 <sup>c</sup>    | $8.6 \times 10^{-9}$ D  | $1.3 \times 10^{-8}$   |
| Cobalt-60                  | $4.1 \times 10^{-8}$ Y  | $7.0 \times 10^{-9}$   |
| Iodine-129 <sup>c</sup>    | $4.0 \times 10^{-8}$ D  | $6.4 \times 10^{-8}$   |
| Iodine-131 <sup>c</sup>    | $8.2 \times 10^{-9}$ D  | $1.3 \times 10^{-8}$   |
| Iodine-133                 | $1.5 \times 10^{-9}$ D  | $2.7 \times 10^{-9}$   |
| Krypton-85                 | NA  | NA   |
| Lanthanum-140              | $1.2 \times 10^{-9}$ W  | $2.1 \times 10^{-9}$   |
| Neptunium-237 <sup>c</sup> | $5.5 \times 10^{-5}$ W  | $4.5 \times 10^{-7}$   |
| Niobium-95 <sup>c</sup>    | $1.7 \times 10^{-9}$ Y  | $6.8 \times 10^{-10}$  |
| Plutonium-238 <sup>c</sup> | $1.1 \times 10^{-4}$ W  | $8.8 \times 10^{-7}$   |
| Plutonium-239 <sup>c</sup> | $1.2 \times 10^{-4}$ W  | $9.7 \times 10^{-7}$   |
| Plutonium-240              | $1.4 \times 10^{-4}$ W  | $1.2 \times 10^{-6}$   |
| Plutonium-241 <sup>c</sup> | $2.3 \times 10^{-6}$ W  | $1.9 \times 10^{-8}$   |
| Protactinium-233           | $2.3 \times 10^{-9}$ Y  | $8.9 \times 10^{-10}$  |
| Ruthenium-103 <sup>c</sup> | $2.5 \times 10^{-9}$ Y  | $8.1 \times 10^{-10}$  |
| Ruthenium-106 <sup>c</sup> | $1.3 \times 10^{-7}$ Y  | $7.5 \times 10^{-9}$   |
| Strontium-89               | $1.0 \times 10^{-8}$ Y  | $2.4 \times 10^{-9}$   |
| Strontium-90 <sup>c</sup>  | $6.0 \times 10^{-8}$ D  | $3.5 \times 10^{-8}$   |
| Technetium-99              | $2.0 \times 10^{-9}$ W  | $3.5 \times 10^{-10}$  |
| Thorium-232                | $4.3 \times 10^{-4}$ W  | $7.6 \times 10^{-7}$   |
| Uranium-234                | $3.5 \times 10^{-5}$ Y  | $7.0 \times 10^{-8}$   |
| Uranium-235                | $3.2 \times 10^{-5}$ Y  | $6.8 \times 10^{-8}$   |
| Uranium-238                | $3.2 \times 10^{-5}$ Y  | $6.2 \times 10^{-8}$   |

TABLE 4-3

COMMITTED EFFECTIVE DOSE EQUIVALENT FACTORS  
FOR INHALED AND INGESTED RADIONUCLIDES<sup>a</sup>

| Nuclide                   | Adult Inhalation Committed Effective Dose Equivalent Factors (Sv/Bq inhaled) <sup>b</sup> | Adult Ingestion Committed Effective Dose Equivalent Factors (Sv/Bq ingested) |
|---------------------------|---|--|
| Xenon-133                 | NA  | NA   |
| Zirconium-95 <sup>c</sup> | 7.3 x 10 <sup>-9</sup> D  | 1.1 x 10 <sup>-9</sup>   |

NA = Not Applicable

- a DOE/EH-0071, "Internal Dose Conversion Factors for Calculation of Dose to the Public." U.S. Department of Energy, July 1988, unless otherwise noted.
- b The letters after the values indicate the lung clearance class for inhaled material (D for days, W for weeks, or Y for years) associated with the selected value. For inhalation and ingestion, the highest dose factors for each nuclide were selected, across all lung clearance classes and gastrointestinal absorption factors.
- c ICRP Publication 56, "Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 1." 1990.

TABLE 4-4

## EFFECTIVE DOSE EQUIVALENT RATE FACTORS FOR EXTERNAL EXPOSURE TO RADIONUCLIDES\*

| Radionuclide(s)<br><i>Bold values used in screening; others are intermediate values for parent-daughter chains.</i> | Immersion in Contaminated Water<br>(Sv/y per Bq/cm <sup>3</sup> ) | Immersion in Contaminated Air<br>(Sv/y per Bq/cm <sup>3</sup> ) | Irradiation from Contaminated Ground Surface<br>(Sv/y per Bq/cm <sup>2</sup> ) |
|---|---|---|--|
| <b>americium-241</b>  | 6.39 x 10 <sup>-05</sup>  | 2.61 x 10 <sup>-02</sup>  | 8.25 x 10 <sup>-06</sup>   |
| <b>argon-41</b>   | 3.95 x 10 <sup>-03</sup>  | 1.82  | 3.26 x 10 <sup>-04</sup>   |
| <b>barium-137m</b>  | 1.80 x 10 <sup>-03</sup>  | 8.39 x 10 <sup>-01</sup>  | 1.69 x 10 <sup>-04</sup>   |
| <b>barium-140</b>   | 5.67 x 10 <sup>-04</sup>  | 2.62 x 10 <sup>-01</sup>  | 5.92 x 10 <sup>-05</sup>   |
| <b>Ba-140 + La-140 daughter<sup>b</sup></b>   | 8.96 x 10 <sup>-03</sup>  | 4.15  | 7.46 x 10 <sup>-04</sup>   |
| <b>cerium-144</b>   | 5.76 x 10 <sup>-05</sup>  | 2.55 x 10 <sup>-02</sup>  | 5.92 x 10 <sup>-06</sup>   |
| <b>Ce-144 + Pr-144 daughter<sup>c</sup></b>   | 1.89 x 10 <sup>-04</sup>  | 9.95 x 10 <sup>-02</sup>  | 4.85 x 10 <sup>-05</sup>   |
| <b>cesium-137</b>   | 2.49 x 10 <sup>-06</sup>  | 2.36 x 10 <sup>-03</sup>  | 1.08 x 10 <sup>-06</sup>   |
| <b>Cs-137 + Ba-137m daughter<sup>d</sup></b>  | 1.71 x 10 <sup>-03</sup>  | 7.96 x 10 <sup>-01</sup>  | 1.61 x 10 <sup>-04</sup>   |
| <b>cobalt-60</b>  | 7.72 x 10 <sup>-03</sup>  | 3.56  | 6.22 x 10 <sup>-04</sup>   |
| <b>iodine-129</b>   | 2.96 x 10 <sup>-05</sup>  | 1.16 x 10 <sup>-02</sup>  | 6.09 x 10 <sup>-06</sup>   |
| <b>iodine-131</b>   | 1.14 x 10 <sup>-03</sup>  | 5.26 x 10 <sup>-01</sup>  | 1.12 x 10 <sup>-04</sup>   |
| <b>iodine-133</b>   | 1.83 x 10 <sup>-03</sup>  | 8.49 x 10 <sup>-01</sup>  | 1.78 x 10 <sup>-04</sup>   |
| <b>krypton-85</b>   | 1.11 x 10 <sup>-05</sup>  | 7.30 x 10 <sup>-03</sup>  | 4.46 x 10 <sup>-06</sup>   |
| <b>lanthanum-140</b>  | 7.30 x 10 <sup>-03</sup>  | 3.38  | 5.97 x 10 <sup>-04</sup>   |
| <b>molybdenum-99</b>  | 4.82 x 10 <sup>-04</sup>  | 2.26 x 10 <sup>-01</sup>  | 5.28 x 10 <sup>-05</sup>   |
| <b>Mo-99 + Tc-99m daughter<sup>d</sup></b>  | 8.79 x 10 <sup>-04</sup>  | 4.03 x 10 <sup>-01</sup>  | 9.23 x 10 <sup>-05</sup>   |
| <b>neptunium-237</b>  | 7.35 x 10 <sup>-05</sup>  | 3.15 x 10 <sup>-02</sup>  | 8.96 x 10 <sup>-06</sup>   |
| <b>Np-237 + Pa-233 daughter<sup>f</sup></b>   | 4.23 x 10 <sup>-04</sup>  | 1.90 x 10 <sup>-01</sup>  | 4.37 x 10 <sup>-05</sup>   |
| <b>niobium-95</b>   | 2.34 x 10 <sup>-03</sup>  | 1.09  | 2.13 x 10 <sup>-04</sup>   |
| <b>praseodymium-144</b>   | 1.34 x 10 <sup>-04</sup>  | 7.51 x 10 <sup>-02</sup>  | 4.32 x 10 <sup>-05</sup>   |

TABLE 4-4

## EFFECTIVE DOSE EQUIVALENT RATE FACTORS FOR EXTERNAL EXPOSURE TO RADIONUCLIDES\*

| Radionuclide(s)<br><i>Bold values used in screening; others are intermediate values for parent-daughter chains.</i> | Immersion in Contaminated Water<br>(Sv/y per Bq/cm <sup>3</sup> ) | Immersion in Contaminated Air<br>(Sv/y per Bq/cm <sup>3</sup> ) | Irradiation from Contaminated Ground Surface<br>(Sv/y per Bq/cm <sup>2</sup> ) |
|---|---|---|--|
| <b>plutonium-238</b>  | 3.24 x 10 <sup>-07</sup>  | 1.27 x 10 <sup>-04</sup>  | 2.51 x 10 <sup>-07</sup>   |
| <b>plutonium-239</b>  | 2.73 x 10 <sup>-07</sup>  | 1.15 x 10 <sup>-04</sup>  | 1.10 x 10 <sup>-07</sup>   |
| <b>plutonium-240</b>  | 3.18 x 10 <sup>-07</sup>  | 1.25 x 10 <sup>-04</sup>  | 2.40 x 10 <sup>-07</sup>   |
| plutonium-241   | 0.00  | 0.00  | 0.00   |
| <b>Pu-241 + Am-241 daughter<sup>a</sup></b>   | 8.48 x 10 <sup>-09</sup>  | 3.46 x 10 <sup>-06</sup>  | 1.09 x 10 <sup>-09</sup>   |
| <b>protactinium-233</b>   | 6.51 x 10 <sup>-04</sup>  | 2.95 x 10 <sup>-01</sup>  | 6.47 x 10 <sup>-05</sup>   |
| rhodium-103m  | 7.31 x 10 <sup>-07</sup>  | 2.82 x 10 <sup>-04</sup>  | 3.25 x 10 <sup>-07</sup>   |
| rhodium-106   | 6.57 x 10 <sup>-04</sup>  | 3.18 x 10 <sup>-01</sup>  | 9.89 x 10 <sup>-05</sup>   |
| ruthenium-103   | 1.44 x 10 <sup>-03</sup>  | 6.63 x 10 <sup>-01</sup>  | 1.37 x 10 <sup>-04</sup>   |
| <b>Ru-103 + Rh-103m daughter<sup>b</sup></b>  | 1.44 x 10 <sup>-03</sup>  | 6.63 x 10 <sup>-01</sup>  | 1.37 x 10 <sup>-04</sup>   |
| ruthenium-106   | 0.00  | 0.00  | 0.00   |
| <b>Ru-106 + Rh-106 daughter<sup>c</sup></b>   | 6.57 x 10 <sup>-04</sup>  | 3.18 x 10 <sup>-01</sup>  | 9.89 x 10 <sup>-05</sup>   |
| <b>strontium-89</b>   | 1.30 x 10 <sup>-05</sup>  | 1.20 x 10 <sup>-02</sup>  | 1.60 x 10 <sup>-05</sup>   |
| strontium-90  | 3.16 x 10 <sup>-06</sup>  | 3.00 x 10 <sup>-03</sup>  | 1.58 x 10 <sup>-06</sup>   |
| <b>Sr-90 + Y-90 daughter<sup>d</sup></b>  | 2.44 x 10 <sup>-05</sup>  | 2.30 x 10 <sup>-02</sup>  | 2.89 x 10 <sup>-05</sup>   |
| <b>technetium-99</b>  | 6.37 x 10 <sup>-07</sup>  | 6.06 x 10 <sup>-04</sup>  | 1.71 x 10 <sup>-10</sup>   |
| technetium-99m  | 4.08 x 10 <sup>-04</sup>  | 1.81 x 10 <sup>-01</sup>  | 4.05 x 10 <sup>-05</sup>   |
| <b>thorium-232</b>  | 6.30 x 10 <sup>-07</sup>  | 2.60 x 10 <sup>-04</sup>  | 1.93 x 10 <sup>-07</sup>   |
| uranium-234   | 5.08 x 10 <sup>-07</sup>  | 2.16 x 10 <sup>-04</sup>  | 2.35 x 10 <sup>-07</sup>   |
| uranium-235   | 4.71 x 10 <sup>-04</sup>  | 2.11 x 10 <sup>-01</sup>  | 4.68 x 10 <sup>-05</sup>   |
| <b>uranium-238</b>  | 3.66 x 10 <sup>-07</sup>  | 1.47 x 10 <sup>-04</sup>  | 1.89 x 10 <sup>-07</sup>   |

TABLE 4-4

## EFFECTIVE DOSE EQUIVALENT RATE FACTORS FOR EXTERNAL EXPOSURE TO RADIONUCLIDES\*

| Radionuclide(s)<br><i>Bold values used in screening; others are intermediate values for parent-daughter chains.</i> | Immersion in Contaminated Water<br>(Sv/y per Bq/cm <sup>3</sup> ) | Immersion in Contaminated Air<br>(Sv/y per Bq/cm <sup>3</sup> ) | Irradiation from Contaminated Ground Surface<br>(Sv/y per Bq/cm <sup>2</sup> ) |
|---|---|---|--|
| <b>xenon-133</b>  | 1.16 x 10 <sup>-04</sup>  | 4.91 x 10 <sup>-02</sup>  | 1.39 x 10 <sup>-05</sup>   |
| <b>yttrium-90</b>   | 2.12 x 10 <sup>-05</sup>  | 1.99 x 10 <sup>-02</sup>  | 2.73 x 10 <sup>-05</sup>   |
| <b>zirconium-95</b>   | 2.25 x 10 <sup>-03</sup>  | 1.04  | 2.05 x 10 <sup>-04</sup>   |
| <b>Zr-95 + Nb-95 daughter<sup>a</sup></b>   | 3.46 x 10 <sup>-03</sup>  | 1.61  | 3.15 x 10 <sup>-04</sup>   |

a DOE/EH-0070, "External Dose-Rate Conversion Factors for Calculation of Dose to the Public." USDOE, July 1988.

- Effective dose rate factors were modified by addition of the skin dose rate factors times a weighting factor of 0.01. Units were also converted.
- b La-140 reaches equilibrium with Ba-140 in about 15 days. The effective dose rate conversion factor for the parent plus daughter is estimated as the Ba-140 factor plus 1.15 times the La-140 factor, where 1.15 is the approximate ratio of daughter to parent activity at equilibrium.
- c Because Pr-144 reaches equilibrium with Ce-144 in about 4 hours, the effective dose rate conversion factor for the parent plus daughter is estimated as the Ce-144 factor plus 0.986 times the Pr-144 factor, where 0.986 is the ratio of daughter to parent activity at equilibrium.
- d Because Ba-137m reaches equilibrium with Cs-137 in less than one day, the effective dose rate factor for the parent plus daughter is estimated as the Cs-137 factor plus 0.946 times the Ba-137m factor, where 0.946 is the ratio of daughter to parent activity at equilibrium.
- e Because Tc-99m reaches equilibrium with Mo-99 in about 4 days, the effective dose rate factor for the parent plus daughter is estimated as the Mo-99 factor plus 0.975 times the Tc-99m factor, where 0.975 is the ratio of daughter to parent activity at equilibrium.
- f Pa-233 reaches equilibrium with Np-237 in about 200 days. For screening purposes, the effective dose rate factor for the parent plus daughter is estimated as the Np-237 factor plus 0.5 times the Pa-233 factor, where 0.5 is the approximate ratio of daughter to parent activity after 30 days of decay of the parent.
- g Because it has a longer half-life than its parent, Am-241 does not reach equilibrium with Pu-241. For screening purposes, the effective dose rate factor for the parent plus daughter is estimated as the Pu-241 factor (which is zero) plus 0.00013 times the Am-241 factor, where 0.00013 is the approximate ratio of daughter to parent activity after 30 days of decay of the parent.
- h Because Rh-103m reaches equilibrium with Ru-103 in about 12 hours, the effective dose rate factor for the parent plus daughter is estimated as the Ru-103 factor plus 0.998 times the Rh-103m factor, where 0.998 is the ratio of daughter to parent activity at equilibrium.
- i Because Rh-106 reaches equilibrium with Ru-106 in less than one day, the effective dose rate factor for the parent plus daughter is estimated as the Ru-106 factor (which is zero) plus 1.0 times the Rh-106 factor, where 1.0 is the ratio of daughter to parent activity at equilibrium.
- j Y-90 reaches equilibrium with Sr-90 in about 20 days. The effective dose rate conversion factor for the parent plus daughter is estimated as the Sr-90 factor plus 1.0 times the Y-90 factor, where 1.0 is the approximate ratio of daughter to parent activity at equilibrium.
- k Over one year of decay is required for Nb-95 to reach equilibrium with Zr-95. For screening purposes, the effective dose rate factor for the parent plus daughter is estimated as the Zr-95 factor plus 0.52 times the Nb-95 factor, where 0.52 is the approximate ratio of daughter to parent activity after 30 days of decay of the parent.

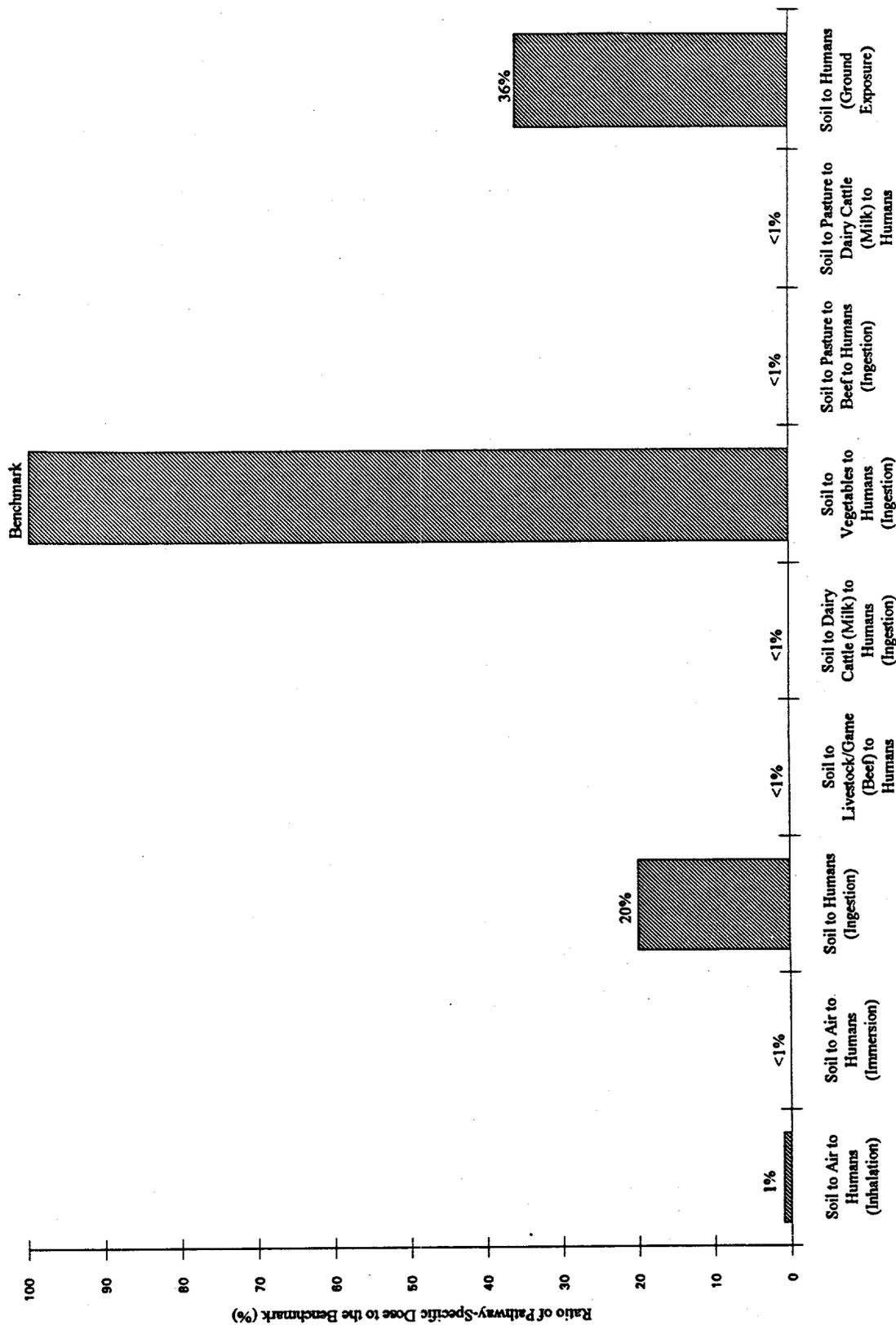


FIGURE 4-1  
EVALUATION OF RELATIVE IMPORTANCE OF EXPOSURE  
PATHWAYS FOR PROTACTINIUM-233 IN SOIL/SEDIMENT

TABLE 4-5

COMPARISON OF COMPLETE EXPOSURE PATHWAYS WITHIN THE AIR MEDIUM

| Material             | Pathway | Air to Humans (inhalation) | Air to Humans (immersion) | Air to Livestock/Game (beef) to Humans (ingestion) | Air to Dairy Cattle (milk) to Humans (ingestion) | Air to Vegetables to Humans (ingestion) | Air to Pasture to Livestock/Game (beef) to Humans (ingestion) | Air to Pasture to Dairy Cattle (milk) to Humans (ingestion) |
|----------------------|---------|----------------------------|---------------------------|--|--|---|---|---|
| <b>RADIONUCLIDES</b> |         |                            |                           |  |  |   |   |   |
| Argon-41             |         |                            | ■                         |  |  |   |   |   |
| Barium-140           |         | ✓                          | ✓                         |  |  | ■                                       | ✓   | ✓   |
| Cerium-144           |         | ■                          |                           |  |  | ✓                                       | ✓   | ✓   |
| Cesium-137           |         | ✓                          |                           |  |  | ✓                                       | ■   | ✓   |
| Cobalt-60            |         | ✓                          |                           |  |  | ✓                                       | ■   | ✓   |
| Iodine-129           |         |                            |                           |  |  | ✓                                       | ✓   | ■   |
| Iodine-131           |         |                            |                           |  |  | ✓                                       | ✓   | ■   |
| Iodine-133           |         |                            |                           |  |  | ✓                                       | ✓   | ■   |
| Krypton-85           |         |                            | ■                         |  |  |   |   |   |
| Lanthanum-140        |         | ✓                          | ✓                         |  |  | ■                                       | ✓   | ✓   |
| Neptunium-237        |         | ■                          |                           |  |  | ✓                                       |   |   |
| Niobium-95           |         |                            |                           |  |  | ✓                                       | ■   | ✓   |
| Plutonium-238        |         | ■                          |                           |  |  | ✓                                       |   |   |
| Plutonium-239/240    |         | ■                          |                           |  |  | ✓                                       |   |   |
| Plutonium-241        |         | ■                          |                           |  |  | ✓                                       |   |   |
| Protactinium-233     |         | ✓                          |                           |  |  | ■                                       |   |   |
| Ruthenium-103        |         | ✓                          |                           |  |  | ✓                                       | ✓   |   |
| Ruthenium-106        |         | ■                          |                           |  |  | ✓                                       | ✓   |   |
| Strontium-89         |         | ✓                          |                           |  |  | ■                                       | ✓   | ✓   |
| Strontium-90         |         | ✓                          |                           |  |  | ■                                       | ✓   | ✓   |
| Technetium-99        |         | ✓                          |                           |  |  | ✓                                       | ✓   | ■   |
| Thorium-232          |         | ■                          |                           |  |  | ✓                                       |   |   |
| Uranium-234, 235     |         | ■                          |                           |  |  | ✓                                       |   |   |
| Uranium-238          |         | ■                          |                           |  |  | ✓                                       |   |   |

TABLE 4-5

COMPARISON OF COMPLETE EXPOSURE PATHWAYS WITHIN THE AIR MEDIUM

| Material                          | Pathway | Air to Humans (inhalation) | Air to Humans (immersion) | Air to Livestock/Game (beef) to Humans (ingestion) | Air to Dairy Cattle (milk) to Humans (ingestion) | Air to Vegetables to Humans (ingestion) | Air to Pasture to Livestock/Game (beef) to Humans (ingestion) | Air to Pasture to Dairy Cattle (milk) to Humans (ingestion) |
|-----------------------------------|---------|----------------------------|---------------------------|--|--|---|---|---|
| Xenon-133                         |         |                            | ■                         |  |  |   |   |   |
| Zirconium-95                      |         | ✓                          | ✓                         |  |  | ■                                       | ✓   | ✓   |
| <b>NONRADIOACTIVE METALS</b>      |         |                            |                           |  |  |   |   |   |
| Arsenic - (Carcinogenic)          |         | ■                          |                           |  |  | ✓                                       | ✓   | ✓   |
| Arsenic - (Noncarcinogenic)       |         | ✓                          |                           |  |  | ■                                       | ✓   | ✓   |
| Beryllium                         |         | ✓                          |                           |  |  | ■                                       | ✓   |   |
| Chromium (III)                    |         | ✓                          |                           |  |  | ✓                                       | ■   | ✓   |
| Chromium (VI) - (Carcinogenic)    |         | ■                          |                           |  |  |   | ■   |   |
| Chromium (VI) - (Noncarcinogenic) |         |                            |                           |  |  | ✓                                       | ■   | ✓   |
| Lead                              |         | ✓                          |                           |  |  | ■                                       | ✓   | ✓   |
| Mercury                           |         | ✓                          |                           |  |  | ✓                                       | ■   | ✓   |
| Nickel                            |         | ✓                          |                           |  |  | ■                                       | ✓   | ✓   |
| <b>ORGANICS</b>                   |         |                            |                           |  |  |   |   |   |
| Carbon Tetrachloride              |         | ■                          |                           |  |  |   |   |   |
| Methylene Chloride                |         | ■                          |                           |  |  |   |   |   |
| Polychlorinated Biphenyls         |         |                            |                           |  |  | ✓                                       | ■   | ✓   |
| Tetrachloroethylene               |         | ■                          |                           |  |  |   |   |   |
| 1,1,1-Trichloroethane             |         | ■                          |                           |  |  |   |   |   |
| Trichloroethylene                 |         | ■                          |                           |  |  |   |   |   |

■ Most Important Exposure Pathway (benchmark)  
 ✓ Exposure pathways contributing greater than or equal to 1.0% of the most important pathway

cattle to human pathways are not important for any of the contaminants and will not be evaluated further in this assessment. The apparent importance of immersion, as evidenced by the fact that it is the most important pathway for three of the radionuclides, is somewhat misleading, since it is the only pathway for which there is a dose coefficient for the noble gases argon-41, krypton-85 and xenon-133. Otherwise, immersion contributes to the total dose (i.e., greater than 1% of the dominant pathway) for only three other radionuclides released from the ORR (barium-140, lanthanum-140 and zirconium-95).

#### **4.2 Surface Water Pathway Comparisons**

The results of the evaluation of the relative importance of complete pathways within the surface water medium are summarized in Table 4-6. The numerical values used to create this table are presented in Appendix D. Direct ingestion represents the most important pathway for the majority of the contaminants, and fish ingestion is most important for the remaining contaminants. Both of these pathways are important for nearly all of the contaminants released from the ORR. The remaining three pathways are also considered important for at least a few contaminants. As such, all of the surface water pathways are evaluated further in this report.

#### **4.3 Soil and Sediment Pathway Comparisons**

Table 4-7 presents the results of the evaluation of the relative importance of complete pathways within the soil/sediment medium. The numerical values used to create this table are presented in Appendix D. For this medium, one of two pathways, i.e., inhalation following resuspension or ingestion of vegetables, represents the most important for nearly all of the contaminants. Immersion following resuspension is not important for any of the radionuclides. The remaining pathways are considered important for at least some of the contaminants released from the ORR. As such, all of the soil pathways except immersion following resuspension are evaluated further in this assessment.

### **5.0 COMPARISON BETWEEN ENVIRONMENTAL MEDIA**

A large number of exposure pathways have been identified as being complete and potentially important with respect to historical off-site exposures. However, even though a pathway may be important (i.e., contribute to exposure) for a particular contaminant in a particular medium (e.g., direct inhalation of air), the associated health risk may be insignificant compared to another pathway for that contaminant in another medium (e.g., ingestion of surface water). The objective of a comparison between media is to further narrow the list of exposure pathways warranting detailed consideration by evaluating their relative importance across media. This type of evaluation requires information regarding airborne and/or waterborne releases and environmental media concentrations of the contaminants near populations. The availability of

TABLE 4-6

COMPARISON OF COMPLETE EXPOSURE PATHWAYS WITHIN THE SURFACE WATER MEDIUM

| Material             | Pathway | Water to Humans (ingestion) | Water to Livestock/Game (beef) to Humans (ingestion) | Water to Dairy Cattle (milk) to Humans (ingestion) | Water to Fish to Humans (ingestion) | Water to Humans (Recreational) (immersion/dermal contact) |
|----------------------|---------|-----------------------------|--|--|-------------------------------------|---|
| <b>RADIONUCLIDES</b> |         |                             |  |  |                                     |   |
| Barium-140           |         | ■                           |  |  | ✓                                   | ✓   |
| Cerium-144           |         | ✓                           |  |  | ■                                   |   |
| Cesium-137           |         |                             |  |  | ■                                   |   |
| Cobalt-60            |         | ✓                           |  |  | ■                                   |   |
| Iodine-129           |         | ■                           | ✓  | ✓  | ✓                                   |   |
| Iodine-131           |         | ■                           | ✓  | ✓  | ✓                                   |   |
| Iodine-133           |         | ■                           | ✓  | ✓  | ✓                                   |   |
| Lanthanum-140        |         | ■                           |  |  | ✓                                   | ✓   |
| Neptunium-237        |         |                             |  |  | ■                                   |   |
| Niobium-95           |         |                             |  |  | ■                                   |   |
| Plutonium-238        |         | ■                           |  |  | ✓                                   |   |
| Plutonium-239/240    |         | ■                           |  |  | ✓                                   |   |
| Plutonium-241        |         | ■                           |  |  | ✓                                   |   |
| Protactinium-233     |         | ■                           |  |  | ✓                                   | ✓   |
| Ruthenium-103        |         | ■                           |  |  | ✓                                   |   |
| Ruthenium-106        |         | ■                           |  |  | ✓                                   |   |
| Strontium-89         |         | ■                           |  |  | ✓                                   |   |
| Strontium-90         |         | ■                           |  |  | ✓                                   |   |
| Technetium-99        |         | ✓                           |  | ✓  | ■                                   |   |
| Thorium-232          |         | ✓                           |  |  | ■                                   |   |
| Uranium-234/235      |         | ■                           |  |  | ✓                                   |   |
| Uranium-238          |         | ■                           |  |  | ✓                                   |   |
| Zirconium-95         |         | ■                           | ✓  |  | ✓                                   | ✓   |

TABLE 4-6

COMPARISON OF COMPLETE EXPOSURE PATHWAYS WITHIN THE SURFACE WATER MEDIUM

| Material                     | Pathway | Water to Humans (ingestion) | Water to Livestock/Game (beef) to Humans (ingestion) | Water to Dairy Cattle (milk) to Humans (ingestion) | Water to Fish to Humans (ingestion) | Water to Humans (Recreational) (immersion/dermal contact) |
|------------------------------|---------|-----------------------------|--|--|-------------------------------------|---|
| <b>NONRADIOACTIVE METALS</b> |         |                             |  |  |                                     |   |
| Arsenic (Noncarcinogenic)    |         | ■                           |  |  | ✓                                   |   |
| Arsenic (Carcinogenic)       |         | ■                           |  |  | ✓                                   |   |
| Beryllium                    |         | ■                           |  |  | ✓                                   |   |
| Chromium (III)               |         | ■                           | ✓  |  | ✓                                   |   |
| Chromium (VI)                |         | ■                           | ✓  |  | ✓                                   |   |
| Lead                         |         | ✓                           |  |  | ■                                   |   |
| Mercury                      |         |                             |  |  | ■                                   |   |
| Nickel                       |         | ✓                           |  |  | ■                                   |   |
| <b>ORGANICS</b>              |         |                             |  |  |                                     |   |
| Polychlorinated Biphenyls    |         |                             |  |  | ■                                   |   |

■ Most Important Exposure Pathway (benchmark)  
 ✓ Exposure pathways contributing greater than or equal to 1.0% of the most important pathway

TABLE 4-7

COMPARISON OF COMPLETE EXPOSURE PATHWAYS WITHIN THE SOIL/SEDIMENT MEDIUM

| Material             | Pathway | Soil/Sediment to Air to Humans (inhalation) | Soil/Sediment to Air to Humans (immersion) | Soil/Sediment to Humans (ingestion) | Soil/Sediment to Livestock/Game (beef) to Humans (ingestion) | Soil/Sediment to Dairy Cattle (milk) to Humans (ingestion) | Soil/Sediment to Vegetables to Humans (ingestion) | Soil/Sediment to Pasture to Livestock/Game (beef) to Humans (ingestion) | Soil/Sediment to Pasture to Dairy Cattle (milk) to Humans (ingestion) | Soil/Sediment to Humans (Ground Exposure/ Dermal Contact) |
|----------------------|---------|---|--|-------------------------------------|--|--|---|---|---|---|
| <b>RADIONUCLIDES</b> |         |   |  |                                     |  |  |   |   |   |   |
| Barium-140           |         |   |  | ✓                                   |  | ✓  | ■   | ✓   | ✓   | ✓   |
| Cerium-144           | ✓       |   |  | ✓                                   | ✓  | ✓  | ■   | ✓   | ✓   | ✓   |
| Cesium-137           |         |   |  | ✓                                   | ✓  | ✓  | ■   | ✓   | ✓   |   |
| Cobalt-60            |         |   |  | ✓                                   | ✓  | ✓  | ■   | ✓   |   | ✓   |
| Iodine-129           |         |   |  | ✓                                   | ✓  | ✓  | ■   | ✓   | ✓   |   |
| Iodine-131           |         |   |  | ✓                                   | ✓  | ✓  | ■   | ✓   | ✓   |   |
| Iodine-133           |         |   |  | ✓                                   | ✓  | ✓  | ■   | ✓   | ✓   |   |
| Lanthanum-140        |         |   |  | ✓                                   | ✓  |  | ✓   |   |   | ■   |
| Neptunium-237        |         | ■   |  |                                     |  |  | ✓   |   |   |   |
| Niobium-95           |         |   |  |                                     | ■  | ✓  | ✓   | ✓   | ✓   | ✓   |
| Plutonium-238        |         | ■   |  | ✓                                   |  |  | ✓   |   |   |   |
| Plutonium-239/240    |         | ■   |  | ✓                                   |  |  | ✓   |   |   |   |
| Plutonium-241        |         | ■   |  | ✓                                   |  |  | ✓   |   |   |   |
| Protactinium-233     | ✓       |   |  | ✓                                   |  |  | ■   |   |   | ✓   |
| Ruthenium-103        |         |   |  | ✓                                   | ✓  |  | ■   | ✓   |   | ✓   |
| Ruthenium-106        | ✓       |   |  | ✓                                   | ✓  |  | ■   | ✓   |   | ✓   |
| Strontium-89         |         |   |  |                                     |  |  | ■   |   | ✓   |   |
| Strontium-90         |         |   |  |                                     |  |  | ■   | ✓   | ✓   | ✓   |
| Technetium-99        |         |   |  |                                     |  |  | ✓   | ✓   | ✓   | ■   |

TABLE 4-7

COMPARISON OF COMPLETE EXPOSURE PATHWAYS WITHIN THE SOIL/SEDIMENT MEDIUM

| Material                        | Pathway | Soil/Sediment to Air to Humans (inhalation) | Soil/Sediment to Air to Humans (immersion) | Soil/Sediment to Humans (ingestion) | Soil/Sediment to Livestock/Game (beef) to Humans (ingestion) | Soil/Sediment to Dairy Cattle (milk) to Humans (ingestion) | Soil/Sediment to Vegetables to Humans (ingestion) | Soil/Sediment to Pasture to Livestock/Game (beef) to Humans (ingestion) | Soil/Sediment to Pasture to Dairy Cattle (milk) to Humans (ingestion) | Soil/Sediment to Humans (Ground Exposure/ Dermal Contact) |
|---------------------------------|---------|---|--|-------------------------------------|--|--|---|---|---|---|
| Thorium-232                     |         | ■   |  | ✓                                   |  |  | ✓   |   |   |   |
| Uranium-234/235                 |         | ✓   |  | ✓                                   |  |  | ■   |   |   |   |
| Uranium-238                     |         | ✓   |  | ✓                                   |  |  | ■   |   |   |   |
| Zirconium-95                    |         | ✓   |  | ✓                                   | ✓  |  | ✓   |   |   | ■   |
| <b>NONRADIOACTIVE METALS</b>    |         |   |  |                                     |  |  |   |   |   |   |
| Arsenic (Noncarcinogenic)       |         |   |  | ✓                                   | ✓  | ✓  | ■   | ✓   | ✓   | ✓   |
| Arsenic (Carcinogenic)          |         | ✓   |  | ✓                                   | ✓  | ✓  | ■   | ✓   | ✓   | ✓   |
| Beryllium                       |         | ✓   |  | ✓                                   | ✓  | ✓  | ■   | ✓   | ✓   | ✓   |
| Chromium (III)                  |         |   |  | ✓                                   | ■  | ✓  | ✓   | ✓   | ✓   | ✓   |
| Chromium (VI) (Carcinogenic)    |         | ■   |  |                                     |  |  |   |   |   |   |
| Chromium (VI) (Noncarcinogenic) |         |   |  | ✓                                   | ■  | ✓  | ✓   | ✓   | ✓   | ✓   |
| Lead                            |         |   |  | ✓                                   | ✓  | ✓  | ■   | ✓   | ✓   | ✓   |
| Mercury                         |         |   |  |                                     | ✓  |  | ✓   | ■   |   |   |
| Nickel                          |         |   |  | ✓                                   | ✓  | ✓  | ■   | ✓   | ✓   | ✓   |
| <b>ORGANICS</b>                 |         |   |  |                                     |  |  |   |   |   |   |
| Polychlorinated Biphenyls       |         |   |  | ✓                                   | ■  | ✓  | ✓   | ✓   | ✓   | ✓   |

■ Most Important Exposure Pathway (benchmark)

✓ Exposure pathways contributing greater than or equal to 1.0% of the most important pathway.

these types of data is limited at this stage in the project; however, information gathered as part of Tasks 1 & 2 is used to identify preliminary source-term estimates and contaminant concentrations in air, surface water, soil/sediment, and fish for the majority of the contaminants of concern released from the ORR. It is important to note that the accuracy of this comparison is dependent primarily upon the availability and quality of the effluent and environmental monitoring data that we have had a limited opportunity to review and have not verified. In addition, due to differences in how some data were recorded or measured, not all source terms were calculated in the same way and may contain differing levels of conservatism. **This evaluation should therefore not be considered as the definitive assessment of health hazards from contaminant releases from the ORR, and the conclusions reached in this feasibility study are subject to change during later phases of the health studies.**

The exposure pathway equations and exposure parameters described previously are again used in this evaluation. However, instead of a unit concentration, actual concentrations of a contaminant in all relevant environmental media are required. For the purposes of this assessment, these actual concentrations are based on preliminary effluent data summarized in Task 1 and environmental monitoring data summarized in Task 2. How these data are used to generate representative concentrations is described in the following sections.

## 5.1 Airborne Releases

Although the monitoring of ambient air both on and off the plant site has been conducted at the ORR since the late 1950s, the number of samples and their locations are of limited use in estimating air concentrations to which off-site populations could have been exposed. On the other hand, direct monitoring of airborne releases from the plant stacks began as early as the late 1940s, and these data can be used to provide an initial estimate of the amount of a contaminant that was released to the atmosphere as a result of a particular process during a particular time period. For unmonitored processes, release estimates can be made from information about the process itself. The effluent monitoring data or estimates can be used in conjunction with a simple air transport model to estimate representative environmental concentrations at selected locations. Given that this is a feasibility study and the type of information that is available at this stage in the process is often screening-level in nature, a maximum, one-year release estimate is identified for use in this analysis. The basis for the source-term estimates for each plant site is provided below.

### 5.1.1 Air Source-Term Estimates for X-10

Contaminants were likely released to the atmosphere as a result of these historical operations and occurrences at the X-10 site:

- Radioactive Lanthanum (RaLa) Processing
- Thorex Processing of Short-Decay Irradiated Thorium
- Chemical Separation of Plutonium from Clinton Pile Fuel
- Graphite Reactor Fuel Slug Ruptures
- Air Cooling of the Graphite Reactor
- Radioisotope Processing Programs

Each of these operations or occurrences is described in some detail in Appendix E, in which estimates of maximum annual release quantities for associated contaminants are also identified. These maximum, single-year airborne emission estimates to be used in the comparison between media for contaminants released from X-10 are presented in Table 5-1. A brief description of each of the operations or occurrences listed above is provided in this section. These brief discussions identify the contaminants that were available for release to the atmosphere as a result of the contaminants and processes involved.

#### Radioactive Lanthanum Processing

Irradiated uranium fuel slugs from Oak Ridge and Hanford, Washington reactors were processed at X-10 from 1944 to 1956 for separation and purification of fission product barium as a source of radioactive lanthanum, often referred to as "RaLa," for weapons development. The RaLa process involved dissolving batches of the metal slugs in acid, followed by a series of chemical separation and purification steps. Barium-140, which is formed when uranium-235 undergoes fission, decays to form the desired product lanthanum-140.

Because barium-140 decays with a half-life of only 12.8 days, the slugs had to be dissolved shortly after discharge from the reactors, and large quantities of other fission products were also released from the dissolved fuel. Of key importance is iodine-131, which can result in off-site exposure via the air to pasture to dairy cattle (milk) pathway and concentrate in the thyroid glands of exposed individuals. Other fission products likely to have been released include barium-140, cerium-144, cesium-137, iodine-129, iodine-133, lanthanum-140, niobium-95, ruthenium-103, ruthenium-106, strontium-89, strontium-90, zirconium-95, and fission gases krypton-85 and xenon-133. Uranium and plutonium were also available for release from the dissolved slugs. Plutonium was formed when uranium-238 absorbed neutrons that were emitted in the induced fissioning of uranium-235.

The years in which the highest quantities of barium were processed from Oak Ridge fuel and from Hanford fuel were selected for screening purposes. These years were 1947 for processing of Oak Ridge slugs and 1952 for Hanford slugs. RaLa processing in 1947 was selected as the year of peak releases of iodine-133, xenon-133, and lanthanum-140. RaLa processing in 1952 was selected as the year of the peak releases of iodine-131 and barium-140. Short-lived

TABLE 5-1

PREDICTED MAXIMUM AVERAGE ANNUAL AIR CONCENTRATIONS OFF-SITE  
FOR SCREENING EVALUATION OF CONTAMINANTS RELEASED FROM X-10

| Material          | Estimated Maximum Amount Released (Ci/yr) | Year or Time Period of Maximum Emission | Emission Rate (pCi/sec) | Long-Term Dispersion Factor ( $\chi/Q$ ) <sup>a</sup> (sec/m <sup>3</sup> ) | Predicted Air Concentration* (pCi/m <sup>3</sup> ) |
|-------------------|---|---|-------------------------|---|--|
| Argon-41          | 170,000                                   | 1943-1963                               | 5,400,000,000           | $1.0 \times 10^{-8}$  | 54   |
| Barium-140        | 210 <sup>c</sup>                          | 1952                                    | 6,700,000               | $3.5 \times 10^{-8}$  | 0.23   |
| Cerium-144        | 72 <sup>c</sup>                           | 1944                                    | 2,300,000               | $5.5 \times 10^{-8}$  | 0.13   |
| Cesium-137        | 2.0 <sup>c</sup>                          | 1944                                    | 63,000                  | $5.5 \times 10^{-8}$  | 0.0035   |
| Cobalt-60         | NA  | NA                                      | NA                      | NA  | NA   |
| Iodine-129        | 0.00049 <sup>d</sup>                      | 1944                                    | 16                      | $5.5 \times 10^{-8}$  | 0.0000088  |
| Iodine-131        | 67,000 <sup>d</sup>                       | 1952                                    | 2,100,000,000           | $3.5 \times 10^{-8}$  | 74   |
| Iodine-133        | 71,000 <sup>d</sup>                       | 1947                                    | 2,300,000,000           | $5.5 \times 10^{-8}$  | 130  |
| Krypton-85        | 350 <sup>b</sup>                          | 1957                                    | 11,000,000              | $5.5 \times 10^{-8}$  | 0.61   |
| Lanthanum-140     | 130 <sup>c</sup>                          | 1947                                    | 4,100,000               | $5.5 \times 10^{-8}$  | 0.23   |
| Niobium-95        | 270 <sup>c</sup>                          | 1944                                    | 8,600,000               | $5.5 \times 10^{-8}$  | 0.47   |
| Plutonium-238     | ND  | ND                                      | ND                      | NA  | NA   |
| Plutonium-239/240 | 0.031 <sup>c</sup>                        | 1944                                    | 980                     | $5.5 \times 10^{-8}$  | 0.000054   |
| Plutonium-241     | ND  | ND                                      | ND                      | NA  | NA   |
| Protactinium-233  | 43,000 <sup>c</sup>                       | 1957                                    | 1,400,000,000           | $5.5 \times 10^{-8}$  | 77   |

TABLE S-1

PREDICTED MAXIMUM AVERAGE ANNUAL AIR CONCENTRATIONS OFF-SITE  
FOR SCREENING EVALUATION OF CONTAMINANTS RELEASED FROM X-10

| Material        | Estimated Maximum Amount Released (Ci/yr) | Year or Time Period of Maximum Emission | Emission Rate (pCi/sec) | Long-Term Dispersion Factor ( $\chi/Q$ ) <sup>a</sup> (sec/m <sup>3</sup> ) | Predicted Air Concentration <sup>a</sup> (pCi/m <sup>3</sup> ) |
|-----------------|---|---|-------------------------|---|--|
| Ruthenium-103   | 120 <sup>c</sup>                          | 1944                                    | 3,800,000               | $5.5 \times 10^{-8}$  | 0.21   |
| Ruthenium-106   | 3.6 <sup>c</sup>                          | 1944                                    | 110,000                 | $5.5 \times 10^{-8}$  | 0.0061   |
| Strontium-89    | 180 <sup>c</sup>                          | 1944                                    | 5,700,000               | $5.5 \times 10^{-8}$  | 0.31   |
| Strontium-90    | 2.2 <sup>c</sup>                          | 1944                                    | 70,000                  | $5.5 \times 10^{-8}$  | 0.0039   |
| Tritium         | 44,000                                    | 1987                                    | 1,400,000,000           | $3.5 \times 10^{-8}$  | 49   |
| Uranium-234/235 | 0.0015 <sup>c</sup>                       | 1944                                    | 48                      | $5.5 \times 10^{-8}$  | 0.0000026  |
| Uranium-238     | 0.21 <sup>c</sup>                         | 1944                                    | 6,700                   | $5.5 \times 10^{-8}$  | 0.00037  |
| Xenon-133       | 180,000 <sup>b</sup>                      | 1947                                    | 5,700,000,000           | $5.5 \times 10^{-8}$  | 310  |
| Zirconium-95    | 220 <sup>c</sup>                          | 1944                                    | 7,000,000               | $5.5 \times 10^{-8}$  | 0.39   |

NA = Not Applicable

ND = No Data

a Corresponds to location of nearest residence, which is located approximately 2.5 miles from X-10.

b A release fraction of 100% has been applied to estimated quantities available.

c A release fraction of 0.1% has been applied to estimated quantities available.

d A release fraction of 80% has been applied to estimated quantities available.

radionuclides such as iodine-133 were less important during processing of Hanford slugs due to the additional 4 days of decay in transit from Washington. Release estimates for fission products, plutonium, and uranium from Oak Ridge RaLa processing in 1947 and 1952 are presented in Tables E-1 and E-2.

#### Thorex Processing of Short-Decay Irradiated Thorium

The Thorex process was used at X-10 to separate uranium-233, thorium, and protactinium-233 from each other and from fission products formed during irradiation of thorium metal. Uranium-233 and protactinium-233 are formed after thorium-232 absorbs neutrons while inside a reactor to form thorium-233; they are called thorium activation products. During 1956 and 1957, irradiated thorium metal that had been allowed to decay for periods shorter than the material normally processed in the Thorex pilot plant was used to test plant equipment and processes under high radiation conditions. That thorium metal had also been irradiated until it contained higher levels of fission and activation products than the thorium that had previously been processed in the Thorex pilot plant. The thorium metal was processed before many of the short half-life fission and activation products had time to decay.

Fission products likely to have been released from the irradiated thorium metal when it was dissolved included barium-140, cerium-141, cerium-144, iodine-131, lanthanum-140, niobium-95, ruthenium-103, ruthenium-106, zirconium-95, and fission gases krypton-85 and xenon-133. Typical amounts of these radionuclides found in the thorium metal processed in the short-decay Thorex runs are shown in Table E-3. Because thorium-232 itself is not fissionable, and fission products are produced from the neutron-induced fission of uranium-233 (the daughter of activation product protactinium-233), levels of fission products were significantly lower in the material processed in the Thorex process than the fuel slugs processed in RaLa and plutonium separation processing.

Release estimates for uranium-233, protactinium-233, and the fission products listed above are presented for each Thorex short-decay run in Table E-4. The year in which the largest quantity of thorium was dissolved, calendar year 1957, was selected as the year of peak protactinium-233 releases from the ORR for screening purposes.

#### Chemical Separation of Plutonium from Clinton Pile Fuel

The original mission of the X-10 Site was to produce and chemically separate and purify plutonium to support wartime atomic weapons development efforts. Plutonium was formed in the pile (later called the graphite reactor) when uranium-238 absorbed neutrons emitted in the neutron-induced fissioning of uranium-235. The chemical processing pilot plant operated full-scale from January 1944 until production ended in January 1945.

Fission products likely to have been released from the dissolved fuel slugs include barium-140, cerium-144, cesium-137, iodine-129, iodine-131, iodine-133, lanthanum-140, niobium-95, ruthenium-103, ruthenium-106, strontium-89, strontium-90, zirconium-95, and fission gases krypton-85 and xenon-133. Uranium and plutonium were also available for release from the dissolved slugs.

Release estimates for uranium-235, uranium-238, plutonium (evaluated as plutonium-239), and the fission products listed above for the period of chemical separation of plutonium (essentially calendar year 1944) are presented in Table E-5. Calendar year 1944 was selected as the year of peak releases of uranium-235, uranium-238, plutonium, and fission products iodine-129, cerium-144, cesium-137, zirconium-95, niobium-95, ruthenium-103, ruthenium-106, strontium-89, and strontium-90 from the ORR for screening purposes.

#### Graphite Reactor Fuel Slug Ruptures

The Oak Ridge graphite reactor was fueled with thousands of natural uranium metal slugs canned in aluminum. Starting in 1944, a small fraction of the slugs began to experience failure of their aluminum jackets. When exposed to the air, the uranium metal oxidized and expanded, often causing the slugs to rupture severely and release uranium oxide powder to the pile cooling air. Uranium, plutonium, and various fission products were released from the ruptured slugs. Particulate releases from the reactor went unfiltered until late 1948, and gaseous releases continued until the reactor was shut down in 1963.

Fission products likely to have been released from the ruptured slugs include barium-140, cerium-144, cesium-137, iodine-129, iodine-131, iodine-133, lanthanum-140, niobium-95, ruthenium-103, ruthenium-106, strontium-89, strontium-90, zirconium-95, and fission gases krypton-85 and xenon-133. Uranium and plutonium were also available for release from the slugs.

Calendar year 1947 was the year in which the most slug ruptures were experienced prior to addition of the graphite reactor filter house. Table E-6 presents estimated releases of fission products, uranium, and plutonium from the approximately 25 slugs that ruptured in 1947. Based on calculations described in Appendix E, graphite reactor slug ruptures do not appear to have been the most significant source of releases from X-10 of any of the identified radionuclides. Ten of the radionuclides included in the assessment of slug rupture releases could be elevated to roughly the magnitude of the current most significant airborne emission source of the nuclide in question if the particulate release fraction were to increase significantly from the 10% used in the screening calculations. The following values of particulate release fraction would be required for releases of the identified radionuclides from graphite reactor slug ruptures in 1947 to rival the most significant releases of that nuclide:

|               |      |
|---------------|------|
| cesium-137    | 15%  |
| strontium-90  | 15%  |
| plutonium     | 26%  |
| ruthenium-106 | 30%  |
| cerium-144    | 34%  |
| lanthanum-140 | 50%  |
| barium-140    | 81%  |
| zirconium-95  | 89%  |
| strontium-89  | 96%  |
| niobium-95    | 100% |

#### Air Cooling of the Graphite Reactor

During its operation from 1943 to 1963, the graphite reactor was cooled by air drawn through its fuel channels and exhausted up a 200-foot stack. While passing through the reactor, the stable argon-40 gas, which makes up about 0.9% of our atmosphere, absorbed neutrons and formed radioactive argon-41. Argon-41 has a half-life of about 110 minutes, and the 200-foot stack was intended to provide for dilution and decay before the gas could reach ground.

The release rate of argon-41 from the graphite reactor stack was estimated to be 470 curies per day when the pile was operated at a power level of 3.6 megawatts (Morgan, 1949). Available information indicates that the reactor was operated at a power level around 3.5 megawatts throughout a majority of its years of operation (after upgrades in 1944). During the last several years of its operation, the graphite reactor operated for only a short period each day. Annual airborne releases of argon-41 are not likely to have varied significantly from the corresponding rate of approximately 170,000 curies per year. This value was selected for use in screening calculations.

#### Radioisotope Processing Programs

Building 3033 was built in the late 1940s for processing of tritium and krypton. While some airborne tritium was likely emitted from X-10 reactor and fuel processing operations, available data indicate that the most significant source of airborne tritium releases was the handling of tritium that was received from Savannah River after 1952, purified, and repackaged for commercial distribution. Documented quantities of tritium shipped from X-10 provide an indication of trends of quantities of the nuclide that were processed. Shipments appear to have peaked at 2,400,000 curies in 1987.

Reporting of airborne tritium releases from X-10 began in 1972. Reported releases were based on inventory shortages prior to 1984, when reporting based on monitoring began. Consistent

with the quantities shipped, reported airborne tritium releases peaked in 1987. Reported quantities of tritium shipped annually from ORNL and quantities reported to have been released in X-10 airborne effluents are depicted in Figure E-1. Because the information that has been reviewed does not identify any sources of airborne tritium releases in the 1950s through 1960s that likely approached the magnitude of reported releases from isotope processing during the 1980s, the peak annual tritium emission of 44,000 curies reported for 1987 was used for screening calculations.

### 5.1.2 Air Source-Term Estimates for K-25

The maximum single year airborne release estimates for contaminants released from K-25 are presented in Table 5-2. The release estimates for technetium-99, uranium-234/235 and uranium-238 are based on information provided in the 1988 U.S. DOE Historical Radionuclide Releases from Current DOE Oak Ridge Operations Office Facilities (hereafter the Radionuclide Release Report) and an update provided by Martin Marietta Energy Systems, Inc (MMES, 1991a). It should be noted that the information presented in this report has not been independently verified and the source-term estimates should be considered preliminary. Neptunium-237 and plutonium-239 are not believed to have been released to the air (USDOE, 1979; Lay, 1993; Legeay, 1993).

The highest annual release of technetium-99 reportedly occurred in 1976. The release estimate listed in Table 5-2 was taken directly from the Radionuclide Release Report. For uranium, the highest annual release occurred in 1958, but was reported in terms of total activity (Ci) and total quantity (kg), not in terms of specific isotopes. Using the information provided in the Radionuclide Release Report for 1958 and estimated specific activity values for uranium-234/235 and uranium-238, a series of algebraic equations was solved to determine the percentage of the total that was released as enriched and depleted uranium. These equations are presented in Appendix E and the results are listed in Table 5-2.

Airborne release estimates could not be made for four of the nine chemicals released from K-25, since adequate information could not be obtained as part of this feasibility study. Additional research will be necessary in any future phases of the health studies to evaluate the potential off-site health impacts of these contaminants. For the remaining five chemicals, source term information was obtained from a variety of sources, including the Oak Ridge Gaseous Diffusion Plant Historical Chemical Release Report (MMES, 1986a; hereafter the Chemical Release Report), personal interviews with a current plant employee, Site Quarterly Progress Reports and fiscal year inventories. As with the radionuclides, the information obtained from the above sources was not independently verified.

TABLE 5-2

PREDICTED MAXIMUM AVERAGE ANNUAL AIR CONCENTRATIONS OFF-SITE FOR SCREENING EVALUATION OF CONTAMINANTS RELEASED FROM K-25

| Radionuclides   | Estimated Maximum Amount Released (Ci/yr) | Year or Time Period of Maximum Release | Emission Rate (pCi/sec) | Long-Term Dispersion Factor (X/Q) <sup>a</sup> (sec/m <sup>3</sup> ) | Predicted Air Concentration <sup>a</sup> (pCi/m <sup>3</sup> ) |
|-----------------|---|--|-------------------------|--|--|
| Neptunium-237   | NA  | NA                                     | NA                      | NA   | NA   |
| Plutonium-239   | NA  | NA                                     | NA                      | NA   | NA   |
| Technetium-99   | 6.8                                       | 1976                                   | 220,000                 | 2.6 x 10 <sup>-7</sup>   | 0.057  |
| Uranium-234/235 | 0.82                                      | 1958                                   | 26,000                  | 2.6 x 10 <sup>-7</sup>   | 0.0068   |
| Uranium-238     | 0.97                                      | 1958                                   | 31,000                  | 2.6 x 10 <sup>-7</sup>   | 0.0081   |

| Chemicals                 | Estimated Maximum Amount Released (kg/yr) | Year or Time Period of Maximum Release | Emission Rate (mg/sec) | Long-Term Dispersion Factor (X/Q) <sup>a</sup> (sec/m <sup>3</sup> ) | Predicted Air Concentration <sup>a</sup> (mg/m <sup>3</sup> ) |
|---------------------------|---|--|------------------------|--|---|
| Beryllium                 | ND  | ND                                     | ND                     | NA   | NA  |
| Chromium (III)            | ND  | ND                                     | ND                     | NA   | NA  |
| Chromium (VI)             | ND  | ND                                     | ND                     | NA   | NA  |
| Nickel                    | 1,800                                     | 1982 - 1983                            | 57                     | 2.6 x 10 <sup>-7</sup>   | 0.000015  |
| Carbon Tetrachloride      | 32,000                                    | 1949 - 1952                            | 1,000                  | 2.6 x 10 <sup>-7</sup>   | 0.00026   |
| Methylene Chloride        | 5,300                                     | 1983                                   | 170                    | 2.6 x 10 <sup>-7</sup>   | 0.000044  |
| Polychlorinated Biphenyls | ND  | ND                                     | ND                     | NA   | NA  |
| 1,1,1-Trichloroethane     | 1,000,000                                 | 1980 - 1984                            | 32,000                 | 2.6 x 10 <sup>-7</sup>   | 0.0082  |
| Trichloroethylene         | 37,000                                    | mid 1951-mid 1952                      | 1,200                  | 2.6 x 10 <sup>-7</sup>   | 0.00031   |

NA = Not Applicable

ND = No Data

<sup>a</sup> Corresponds to location of nearest residence, which is located approximately 0.75 miles from K-25.

For methylene chloride and 1,1,1-trichloroethylene, the largest quantity used during the years covered by the Chemical Release Report was assumed to have been entirely released to the atmosphere and was used in this analysis. For nickel, carbon tetrachloride and trichloroethylene, information provided in one or more of the aforementioned sources was used to develop the source-term estimates listed in Table 5-2. As with methylene chloride and 1,1,1-trichloroethane, the amount used was assumed to have been entirely released to the atmosphere. A detailed discussion as to how these source-term estimates were calculated is provided in Appendix F.

### 5.1.3 Air Source-Term Estimates for Y-12

The maximum, single year airborne release estimates for contaminants released from Y-12 are presented in Table 5-3. Airborne release estimates could not be made as part of this feasibility study for seven of the nine radionuclides and five of the eleven chemicals released from Y-12. Additional research will be necessary in later phases of the health studies to evaluate the potential off-site health impacts of these contaminants.

Uranium-234/235 and uranium-238 were the only radionuclides released from Y-12 for which airborne release information could be obtained. Information on airborne release estimates of these contaminants was obtained from several sources, including the aforementioned Radionuclide Release Report, an update provided by Martin Marietta Energy Systems, Inc. (MMES, 1991b), a report on uranium losses from the late 1950s (Griffith, 1957) and another radionuclide release report from the mid-1980s (Owings, 1986). Additional information was also located in a series of annual reports (USDOE, 1985-1992; MMES, 1985-1992). The complete list of references is provided in Appendix G. Based on the information provided in these reports, a table summarizing both measured and estimated releases of natural uranium, uranium-234/235 and uranium-238 was created. This table is presented in Appendix G. The largest annual release occurred in 1956. As shown in Appendix G, the portion of the estimated release of natural uranium for this year that consisted of uranium-234/235 and uranium-238 was calculated based on the known composition of natural uranium. These estimates were combined with the isotopic-specific release estimates for 1956, and the resulting totals are shown in Table 5-3.

Information regarding airborne releases was located for six of the eleven chemicals released from Y-12. For one of these contaminants, mercury, only very limited airborne release information was available. The Mercury Task Force (UCC, 1983) identified total release quantities of 13,300 and 33,250 pounds of mercury for the periods 1953 through 1956 and 1957 through 1963, respectively. For the purpose of this screening-level analysis, it was assumed that the release rate was constant during these two periods, resulting in annual release estimates of 3,325 or 4,750 pounds. The higher of these two estimates, or 4,750 pounds (2,200 kg), is used in this analysis. For the remaining five chemicals, the source of information was the Historical

TABLE 5-3

PREDICTED MAXIMUM AVERAGE ANNUAL AIR CONCENTRATIONS  
OFF-SITE FOR SCREENING EVALUATION OF CONTAMINANTS RELEASED FROM Y-12

| Radionuclides     | Estimated Maximum Amount Released (Ci/yr) | Year or Time Period of Maximum Release | Emission Rate (pCi/sec) | Long-Term Dispersion Factor $(\chi/Q)^a$ (sec/m) | Predicted Air Concentration* (pCi/m) |
|-------------------|---|--|-------------------------|--|--------------------------------------|
| Neptunium-237     | NA  | NA                                     | NA                      | NA   | NA                                   |
| Plutonium-238     | ND  | ND                                     | ND                      | NA   | NA                                   |
| Plutonium-239/240 | ND  | ND                                     | ND                      | NA   | NA                                   |
| Plutonium-241     | ND  | ND                                     | ND                      | NA   | NA                                   |
| Technetium-99     | ND  | ND                                     | ND                      | NA   | NA                                   |
| Thorium-232       | ND  | ND                                     | ND                      | NA   | NA                                   |
| Tritium           | ND  | ND                                     | ND                      | NA   | NA                                   |
| Uranium-234/235   | 2.3                                       | 1956                                   | 73,000                  | $3.3 \times 10^{-7}$                             | 0.024                                |
| Uranium-238       | 1.2                                       | 1956                                   | 38,000                  | $3.3 \times 10^{-7}$                             | 0.013                                |

| Chemicals                 | Estimated Maximum Amount Released (kg/yr) | Year or Time Period of Maximum Release | Emission Rate (mg/sec) | Long-Term Dispersion Factor $(\chi/Q)^a$ (sec/m) | Predicted Air Concentration* (mg/m) |
|---------------------------|---|--|------------------------|--|-------------------------------------|
| Beryllium                 | ND  | ND                                     | ND                     | NA   | NA                                  |
| Chromium (III)            | ND  | ND                                     | ND                     | NA   | NA                                  |
| Chromium (VI)             | ND  | ND                                     | ND                     | NA   | NA                                  |
| Lead                      | ND  | ND                                     | ND                     | NA   | NA                                  |
| Mercury                   | 2,200                                     | 1957 - 1963                            | 70                     | $3.3 \times 10^{-7}$                             | 0.000023                            |
| Carbon Tetrachloride      | 720,000                                   | 1944                                   | 23,000                 | $3.3 \times 10^{-7}$                             | 0.0076                              |
| Methylene Chloride        | 13,000                                    | 1982                                   | 410                    | $3.3 \times 10^{-7}$                             | 0.00014                             |
| Polychlorinated Biphenyls | ND  | ND                                     | ND                     | NA   | NA                                  |
| Tetrachloroethylene       | 690,000                                   | 1983                                   | 22,000                 | $3.3 \times 10^{-7}$                             | 0.0073                              |
| 1,1,1-Trichloroethane     | 85,000                                    | 1982                                   | 2,700                  | $3.3 \times 10^{-7}$                             | 0.00089                             |
| Trichloroethylene         | 37  | 1980                                   | 1.2                    | $3.3 \times 10^{-7}$                             | 0.00000039                          |

NA = Not Applicable  
ND = No Data

a Corresponds to location of nearest residence, which is located approximately 0.31 miles from Y-12.

Chemical Release Report for Y-12 (MMES, 1986b). As with a similar report for K-25, the information presented in Y-12's chemical release report was not independently verified. For the purpose of this analysis, the largest quantity used during the years covered by the report was assumed to have been entirely released to the atmosphere (see Table 5-3).

#### 5.1.4 Air Dispersion Modeling

For the purposes of this air screening assessment, the Industrial Source Complex (ISC) air dispersion model is used to predict off-site contaminant concentrations in air. The ISC model is a Gaussian plume model that can account for multiple point, area, and volume sources; building downwash effects; limited terrain adjustment; and settling and dry deposition of particulates. The ISC model uses hourly meteorological data to predict average annual air concentrations at user-specified locations. High quality meteorological data are available for each plant site from the mid-1980s to the present. Specifically, meteorological data for X-10 and Y-12 are available from 1987 through 1992, and meteorological data for K-25 are available from 1986 through 1992, with the exception of 1988. The ISC model is run with a unit emission rate (e.g., 1 g/sec) to determine a long-term dispersion factor ( $\chi/Q$ ) for each emission source at each plant. This factor is expressed in units of seconds per cubic meter ( $\text{sec}/\text{m}^3$ ). For a given location, the predicted air concentration can be determined by multiplying the  $\chi/Q$  by the annual emission rate in pCi/sec or mg/sec.

In addition to a unit emission rate, other required input data for the ISC model consist of the stack parameters (i.e., height and diameter), exhaust characteristics and stack to receptor distance. These are summarized in Table 5-4 for each plant site and are based on information gathered from published reports and interviews with current plant employees. For the purpose of this analysis,  $\chi/Q$  values were determined at the locations of the nearest residences to each of the plant sites. This corresponds to approximately 2.5, 0.75 and 0.31 miles from X-10, K-25 and Y-12, respectively (Figure 5-1). Using these parameters, the ISC model was run for each year of meteorological data to determine an average  $\chi/Q$  value for each emission source (Sharp, 1993). The ISC output has been compiled in a separate document (ChemRisk, 1993d). It should be noted that settling and dry deposition were not taken into account in this screening analysis. This omission likely resulted in an over-estimation of the  $\chi/Q$  values. The average  $\chi/Q$  values that correspond to the receptor locations selected for each of the facilities and the predicted annual air concentrations for each contaminant were incorporated in Tables 5-1 through 5-3 presented earlier.

TABLE 5-4

## AIR DISPERSION MODEL INPUT PARAMETERS

| Parameter   | Value | Source/Rationale  |
|---|-------|---|
| <b>X-10 CENTRAL STACK (BUILDING 3039)</b>                   |       |   |
| Stack Height (m)  | 76    | Binford et al., 1970  |
| Stack Inside Diameter (m)                                   | 2.4   | Binford et al., 1970  |
| Stack Exit Velocity (m/sec)                                 | 12.1  | (Based on above diameter and flow rate of 120,000 cfm; Bradshaw & Cottrell, 1954) |
| Stack Exit Temperature (°K)                                 | 293   | Ambient temperature (Professional Judgement)                                      |
| Distance to Receptor (m)                                    | 4,000 | Nearest resident is approximately 2.5 miles from X-10 (ChemRisk, 1993b)           |
| <b>X-10 CHEMICAL PROCESSING PLANT STACK (BUILDING 3020)</b> |       |   |
| Stack Height (m)  | 61    | (Binford et al., 1970)  |
| Stack Inside Diameter (m)                                   | 0.91  | (Binford et al., 1970)  |
| Stack Exit Velocity (m/sec)                                 | 26    | Building 3019 Emergency Manual (based on 36,200 cfm and above diameter)           |
| Stack Exit Temperature (°K)                                 | 293   | Ambient temperature   |
| Distance to Receptor (m)                                    | 4,000 | Nearest resident is approximately 2.5 miles from X-10 (ChemRisk, 1993b)           |
| <b>X-10 GRAPHITE REACTOR STACK</b>                          |       |   |
| Stack Height (m)  | 61    | (Cowen, 1953)   |
| Stack Inside Diameter (m)                                   | 1.52  | (Leverett, Date Unknown)  |
| Stack Exit Velocity (m/sec)                                 | 31    | (Based on above diameter and 120,000 cfm; Rupp and Cox, 1955)                     |
| Stack Exit Temperature (°K)                                 | 363   | 90°C (Leverett, Date Unknown)   |
| Distance to Receptor (m)                                    | 4,000 | Nearest resident is approximately 2.5 miles from X-10 (ChemRisk, 1993b)           |

TABLE 5-4

AIR DISPERSION MODEL INPUT PARAMETERS

| Parameter                   | Value | Source/Rationale   |
|-----------------------------|-------|--|
| <b>K-25</b>                 |       |  |
| Stack Height (m)            | 23    | 1981 permit for purge cascade stack, Building 402-9 (Hodgson, 1993)  |
| Stack Inside Diameter (m)   | 0.3   | 1981 permit for purge cascade stack, Building 402-9 (Hodgson, 1993)  |
| Stack Exit Velocity (m/sec) | 9.8   | 1981 permit for purge cascade stack, Building 402-9 (Hodgson, 1993)  |
| Stack Exit Temperature (°K) | 293   | Ambient temperature  |
| Distance to Receptor (m)    | 1200  | Nearest resident is approximately 0.75 miles from K-25 (ChemRisk, 1993b)                                   |
| <b>Y-12</b>                 |       |  |
| Stack Height (m)            | 9.1   | Approximate building height, Building 9212 and 9206 (Y-12 emissions are from rooftop vents; Fellers, 1993) |
| Stack Inside Diameter (m)   | 1.4   | Health physics monitoring log books (Rutherford, 1956; Hunt 1993)  |
| Stack Exit Velocity (m/sec) | 18    | Based on data for C-wing, Building 9212 (Rutherford, 1956; Hunt 1993)                                      |
| Stack Exit Temperature (°K) | 293   | Ambient temperature  |
| Distance to Receptor (m)    | 500   | Nearest resident is approximately 0.31 miles from Y-12 (ChemRisk, 1993b)                                   |

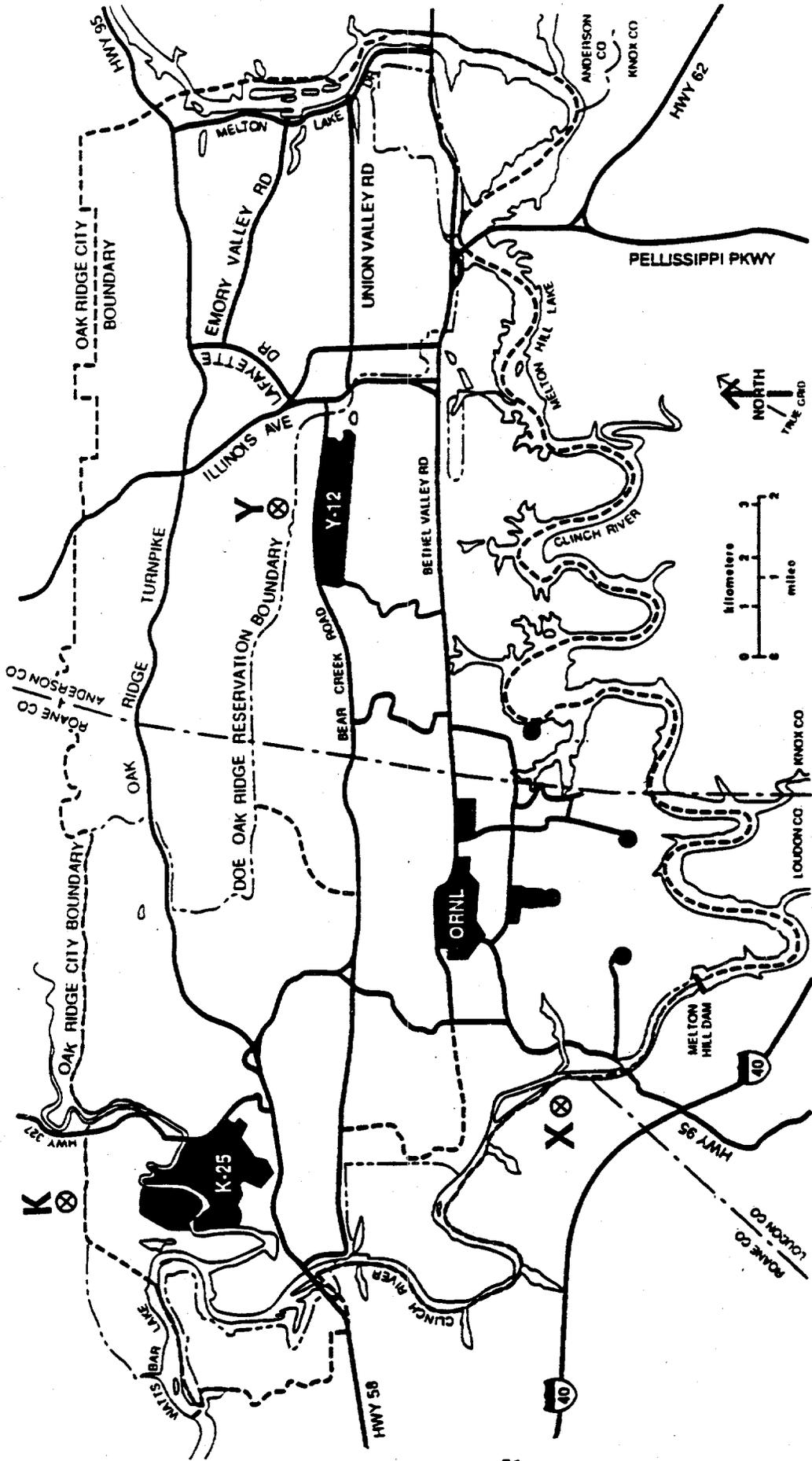


FIGURE 5-1  
LOCATION OF NEAREST RESIDENTS TO  
THE THREE OAK RIDGE PLANTS

**LEGEND**

- X Nearest resident to X-10
- K Nearest resident to K-25
- Y Nearest resident to Y-12

## 5.2 Contaminant Concentrations in Surface Water, Soil/Sediment, and Fish

Surface water, soil/sediment, and fish data were gathered from a review of data reported in approximately 100 studies of the environment on or near the ORR. These studies have been summarized in detail in the Final Tasks 1 & 2 report (ChemRisk, 1993a). In general, for a given contaminant and a given medium, the maximum concentration at or near the surface water location of interest for each of the three plant sites was selected for use in this screening evaluation. These locations represent the nearest location downstream of the plant facilities where people could have realistically come into contact with surface water. For contaminants released from X-10, data from samples collected in the Clinch River at or just downstream of the confluence of the Clinch River and White Oak Creek [Clinch River Mile (CRM) 20.8] were evaluated. Data collected in the Clinch River at its confluence with Poplar Creek (CRM 12.0) were evaluated for contaminants released from K-25, with the exception of data for technetium-99 in fish, for which data collected at Poplar Creek Mile (PCM) 0.2 were also considered. For Y-12, data collected in East Fork Poplar Creek (EFPC) between the Y-12 outfall at New Hope Pond and approximately EFPC Mile 8.8 were evaluated. It should be noted that while we have assumed that there is an association between the concentration of a contaminant at one of these locations with the release of that contaminant from a particular plant site at the ORR, in many cases, there could be other confounding factors (i.e., natural background concentrations of the contaminant, contributions from upgradient sources) that are not being considered during this feasibility study.

For the purpose of this evaluation, several assumptions regarding the available data were made:

- All reported chromium data were assumed to be chromium (III).
- Data for specific uranium isotopes in water were not reported. The value reported for total uranium was conservatively used for both uranium-234/235 and uranium-238.
- The concentrations for uranium-234 and uranium-235 in fish in the Clinch River (applicable to X-10 and K-25) were reported separately. Since the concentration of these contaminants in other media was reported as a combined value, the uranium-234 and uranium-235 concentrations in fish were summed.
- The concentration of zirconium-95 and its daughter niobium-95 in water, sediment and fish were reported as a combined value. It was therefore assumed that the concentration of each isotope was equal to one-half of the reported value.

- Measured concentrations in soil were used where available. However, in the absence of soil data, measured concentrations in sediment were used to evaluate this medium, since exposure to sediments may occur as a result of dredging and subsequent use of dredge spoils as fill material. Exposure may also occur when sediments are exposed as a result of decreasing water levels or dispersion by flood waters.

A complete listing of all of the data considered for this analysis is provided in Appendix H. The surface water, soil/sediment, and fish concentrations selected for the comparison between media are presented in Tables 5-5 through 5-7 for X-10, K-25, and Y-12, respectively.

### 5.3 Results of Comparisons Between Environmental Media

As stated earlier, the exposure pathway equations and exposure parameters described previously for the within-medium comparisons are also used in this between-media evaluation. However, in this case, the preliminary representative concentrations listed in Tables 5-1 through 5-3 and Tables 5-5 through 5-7 were used instead of unit concentrations. It should be noted that a measured concentration in fish tissue was used whenever possible. However, if only a surface water concentration was available, the fish ingestion pathway was evaluated using the surface water concentration and a contaminant-specific bioconcentration factor. Additionally, both the water ingestion and fish ingestion pathways were included in the between-media analysis if data were available in both media regardless of the relative importance of these pathways determined in the previous section. This exception was made because the relative importance of the fish ingestion pathway is based on a bioconcentration factor, which may artificially inflate the importance of this pathway.

The results of the comparisons between environmental media are summarized in the following sections. The calculation spreadsheets used in this evaluation are compiled in a separate document (ChemRisk, 1993c). It is important to note that these results are largely dependent on the information that could be gathered as part of this feasibility study. In many cases, information of varying quality and quantity had to be combined in order to achieve as complete a picture as possible regarding historical releases from the ORR. Consequently, the results presented in this report should be considered preliminary and subject to change as more information becomes available in any later stages of the health studies.

#### 5.3.1 X-10 Pathway Comparisons

The results of the between-media comparisons for contaminants released from X-10 are presented in Table 5-8. The numerical values used to create this table are presented in Appendix I. For the majority of the contaminants, air represents the most important medium.

TABLE 5-5

MAXIMUM CONTAMINANT CONCENTRATIONS MEASURED IN WATER, SEDIMENT, AND FISH  
AT OR JUST DOWNSTREAM OF THE CONFLUENCE OF THE CLINCH RIVER WITH WHITE OAK CREEK (CRM 20.8)  
ASSUMED TO RESULT FROM CONTAMINANTS RELEASED FROM X-10

| Medium | Material          | Concentration | Units | Year | Source                  | Comments   |
|--------|-------------------|---------------|-------|------|-------------------------|--|
| Water  | Barium-140        | ND            | NA    | NA   | NA                      |  |
| Water  | Cerium-144        | 4.2           | pCi/L | 1960 | UCC, 1961               |  |
| Water  | Cesium-137        | 1500          | pCi/L | 1985 | MMES, 1986c             |  |
| Water  | Cobalt-60         | 170           | pCi/L | 1985 | MMES, 1986c             |  |
| Water  | Iodine-129        | ND            | NA    | NA   | NA                      |  |
| Water  | Iodine-131        | ND            | NA    | NA   | NA                      |  |
| Water  | Iodine-133        | ND            | NA    | NA   | NA                      |  |
| Water  | Lanthanum-140     | ND            | NA    | NA   | NA                      |  |
| Water  | Niobium-95        | 0.45          | pCi/L | 1962 | UCC, 1963               | Value is one-half the reported maximum value for Zr-Nb-95.     |
| Water  | Plutonium-238     | ND            | NA    | NA   | NA                      |  |
| Water  | Plutonium-239/240 | ND            | NA    | NA   | NA                      |  |
| Water  | Plutonium-241     | ND            | NA    | NA   | NA                      |  |
| Water  | Protactinium-233  | ND            | NA    | NA   | NA                      |  |
| Water  | Ruthenium-103     | 180           | pCi/L | 1961 | UCC, 1962               | Value is one-half the reported maximum value for Ru-103/Ru-106 |
| Water  | Ruthenium-106     | 770           | pCi/L | 1962 | Cowser and Snyder, 1966 |  |
| Water  | Strontium-89      | ND            | NA    | NA   | NA                      |  |
| Water  | Strontium-90      | 350           | pCi/L | 1985 | MMES, 1986c             |  |
| Water  | Tritium           | 350,000       | pCi/L | 1985 | MMES, 1986c             |  |

TABLE 5-5

MAXIMUM CONTAMINANT CONCENTRATIONS MEASURED IN WATER, SEDIMENT, AND FISH  
 AT OR JUST DOWNSTREAM OF THE CONFLUENCE OF THE CLINCH RIVER WITH WHITE OAK CREEK (CRM 20.8)  
 ASSUMED TO RESULT FROM CONTAMINANTS RELEASED FROM X-10

| Medium   | Material          | Concentration | Units       | Year | Source         | Comments   |
|----------|-------------------|---------------|-------------|------|----------------|--|
| Water    | Uranium-234/235   | 20            | pCi/L       | 1976 | UCC, 1977      | Value reported as uranium only; value for specific isotopes assumed to be the same as for total uranium. |
| Water    | Uranium-238       | 20            | pCi/L       | 1976 | UCC, 1977      | Value reported as uranium only; value for specific isotopes assumed to be the same as for total uranium. |
| Water    | Zirconium-95      | 0.45          | pCi/L       | 1962 | UCC, 1963      | Value is one-half the reported maximum value for Zr-Nb-95.   |
|          |                   |               |             |      |                |  |
| Sediment | Barium-140        | ND            | NA          | NA   | NA             |  |
| Sediment | Cerium-144        | 68            | pCi/g (dry) | 1967 | UCC, 1968      |  |
| Sediment | Cesium-137        | 660           | pCi/g (dry) | 1967 | UCC, 1968      |  |
| Sediment | Cobalt-60         | 59            | pCi/g (dry) | 1956 | Cottrell, 1960 |  |
| Sediment | Iodine-129        | ND            | NA          | NA   | NA             |  |
| Sediment | Iodine-131        | ND            | NA          | NA   | NA             |  |
| Sediment | Iodine-133        | ND            | NA          | NA   | NA             |  |
| Sediment | Lanthanum-140     | ND            | NA          | NA   | NA             |  |
| Sediment | Niobium-95        | 3.1           | pCi/g (dry) | 1962 | UCC, 1963      | Value is one-half the reported maximum value for Zr-Nb-95.   |
| Sediment | Plutonium-238     | ND            | NA          | NA   | NA             |  |
| Sediment | Plutonium-239/240 | ND            | NA          | NA   | NA             |  |
| Sediment | Plutonium-241     | ND            | NA          | NA   | NA             |  |
| Sediment | Protactinium-233  | ND            | NA          | NA   | NA             |  |

TABLE 5-5

MAXIMUM CONTAMINANT CONCENTRATIONS MEASURED IN WATER, SEDIMENT, AND FISH  
AT OR JUST DOWNSTREAM OF THE CONFLUENCE OF THE CLINCH RIVER WITH WHITE OAK CREEK (CRM 20.8)  
ASSUMED TO RESULT FROM CONTAMINANTS RELEASED FROM X-10

| Medium   | Material        | Concentration | Units        | Year    | Source            | Comments  |
|----------|-----------------|---------------|--------------|---------|-------------------|---|
| Sediment | Ruthenium-103   | 43            | pCi/g (dry)  | 1961    | UCC, 1962         | Value is one-half the reported maximum value for Ru-103/Ru-106  |
| Sediment | Ruthenium-106   | 95            | pCi/g (dry)  | 1961    | UCC, 1962         |   |
| Sediment | Strontium-89    | 1             | pCi/g (dry)  | 1984    | TVA, 1985b        |   |
| Sediment | Strontium-90    | 11            | pCi/g (dry)  | 1958    | Cottrell, 1960    |   |
| Sediment | Uranium-234/235 | 2.1           | pCi/g (dry)  | 1989-90 | Cook et al., 1992 | Value is sum of reported values for U-234 and U-235. Samples collected between CRM 12 and CRM 23.1; exact locations not reported. |
| Sediment | Uranium-238     | 1.8           | pCi/g (dry)  | 1989-90 | Cook et al., 1992 | Sample collected between CRM 12 and CRM 23.1; exact location not reported.  |
| Sediment | Zirconium-95    | 3.1           | pCi/g (dry)  | 1962    | UCC, 1963         | Value is one-half the reported maximum value for Zr-Nb-95   |
|          |                 |               |              |         |                   |   |
| Fish     | Barium-140      | ND            | NA           | NA      | NA                |   |
| Fish     | Cerium-144      | ND            | NA           | NA      | NA                |   |
| Fish     | Cesium-137      | 10,000        | pCi/kg (wet) | 1978    | UCC, 1979         |   |
| Fish     | Cobalt-60       | 140           | pCi/kg (wet) | 1981    | UCC, 1982         |   |
| Fish     | Iodine-129      | ND            | NA           | NA      | NA                |   |
| Fish     | Iodine-131      | ND            | NA           | NA      | NA                |   |
| Fish     | Iodine-133      | ND            | NA           | NA      | NA                |   |
| Fish     | Lanthanum-140   | ND            | NA           | NA      | NA                |   |
| Fish     | Niobium-95      | 56            | pCi/kg (wet) | 1976    | UCC, 1977         | Value is one-half the reported maximum value for Zr-Nb-95.  |

TABLE 5-5

MAXIMUM CONTAMINANT CONCENTRATIONS MEASURED IN WATER, SEDIMENT, AND FISH  
AT OR JUST DOWNSTREAM OF THE CONFLUENCE OF THE CLINCH RIVER WITH WHITE OAK CREEK (CRM 20.8)  
ASSUMED TO RESULT FROM CONTAMINANTS RELEASED FROM X-10

| Medium | Material          | Concentration | Units        | Year | Source    | Comments  |
|--------|-------------------|---------------|--------------|------|-----------|---|
| Fish   | Plutonium-238     | 0.88          | pCi/kg (wet) | 1979 | UCC, 1980 |   |
| Fish   | Plutonium-239/240 | 0.88          | pCi/kg (wet) | 1979 | UCC, 1980 |   |
| Fish   | Plutonium-241     | ND            | NA           | NA   | NA        |   |
| Fish   | Protactinium-233  | ND            | NA           | NA   | NA        |   |
| Fish   | Ruthenium-103     | ND            | NA           | NA   | NA        |   |
| Fish   | Ruthenium-106     | 6,500         | pCi/kg (wet) | 1965 | UCC, 1966 | Exact location of sample collection on the Clinch River not reported. |
| Fish   | Strontium-89      | ND            | NA           | NA   | NA        |   |
| Fish   | Strontium-90      | 1,100         | pCi/kg (wet) | 1976 | UCC, 1977 |   |
| Fish   | Uranium-234/235   | 6.4           | pCi/kg (wet) | 1981 | UCC, 1982 | Value is sum of reported values for U-234 and U-235.                  |
| Fish   | Uranium-238       | 3.7           | pCi/kg (wet) | 1981 | UCC, 1982 |   |
| Fish   | Zirconium-95      | 56            | pCi/kg (wet) | 1976 | UCC, 1977 | Value is one-half the reported maximum value for Zr-Nb-95.            |

NA = Not Available

ND = No Data

TABLE 5-6

MAXIMUM CONTAMINANT CONCENTRATIONS MEASURED IN WATER, SEDIMENT, AND FISH  
 IN THE CLINCH RIVER AT OR JUST DOWNSTREAM OF ITS CONFLUENCE WITH POPLAR CREEK (CRM 12.0)  
 ASSUMED TO RESULT FROM CONTAMINANTS RELEASED FROM K-25

| Medium | Material        | Concentration | Units | Year    | Source            | Comments   |
|--------|-----------------|---------------|-------|---------|-------------------|--|
| Water  | Neptunium-237   | ND            | NA    | NA      | NA                |  |
| Water  | Plutonium-239   | ND            | NA    | NA      | NA                |  |
| Water  | Technetium-99   | 0.73          | pCi/L | 1984    | TVA, 1985a        |  |
| Water  | Uranium-234/235 | 21            | pCi/L | 1978    | UCC, 1979         | Value reported as uranium only;<br>value for specific isotopes assumed<br>to be the same as for total uranium. |
| Water  | Uranium-238     | 21            | pCi/L | 1978    | UCC, 1979         | Value reported as uranium only;<br>value for specific isotopes assumed<br>to be the same as for total uranium. |
| Water  | Beryllium       | <0.001        | mg/L  | 1984    | TVA, 1985a        |  |
| Water  | Chromium (III)  | 0.06          | mg/L  | 1972    | UCC, 1973         | Maximum reported value for total<br>chromium; assumed to be Cr(III)  |
| Water  | Chromium (VI)   | ND            | NA    | NA      | NA                |  |
| Water  | Nickel          | 0.2           | mg/L  | 1980    | UCC, 1981         |  |
| Water  | PCBs            | <0.001        | mg/L  | 1989-90 | Cook et al., 1992 |  |

TABLE 5-6

MAXIMUM CONTAMINANT CONCENTRATIONS MEASURED IN WATER, SEDIMENT, AND FISH  
 IN THE CLINCH RIVER AT OR JUST DOWNSTREAM OF ITS CONFLUENCE WITH POPLAR CREEK (CRM 12.0)  
 ASSUMED TO RESULT FROM CONTAMINANTS RELEASED FROM K-25

| Medium   | Material          | Concentration | Units       | Year    | Source               | Comments   |
|----------|-------------------|---------------|-------------|---------|----------------------|--|
| Sediment | Neptunium-237     | ND            | NA          | NA      | NA                   |  |
| Sediment | Plutonium-238     | 0.07          | pCi/g (dry) | 1989-90 | Cook et al., 1992    | Sample collected between CRM 0 and CRM 12; exact location not reported |
| Sediment | Plutonium-239/240 | 1.57          | pCi/g (dry) | 1989-90 | Cook et al., 1992    | Sample collected between CRM 0 and CRM 12; exact location not reported |
| Sediment | Technetium-99     | ND            | NA          | NA      | NA                   |  |
| Sediment | Uranium-234/235   | 6.2           | pCi/g (dry) | 1989-90 | Cook et al., 1992    | Sample collected between CRM 0 and CRM 12; exact location not reported |
| Sediment | Uranium-238       | 4.0           | pCi/g (dry) | 1989-90 | Cook et al., 1992    | Sample collected between CRM 0 and CRM 12; exact location not reported |
| Sediment | Beryllium         | 1.6           | mg/kg (dry) | 1989-90 | Cook et al., 1992    | Sample collected between CRM 0 and CRM 12; exact location not reported |
| Sediment | Chromium (III)    | 244           | mg/kg (dry) | 1979    | UCC, 1980            | Maximum reported value for total chromium; assumed to be Cr(III)       |
| Sediment | Chromium (VI)     | ND            | NA          | NA      | NA                   |  |
| Soil     | Technetium-99     | 1.7           | pCi/g       | 1979    | Hoffman et al., 1980 | Collected at the fence-line perimeter of the K-25 site                 |

TABLE 5-6

MAXIMUM CONTAMINANT CONCENTRATIONS MEASURED IN WATER, SEDIMENT, AND FISH  
IN THE CLINCH RIVER AT OR JUST DOWNSTREAM OF ITS CONFLUENCE WITH POPLAR CREEK (CRM 12.0)  
ASSUMED TO RESULT FROM CONTAMINANTS RELEASED FROM K-25

| Medium   | Material        | Concentration | Units        | Year    | Source            | Comments   |
|----------|-----------------|---------------|--------------|---------|-------------------|--|
| Sediment | Nickel          | 58            | mg/kg (dry)  | 1989-90 | Cook et al., 1992 | Sample collected between CRM 0 and CRM 12; exact location not reported |
| Sediment | PCBs            | <0.1          | mg/kg (dry)  | 1979    | UCC, 1980         |  |
| Fish     | Neptunium-237   | ND            | NA           | NA      | NA                |  |
| Fish     | Plutonium-238   | 0.88          | pCi/kg (wet) | 1979    | UCC, 1980         |  |
| Fish     | Plutonium-239   | 0.88          | pCi/kg (wet) | 1979    | UCC, 1980         |  |
| Fish     | Technetium-99   | 490           | pCi/kg (wet) | 1984    | TVA 1985c         |  |
| Fish     | Uranium-234/235 | 56            | pCi/kg (wet) | 1984    | MMES, 1985        | Value is sum of reported values for U-234 and U-235                    |
| Fish     | Uranium-238     | 30            | pCi/kg (wet) | 1984    | MMES, 1985        |  |
| Fish     | Beryllium       | <0.003        | mg/kg (wet)  | 1989-90 | Cook et al., 1992 |  |
| Fish     | Chromium (III)  | 0.92          | mg/kg (wet)  | 1977    | Loar et al., 1981 | Maximum reported value for total chromium; assumed to be Cr(III)       |
| Fish     | Chromium (VI)   | ND            | NA           | NA      | NA                |  |
| Fish     | Nickel          | 1.2           | mg/kg (wet)  | 1977    | Loar et al., 1981 |  |
| Fish     | PCBs            | 12            | mg/kg(wet)   | 1984    | TVA, 1985c        |  |

NA = Not Applicable  
ND = No Data

TABLE 5-7

MAXIMUM CONTAMINANT CONCENTRATIONS MEASURED IN EAST FORK POPLAR CREEK WATER, SEDIMENT OR FLOODPLAIN SOIL, AND FISH AT OR NEAR EAST FORK POPLAR CREEK MILE 13.5 ASSUMED TO RESULT FROM CONTAMINANTS RELEASED FROM Y-12

| Medium | Material          | Concentration | Units | Year | Source     | Comments  |
|--------|-------------------|---------------|-------|------|------------|---|
| Water  | Neptunium-237     | ND            | NA    | NA   | NA         |   |
| Water  | Plutonium-238     | ND            | NA    | NA   | NA         |   |
| Water  | Plutonium-239/240 | ND            | NA    | NA   | NA         |   |
| Water  | Plutonium-241     | ND            | NA    | NA   | NA         |   |
| Water  | Technetium-99     | ND            | NA    | NA   | NA         |   |
| Water  | Thorium-232       | ND            | NA    | NA   | NA         |   |
| Water  | Tritium           | 400           | pCi/L | 1984 | TVA, 1985a |   |
| Water  | Uranium-234/235   | 1,000         | pCi/L | 1972 | UCC, 1973  | Value reported as uranium only; value for specific isotopes assumed to be the same as for total uranium |
| Water  | Uranium-238       | 1,000         | pCi/L | 1972 | UCC, 1973  | Value reported as uranium only; value for specific isotopes assumed to be the same as for total uranium |
| Water  | Beryllium         | <0.001        | mg/L  | 1984 | TVA, 1985a |   |
| Water  | Chromium (III)    | 0.55          | mg/L  | 1971 | UCC, 1972  | Maximum reported value for total chromium; assumed to be Cr(III)  |
| Water  | Chromium (VI)     | ND            | NA    | NA   | NA         |   |
| Water  | Lead              | 0.4           | mg/L  | 1974 | UCC, 1975  |   |
| Water  | Mercury           | 0.026         | mg/L  | 1984 | TVA, 1985a |   |
| Water  | PCBs              | <0.0001       | mg/L  | 1984 | TVA, 1985a |   |

TABLE 5-7

MAXIMUM CONTAMINANT CONCENTRATIONS MEASURED IN EAST FORK POPLAR CREEK WATER, SEDIMENT OR FLOODPLAIN SOIL, AND FISH AT OR NEAR EAST FORK POPLAR CREEK MILE 13.5 ASSUMED TO RESULT FROM CONTAMINANTS RELEASED FROM Y-12

| Medium        | Material          | Concentration | Units | Year | Source         | Comments  |
|---------------|-------------------|---------------|-------|------|----------------|---|
| Sediment/Soil | Neptunium-237     | ND            | NA    | NA   | NA             |   |
| Sediment      | Plutonium-238     | 0.013         | pCi/g | 1984 | Hibbitts, 1984 |   |
| Sediment/Soil | Plutonium-239/240 | ND            | NA    | NA   | NA             |   |
| Sediment/Soil | Plutonium-241     | ND            | NA    | NA   | NA             |   |
| Sediment/Soil | Technetium-99     | ND            | NA    | NA   | NA             |   |
| Soil          | Thorium-232       | 10            | pCi/g | 1984 | Hibbitts, 1984 | Value measured in the EFPC floodplain   |
| Sediment/Soil | Tritium           | ND            | NA    | NA   | NA             |   |
| Soil          | Uranium-234/235   | 5.9           | pCi/g | 1984 | Hibbitts, 1984 | Value measured in the EFPC floodplain   |
| Soil          | Uranium-238       | 70            | pCi/g | 1984 | Hibbitts, 1984 | Value measured in the EFPC floodplain   |
| Soil          | Beryllium         | 1.2           | mg/kg | 1983 | Hibbitts, 1984 | Value measured in the EFPC floodplain   |
| Soil          | Chromium (III)    | 220           | mg/kg | 1984 | Hibbitts, 1984 | Value measured in the EFPC floodplain. Maximum reported value for total chromium; assumed to be CR(III) |
| Sediment/Soil | Chromium (VI)     | ND            | NA    | NA   | NA             |   |
| Soil          | Lead              | 260           | mg/kg | 1984 | Hibbitts, 1984 | Value measured in the EFPC floodplain   |
| Soil          | Mercury           | 2,100         | mg/kg | 1984 | Hibbitts, 1984 | Value measured in the EFPC floodplain   |

TABLE 5-7

MAXIMUM CONTAMINANT CONCENTRATIONS MEASURED IN EAST FORK POPLAR CREEK WATER, SEDIMENT OR FLOODPLAIN SOIL, AND FISH AT OR NEAR EAST FORK POPLAR CREEK MILE 13.5 ASSUMED TO RESULT FROM CONTAMINANTS RELEASED FROM Y-12

| Medium | Material          | Concentration | Units       | Year | Source                  | Comments   |
|--------|-------------------|---------------|-------------|------|-------------------------|--|
| Soil   | PCBs              | 6.8           | mg/kg       | 1984 | Hibbitts, 1984          |  |
| Fish   | Neptunium-237     | ND            | NA          | NA   | NA                      |  |
| Fish   | Plutonium-238     | ND            | NA          | NA   | NA                      |  |
| Fish   | Plutonium-239/240 | ND            | NA          | NA   | NA                      |  |
| Fish   | Plutonium-241     | ND            | NA          | NA   | NA                      |  |
| Fish   | Technetium-99     | 1.4           | pCi/g (wet) | 1984 | TVA, 1985c              |  |
| Fish   | Thorium-232       | ND            | NA          | NA   | NA                      |  |
| Fish   | Tritium           | ND            | NA          | NA   | NA                      |  |
| Fish   | Uranium-234/235   | ND            | NA          | NA   | NA                      |  |
| Fish   | Uranium-238       | ND            | NA          | NA   | NA                      |  |
| Fish   | Beryllium         | <0.100        | mg/kg (wet) | 1984 | TVA, 1985c              |  |
| Fish   | Chromium (III)    | 0.14          | mg/kg (wet) | 1984 | TVA, 1985c              | Maximum reported value for total chromium; assumed to be Cr(III) |
| Fish   | Chromium (VI)     | ND            | NA          | NA   | NA                      |  |
| Fish   | Lead              | 0.23          | mg/kg (wet) | 1984 | TVA, 1985c              |  |
| Fish   | Mercury           | 2.7           | mg/kg (wet) | 1982 | Van Winkle et al., 1982 |  |
| Fish   | PCBs              | 1.7           | mg/kg (wet) | 1984 | TVA, 1985c              |  |

NA = Not Applicable

ND = No Data

0

TABLE 5-8

**RELATIVE IMPORTANCE OF EXPOSURES TO CONTAMINANTS  
IN ENVIRONMENTAL MEDIA BASED ON HIGHEST IDENTIFIED CONCENTRATIONS  
X-10 RELEASES<sup>a</sup>**

| Material             | Air | Surface Water | Soil/Sediment |
|----------------------|-----|---------------|---------------|
| <b>Radionuclides</b> |     |               |               |
| Argon-41             | ■   | NA            | NA            |
| Barium-140           | ■   | ND            | ND            |
| Cerium-144           | ■   | 49%           | 20%           |
| Cesium-137           | <1% | 71%           | ■             |
| Cobalt-60            | NA  | ■             | 42%           |
| Iodine-129           | ■   | ND            | ND            |
| Iodine-131           | ■   | ND            | ND            |
| Iodine-133           | ■   | ND            | ND            |
| Krypton-85           | ■   | NA            | NA            |
| Lanthanum-140        | ■   | ND            | ND            |
| Niobium-95           | ■   | <1%           | <1%           |
| Plutonium-238        | ND  | ■             | ND            |
| Plutonium-239        | ■   | 35%           | ND            |
| Protactinium-233     | ■   | ND            | ND            |
| Ruthenium-103        | 13% | ■             | 14%           |
| Ruthenium-106        | <1% | ■             | 8%            |
| Strontium-89         | ■   | ND            | 9%            |
| Strontium-90         | <1% | ■             | 18%           |
| Uranium-234/235      | <1% | ■             | 7%            |
| Uranium-238          | 7%  | ■             | 6%            |
| Xenon-133            | ■   | NA            | NA            |
| Zirconium-95         | ■   | 2%            | 1%            |

NA = Not Applicable  
 ND = No Data

a For each material, the medium associated with the highest health hazard (i.e., cancer risk or hazard index) is marked by a ■ (dominant medium). The relative magnitude of the health hazard associated with exposure to the contaminant in other media is indicated in terms of the percent of the dominant medium.

Surface water was the most important medium for all but one of the remaining contaminants. In addition, when information was available for more than a single medium, the most important medium generally dominated significantly over the other media. For example, air, surface water, and soil/sediment concentrations were predicted or measured for nine contaminants (cerium-144, cesium-137, niobium-95, ruthenium-103, ruthenium-106, strontium-90, uranium-234/235, uranium-238, and zirconium-95). In all but two of these nine cases, i.e., cerium-144 and cesium-137, the next closest medium was generally less than 20%, and often less than 1%, of the most important medium. Only with cerium-144 and cesium-137 were the estimated exposures distributed somewhat evenly over two or all three media. These results indicate that exposure pathways associated with the air medium represent the most significant pathways for the majority of contaminants released from X-10.

### 5.3.2 K-25 Pathway Comparisons

Table 5-9 presents the results of the between-media comparisons for contaminants released from K-25. The most important medium with respect to historical off-site exposure to these contaminants is nearly equally divided among air, surface water, and soil/sediment. For K-25, information for all three media were available for only four contaminants (technetium-99, uranium-234/235, uranium-238, and nickel). For technetium-99 and nickel, the most important medium (soil/sediment and surface water, respectively) clearly dominates over the other two media. On the other hand, the estimated exposures for uranium-234/235 and uranium-238 were distributed somewhat evenly over two media.

### 5.3.3 Y-12 Pathway Comparisons

The results of the between-media comparisons for contaminants released from Y-12 are presented in Table 5-10. The results from the comparison between media for Y-12 are very similar to those from K-25. Again, the most important medium for the various contaminants is nearly equally divided among air, surface water, and soil/sediment. Information for all three media were available for only three contaminants (uranium-234/235, uranium-238, and mercury). For mercury, exposures associated with one medium clearly dominate over the other two. However, for uranium-234/235 and uranium-238, exposure estimates are distributed more evenly over two or three media, respectively.

### 5.3.4 Summary of Comparisons Between Environmental Media

In summary, the results of the comparisons between media for contaminants released from all three plant sites indicate that exposures to contaminants in a single medium in some cases clearly dominate over exposures to contaminants in other media. For the X-10 site, these preliminary results suggest that airborne releases represent the most significant contributor to historical

TABLE 5-9

**RELATIVE IMPORTANCE OF EXPOSURES TO CONTAMINANTS  
IN ENVIRONMENTAL MEDIA BASED ON HIGHEST IDENTIFIED CONCENTRATIONS  
K-25 RELEASES<sup>a</sup>**

| Material                         | Air  | Surface Water | Soil/Sediment |
|----------------------------------|------|---------------|---------------|
| <b>RADIONUCLIDES</b>             |      |               |               |
| Neptunium-237                    | NA   | ND            | ND            |
| Plutonium-238                    | NA   | ■             | 38%           |
| Plutonium-239                    | NA   | 12%           | ■             |
| Technetium-99                    | < 1% | < 1%          | ■             |
| Uranium-234/235                  | ■    | 89%           | 2%            |
| Uranium-238                      | ■    | 70%           | 9%            |
| <b>CARCINOGENIC CHEMICALS</b>    |      |               |               |
| Beryllium                        | ND   | ND            | ■             |
| Carbon Tetrachloride             | ■    | NA            | NA            |
| Chromium(VI)                     | ND   | ND            | ND            |
| Methylene Chloride               | ■    | NA            | NA            |
| Polychlorinated Biphenyls        | ND   | ■             | ND            |
| Trichloroethylene                | ■    | NA            | NA            |
| <b>NONCARCINOGENIC CHEMICALS</b> |      |               |               |
| Chromium(III)                    | ND   | ■             | 85%           |
| Nickel                           | 1%   | ■             | 12%           |
| 1,1,1-Trichloroethane            | ■    | NA            | NA            |

NA = Not Applicable  
ND = No Data

a For each material, the medium associated with the highest health hazard (i.e., cancer risk or hazard index) is marked by a ■ (dominant medium). The relative magnitude of the health hazard associated with exposure to the contaminant in other media is indicated in terms of the percent of the dominant medium.

TABLE 5-10

**RELATIVE IMPORTANCE OF EXPOSURES TO CONTAMINANTS  
IN ENVIRONMENTAL MEDIA BASED ON HIGHEST IDENTIFIED CONCENTRATIONS  
Y-12 RELEASES<sup>a</sup>**

| Material                         | Air | Surface Water | Soil/Sediment |
|----------------------------------|-----|---------------|---------------|
| <b>RADIONUCLIDES</b>             |     |               |               |
| Neptunium-237                    | NA  | ND            | ND            |
| Plutonium-238                    | ND  | ND            | ■             |
| Technetium-99                    | ND  | ■             | ND            |
| Thorium-232                      | ND  | ND            | ■             |
| Uranium-234/235                  | 55% | ■             | 2%            |
| Uranium-238                      | 31% | ■             | 30%           |
| <b>CARCINOGENIC CHEMICALS</b>    |     |               |               |
| Beryllium                        | ND  | ND            | ■             |
| Carbon Tetrachloride             | ■   | NA            | NA            |
| Chromium(VI)                     | ND  | ND            | ND            |
| Methylene Chloride               | ■   | NA            | NA            |
| Polychlorinated Biphenyls        | ND  | ■             | 25%           |
| Tetrachloroethylene              | ■   | NA            | NA            |
| Trichlorethylene                 | ■   | NA            | NA            |
| <b>NONCARCINOGENIC CHEMICALS</b> |     |               |               |
| Chromium(III)                    | ND  | 20%           | ■             |
| Lead                             | ND  | 6%            | ■             |
| Mercury                          | <1% | <1%           | ■             |
| 1,1,1-Trichloroethane            | ■   | NA            | NA            |

NA = Not Applicable  
 ND = No Data

a For each material, the medium associated with the highest health hazard (i.e., cancer risk or hazard index) is marked by a ■ (dominant medium). The relative magnitude of the health hazard associated with exposure to the contaminant in other media is indicated in terms of the percent of the dominant medium.

off-site health impacts. For K-25 and Y-12, exposures to contaminants in each of the three media, i.e., air, surface water, or soil/sediment, are dominant for at least one of the contaminants that were evaluated. While these preliminary analyses are not sufficient to suggest that one or more media could be eliminated from further consideration, they should aid in focussing initial study efforts in any future health studies.

#### 5.4 Relative Importance of Releases from the Oak Ridge Reservation

Although preliminary, the results of this analysis can be used to begin to put into perspective the relative importance of the releases of different contaminants from the ORR. Using the quantitative results from the between-media comparison (Appendix I), the radionuclides, carcinogenic chemicals and noncarcinogenic chemicals have each been ranked as shown in Table 5-11. When looking at this table, it is important to keep in mind that the screening hazard values from one group (i.e., radionuclides, carcinogenic chemicals or noncarcinogenic chemicals) cannot be compared to the screening hazard values from another group. It is also important to note that the values presented in this table are based on data of varying quality and that this analysis contains numerous assumptions, and the absolute magnitude of the screening values have no real meaning. Any interpretations of these data should focus on the relative magnitudes of the potential hazards of contaminants within each group with respect to other contaminants within the same group. Since the data used to produce the ranking come from various sources having somewhat different levels of conservatism built into them, caution should also be exercised in placing too much emphasis on the exact rank order of the contaminants. Instead, emphasis should be placed on comparing the order-of-magnitude of the hazards posed, recognizing that, due to inconsistency in the assumptions, the rank order of any one contaminant could actually fall anywhere within the particular order-of-magnitude estimate.

For radionuclides, the release of iodine-131 from X-10 represents the most important contaminant with respect to potential off-site health impacts from maximum, single-year releases. Iodine-133 and cesium-137 releases from X-10 are also considered important, since they represent approximately 60% and 6% of the screening hazard value calculated for iodine-131, respectively. The screening hazard values for the remaining radionuclides are less than or equal to 2% of the value for iodine-131.

Because radioiodine has been identified as a high priority material, several factors pertaining to radioiodine exposures should be noted. First, it is important to point out that the screening calculations described in this report did not take into account the radioactive decay of radionuclides between the time of emission from the Oak Ridge facilities and the time of human intake. Because of this, actual off-site intakes of iodine-133 (20.3 hours) were likely lower than indicated by about a factor of ten or more, depending on the length of time assumed between release and consumption. Estimates of iodine-131 (8.05 days) intakes are more accurate because

TABLE 5-11

## PRELIMINARY RANKING OF POTENTIAL HAZARDS\*

| Material             | Location | Screening Hazard Value | Relative Hazard Ranking |
|----------------------|----------|------------------------|-------------------------|
| <b>RADIONUCLIDES</b> |          |                        |                         |
| Iodine-131           | X-10     | $1 \times 10^{-3}$     | 100%                    |
| Iodine-133           | X-10     | $6 \times 10^{-4}$     | 60%                     |
| Cesium-137           | X-10     | $6 \times 10^{-5}$     | 6%                      |
| Uranium-234/235      | Y-12     | $2 \times 10^{-5}$     | 2%                      |
| Uranium-238          | Y-12     | $2 \times 10^{-5}$     | 2%                      |
| Strontium-90         | X-10     | $2 \times 10^{-5}$     | 2%                      |
| Tritium              | X-10     | $1 \times 10^{-5}$     | 1%                      |
| Protactinium-233     | X-10     | $9 \times 10^{-6}$     | 0.9%                    |
| Technetium-99        | K-25     | $9 \times 10^{-6}$     | 0.9%                    |
| Ruthenium-106        | X-10     | $8 \times 10^{-6}$     | 0.8%                    |
| Niobium-95           | X-10     | $4 \times 10^{-6}$     | 0.4%                    |
| Uranium-238          | K-25     | $4 \times 10^{-6}$     | 0.4%                    |
| Uranium-234/235      | K-25     | $3 \times 10^{-6}$     | 0.4%                    |
| Thorium-232          | Y-12     | $3 \times 10^{-6}$     | 0.3%                    |
| Cobalt-60            | X-10     | $2 \times 10^{-6}$     | 0.2%                    |
| Uranium-234/235      | X-10     | $2 \times 10^{-6}$     | 0.2%                    |
| Uranium-238          | X-10     | $1 \times 10^{-6}$     | 0.2%                    |
| Cerium-144           | X-10     | $3 \times 10^{-7}$     | 0.03%                   |
| Ruthenium-103        | X-10     | $3 \times 10^{-7}$     | 0.03%                   |
| Plutonium-239/240    | K-25     | $2 \times 10^{-7}$     | 0.02%                   |
| Strontium-89         | X-10     | $2 \times 10^{-7}$     | 0.02%                   |
| Zirconium-95         | X-10     | $1 \times 10^{-7}$     | 0.01%                   |
| Argon-41             | X-10     | $1 \times 10^{-7}$     | 0.01%                   |
| Plutonium-239/240    | X-10     | $7 \times 10^{-8}$     | 0.007%                  |
| Barium-140           | X-10     | $7 \times 10^{-8}$     | 0.007%                  |
| Lanthanum-140        | X-10     | $6 \times 10^{-8}$     | 0.006%                  |
| Plutonium-238        | K-25     | $2 \times 10^{-8}$     | 0.002%                  |
| Plutonium-238        | X-10     | $2 \times 10^{-8}$     | 0.002%                  |
| Xenon-133            | X-10     | $2 \times 10^{-8}$     | 0.002%                  |

TABLE 5-11

PRELIMINARY RANKING OF POTENTIAL HAZARDS<sup>a</sup>

| Material                         | Location | Screening Hazard Value | Relative Hazard Ranking |
|----------------------------------|----------|------------------------|-------------------------|
| Technetium-99                    | Y-12     | $1 \times 10^{-8}$     | 0.001%                  |
| Plutonium-238                    | Y-12     | $1 \times 10^{-9}$     | 0.0001%                 |
| Iodine-129                       | X-10     | $1 \times 10^{-10}$    | 0.00001%                |
| Krypton-85                       | X-10     | $5 \times 10^{-12}$    | 0.0000005%              |
| <b>CARCINOGENIC CHEMICALS</b>    |          |                        |                         |
| PCBs                             | K-25     | $4 \times 10^{-4}$     | 100%                    |
| PCBs                             | Y-12     | $8 \times 10^{-5}$     | 20%                     |
| Carbon Tetrachloride             | Y-12     | $6 \times 10^{-7}$     | 0.1%                    |
| Beryllium                        | K-25     | $2 \times 10^{-7}$     | 0.04%                   |
| Beryllium                        | Y-12     | $1 \times 10^{-7}$     | 0.03%                   |
| Methylene Chloride               | Y-12     | $4 \times 10^{-8}$     | 0.009%                  |
| Tetrachloroethylene              | Y-12     | $2 \times 10^{-8}$     | 0.005%                  |
| Carbon Tetrachloride             | K-25     | $2 \times 10^{-8}$     | 0.005%                  |
| Trichloroethylene                | K-25     | $3 \times 10^{-9}$     | 0.001%                  |
| Methylene Chloride               | K-25     | $1 \times 10^{-10}$    | 0.00003%                |
| Trichloroethylene                | Y-12     | $4 \times 10^{-12}$    | 0.000001%               |
| <b>NONCARCINOGENIC CHEMICALS</b> |          |                        |                         |
| Mercury                          | Y-12     | $1 \times 10^{+3}$     | 100%                    |
| Lead                             | Y-12     | $9 \times 10^{-1}$     | 0.07%                   |
| Nickel                           | K-25     | $2 \times 10^{-1}$     | 0.01%                   |
| 1,1,1-Trichloroethane            | K-25     | $3 \times 10^{-3}$     | 0.0002%                 |
| Chromium (III)                   | K-25     | $2 \times 10^{-3}$     | 0.0002%                 |
| Chromium (III)                   | Y-12     | $1 \times 10^{-3}$     | 0.0001%                 |
| 1,1,1-Trichloroethane            | Y-12     | $3 \times 10^{-4}$     | 0.00002%                |

- a The screening hazard values for one group (i.e., radionuclides, carcinogenic chemicals or noncarcinogenic chemicals) are not comparable to the screening hazard values for another group.

of its longer half-life. At the same time, some key factors relating to the dosimetry of radioiodine indicate that actual doses and health risks to specific organs and population age groups could have been significantly higher than the adult effective doses and corresponding health risks that have been calculated and presented in this report as screening estimates:

- The actual magnitude of radioiodine present in food products is largely a function of the chemical form of iodine that was released. Elemental iodine ( $I_2$ ) is most reactive, and releases in this form will generally result in the highest doses. Organic forms (e.g.,  $CH_3I$ ) are less reactive, acting almost like noble gases in the environment. When released to the environment, organic forms of radioiodine will generally result in significantly lower doses than will releases of elemental iodine. The chemical forms of radioiodine that were released from X-10 processes have not yet been characterized.
- Iodine can enter the human body via inhalation or ingestion. After intake, iodine concentrates in the thyroid gland, which is located in the neck. As a result of this concentration by a factor of about 1000 to 1 compared to the blood (Sagan, 1982), the highest radiation doses after intake of radioiodine occur in the thyroid. After intake of iodine-131, committed dose equivalent to the thyroid exceeds the dose to any other organ by over a factor of 1000 (ICRP, 1990b). A tissue weighing factor of 0.05 is applied to thyroid doses when calculating effective dose equivalents, per ICRP's 1990 recommendations, to account for the low probability of radiation-induced mortality from thyroid cancer with respect to what would occur if a similar level of dose were to be applied uniformly over the entire body (ICRP, 1990a).
- Examination of age-dependant dose conversion factors shows that the highest thyroid doses per unit intake of iodine-131 activity occur in infants and children. This is due primarily to enhanced thyroid uptake in the newborn (ICRP, 1990b) and the distribution of radiation energy in a thyroid gland that is considerably smaller in infants and children than in adults. For example, the mass of a child's thyroid before age two is about 1 to 2 grams, compared to mean weights of 15 and 18 grams for female and male adults, respectively (ICRP, 1975)). Because absorbed dose is defined as energy imparted per unit tissue mass, for a given intake the absorbed dose decreases as organ mass increases. Per unit intake of iodine-131, the committed dose equivalent to the infant thyroid is 8.4 times the committed dose equivalent for the adult thyroid, and 285 times the adult committed effective dose equivalent (ICRP, 1990b).
- Because milk consumption rates for newborns and infants (0.7 liter/day) and children (0.5 liter/day) are greater than those for adults (0.2 to 0.3 liter/day), the doses per unit intake are magnified by larger daily intakes (NCRP, 1984). The milk consumption rate used in the screening calculations was 0.28 liters per day.

- The thyroid gland is one of the organs known to develop cancer after exposure to radiation. One study showed that about 30% of thyroid glands in the United States contain some thyroid cancer (Sagan, 1982). While about 99.9% of people with thyroid cancer do not die of that disease, but of other concurrent disease (Sagan, 1982), the ICRP proposes a lethality fraction of 0.10 for thyroid cancer (ICRP, 1990a).
- Radiation exposure to the thyroid gland also results in noncancerous thyroid neoplasms, or lumps on the thyroid. Functional effects may be absent, or may include decrease of glandular secretions (ICRP, 1990a). Some effects are temporary, with function returning to normal after a period of repair or recovery.
- As stated earlier, a value of 7.3%/Sv was used for the screening calculations described in this report. It combines ICRP's 5%, 1%, and 1.3% values for fatal cancer, non-fatal cancer, and severe hereditary effects, respectively. A summary of risk conversion factors for radiation is as follows:

|                             |                                    |
|-----------------------------|------------------------------------|
| Fatal Cancer (chronic dose) | 5.0% per sievert (per ICRP, 1990a) |
| Fatal Cancer (acute dose)   | 8.0% per sievert (per NRC, 1990)   |
|                             | 10% per sievert (per ICRP, 1990a)  |
| Non-fatal Cancer            | 1.0% per sievert (per ICRP, 1990a) |
| Severe Hereditary Effects   | 1.3% per sievert (per ICRP, 1990a) |

It is important to note that ICRP's risk coefficients for non-fatal cancer and severe hereditary effects were derived after weighting for quality of life considerations (ICRP, 1990a). As a result, these risk conversion factors do not reflect the actual relative incidences of nonfatal health effects and fatal cancers. For example, although non-fatal thyroid and skin cancers are reported to be 10 and 500 times more common than fatal cancers of these organs, the ICRP method applies a maximum weighting factor of two to account for non-fatal cancers.

The radiation weighting factors used in converting absorbed doses to dose equivalents were determined for effects such as cancer. As a result, equivalent doses are not always appropriate for dealing with effects like non-cancer thyroid neoplasms. Risk coefficients based on absorbed dose (in grays) are often used instead. For non-cancer thyroid neoplasms, data indicate incidence rates of about 8 per gray (NRC, 1990). For low linear energy transfer (LET) radiations such as gamma rays, X rays, and beta particles, 1 gray is roughly equivalent to 1 sievert.

Based on these special considerations regarding the dosimetry of radioiodine exposures, it can be concluded that: 1) doses to infants and children from historical radioiodine releases from the Oak Ridge Reservation were likely considerably higher than the adult committed effective dose equivalent values that resulted from the screening calculations described in this report; 2) doses to the thyroid gland were likely significantly higher than the effective doses presented; 3) non-fatal cancer incidence has likely been underestimated due to use of ICRP risk coefficients; and 4) non-cancer thyroid disease incidence has likely been underestimated due to the use of the ICRP risk coefficient.

For the carcinogenic chemicals, PCBs released from K-25 or Y-12 represents the most important contaminant based on PCB levels measured in fish. It is important to note, however, that 1) specific sources of PCB releases were not identified for either plant site in Tasks 1 & 2 and 2) this screening analysis does not account for PCBs coming from sources other than the ORR. As such, attributing this hazard to either K-25 or Y-12 may be misleading. All of the screening hazard values for the remaining carcinogenic chemicals are more than a factor of one hundred lower than the values for PCBs. Finally, for the noncarcinogenic chemicals, the release of mercury from Y-12 represents the most important contaminant with respect to off-site health effects. The screening hazard values for the remaining noncarcinogenic materials are more than a factor of one thousand lower than the value for mercury.

## 6.0 CONCLUSIONS

While each of the three different screening comparisons made in this report (i.e., within-medium evaluation, between-media evaluation and relative importance grouping) individually provides information potentially of value in focussing future studies, each one is subject to a variety of limitations, the most important being associated with the absence or variable quality of environmental data for a number of the contaminants and media. **These screening exercises are intended to provide an initial framework for approaching the study of an extremely complex site.** Other approaches could very well yield somewhat different priorities, and the identification or reinterpretation of data in subsequent detailed studies are likely to invalidate some of the results of these screening exercises. However, these evaluations provide a logical approach to defining initial off-site health impact study priorities for the ORR. Therefore, while care must be taken in attempting to make any broad generalizations or greatly simplifying assumptions with regard to the potential health hazards posed by the complex releases from the Reservation, Table 6-1 represents an attempt to summarize a set of recommendations that are derived from the screening exercises presented in this report. Table 6-1 identifies the facilities, processes and contaminants believed to have the highest potential for resulting in off-site health impacts. Table 6-2 identifies contaminants for which no ranking could be performed as part of this feasibility study, because of the absence of any appropriate data for any environmental medium.

TABLE 6-1

HIGHEST PRIORITY OPERATIONS/CONTAMINANTS  
FOR FURTHER STUDY BASED ON QUANTITATIVE SCREENING

| Facility  | Operation                                   | Years of Operation | Contaminant(s)            |
|-----------|---|--------------------|---------------------------|
| X-10      | Radioactive Lanthanum (RaLa) Processing     | 1944-1956          | Iodine-131, -133          |
| X-10      | Various Chemical Separation Processes       | Late 1944-1960s    | Cesium-137                |
| Y-12      | Lithium Separation and Enrichment Operation | 1955-1963          | Mercury                   |
| K-25/Y-12 | Transformers/Machining                      | Indeterminate      | Polychlorinated Biphenyls |

TABLE 6-2

CONTAMINANTS THAT COULD NOT BE QUANTITATIVELY EVALUATED  
FOR ANY MEDIUM AS PART OF PHASE I OF THE HEALTH STUDIES

| Facility  | Operation   | Contaminant(s)           |
|-----------|---|--------------------------|
| K-25/Y-12 | Cooling towers  | Chromium(VI)             |
| K-25/Y-12 | Waste disposal ponds  | Neptunium-237            |
| X-10/Y-12 | Plutonium separation at X-10 (plutonium-240, -241 only)/feed material from Savannah River Plant at Y-12 | Plutonium-239, -240, 241 |
| Y-12      | Lithium deuteride production  | Tritium                  |
| Y-12      | Coal Ash Piles  | Arsenic                  |

It should be noted that in some cases very limited information, often in only a single environmental medium, was available to perform the quantitative evaluation. In addition, the data that were available came from a variety of sources of differing quality or conservatism. The lack of information in one or more media or inconsistent levels of conservatism may have resulted in an incorrect placement in the hazard ranking. For these and other reasons, the results presented in this report should be considered preliminary and subject to change as more information becomes available.

## 7.0 REFERENCES

ATSDR, 1993. Agency for Toxic Substances and Disease Registry. Comments to ChemRisk Draft Task 3 & 4 Report from J. Hanley, ATSDR. July 23, 1993.

Binford et al., 1970. Binford, F.T., T.P. Hamrick, and B.H. Cope. "Some Techniques for Estimating the Results of the Emission of Radioactive Effluent from ORNL Stacks." Report ORNL-TM-3187. October 1, 1970.

Boyle et al., 1982. Boyle, J.W., R. Blumberg, S.J. Cotter, G.S. Hill, C.R. Kerley, R.H. Ketelle, R.L. Kroodsmas, D.W. Lee, R.C. Martin, R.D. Koop, D.N. Secora, W.P. Staub, and R.E. Thoma. "Environmental Analysis of the Operation of Oak Ridge National Laboratory (X-10 Site)." Energy Division. Report ORNL-5870. November 1982. ChemRisk Repository No. 1060.

Bradshaw and Cottrell, 1954. Bradshaw, R.L. and W.D. Cottrell. "A Study of the Contribution of the RaLa Process to Atmospheric Contamination at ORNL." ORNL Central Files No. 54-11-186. November 1, 1954.

Chapman et al., 1968. Chapman, C.H., H.L. Fisher, and M.W. Pratt. Concentration Factors of Chemical Elements in Edible Aquatic Organisms. Lawrence Radiation Laboratory, University of California Livermore. UCRL-50564. December 30, 1968.

ChemRisk, 1993a. "A Summary of Historical Activities on the Oak Ridge Reservation With Emphasis on Information Concerning Off-Site Emissions of Hazardous Materials." Oak Ridge Health Studies Phase I Report, Volume II - Part A. September 1993.

ChemRisk, 1993b. "A Summary of Information Concerning Historical Locations and Activities of Populations Potentially Affected by Releases from the Oak Ridge Reservation." Oak Ridge Health Studies Phase I Report, Volume II - Part C. September 1993.

ChemRisk, 1993c. Calculation Spreadsheets for Tasks 3 & 4. August 1993. ChemRisk Repository No. 1208.

ChemRisk, 1993d. Industrial Source Complex (ISC) Air Dispersion Modeling Output for Tasks 3 and 4. August 1993. ChemRisk Repository No. 1209.

Clement, 1988. Multi-Pathway Health Risk Assessment Input Parameters Guidance Document. Prepared for the South Coast Air Quality Management District. June 1988.

Cook et al., 1992. Cook, R.B., S.M. Adams, J.J. Beauchamp, M.S. Bevelhimer, B.G. Blaylock, C.C. Brandt, C.J. Ford, M.L. Frank, M.J. Gentry, S.K. Holladay, L.A. Hook, D.A. Levine, R.C. Longman, C.W. McGinn, J.L. Skiles, G.W. Suter, and L.F. Williams. "Phase 1 Data Summary Report for the Clinch River Remedial Investigation: Health Risk and Ecological Risk Screening Assessment." Environmental Sciences Division. Report ORNL/ER-155. December 1992.

Cottrell, 1960. Cottrell, W.D. "Radioactivity in Silt of the Clinch and Tennessee Rivers." Report ORNL-2847. ChemRisk Repository No. 143. June 7, 1960.

Cowen, 1953. Cowen, D.D. "The Oak Ridge National Laboratory Graphite Reactor." ORNL Central Files No. 53-12-126. 1953.

Cowser and Snyder, 1966. Cowser, K.E. and W.S. Snyder. "Safety Analysis of Radionuclide Release to the Clinch River. Supplement No. 3 to Status Report No. 5 on Clinch River Study. Progress Report No. 3 (Final) of Subcommittee on Safety Evaluation." Report ORNL-3721, Suppl. 3. ChemRisk Repository No. 149. May 1966.

Dilling et al., 1975. Dilling, W.L., N.B. Tefertiller, and G.J. Kallos. "Evaporation Rates and Reactivities of Methylene Chloride, Chloroform, 1,1,1-Trichloroethane, Trichloroethylene, Tetrachloroethylene, and Other Chlorinated Compounds in Dilute Aqueous Solutions." Env. Sci. and Tech., 9(9):833-838. September 1975.

Fellers, 1993. Fellers, H. Memorandum Report from H. Fellers (Y-12) to J. Buddenbaum (ChemRisk) regarding stack heights at the Y-12 Plant. May 27, 1993.

Griffith, 1957. Griffith, W.L. "Uranium Losses from the Y-12 Plant to the Environment." Report Y-B92-13. (Deleted Revision)—Sanitized document from classified version. 1957 (approximate year).

HDR, 1988. HDR Engineering, Inc. "Health Risk Assessment for Glendon Energy Company Resource Recovery Facility." Prepared for Glendon Energy Company. March 1988.

HEAST, 1991. Health Effects Assessment Summary Tables (HEAST) - Annual FY 1991. Office of Emergency and Remedial Response, Washington, D.C. OERR 9200.6-303 (91-1).

HEAST, 1992. Health Effects Assessment Summary Tables (HEAST)—Annual FY 1992. Office of Solid Waste and Emergency Response, Washington, D.C. OERR 9200.6-303 (92-3). March 1992.

Hibbitts, 1984. Hibbitts, H.W. "Transmittal of Environmental Sampling Data for Mercury." February - December 1984. ChemRisk Repository No. 536.

Hinds, 1982. Hinds, W. Aerosol Technology—Properties, Behavior and Measurement of Airborne Particles. John Wiley & Sons, New York. 1992.

Hodgson, 1993. Hodgson, A.G. Personal Communication with A.G. Hodgson and ChemRisk notes taken during the communication.

Hoffman et al., 1980. Hoffman, F.O., J.W. Huckabee, D.M. Lucas, C.T. Garten, Jr., T.G. Scott, R.L. Walker, P.S. Gouge, and C.V. Holmes. "Sampling of Technetium-99 in Vegetation and Soils in the Vicinity of Operational Gaseous Diffusion Facilities." ORNL Environmental Sciences Division. Report ORNL/TM-7386. October 1980.

HSW, 1991. HSW Environmental Consultants, Inc. "Groundwater Quality Assessment for the Bear Creek Hydrogeologic Regime at the Y-12 Plant: Data Interpretations and Proposed Program Modifications." Prepared for Environmental Management Dept., Oak Ridge Y-12 Plant. Report Y/SUB/91-YP507C/1. Part 2. June 1991. ChemRisk Repository No. 1099.

Hunt, 1993. Hunt, J.B. Personal Communication with Jerry B. Hunt. 1992 and 1993.

ICRP, 1990a. International Commission on Radiological Protection. 1990 Recommendation of the International Commission on Radiological Protection. ICRP Publication 60. Annals of the ICRP. Vol. 21, No. 1-3. Pergamon Press, Oxford. ISSN 0146-0653. November 1990.

ICRP, 1990b. International Commission on Radiological Protection. Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 1. ICRP Publication 56. Annals of the ICRP. Vol. 20, No. 2. Pergamon Press, Oxford. ISSN 0146-6453. April 1989.

IRIS, 1993. Integrated Risk Information System. On-Line Data Base. 1993.

Kornegay, 1993. Personal Communication with F. Kornegay, Office of Environmental Compliance, Oak Ridge National Laboratory. June 23, 1993.

Lay, 1993. Lay, A. Personal Communication on June 9, 1993.

Legeay, 1993. Legeay, G. Personal Communication on June 9, 1993.

Leverett, Date Unknown. Leverett, M.C. "Air Flow and Heat Removal in the Clinton Pile." A pre-printing of Chapter XI, Volume V, "Graphite Production Piles" of the Plutonium Project Record. Clinton Laboratories Report MonN-157. Date Unknown.

Loar et al., 1981. Loar, J.M., F.A. Burkhart, G.F. Cada, J.W. Huckabee, J.T. Kitchings, K.D. Kumar, A.M. Sasson, J.A. Solomon, and J.D. Story. "Ecological Studies in the Biotic Communities in the Vicinity of the Oak Ridge Gaseous Diffusion Plant." Environmental Sciences Division. Report ORNL/TM-6714. ChemRisk Repository No. 250. October 1981.

MMES, 1984. Martin Marietta Energy Systems. "Environmental Monitoring Report. United States Department of Energy, Oak Ridge Facilities." Report Y/UB-19. ChemRisk Repository No. 954. Calendar Year 1983.

MMES, 1985. Martin Marietta Energy Systems. "Environmental Monitoring Report. United States Department of Energy, Oak Ridge Facilities." Report ORNL-6209. ChemRisk Repository No. 955. Calendar Year 1984.

MMES, 1986a. Martin Marietta Energy Systems, Inc. "Oak Ridge Gaseous Diffusion Plant Historical Chemical Release Report." Prepared by S.T. Goodpasture and J.G. Rogers for the U.S. Department of Energy. K/HS-106. April 29, 1986.

MMES, 1986b. Martin Marietta Energy Systems, Inc. "Historic Chemical Release Report—Y-12 Plant." Transmitted to W.F. Furth by G.G. Fee on April 15, 1986.

MMES, 1986c. Martin Marietta Energy Systems. "Environmental Surveillance of the Oak Ridge Reservations and Surrounding Environs During 1985." Report ORNL-6271. ChemRisk Repository No. 199.

MMES, 1990. Martin Marietta Energy Systems, Inc. "Oak Ridge Reservation Environmental Report for 1989—Volume 2: Data Presentation." Report ES/ESH-13/V2. ChemRisk Repository No. 227.

MMES, 1991a. Martin Marietta Energy Systems, Inc. "Historical Radionuclide Release Report Update." Internal correspondence from L.E. Hall to M.E. Mitchell dated January 15, 1991.

MMES, 1991b. Martin Marietta Energy Systems, Inc. "Historical Radionuclide Release Report Update." Internal correspondence from T.R. Butz to M.E. Mitchell dated January 18, 1991.

MMES, 1991c. Martin Marietta Energy Systems, Inc. "Oak Ridge Reservation Environmental Report for 1990. Volume 1: Narrative, Summary and Conclusions." Report ES/ESH-18/V1. ChemRisk Repository No. 582.

McKone and Daniels, 1991. McKone, T.E. and J.I. Daniels. "Estimating Human Exposure through Mutiple Pathways from Air, Water, and Soil." Reg. Tox. and Pharm., 13:36-61.

Moore, 1989. Moore, G.K. "Groundwater Parameters and Flow Systems Near Oak Ridge National Laboratory." Environmental Sciences Division. Report ORNL/TM-11368. September 1989. ChemRisk Repository No. 364.

Morgan, 1949. Morgan, K.Z. "Air Contamination." Letter to Dr. Stuart McLain, Argonne National Laboratory. ORNL Central Files Number CF 49-11-134. November 9, 1949.

NCRP, 1979. National Council on Radiation Protection and Measurements. Tritium in the Environment, NCRP Report No. 62, Washington, D.C.

NCRP, 1984. National Council on Radiation Protection and Measurements. Radiological Assessment: Predicting the Transport, Bioaccumulation, and Uptake by Man of Radionuclides Released to the Environment. NCRP Report No. 76, Washington, D.C.

NCRP, 1991. National Council on Radiation Protection and Measurements. Screening Models for Releases of Radionuclides to Air, Surface Water and Ground Water. Description of Models. Draft Document.

Ng, 1982. Ng, Y.C. "A Review of Transfer Factors for Assessing the Dose from Radionuclides in Agricultural Products." Nuclear Safety, 23(1):57-71.

NRC, 1990. National Research Council. Health Effects of Exposure to Low Levels of Ionizing Radiation. BEIR V, National Academy Press, Washington, D.C.

Owings, 1986. Owings, E. "Oak Ridge Y-12 Plant Historical Uranium and Radionuclide Release Report." Report Y/DG-17723. May 1986.

Peterson, 1983. Peterson, Jr., H.T. "Terrestrial and Aquatic Food Chain Pathways." In: Radiological Assessment, a Textbook on Environmental Dose Analysis. J.E. Till and H.R. Meyer, Eds. NUREG/CR-3332. September 1983.

Rupp and Cox, 1955. Rupp, A.F. and J.A. Cox. "Operation of the ORNL Graphite Reactor and the Low-Intensity Test Reactor—1954." Operations Division. Report ORNL-1866. September 16, 1955.

Rutherford, 1956. Rutherford, B.F. "Health Physics Logbook Pertaining to Y-12 Stack Monitoring Parameters." August 21, 1956.

Sagan, 1982. Sagan, Leonard A. "Opening Remarks." In: Selected Technical Papers: Use of Potassium Iodide in Emergency Planning for Nuclear Power Plants. Presented at a conference entitled "Radiation Issues for the Nuclear Industry." October 3-6, 1982. Published by the Atomic Industrial Forum. November 1982.

Sharp, 1993. Sharp, R. Industrial Source Complex (ISC) Modeling Documentation for the Tasks 3 & 4 Report. ChemRisk Repository No. 1209.

Sherwood and Borders, 1987. Sherwood, C.B. and D.M. Borders. "Annual Summary of Hydrologic Data for the White Oak Creek Watershed." Report ORNL/RAP/LTR/87-43. August 31, 1987. ChemRisk Repository No. 1046.

Till, 1983. Till, E.J. "Models for Special-Case Radionuclides." In: Radiological Assessment, a Textbook on Environmental Dose Analysis, J.E. Till and H.R. Meyer, Eds. NUREG/CR-3332. September 1983.

Tucci, 1992. Tucci, P. "Hydrology of Melton Valley at Oak Ridge National Laboratory, Tennessee." U.S. Geological Survey. Water Resources Investigation Report 92-4131. Nashville, Tennessee. 1992.

TVA, 1985a. Tennessee Valley Authority. "Instream Contaminant Study, Task 1: Water Sampling and Analysis." Office of Natural Resources and Economic Development, Knoxville, Tennessee. ChemRisk Repository No. 840. April 1985.

TVA, 1985b. Tennessee Valley Authority. "Instream Contaminant Study, Task 2: Sediment Characterization, Volume II- Appendices." Office of Natural Resources and Economic Development, Knoxville, Tennessee. ChemRisk Repository No. 842. January 1985.

TVA, 1985c. Tennessee Valley Authority. "Instream Contaminant Study, Task 4: Fish Sampling and Analysis." Office of Natural Resources and Economic Development, Knoxville, Tennessee. ChemRisk Repository No. 844. April 1985.

UCC, 1961. Union Carbide Corporation. "Applied Health Physics Annual Report for 1960." Report ORNL-3159. ChemRisk Repository No. 542

UCC, 1962. Union Carbide Corporation. "Applied Health Physics Annual Report for 1961." Report ORNL-3284. ChemRisk Repository No. 543.

UCC, 1963. Union Carbide Corporation. "Applied Health Physics Annual Report for 1962." Report ORNL-3490. ChemRisk Repository No. 544.

UCC, 1966. Union Carbide Corporation. "Applied Health Physics Annual Report for 1965." Report ORNL-3969. ChemRisk Repository No. 547.

UCC, 1968. Union Carbide Corporation. "Applied Health Physics Annual Report for 1967." Report ORNL-4286. ChemRisk Repository No. 549.

UCC, 1972. Union Carbide Corporation. "Environmental Monitoring Report, United States Atomic Energy Commission, Oak Ridge Facilities. Calendar Year 1971." Report UCC-ND-221. ChemRisk Repository No. 942.

UCC, 1973. Union Carbide Corporation. "Environmental Monitoring Report, United States Atomic Energy Commission, Oak Ridge Facilities. Calendar Year 1972." Report UCC-ND-244. ChemRisk Repository No. 943.

UCC, 1975. Union Carbide Corporation. "Environmental Monitoring Report, United States Energy Research and Development Administration, Oak Ridge Facilities. Calendar Year 1974." Report UCC-ND-302. ChemRisk Repository No. 945.

UCC, 1976. Union Carbide Corporation. "Environmental Monitoring Report, United States Energy Research and Development Administration, Oak Ridge Facilities. Calendar Year 1975." Report Y/UB-4. ChemRisk Repository No. 946.

UCC, 1977. Union Carbide Corporation. "Environmental Monitoring Report, United States Energy Research and Development Administration, Oak Ridge Facilities. Calendar Year 1976." Report Y/UB-6. ChemRisk Repository No. 947.

UCC, 1979. Union Carbide Corporation. "Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities. Calendar Year 1978." Report Y/UB-10. ChemRisk Repository No. 949.

UCC, 1980. Union Carbide Corporation. "Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities. Calendar Year 1979." Report Y/UB-13. ChemRisk Repository No. 950.

UCC, 1981. Union Carbide Corporation. "Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities. Calendar Year 1980." Report Y/UB-15. ChemRisk Repository No. 951.

UCC, 1982. Union Carbide Corporation. "Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities. Calendar Year 1981." Report Y/UB-16. ChemRisk Repository No. 952.

UCC, 1983. Union Carbide Corporation. "Mercury at Y-12 Plant: A Study of Mercury Use at the Y-12 Plant, Accountability, and Impacts on Y-12 Workers and the Environment—1950 to 1983." Compiled by the 1983 Mercury Task Force. Report Y/EX-24. August 18, 1984.

USDOE, 1979. U.S. Department of Energy. "Environmental Assessment for the Oak Ridge Gaseous Diffusion Plant".

USDOE, 1988a. U.S. Department of Energy. "Historical Radionuclide Releases from Current DOE Oak Ridge Operations Office Facilities". Oak Ridge Operations Office, Oak Ridge TN. May 1988.

USDOE, 1988b. U.S. Department of Energy. Internal Dose Conversion Factors for Calculation of Dose to the Public. DOE/EH-0071. July 1988.

USDOE, 1988c. U.S. Department of Energy. External Dose Conversion Factors for Calculation of Dose to the Public. DOE/EH-0070. July 1988.

USEPA, 1979. U.S. Environmental Protection Agency. AIRDOS-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides. Prepared by the Oak Ridge National Laboratory for the Office of Radiation Programs, Washington D.C. EPA 520/1-79-009

USEPA, 1986. U.S Environmental Protection Agency. Superfund Public Health Evaluation Manual. Office of Emergency and Remedial Response, Washington, D.C. EPA/540/1-86/060. October 1986.

USEPA, 1989a. U.S. Environmental Protection Agency. Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A)—Interim Final. Office of Emergency and Remedial Response, Washington D.C. EPA/540/1-89/002. December 1989.

USEPA, 1989b. U.S. Environmental Protection Agency. Risk Assessment Methodology, Environmental Impact Statement, NESHAPS for Radionuclides. Background Information Document, Volume 1. Office of Radiation Programs. EPA/520/1-89-005. September 1989.

USEPA, 1991. U.S Environmental Protection Agency. Interim Guidance for Dermal Exposure Assessment. Office of Research and Development, Washington, D.C. EPA/600/8-91/011A. March 1991.

USNRC, 1977. United States Nuclear Regulatory Commission. Regulatory Guide 1.109. Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I. Revision 1. Office of Standards Development. October 1977.

Van Winkle et al., 1982. W. Van Winkle, R.W. Counts, J.G. Dorsey, J.W. Elwood, V.W. Lowe, Jr., R. McElhaney, S.D. Schlotzhauer, F.G. Taylor, Jr., and R.R. Turner. (1982). "Mercury Contamination in East Fork Poplar Creek and Bear Creek." Report ORNL/TM-8894. ChemRisk Repository No. 171. February 1984.

**APPENDIX A**  
**TRITIUM EXPOSURE MODELING**

## APPENDIX A

### TRITIUM EXPOSURE MODELING

Tritium is known to have been released into the environment from the Oak Ridge Reservation (ORR) as part of radioisotope processing programs, reactor operations, and chemical processing of nuclear materials at X-10. The approaches to evaluating the environmental fate and transport of tritium differ from the other materials released from the ORR. Since tritium released as tritiated water or hydrogen gas readily mixes with its stable counterparts in nature, specific exposure pathways are not identified. Instead, numerous alternative methodologies have been proposed for evaluating exposure to tritium. In 1969, Evans proposed what is referred to as the specific activity method (Till, 1983), which assumes that the concentrations of tritium in the atmosphere, water, biota and humans are equal at a given location. Since this is an unlikely condition, the National Council on Radiation Protection and Measurements (NCRP) proposed a variation of this method that can be used when the tritium concentrations in air, water and food products are known or can be estimated (NCRP, 1979). The NCRP model assumes the dose from tritium through various exposure pathways depends on the relative contributions of several water sources to the total water intake of a reference individual. The annual dose equivalent per unit concentration for a water intake of 3 liters per day can be described by the following equation:

$$D = (1.22C_w + 1.27C_{f1} + 0.29C_{f2} + 0.22C_a) \times 1/3.0 \times DRF$$

where:

- D = annual dose equivalent (mrem),
- $C_w$  = concentration of tritium in drinking water (pCi/L),
- $C_{f1}$  = concentration of tritium in water in food (pCi/L),
- $C_{f2}$  = concentration of tritium oxidized to water upon metabolism of food (pCi/L),
- $C_a$  = concentration of tritium in atmospheric water, and
- DRF = dose equivalent rate factor (mrem/yr per pCi/L). The dose equivalent rate factor used by the NCRP is  $95 \times 10^{-6}$  (mrem/yr per pCi/L).

The concentration of tritium in atmospheric water (pCi/L) is determined by the following equation:

$$C_a = C_{air} \div AH$$

where:

- $C_a$  = concentration of tritium in atmospheric water (pCi/L),
- $C_{air}$  = concentration of tritium in the atmosphere (pCi/m<sup>3</sup>), and
- AH = absolute humidity (g<sub>water</sub>/m<sup>3</sup><sub>air</sub> or ml<sub>water</sub>/m<sup>3</sup><sub>air</sub>).

Since results of tritium concentration measurements in air and food products were not compiled as part of the feasibility study, these values were estimated using the maximum annual airborne release, an air dispersion model (see Section 5.1.4) and professional judgement. For water, the maximum tritium concentration detected in surface water at or near the confluence of White Oak Creek and the Clinch River was used. The following input parameters were used in the calculations to support evaluation of associated exposure pathways:

| Parameter   | Value | Reference              |
|---|-------|------------------------|
| Absolute Humidity                                       | 8.4   | Etnier, 1980           |
| Food Concentration as a Percentage of Air Concentration | 100%  | Professional Judgement |

As shown in Table 5-11 of the main text, the resulting screening hazard value for tritium released from X-10 using the NCRP method is  $1 \times 10^{-5}$ . Based on comments received on the Draft Tasks 3 & 4 Report, tritium was also evaluated for comparison purposes using the same model that was developed for the other contaminants of concern. The predicted maximum annual air concentration and measured maximum surface water concentration used above were also used in this example. Dose estimates were calculated for all of the complete exposure pathways associated with internal exposure for these two media. External exposure pathways (i.e., immersion in air or surface water) are not complete exposure pathways for tritium, which is a weak beta emitter. A committed effective dose equivalent factor of  $1.7 \times 10^{-11}$  sieverts/becquerel from the U.S. Department of Energy's "Internal Dose Conversion Factors for Calculations of Dose to the Public" (USDOE, 1988) was used for both inhalation and ingestion. The resulting dose estimates were summed, and the total multiplied by a whole body risk conversion factor of 7.3%/sievert. The resulting screening hazard value was  $8 \times 10^{-6}$ , a value that is essentially the same as that calculated using the NCRP method. The calculation spreadsheets used for this example are included with all of the other spreadsheets that document the Tasks 3 & 4 results (ChemRisk, 1993).

## REFERENCES

ChemRisk, 1993. Calculation Spreadsheets for Tasks 3 & 4 Report. August. ChemRisk Repository No. 1208.

Etnier, 1980. Etnier, E. L. "Regional and Site-Specific Absolute Humidity Data for Use in Tritium Dose Calculations." Health Physics, 39(2):318-320. 1980.

NCRP, 1979. NCRP. National Council on Radiation Protection and Measurements (NCRP). Tritium in the Environment, NCRP Report No. 62, Washington D.C. 1979.

Till, 1983. Till, J. E. "Models for Special-Case Radionuclides." In: Radiological Assessment, a Textbook on Environmental Dose Analysis, edited by J. E. Till and H. R. Meyer. United States Nuclear Regulatory Commission, Washington D.C. 1983.

USDOE, 1988. U.S. Department of Energy. "Internal Dose Conversion Factors for Calculation of Dose to the Public." DOE/EH-0071. July 1988.

**APPENDIX B**  
**EXPOSURE PATHWAY EQUATIONS**

## APPENDIX B

### EXPOSURE PATHWAY EQUATIONS

This appendix presents the exposure pathway equations used in this assessment to calculate the intake of the chemicals and radionuclides of concern. These equations are consistent with those that have been developed by various regulatory agencies for evaluating exposure to radionuclides (USEPA, 1979; NCRP, 1991) and chemicals (USEPA, 1989). For three exposure pathways that apply only to radionuclides, i.e., immersion in air, immersion in water and ground exposure, the determination of intake is not appropriate, because exposure occurs without the material being taken up by the body. In these cases, the equations presented in this appendix are used to calculate radiation dose.

As discussed in more detail in Section 4.0 of the main text, the calculated intakes for chemicals are used in conjunction with toxicity criteria to estimate cancer risk or hazard. For radionuclides, the calculated intakes are multiplied by a route-specific dose conversion factor to estimate radiation dose. Calculated dose equivalents in sieverts can be converted to rem by multiplying by 100. Radiation dose can be used in conjunction with a risk conversion factor to estimate cancer risk.

#### REFERENCES

NCRP, 1991. National Council on Radiation Protection and Measurements (NCRP). Screening Models for Releases of Radionuclides to Air, Surface Water and Ground Water. Description of Models. Draft Document.

USEPA, 1979. U.S. Environmental Protection Agency. AIRDOS-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides. Prepared by the Oak Ridge National Laboratory for the Office of Radiation Programs, Washington, D.C. EPA 520/1-79-009.

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

### Air → Humans (Inhalation)

---

$$I_{air} = \frac{C_{air} U_{air}}{BW} f_t f_s \quad (\text{Chemicals})$$

$$I_{air} = C_{air} U_{air} f_t f_s \quad (\text{Radionuclides})$$

where:

- $I_{air}$  = Daily intake of contaminant due to inhalation, mg/kg-day or pCi/day;
- $C_{air}$  = Average concentration of contaminant in air, mg/m<sup>3</sup> or pCi/m<sup>3</sup>;
- $U_{air}$  = Average volume of air inhaled per day, m<sup>3</sup>/day;
- $f_t$  = Fraction of time that a person is exposed, dimensionless;
- $f_s$  = Indoor/outdoor shielding factor, dimensionless; and
- $BW$  = Average body weight, kg.

### Air → Humans (Immersion)

---

For radionuclides only:

$$Dose_{imm} = C_{air} f_t f_s Cf_1 Cf_2 DCF_{imm}$$

where:

- $Dose_{imm}$  = Dose equivalent rate due to air immersion, Sv/year;
- $C_{air}$  = Average concentration of contaminant in air, pCi/m<sup>3</sup>;
- $f_t$  = Fraction of time exposed, dimensionless;
- $f_s$  = Indoor/outdoor shielding factor, dimensionless;
- $Cf_1$  = Conversion factor, Bq/pCi;
- $Cf_2$  = Conversion factor, m<sup>3</sup>/cm<sup>3</sup>; and
- $DCF_{imm}$  = Effective dose equivalent rate factor for immersion in an infinite cloud, Sv - cm<sup>3</sup>/Bq - year.

Air → Livestock/Game (Beef) → Humans (Ingestion)

---

Equation #1

$$C_{beef(air)} = C_{air} Q_{air(b)} F_f$$

where:

- $C_{beef(air)}$  = Equilibrium concentration of contaminant in beef due to inhalation, mg/kg or pCi/kg;
- $C_{air}$  = Average concentration of contaminant in air, mg/m<sup>3</sup> or pCi/m<sup>3</sup>;
- $Q_{air(b)}$  = Daily inhalation rate of beef cattle, m<sup>3</sup>/day; and
- $F_f$  = Biotransfer factor from cattle intake to meat concentration, (mg/kg)/(mg/day) or (pCi/kg)/(pCi/day).

Equation #2

$$I_{beef(air)} = \frac{C_{beef(air)} U_{beef}}{BW} f_{cb} \quad \text{(Chemicals)}$$

$$I_{beef(air)} = C_{beef(air)} U_{beef} f_{cb} \quad \text{(Radionuclides)}$$

where:

- $I_{beef(air)}$  = Daily intake of contaminant due to beef ingestion (air pathway), mg/kg-day or pCi/day;
- $C_{beef(air)}$  = Equilibrium concentration of contaminant in beef due to inhalation, mg/kg or pCi/kg;
- $U_{beef}$  = Average daily consumption of beef, kg/day;
- $BW$  = Average body weight, kg; and
- $f_{cb}$  = Fraction of beef consumed that is contaminated, dimensionless.

Air → Dairy Cattle (Milk) → Humans (Ingestion)

---

Equation #1

$$C_{milk(air)} = C_{air} Q_{air(d)} F_m$$

where:

$C_{milk(air)}$  = Equilibrium concentration of contaminant in milk due to inhalation, mg/L or pCi/L;

$C_{air}$  = Average concentration of contaminant in air, mg/m<sup>3</sup> or pCi/m<sup>3</sup>;

$Q_{air(d)}$  = Daily inhalation rate of dairy cattle, m<sup>3</sup>/day; and

$F_m$  = Biotransfer factor from cattle intake to milk concentration, (mg/L)/(mg/day) or (pCi/L)/(pCi/day).

Equation #2

$$I_{milk(air)} = \frac{C_{milk(air)} U_{milk}}{BW} f_{cm} \quad \text{(Chemicals)}$$

$$I_{milk(air)} = C_{milk(air)} U_{milk} f_{cm} \quad \text{(Radionuclides)}$$

where:

$I_{milk(air)}$  = Daily intake of contaminant due to milk ingestion (air pathway), mg/kg-day or pCi/day;

$C_{milk(air)}$  = Equilibrium concentration of contaminant in milk due to inhalation, mg/L or pCi/L;

$U_{milk}$  = Average daily consumption of milk, L/day;

$BW$  = Average body weight, kg; and

$f_{cm}$  = Fraction of milk consumed that is contaminated, dimensionless.

Air (Particulates) → Vegetables → Humans (Ingestion)

---

Equation #1

$$C_{veg(air)} = C_{air} V_{D(veg)} \left( \frac{1 - e^{-k_w T_g}}{k_w} \right) f_w$$

where:

- $C_{veg(air)}$  = Equilibrium concentration of contaminant on washed leafy vegetables (wet weight), mg/kg or pCi/kg;
- $C_{air}$  = Average concentration of contaminant in air, mg/m<sup>3</sup> or pCi/m<sup>3</sup>;
- $V_{D(veg)}$  = Wet/Dry deposition velocity per unit mass of vegetation [(m/day)/(kg/m<sup>2</sup>)];
- $k_w$  = Weathering rate constant, day<sup>-1</sup>;
- $T_g$  = Growth period or exposure period, day; and
- $f_w$  = Fraction of contaminant remaining after washing, dimensionless.

Air (Particulates) → Vegetables → Humans (Ingestion)  
(Continued)

---

Equation #2

$$I_{veg(air)} = \frac{C_{veg} U_{veg}}{BW} f_{cv} \quad \text{(Chemicals)}$$

$$I_{veg(air)} = C_{veg} U_{veg} f_{cv} \quad \text{(Radionuclides)}$$

where:

- $I_{veg(air)}$  = Daily intake of contaminant due to leafy vegetables ingestion, mg/kg-day or pCi/day;
- $C_{veg(air)}$  = Equilibrium concentration of contaminant on washed leafy vegetables (wet weight), mg/kg or pCi/kg;
- $U_{veg}$  = Average daily consumption of vegetables (wet weight), kg/day;
- $BW$  = Average body weight, kg; and
- $f_{cv}$  = Fraction of vegetables consumed that is contaminated, dimensionless.

Air (Vapors/Gases) → Vegetables → Humans (Ingestion)

---

Equation #1

$$C_{veg(air)} = C_{air} \left( \frac{RT}{H} \right) (0.9 + 0.1 K_{ow}) Cf_1 Cf_2$$

where:

- $C_{veg(air)}$  = Equilibrium concentration of contaminant on washed leafy vegetables (wet weight), mg/kg or pCi/kg;
- $C_{air}$  = Average concentration of contaminant in air, mg/m<sup>3</sup> or pCi/m<sup>3</sup>;
- $R$  = Universal gas constant, atm-m<sup>3</sup>/mole-°K;
- $T$  = Temperature, °K;
- $H$  = Henry's Law constant, atm-m<sup>3</sup>/mole;
- $K_{ow}$  = Octanol-water partition coefficient, dimensionless;
- $Cf_1$  = Conversion factor, m<sup>3</sup>/L; and
- $Cf_2$  = Conversion factor (density of water), L/kg.

Air (Vapors/Gases) → Vegetables → Humans (Ingestion)  
(Continued)

---

Equation #2

$$I_{veg(air)} = \frac{C_{veg(air)} U_{veg}}{BW} f_{cv} \quad \text{(Chemicals)}$$

$$I_{veg(air)} = C_{veg(air)} U_{veg} f_{cv} \quad \text{(Radionuclides)}$$

where:

- $I_{veg(air)}$  = Daily intake of contaminant due to leafy vegetables ingestion, mg/kg-day or pCi/day;
- $C_{veg(air)}$  = Equilibrium concentration of contaminant on washed leafy vegetables (wet weight), mg/kg or pCi/kg;
- $U_{veg}$  = Average daily consumption of vegetables (wet weight), kg/day;
- $BW$  = Average body weight, kg; and
- $f_{cv}$  = Fraction of vegetables consumed that is contaminated, dimensionless.

Air (Particulates) → Pasture → Livestock/Game (Beef) → Humans (Ingestion)

---

Equation #1

$$C_{past(air)} = C_{air} V_{D(past)} \left( \frac{1 - e^{-k_w T_g}}{k_w} \right)$$

where:

- $C_{past(air)}$  = Equilibrium concentration of contaminant on pasture (dry weight), mg/kg or pCi/kg;
- $C_{air}$  = Average concentration of contaminant in air, mg/m<sup>3</sup> or pCi/m<sup>3</sup>;
- $V_{D(past)}$  = Wet/Dry deposition velocity per unit mass of vegetation [(m/day)/(kg/m<sup>2</sup>)];
- $k_w$  = Weathering rate constant, day<sup>-1</sup>; and
- $T_g$  = Growth period or exposure period, day.

Equation #2

$$C_{beef(past)} = C_{past(air)} Q_{past(b)} F_f f_{pb}$$

where:

- $C_{beef(past)}$  = Equilibrium concentration of contaminant in beef (air pathway), mg/kg or pCi/kg;
- $C_{past(air)}$  = Equilibrium concentration of contaminant on pasture (dry weight), mg/kg or pCi/kg;
- $Q_{past(b)}$  = Daily ingestion of pasture (dry weight) by beef cattle, kg/day;
- $F_f$  = Biotransfer factor from cattle intake to meat concentration, (mg/kg)/(mg/day) or (pCi/kg)/(pCi/day); and
- $f_{pb}$  = Fraction of feed ingested by beef cattle that is pasture, dimensionless.

Air (Particulates) → Pasture → Livestock/Game (Beef) → Humans (Ingestion)  
(Continued)

---

Equation #3

$$I_{beef(past)} = \frac{C_{beef(past)} U_{beef}}{BW} f_{cb} \quad \text{(Chemicals)}$$

$$I_{beef(past)} = C_{beef(past)} U_{beef} f_{cb} \quad \text{(Radionuclides)}$$

where:

- $I_{beef(past)}$  = Daily intake of contaminant due to beef ingestion (pasture), mg/kg-day or pCi/day;
- $C_{beef(past)}$  = Equilibrium concentration of contaminant in beef due to pasture, mg/kg or pCi/kg;
- $U_{beef}$  = Average daily consumption of beef, kg/day;
- $BW$  = Average body weight, kg; and
- $f_{cb}$  = Fraction of beef consumed that is contaminated, dimensionless.

Air (Vapor/Gases) → Pasture → Livestock/Game (Beef) → Humans (Ingestion)

Equation #1

$$C_{past(air)} = C_{air} \left( \frac{RT}{H} \right) (0.9 + 0.1 K_{ow}) Cf_1 Cf_2$$

where:

- $C_{past(air)}$  = Equilibrium concentration of contaminant on pasture (dry weight), mg/kg or pCi/kg;
- $C_{air}$  = Average contaminant concentration in air, mg/m<sup>3</sup> or pCi/m<sup>3</sup>;
- $R$  = Universal gas constant, atm-m<sup>3</sup>/mole-°K;
- $T$  = Temperature, °K;
- $H$  = Henry's Law constant, atm-m<sup>3</sup>/mole;
- $K_{ow}$  = Octanol-water partition coefficient, dimensionless;
- $Cf_1$  = Conversion factor, m<sup>3</sup>/L; and
- $Cf_2$  = Conversion factor (density of water), L/kg.

Equation #2

$$C_{beef(past)} = C_{past(air)} Q_{past(b)} F_f f_{pb}$$

where:

- $C_{beef(past)}$  = Equilibrium concentration of contaminant in beef (air pathway), mg/kg or pCi/kg;
- $C_{past(air)}$  = Equilibrium concentration of contaminant on pasture (dry weight), mg/kg or pCi/kg;
- $Q_{past(b)}$  = Daily ingestion of pasture (dry weight) by beef cattle, kg/day;
- $F_f$  = Biotransfer factor from cattle intake to meat concentration, (mg/kg)/(mg/day) or (pCi/kg)/(pCi/day); and
- $f_{pb}$  = Fraction of feed ingested by beef cattle that is pasture, dimensionless.

Air (Particulates) → Pasture → Livestock/Game (Beef) → Humans (Ingestion)  
(Continued)

---

Equation #3

$$I_{beef(past)} = \frac{C_{beef(past)} U_{beef}}{BW} f_{cb} \quad (\text{Chemicals})$$

$$I_{beef(past)} = C_{beef(past)} U_{beef} f_{cb} \quad (\text{Radionuclides})$$

where:

- $I_{beef(past)}$  = Daily intake of contaminant due to beef ingestion (pasture), mg/kg-day or pCi/day;
- $C_{beef(past)}$  = Equilibrium concentration of contaminant in beef due to pasture, mg/kg or pCi/kg;
- $U_{beef}$  = Average daily consumption of beef, kg/day;
- $BW$  = Average body weight, kg; and
- $f_{cb}$  = Fraction of beef consumed that is contaminated, dimensionless.

Air (Particulates) → Pasture → Dairy Cattle (Milk) → Humans (Ingestion)

---

Equation #1

$$C_{past(air)} = C_{air} V_{D(past)} \left( \frac{1 - e^{-k_w T_g}}{k_w} \right)$$

where:

- $C_{past(air)}$  = Equilibrium concentration of contaminant on pasture (dry weight), mg/kg or pCi/kg;
- $C_{air}$  = Average concentration of contaminant in air, mg/m<sup>3</sup> or pCi/m<sup>3</sup>;
- $V_{D(past)}$  = Wet/Dry deposition velocity per unit mass of vegetation [(m/day)/(kg/m<sup>2</sup>)];
- $k_w$  = Weathering rate constant, day<sup>-1</sup>; and
- $T_g$  = Growth period or exposure period, day.

Equation #2

$$C_{milk(past)} = C_{past(air)} Q_{past(d)} F_m f_{pd}$$

where:

- $C_{milk(past)}$  = Equilibrium concentration of contaminant in milk (air pathway), mg/L or pCi/L;
- $C_{past(air)}$  = Equilibrium concentration of contaminant on pasture (dry weight), mg/kg or pCi/kg;
- $Q_{past(d)}$  = Daily ingestion of pasture (dry weight) by dairy cattle, kg/day;
- $F_m$  = Biotransfer factor from cattle intake to milk concentration, (mg/L)/(mg/day) or (pCi/L)/(pCi/day); and
- $f_{pd}$  = Fraction of feed ingested by dairy cattle that is pasture, dimensionless.

Air (Particulates) → Pasture → Dairy Cattle (Milk) → Humans (Ingestion)  
(Continued)

---

Equation #3

$$I_{milk(past)} = \frac{C_{milk(past)} U_{milk}}{BW} f_{cm} \quad \text{(Chemicals)}$$

$$I_{milk(past)} = C_{milk(past)} U_{milk} f_{cm} \quad \text{(Radionuclides)}$$

where:

- $I_{milk(past)}$  = Daily intake of contaminant due to milk ingestion (pasture), mg/kg-day or pCi/day;
- $C_{milk(past)}$  = Equilibrium concentration of contaminant in milk due to pasture, mg/L or pCi/L;
- $U_{milk}$  = Average daily consumption of milk, L/day;
- $BW$  = Average body weight, kg; and
- $f_{cm}$  = Fraction of milk consumed that is contaminated, dimensionless.

Air (Vapors/Gases) → Pasture → Dairy Cattle (Milk) → Humans (Ingestion)

Equation #1

$$C_{past(air)} = C_{air} \left( \frac{RT}{H} \right) (0.9 + 0.1 K_{ow}) Cf_1 Cf_2$$

where:

- $C_{past(air)}$  = Equilibrium concentration of contaminant on pasture (dry weight), mg/kg or pCi/kg;
- $C_{air}$  = Average concentration of contaminant in air, mg/m<sup>3</sup> or pCi/m<sup>3</sup>;
- $R$  = Universal gas constant, atm-m<sup>3</sup>/mole-°K;
- $T$  = Temperature, °K;
- $H$  = Henry's Law constant, atm-m<sup>3</sup>/mole;
- $K_{ow}$  = Octanol-water partition coefficient, dimensionless;
- $Cf_1$  = Conversion factor, m<sup>3</sup>/L; and
- $Cf_2$  = Conversion factor (density of water), L/kg.

Equation #2

$$C_{milk(past)} = C_{past(air)} Q_{past(d)} F_m f_{pd}$$

where:

- $C_{milk(past)}$  = Equilibrium concentration of contaminant in milk (air pathway), mg/L or pCi/L;
- $C_{past(air)}$  = Equilibrium concentration of contaminant on pasture (dry weight), mg/kg or pCi/kg;
- $Q_{past(d)}$  = Average daily ingestion of pasture (dry weight) by dairy cattle, kg/day;
- $F_m$  = Biotransfer factor from cattle intake to milk concentration, (mg/L)/(mg/day) or (pCi/L)/(pCi/day); and
- $f_{pd}$  = Fraction of feed ingested by dairy cattle that is pasture, dimensionless.

Air (Vapors/Gases) → Pasture → Dairy Cattle (Milk) → Humans (Ingestion)  
(Continued)

---

Equation #3

$$I_{milk(past)} = \frac{C_{milk(past)} U_{milk}}{BW} f_{cm} \quad \text{(Chemicals)}$$

$$I_{milk(past)} = C_{milk(past)} U_{milk} f_{cm} \quad \text{(Radionuclides)}$$

where:

- $I_{milk(past)}$  = Daily intake of contaminant due to milk ingestion (pasture), mg/kg-day or pCi/day;
- $C_{milk(past)}$  = Equilibrium concentration of contaminant in beef due to pasture, mg/L or pCi/L;
- $U_{milk}$  = Average daily consumption of milk, L/day;
- $BW$  = Average body weight, kg; and
- $f_{cm}$  = Fraction of milk consumed that is contaminated, dimensionless.

### Water → Humans (Ingestion)

---

$$I_{water} = \frac{C_{water} U_{water}}{BW} f_{cw} \quad (\text{Chemicals})$$

$$I_{water} = C_{water} U_{water} f_{cw} \quad (\text{Radionuclides})$$

where:

- $I_{water}$  = Daily intake of contaminant per unit body weight due to water consumption, mg/kg-day or pCi/day;
- $C_{water}$  = Average concentration of contaminant in water, mg/L or pCi/L;
- $U_{water}$  = Average daily consumption of drinking water, L/day;
- $BW$  = Average body weight, kg; and
- $f_{cw}$  = Fraction of water consumed that is contaminated, dimensionless.

### Water → Livestock/Game (Beef) → Humans (Ingestion)

---

Equation #1

$$C_{beef(water)} = C_{water} Q_{water(b)} F_f f_{cw}$$

where:

- $C_{beef(water)}$  = Equilibrium concentration of contaminant in beef due to drinking contaminated water, mg/kg or pCi/kg;
- $C_{water}$  = Average concentration of contaminant in water, mg/L or pCi/L;
- $Q_{water(b)}$  = Daily intake of water by beef cattle, L/day;
- $F_f$  = Biotransfer factor from cattle intake to meat concentration, (mg/kg)/(mg/day) or (pCi/kg)/(pCi/day); and
- $f_{cw}$  = Fraction of water obtained from a contaminated source, dimensionless.

Water → Livestock/Game (Beef) → Humans (Ingestion)  
(Continued)

---

Equation #2

$$I_{beef(water)} = \frac{C_{beef(water)} U_{beef}}{BW} f_{cb} \quad (\text{Chemicals})$$

$$I_{beef(water)} = C_{beef(water)} U_{beef} f_{cb} \quad (\text{Radionuclides})$$

where:

- $I_{beef(water)}$  = Daily intake of contaminant due to beef ingestion (water pathway), mg/kg-day or pCi/day;
- $C_{beef(water)}$  = Equilibrium concentration of contaminant in beef due to water, mg/kg or pCi/kg;
- $U_{beef}$  = Average daily consumption of beef, kg/day;
- $BW$  = Average body weight, kg; and
- $f_{cb}$  = Fraction of beef consumed that is contaminated

Water → Dairy Cattle (Milk) → Humans (Ingestion)

---

Equation #1

$$C_{milk(water)} = C_{water} Q_{water(d)} F_m f_{cw}$$

where:

- $C_{milk(water)}$  = Equilibrium concentration of contaminant in milk due to drinking contaminated water, mg/L or pCi/L;
- $C_{water}$  = Average concentration of contaminant in water, mg/L or pCi/L;
- $Q_{water(d)}$  = Daily intake of water by dairy cattle, L/day;
- $F_m$  = Biotransfer factor from cattle intake to milk concentration, (mg/L)/(mg/day) or (pCi/L)/(pCi/day); and
- $f_{cw}$  = Fraction of water obtained from a contaminated source, dimensionless.

Equation #2

$$I_{milk(water)} = \frac{C_{milk(water)} U_{milk}}{BW} f_{cm} \quad \text{(Chemicals)}$$

$$I_{milk(water)} = C_{milk(water)} U_{milk} f_{cm} \quad \text{(Radionuclides)}$$

where:

- $I_{milk(water)}$  = Daily intake of contaminant due to milk ingestion (water pathway), mg/kg-day or pCi/day;
- $C_{milk(water)}$  = Equilibrium concentration of contaminant in milk due to water, mg/L or pCi/L;
- $U_{milk}$  = Average daily consumption of milk, L/day;
- $BW$  = Average body weight, kg; and
- $f_{cm}$  = fraction of milk consumed that is contaminated.

Water → Fish → Humans (Ingestion)

---

Equation #1

$$C_{fish} = C_{water} BCF$$

where:

- $C_{fish}$  = Equilibrium concentration of contaminant in fish, mg/kg or pCi/kg;  
 $C_{water}$  = Average concentration of contaminant in water, mg/L or pCi/L; and  
 $BCF$  = Bioconcentration factor, (mg/kg)/(mg/L) or (pCi/kg)/(pCi/L).

Equation #2

$$I_{fish} = \frac{C_{fish} U_{fish}}{BW} f_{cf} \quad \text{(Chemicals)}$$

$$I_{fish} = C_{fish} U_{fish} f_{cf} \quad \text{(Radionuclides)}$$

where:

- $I_{fish}$  = Daily intake of contaminant per unit body weight due to fish ingestion, mg/kg-day or pCi/day;  
 $C_{fish}$  = Equilibrium concentration of contaminant in fish, mg/kg or pCi/kg;  
 $U_{fish}$  = Average daily consumption of fish, kg/day;  
 $BW$  = Average body weight of an age group, kg; and  
 $f_{cf}$  = Fraction of fish consumed that is contaminated, dimensionless.

## Water → Humans (Recreational Immersion)

---

For radionuclides only:

$$Dose_{(water)imm} = C_{water} ET EF Cf_1 Cf_2 Cf_3 DCF_{imm}$$

where:

- $C_{(water)imm}$  = Dose equivalent rate due to water immersion, Sv/yr;
- $C_{water}$  = Average concentration of contaminant in water, pCi/L;
- $ET$  = Exposure time, hours/day;
- $EF$  = Exposure frequency (number of days per year), days/days;
- $Cf_1$  = Conversion factor, Bq/pCi;
- $Cf_2$  = Conversion factor, L/cm<sup>3</sup>;
- $Cf_3$  = Conversion factor, days/hour; and
- $DCF_{imm}$  = Effective dose equivalent rate factor for immersion in contaminated water, Sv-cm<sup>3</sup>/Bq-year.

## Water → Humans (Recreational - Dermal Contact)

---

For chemicals only:

$$Intake_{(water)dermal} = \frac{C_{water} SA PC ET EF Cf_1}{BW}$$

where:

- $Intake_{(water)dermal}$  = daily intake of contaminant due to dermal contact with water during recreational, mg/kg-day;
- $C_{water}$  = Average concentration of contaminant in water, mg/L;
- $SA$  = Skin surface available for contact,  $cm^2$ ;
- $PC$  = Permeability constant, cm/hr;
- $ET$  = Exposure time, hours/day;
- $EF$  = Exposure frequency (number of days per year), days/days;
- $Cf_1$  = Conversion factor,  $L/cm^3$ ; and
- $BW$  = Average body weight, kg.

Soil → Air → Humans (Inhalation)

---

Equation #1

$$C_{(air)resus} = A M F C_{f_1}$$

where:

- $C_{(air)resus}$  = Average concentration of contaminant in air due to resuspension, mg/m<sup>3</sup> or pCi/m<sup>3</sup>;
- $A$  = Equilibrium concentration of contaminant on surface soil, mg/kg or pCi/kg;
- $M$  = Mass loading of particles in ambient air, mg/m<sup>3</sup>;
- $F$  = Enhancement factor, dimensionless; and
- $C_{f_1}$  = Conversion factor, kg/mg.

Equation #2

$$Intake_{(air)resus} = \frac{C_{(air)resus} U_{air} f_t f_s}{BW} \quad (\text{Chemicals})$$

$$Intake_{(air)resus} = C_{(air)resus} U_{air} f_t f_s \quad (\text{Radionuclides})$$

where:

- $Intake_{(air)resus}$  = Daily intake of contaminant due to inhalation of resuspended particulates, mg/kg-day or pCi/day;
- $C_{(air)resus}$  = Average concentration of resuspended contaminant in air, mg/m<sup>3</sup> or pCi/m<sup>3</sup>;
- $U_{air}$  = Average volume of air inhaled per day, m<sup>3</sup>/day;
- $f_t$  = Fraction of time that a person is exposed, dimensionless;
- $f_s$  = Indoor/outdoor shielding factor, dimensionless; and
- $BW$  = Average body weight, kg.

Soil → Air → Humans (Immersion)

---

For radionuclides only:

Equation #1

$$C_{(air)resus} = A M F Cf_1$$

where:

- $C_{(air)resus}$  = Average concentration of contaminant in air due to resuspension, mg/m<sup>3</sup> or pCi/m<sup>3</sup>;
- $A$  = Equilibrium concentration of contaminant on surface soil, mg/kg or pCi/kg;
- $M$  = Mass loading of particles in ambient air, mg/m<sup>3</sup>;
- $F$  = Enhancement factor, dimensionless; and
- $Cf_1$  = Conversion factor, kg/mg.

Equation #2

$$Dose_{(imm)resus} = C_{(air)resus} f_t f_s Cf_1 Cf_2 DCF_{(imm)}$$

where:

- $Dose_{(imm)resus}$  = Dose equivalent rate due to air immersion following resuspension, Sv/yr;
- $C_{(air)resus}$  = Average concentration of resuspended contaminant in air, pCi/m<sup>3</sup>;
- $f_t$  = Fraction of time that a person is exposed, dimensionless;
- $f_s$  = Indoor/outdoor shielding factor, dimensionless;
- $Cf_1$  = Conversion factor, Bq/pCi;
- $Cf_2$  = Conversion factor, m<sup>3</sup>/cm<sup>3</sup>; and
- $DCF_{(imm)}$  = Effective dose equivalent rate factor for immersion in contaminated water, Sv-cm<sup>3</sup>/Bq-year.

Air → Soil → Humans (Ingestion)

---

$$I_{soil} = \frac{C_{soil(surf)} U_{soil}}{BW} f_{sc} \quad (\text{Chemicals})$$

$$I_{soil} = C_{soil(surf)} U_{soil} f_{sc} \quad (\text{Radionuclides})$$

where:

- $I_{soil}$  = Daily intake of contaminant per unit body weight due to surface soil ingestion, mg/kg-day or pCi/day;
- $C_{soil(surf)}$  = Equilibrium concentration of contaminant in surface soil, mg/kg or pCi/kg;
- $U_{soil}$  = Average daily ingestion of soil, kg/day;
- $BW$  = Average body weight kg; and
- $f_{sc}$  = Fraction of soil ingested that is contaminated, dimensionless.

Soil → Livestock/Game (Beef) → Humans (Ingestion)

---

Equation #1

$$C_{beef(soil)} = C_{soil(surf)} Q_{soil(b)} B_{meat} f_{csb}$$

where:

- $C_{beef(soil)}$  = Equilibrium concentration of contaminant in beef due to soil ingestion, mg/kg or pCi/kg;
- $C_{soil(surf)}$  = Equilibrium concentration of contaminant in surface soil, mg/kg or pCi/kg;
- $Q_{soil(b)}$  = Daily ingestion rate of soil by beef cattle, kg/day;
- $B_{meat}$  = Biotransfer factor from cattle intake to meat concentration, (mg/kg)/(mg/day) or (pCi/kg)/(pCi/day); and
- $f_{csb}$  = Fraction of soil ingested by beef cattle that is contaminated, dimensionless.

Equation #2

$$I_{beef(soil)} = \frac{C_{beef(soil)} U_{beef}}{BW} f_{cb} \quad \text{(Chemicals)}$$

$$I_{beef(soil)} = C_{beef(soil)} U_{beef} f_{cb} \quad \text{(Radionuclides)}$$

where:

- $I_{beef(soil)}$  = Daily intake of contaminant per unit body weight due to beef ingestion, mg/kg-day or pCi/day;
- $C_{beef(soil)}$  = Equilibrium concentration of contaminant in beef due to soil ingestion, mg/kg or pCi/kg;
- $U_{beef}$  = Average daily consumption of beef, kg/day;
- $BW$  = Average body weight, kg; and
- $f_{cb}$  = Fraction of beef consumed that is contaminated, dimensionless.

Soil → Dairy Cattle (Milk) → Humans (Ingestion)

---

Equation #1

$$C_{milk(soil)} = C_{soil(surf)} Q_{soil(d)} F_m f_{csd}$$

where:

- $C_{milk(soil)}$  = Equilibrium concentration of contaminant in milk due to soil ingestion, mg/L or pCi/L;
- $C_{soil(surf)}$  = Equilibrium concentration of contaminant in surface soil, mg/kg or pCi/kg;
- $Q_{soil(d)}$  = Daily ingestion rate of soil by dairy cattle, kg/day;
- $F_m$  = Biotransfer factor from cattle intake to milk concentration, (mg/L)/(mg/day) or (pCi/L)/(pCi/day); and
- $f_{csd}$  = Fraction of soil ingested by dairy cattle that is contaminated, dimensionless.

Soil → Dairy Cattle (Milk) → Humans (Ingestion)  
(Continued)

---

Equation #2

$$I_{milk} = \frac{C_{milk(soil)} U_{milk}}{BW} f_{cm} \quad (\text{Chemicals})$$

$$I_{milk} = C_{milk(soil)} U_{milk} f_{cm} \quad (\text{Radionuclides})$$

where:

- $I_{milk}$  = Daily intake of contaminant per unit body weight due to milk ingestion, mg/kg-day or pCi/day;
- $C_{milk(soil)}$  = Equilibrium concentration of contaminant in milk due to soil ingestion, mg/L or pCi/L;
- $U_{milk}$  = Average daily consumption of milk, L/day;
- $BW$  = Average body weight, kg; and
- $f_{cm}$  = Fraction of milk consumed that is contaminated, dimensionless.

---

Soil → Vegetables → Humans (Ingestion)

---

Equation #1

$$C_{veg(soil)} = C_{soil(bulk)} B_{veg}$$

where:

- $C_{veg(soil)}$  = Equilibrium concentration of contaminant in leafy vegetables due to root uptake (wet weight), mg/kg or pCi/kg;
- $C_{soil(bulk)}$  = Average concentration of contaminant in bulk soil, mg/kg or pCi/kg; and
- $B_{veg}$  = Concentration ratio for the transfer of contaminant from dry soil to leafy vegetables (wet weight), dimensionless.

**Soil → Vegetables → Humans (Ingestion)**  
**(Continued)**

---

Equation #2

$$I_{veg(soil)} = \frac{C_{veg(soil)} U_{veg}}{BW} f_{cv} \quad \text{(Chemicals)}$$

$$I_{veg(soil)} = C_{veg(soil)} U_{veg} f_{cv} \quad \text{(Radionuclides)}$$

where:

- $I_{veg(soil)}$  = Daily intake of contaminant due to leafy vegetable ingestion (soil pathway), mg/kg-day or pCi/day;
- $C_{veg(soil)}$  = Equilibrium concentration of contaminant in leafy vegetables due to root uptake (wet weight), mg/kg or pCi/kg;
- $U_{veg}$  = Average daily consumption of vegetables (wet weight), kg/day;
- $BW$  = Average body weight, kg; and
- $f_{cv}$  = Fraction of vegetables consumed that is contaminated, dimensionless.

**Soil → Pasture → Livestock/Game (Beef) → Humans (Ingestion)**

---

Equation #1

$$C_{past(soil)} = C_{soil(bulk)} B_{past}$$

where:

- $C_{past(soil)}$  = Equilibrium concentration of contaminant in pasture due to root uptake (dry weight), mg/kg or pCi/kg;
- $C_{soil(bulk)}$  = Average concentration of contaminant in bulk soil, mg/kg or pCi/kg; and
- $B_{past}$  = Concentration ratio for the transfer of contaminant from dry soil to pasture (dry weight), dimensionless.

Soil → Pasture → Livestock/Game (Beef) → Humans (Ingestion)  
(Continued)

---

Equation #2

$$C_{beef(past)} = C_{past(soil)} Q_{past(b)} F_f f_{pb}$$

where:

- $C_{beef(past)}$  = Equilibrium concentration of contaminant in beef (soil pathway), mg/kg or pCi/kg;
- $C_{past(soil)}$  = Equilibrium concentration of contaminant in pasture due to root uptake (dry weight), mg/kg or pCi/kg;
- $Q_{past(b)}$  = Daily ingestion of pasture (dry weight) by beef cattle, kg/day;
- $F_f$  = Biotransfer factor from cattle intake to meat concentration, (mg/kg)/(mg/day) or (pCi/kg)/(pCi/day); and
- $f_{pb}$  = Fraction of feed ingested by beef cattle that is pasture, dimensionless.

Equation #3

$$I_{beef(past)} = \frac{C_{beef(past)} U_{beef}}{BW} f_{cb} \quad \text{(Chemicals)}$$

$$I_{beef(past)} = C_{beef(past)} U_{beef} f_{cb} \quad \text{(Radionuclides)}$$

where:

- $I_{beef(past)}$  = Daily intake of contaminant due to beef ingestion (pasture), mg/kg-day or pCi/day;
- $C_{beef(past)}$  = Equilibrium concentration of contaminant in beef due to pasture, mg/kg or pCi/kg;
- $U_{beef}$  = Average daily consumption of beef, kg/day;
- $BW$  = Average body weight, kg; and
- $f_{cb}$  = Fraction of beef consumed that is contaminated, dimensionless.

Soil → Pasture → Dairy Cattle (Milk) → Humans (Ingestion)

---

Equation #1

$$C_{past(soil)} = C_{soil(bulk)} B_{past}$$

where:

- $C_{past(soil)}$  = Equilibrium concentration of contaminant in pasture due to root uptake (dry weight), mg/kg or pCi/kg;
- $C_{soil(bulk)}$  = Average concentration of contaminant in bulk soil, mg/kg or pCi/kg; and
- $B_{past}$  = Concentration ratio for the transfer of contaminant from dry soil to pasture (dry weight), dimensionless.

Equation #2

$$C_{milk(past)} = C_{past(d)} Q_{past(d)} F_m f_{pd}$$

where:

- $C_{milk(past)}$  = Equilibrium concentration of contaminant in milk (soil pathway), mg/L or pCi/L;
- $C_{past(soil)}$  = Equilibrium concentration of contaminant in pasture due to root uptake (dry weight), mg/kg or pCi/kg;
- $Q_{past(d)}$  = Daily ingestion of pasture (dry weight) by dairy cattle, kg/day;
- $F_m$  = Biotransfer factor from cattle intake to milk concentration (mg/L)/(mg/day) or (pCi/L)/(pCi/day); and
- $f_{pd}$  = Fraction of feed ingested by dairy cattle that is pasture, dimensionless.

Soil → Pasture → Dairy Cattle (Milk) → Humans (Ingestion)  
(Continued)

---

Equation #3

$$I_{milk(past)} = \frac{C_{milk(past)} U_{milk}}{BW} f_{cm} \quad \text{(Chemicals)}$$

$$I_{milk(past)} = C_{milk(past)} U_{milk} f_{cm} \quad \text{(Radionuclides)}$$

where:

- $I_{milk(past)}$  = Daily intake of contaminant due to milk ingestion (pasture), mg/kg-day or pCi/day;
- $C_{milk(past)}$  = Equilibrium concentration of contaminant in milk due to pasture, mg/L or pCi/L;
- $U_{milk}$  = Average daily consumption of milk, L/day;
- $BW$  = Average body weight, kg; and
- $f_{cm}$  = Fraction of milk consumed that is contaminated, dimensionless.

## Soil → Humans (Ground Exposure)

---

For radionuclides only:

$$Dose_{surf} = C_{soil(surf)} BD SD DCF_{surf} f_t f_s Cf_1 Cf_2$$

where:

- $Dose_{surf}$  = Dose equivalent rate from surface exposure, Sv/year;
- $C_{soil(surf)}$  = Equilibrium concentration of contaminant in surface soil, pCi/kg;
- $BD$  = Soil bulk density, kg/m<sup>3</sup>;
- $SD$  = Soil depth of mixing, cm;
- $DCF_{surf}$  = Effective dose equivalent rate factor for surface exposure to an infinite plane at a point 1m above ground, Sv - cm<sup>2</sup>/Bq yr;
- $f_t$  = Fraction of time exposed, dimensionless;
- $f_s$  = Indoor/outdoor shielding factor, dimensionless;
- $Cf_1$  = Conversion factor, Bq/pCi; and
- $Cf_2$  = Conversion factor, m<sup>3</sup>/cm<sup>3</sup>.

## Soil → Humans (Dermal Contact)

---

For chemical only:

$$I_{soil(dermal)} = \frac{C_{soil(surf)} SA SL f_a}{BW} f_{cs} f_u Cf_1$$

where:

- $I_{soil(dermal)}$  = Daily intake of contaminant due to dermal absorption from soil, mg/kg-day;
- $C_{soil(surf)}$  = Equilibrium concentration of contaminant in surface soil, mg/kg;
- $SA$  = Surface area of exposed skin, cm<sup>2</sup>;
- $SL$  = Soil loading on skin, mg/cm<sup>2</sup>-day;
- $f_a$  = Fraction of contaminant absorbed through skin, dimensionless;
- $BW$  = Average body weight, kg;
- $f_{cs}$  = Fraction of soil that is contaminated, dimensionless; and
- $Cf_1$  = Conversion factor, kg/mg.

**APPENDIX C**  
**EXPOSURE PARAMETERS**

## APPENDIX C

### EXPOSURE PARAMETERS

This appendix presents all of the input parameters that are used in the exposure equations presented in Appendix B. Where possible, site-specific information was used to select the values used in this analysis. For most parameters, however, the values were selected following an extensive review of the scientific literature. Since a primary objective of this report was to identify important pathways for each of the contaminants of concern, we attempted to select the site-specific and literature values in a consistent manner so that the identification of dominant pathways was unbiased. For the purposes of this evaluation, values that are representative of a typical adult individual were selected.

APPENDIX C

EXPOSURE PARAMETERS

| Parameter  | Symbol                  | Value | Units         | Reference              |
|--|-------------------------|-------|---------------|------------------------|
| <b>EXPOSURE PATHWAYS, GENERAL</b>                                    |                         |       |               |                        |
| Average adult body weight by humans,                                 | BW                      | 70    | kg            | 16                     |
| Average daily consumption of beef                                    | U(beef)                 | 0.1   | kg/day        | 17                     |
| Fraction of beef consumed that is contaminated                       | $f_{cb}$                | 0.44  | dimensionless | 17                     |
| Average daily consumption of milk by humans                          | U(milk)                 | 0.28  | L/day         | 17                     |
| Fraction of milk consumed that is contaminated                       | $f_{cm}$                | 0.4   | dimensionless | 17                     |
| Average daily consumption of leafy vegetables (wet weight) by humans | U(veg)                  | 0.2   | kg/day        | 17                     |
| Fraction of vegetables consumed that is contaminated                 | $f_{cv}$                | 0.25  | dimensionless | 4, 16                  |
| Average daily consumption of drinking water by humans                | U(water)                | 1.4   | L/day         | 17                     |
| Fraction of water consumed by humans that is contaminated            | $f_{cw}$                | 0.75  | dimensionless | Professional judgement |
| Average daily consumption of fish by humans                          | U(fish)                 | 0.03  | kg/day        | 17                     |
| Fraction of fish consumed that is contaminated                       | $f_{cf}$                | 0.75  | dimensionless | Professional judgement |
| Daily ingestion of pasture (dry weight) by beef cattle               | Qpast(b)                | 11    | kg/day        | 2, 6, 9, 19            |
| Fraction of feed ingested by beef cattle that is from pasture        | $f_{pb}$                | 0.75  | dimensionless | Professional judgement |
| Daily ingestion of pasture (dry weight) by dairy cattle              | Qpast(d)                | 16    | kg/day        | 2, 5, 6, 9, 19         |
| Fraction of feed ingested by dairy cattle that is from pasture       | $f_{pd}$                | 0.5   | dimensionless | Professional judgement |
| <b>AIR EXPOSURE PATHWAYS</b>   |                         |       |               |                        |
| Dry deposition velocity onto vegetation (iodine)                     | $V_{d-iodine}$          | 2     | cm/sec        | 7                      |
| Dry deposition velocity onto vegetation (small particles)            | $V_{d-small particles}$ | 0.1   | cm/sec        | 7                      |

APPENDIX C

EXPOSURE PARAMETERS

| Parameter   | Symbol                          | Value                     | Units                        | Reference              |
|---|---------------------------------|---------------------------|------------------------------|------------------------|
| Dry deposition velocity onto vegetation (noble gases)       | $V_{d-noble\ gases}$            | $1 \times 10^{-10}$       | cm/sec                       | 7                      |
| Percentage of time precipitation occurs in Oak Ridge area   | $P_{rain}$                      | 7.95%                     | dimensionless                | 13                     |
| Wet deposition velocity (iodine and small particles)        | $V_{w-iodine-small\ particles}$ | 10                        | cm/sec                       | 14                     |
| Wet deposition velocity (noble gases)                       | $V_{w-noble\ gases}$            | 0.01                      | cm/sec                       | Professional judgement |
| Biomass yield (vegetable crops)                             | $Y_{veg}$                       | 2                         | kg/m <sup>2</sup> wet weight | 11                     |
| Biomass yield (pasture)                                     | $Y_{past}$                      | 0.28                      | kg/m <sup>2</sup> wet weight | 19                     |
| Total deposition onto vegetation (iodine)                   | $V_{D-iodine}$                  | 1100 (veg)<br>7900 (past) | (m/day)/(kg/m <sup>2</sup> ) | Footnote a             |
| Total deposition onto vegetation (small particles)          | $V_{D-small\ particles}$        | 385 (veg)<br>2570 (past)  | (m/day)/(kg/m <sup>2</sup> ) | Footnote b             |
| Total deposition onto vegetation (noble gases)              | $V_{D-noble\ gases}$            | 0.35 (veg)<br>2.5 (past)  | (m/day)/(kg/m <sup>2</sup> ) | Footnote c             |
| Quantity of air inhaled per day                             | U(air)                          | 20                        | m <sup>3</sup> /day          | 17                     |
| Fraction of time that person is exposed to contaminated air | $f_t$                           | 0.75                      | dimensionless                | Professional judgement |
| Indoor/outdoor shielding factor                             | $f_s$                           | 0.5                       | dimensionless                | 10                     |
| Daily inhalation rate of beef cattle                        | Qair(b)                         | 122                       | m <sup>3</sup> /day          | 6                      |
| Daily inhalation rate of dairy cattle                       | Qair(d)                         | 150                       | m <sup>3</sup> /day          | 2, 6                   |
| Weathering rate constant for vegetables                     | $k_w$                           | 0.05                      | day <sup>-1</sup>            | 8                      |
| Growth period or exposure period for vegetables             | $T_g$                           | 60                        | day                          | 17                     |
| Fraction of chemical remaining after washing                | $f_w$                           | 0.3                       | dimensionless                | Professional judgement |
| Weathering rate constant for pasture                        | $k_w$                           | 0.05                      | day <sup>-1</sup>            | 8                      |

APPENDIX C

EXPOSURE PARAMETERS

| Parameter   | Symbol         | Value    | Units                   | Reference              |
|---|----------------|----------|-------------------------|------------------------|
| Growth period or exposure period for pasture                                      | $T_p$          | 30       | day                     | 17                     |
| <b>WATER EXPOSURE PATHWAYS</b>  |                |          |                         |                        |
| Daily intake of water by beef cattle  | $Q_{water(b)}$ | 44       | L/day                   | 6                      |
| Daily intake of water by dairy cattle   | $Q_{water(d)}$ | 48       | L/day                   | 6                      |
| Fraction of water consumed by cattle that is contaminated                         | $f_{cw}$       | 1        | dimensionless           | Professional judgement |
| Skin surface available for contact (dermal contact to water)                      | SA             | 19400    | cm <sup>2</sup>         | 17                     |
| Exposure time (dermal/ immersion contact to water)                                | ET             | 2.6      | hours/day               | 18                     |
| Exposure frequency (number of days per year) (dermal/ immersion contact to water) | EF             | 0.0192   | days/days               | 18                     |
| <b>SOIL EXPOSURE PATHWAYS</b>   |                |          |                         |                        |
| Mass loading of particles in ambient air  | M              | 0.065    | mg/m <sup>3</sup>       | 1                      |
| Enhancement factor  | F              | 1        | dimensionless           | Professional judgement |
| Average daily ingestion of soil   | U(soil)        | 5.00E-05 | kg/day                  | 12, 17                 |
| Fraction of soil ingested that is contaminated                                    | $f_{\pm}$      | 0.5      | dimensionless           | Professional judgement |
| Daily ingestion rate of soil by beef cattle                                       | $Q_{soil(b)}$  | 0.34     | kg/day                  | 6                      |
| Fraction of soil ingested by beef cattle that is contaminated                     | $f_{cwb}$      | 1        | dimensionless           | Professional judgement |
| Daily ingestion rate of soil by dairy cattle                                      | $Q_{soil(d)}$  | 0.36     | kg/day                  | 6                      |
| Fraction of soil ingested by dairy cattle that is contaminated                    | $f_{cwd}$      | 1        | dimensionless           | Professional judgement |
| Surface area of exposed skin (dermal contact to soil)                             | SA             | 5800     | cm <sup>2</sup>         | 20                     |
| Soil loading on skin  | SL             | 0.5      | mg/cm <sup>2</sup> -day | 20                     |
| Fraction of contaminant absorbed through skin (metals)                            | $F_s$          | 0.01     | dimensionless           | 3                      |

APPENDIX C

EXPOSURE PARAMETERS

| Parameter  | Symbol   | Value | Units             | Reference              |
|--|----------|-------|-------------------|------------------------|
| Fraction of contaminant absorbed through skin (organics)     | $F_s$    | 0.10  | dimensionless     | 3                      |
| Fraction of soil that is contaminated                        | $F_{cs}$ | 0.5   | dimensionless     | Professional judgement |
| Soil bulk density  | BD       | 1     | kg/m <sup>3</sup> | Professional judgement |
| Soil depth of mixing   | SD       | 1     | cm                | Professional judgement |
| Fraction of day when individual is exposed (ground exposure) | $F_t$    | 0.75  | dimensionless     | Professional judgement |
| Indoor/outdoor ground exposure reduction (shielding) factor  | $f_s$    | 0.3   | dimensionless     | 10                     |

NA Not Applicable

$$a \quad V_{D-\text{soil}} = \frac{V_{d-\text{soil}} \times 1 - P_{\text{rain}} + V_{w-\text{soil}} \times P_{\text{rain}}}{Y_{\text{soil}}}$$

$$b \quad V_{D-\text{small particles}} = \frac{V_{d-\text{small particles}} \times 1 - P_{\text{rain}} + V_{w-\text{small particles}} \times P_{\text{rain}}}{Y_{\text{small particles}}}$$

$$c \quad V_{D-\text{mobile gas}} = \frac{V_{d-\text{mobile gas}} \times 1 - P_{\text{rain}} + V_{w-\text{mobile gas}} \times P_{\text{rain}}}{Y_{\text{mobile gas}}}$$

## REFERENCES

1. Boyle et al., 1982. Boyle, J.W., R. Blumberg, S.J. Cotter, G.S. Hill, C.R. Kerley, R.H. Kettle, R.L. Kroodsmas, D.W. Lee, R.C. Martin, R.D. Roop, D.N. Secora, W.P. Staub, and R.E. Thoma. "Environmental Analysis of the Operation of Oak Ridge National Laboratory (X-10 Site)." Publication ORNL-5870.
2. CAPCOA, 1991. California Air Pollution Control Officers Association. Air Toxics "Hot Spots" Program, AB 2588, Risk Assessment Guidelines. Risk Assessment Committee of CAPCOA. Sacramento, California.
3. Clement, 1988. "Multi-Pathway Health Risk Assessment Input Parameters Guidance Document." Prepared for the South Coast Air Quality Management District. June 1988.
4. Higley, 1991. Higley, K.A. Master of Science Thesis (Draft). Colorado State University. Fort Collins, CO.
5. Hoffman and Baes, 1979. Hoffman, F.O. and C.F. Baes. "A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides." ORNL/NUREG/TM-282. Oak Ridge National Laboratory, Oak Ridge, TN. Prepared for the U.S. Nuclear Regulatory Commission. October 1979.
6. McKone, 1988. McKone, T.E. "Conventional Weapons Demilitarization: A Health and Environmental Effects Data Base Assessment. Methods of Estimating Multi-Pathway Exposure to Environmental Contaminants. Final Report, Phase II." AD UCRL-21064. Lawrence Livermore National Laboratory, Livermore, CA.
7. Miller, 1984. Miller, C.W. ed. "Models and Parameters for Environmental Radiological Assessments". Technical Information Center, Office of Scientific and Technical Information, U.S. Department of Energy.
8. Miller and Hoffman, 1983. Miller, C.W. and F.O. Hoffman. "An Examination of the Environmental Half-time for Radionuclides Deposited on Vegetation." Health Physics 45(3): 731-744.
9. NCRP, 1985. National Council on Radiation Protection and Measurements. "Radiological Assessment: Predicting the Transport, Bioaccumulation, and Uptake by Man of Radionuclides Released to the Environment." NCRP Report No. 76, p. 200. Bethesda, MD.
10. NCRP, 1991. National Council on Radiation Protection and Measurements. "Screening Models for Releases of Radionuclides to Air, Surface Water, and Ground Water, Description of Models (Draft)." NCRP Report No. XX, Volume 1. Bethesda, MD.
11. NRC, 1977. Nuclear Regulatory Commission. "Regulatory Guide 1.109. Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I." USNRC Regulatory Guide, Office of Standards Development. Revision 1. October 1977.
12. Paustenbach, 1987. Paustenbach, D.J. "Assuming the Potential Environmental and Human Health Risks of Contaminated Soils." Comment Toxicol., 1:185-220.
13. Sharp, 1993. Sharp, R. Personal communication with Ron Sharp, Oak Ridge National Laboratory.
14. Slinn, 1984. Slinn, W.G.N. "Precipitation Scavenging." In: Atmospheric Science and Power Production. Edited by Darryl Randerson. Technical Information Center, Office of Scientific and Technical Information, U.S. Department of Energy.
15. USEPA, 1979. U.S. Environmental Protection Agency. "AIRDOS-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides." Oak Ridge National Laboratory, Oak Ridge, TN. p. 86.
16. USEPA, 1985. U.S. Environmental Protection Agency. "Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments." EPA 600-8-85-010. Prepared for USEPA, Washington, D.C., by GCA Corporation, Chapel Hill, NC.
17. USEPA, 1989a. U.S. Environmental Protection Agency. "Exposure Factors Handbook." EPA 600-8-89-043. Washington, D.C.

18. USEPA, 1989b. U.S. Environmental Protection Agency. "Risk Assessment Guidance for Superfund, Volume I. Human Health Evaluation Manual (Part A), Interim Final." EPA 540/1-89/002. Washington, D.C.
19. USEPA, 1989c. U.S. Environmental Protection Agency. "Risk Assessment Methodology, Environmental Impact Statement, NESHAPS for Radionuclides. Background Information Document, Volume 1." EPA 520/1-89-005. Washington, D.C.
20. USEPA, 1992. Dermal Exposure Assessment: Principles and Applications, Interim Report. "Office of Health and Environment Assessment." EPA 600/8-91-011B.SOIL.
21. USEPA, 1992. "New Interim Region IV Guidance for Dermal Absorption." February 11, 1992.
22. Voillequé et al., 1970. Voillequé, P.G., D.R. Adams, and J.B. Echo. "Transfer of Krypton-85 from air to grass." Health Phy., 19(6):835. December 1970.

**APPENDIX D**

**WITHIN-MEDIUM COMPARISON SUMMARY SHEETS**

## APPENDIX D

### WITHIN-MEDIUM COMPARISON SUMMARY SHEETS

This appendix summarizes the results of the within-medium exposure pathway comparisons for each of the chemicals and radionuclides evaluated in Tasks 3 & 4. The objective of these comparisons is to identify the important pathway(s) for each contaminant within each of the media evaluated (i.e., air, surface water, and soil/sediment).

For each of the contaminants released from the ORR and evaluated in Task 3 & 4, the intake associated with each applicable pathway within each medium is estimated for a unit contaminant concentration (e.g., 1 pCi/m<sup>3</sup> for a radionuclide in air, 1 µg/L for a chemical in water) using the exposure equations and exposure parameters presented in Appendices B and C and Table 4-1. It should be noted that the determination of radionuclide intake as a result of immersion or ground exposure is not appropriate, since exposure occurs without the contaminant being taken up by the body. As such, radiation dose is calculated for these pathways. The relative importance of each pathway is then determined by comparing the hypothetical health hazards (i.e., radiation doses, cancer risks, or hazard indices) associated with intake of the hypothetical concentration. The health hazards are calculated from the previously determined intakes and the toxicity criteria (chemicals) or dose conversion factors (radionuclides) presented in Tables 4-2 through 4-4. The hypothetical health hazards for each contaminant in each medium are summarized in the Tables D-1 through D-6.

As shown in Tables D-1 through D-6, the estimated health hazards for all potential exposure pathways within a given medium for a given contaminant were ranked and the highest value (radiation dose, cancer risk, or hazard index) is identified as the "benchmark" to which all other pathways are compared. The ratio of each individual hazard to the benchmark value was then calculated. All pathways for which the calculated health hazard is greater than or equal to 1% of the most important pathway are retained, and are the subject of further evaluation in this report.

TABLE D-1: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN AIR

8/25/93

| Argon-41  |          |                 |                 |
|---|----------|-----------------|-----------------|
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 0        | <1%             | N               |
| Air to Humans (Immersion)                                     | 2.53E-08 | 100%            | Y               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 0        | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 0        | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 0        | <1%             | N               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 0        | <1%             | N               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 0        | <1%             | N               |
| Barium-140  |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 9.82E-08 | 3%              | Y               |
| Air to Humans (Immersion)                                     | 5.76E-08 | 2%              | Y               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 1.62E-11 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.83E-10 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 3.46E-06 | 100%            | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 4.67E-08 | 1%              | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 4.16E-07 | 12%             | Y               |
| Cerium-144  |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 1.01E-05 | 100%            | Y               |
| Air to Humans (Immersion)                                     | 1.38E-09 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 3.15E-10 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 7.90E-11 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 8.60E-06 | 85%             | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 9.11E-07 | 9%              | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.80E-07 | 2%              | Y               |
| Cesium-137  |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 8.71E-07 | 2%              | Y               |
| Air to Humans (Immersion)                                     | 1.10E-08 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 1.88E-08 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.09E-08 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 1.93E-05 | 35%             | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 5.45E-05 | 100%            | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 4.77E-05 | 88%             | Y               |

TABLE D-1: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN AIR

8/25/93

| Cobalt-60   |          |                 |                 |
|---|----------|-----------------|-----------------|
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 4.15E-06 | 29%             | Y               |
| Air to Humans (Immersion)                                     | 4.94E-08 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 4.92E-09 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 4.61E-09 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 1.04E-05 | 73%             | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.42E-05 | 100%            | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.05E-05 | 74%             | Y               |
| Iodine-129  |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 4.05E-06 | <1%             | N               |
| Air to Humans (Immersion)                                     | 1.61E-10 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 3.34E-08 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.44E-07 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 2.71E-04 | 29%             | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 2.76E-04 | 29%             | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 9.36E-04 | 100%            | Y               |
| Iodine-131  |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 8.31E-07 | <1%             | N               |
| Air to Humans (Immersion)                                     | 7.30E-09 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 6.79E-09 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.92E-08 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 5.51E-05 | 29%             | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 5.60E-05 | 29%             | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.90E-04 | 100%            | Y               |
| Iodine-133  |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 1.52E-07 | <1%             | N               |
| Air to Humans (Immersion)                                     | 1.61E-10 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 1.41E-09 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 6.06E-09 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 1.14E-05 | 29%             | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.16E-05 | 29%             | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 3.95E-05 | 100%            | Y               |

TABLE D-1: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN AIR

8/25/93

| Krypton-85  |          |                 |                 |
|---|----------|-----------------|-----------------|
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 0        | <1%             | N               |
| Air to Humans (Immersion)                                     | 1.01E-10 | 100%            | Y               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 0        | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 0        | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 0        | <1%             | N               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 0        | <1%             | N               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 0        | <1%             | N               |
| Lanthanum-140   |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 1.22E-07 | 4%              | Y               |
| Air to Humans (Immersion)                                     | 4.69E-08 | 2%              | Y               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 4.57E-11 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.91E-11 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 3.11E-06 | 100%            | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.32E-07 | 4%              | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 4.34E-08 | 1%              | Y               |
| Neptunium-237   |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 5.57E-03 | 100%            | Y               |
| Air to Humans (Immersion)                                     | 2.64E-09 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 1.79E-09 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 5.10E-10 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 6.67E-04 | 12%             | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 5.18E-06 | <1%             | N               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.16E-06 | <1%             | N               |
| Niobium-95  |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 1.72E-07 | <1%             | N               |
| Air to Humans (Immersion)                                     | 1.51E-08 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 1.23E-08 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 3.09E-09 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 1.01E-06 | 3%              | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.56E-05 | 100%            | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 7.06E-06 | 20%             | Y               |

TABLE D-1: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN AIR

8/25/93

| Plutonium-238   |          |                 |                 |
|---|----------|-----------------|-----------------|
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 1.11E-02 | 100%            | Y               |
| Air to Humans (Immersion)                                     | 1.76E-12 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 6.38E-11 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.00E-11 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 1.30E-03 | 12%             | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.84E-08 | <1%             | N               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 4.55E-08 | <1%             | N               |
| Plutonium-239/240   |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 1.22E-02 | 100%            | Y               |
| Air to Humans (Immersion)                                     | 1.60E-12 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 7.03E-11 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.20E-11 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 1.44E-03 | 12%             | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 2.03E-07 | <1%             | N               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 5.02E-08 | <1%             | N               |
| Plutonium-241   |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 2.33E-04 | 100%            | Y               |
| Air to Humans (Immersion)                                     | 4.80E-14 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 1.38E-12 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 4.31E-13 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 2.82E-05 | 12%             | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.98E-09 | <1%             | N               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 9.82E-10 | <1%             | N               |
| Protactinium-233  |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 2.33E-07 | 18%             | Y               |
| Air to Humans (Immersion)                                     | 4.09E-09 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 6.45E-13 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.01E-12 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 1.32E-06 | 100%            | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.89E-09 | <1%             | N               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.30E-09 | <1%             | N               |

TABLE D-1: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN AIR

8/25/93

| Ruthenium-103   |          |                 |                 |
|---|----------|-----------------|-----------------|
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 2.53E-07 | 21%             | Y               |
| Air to Humans (Immersion)                                     | 9.20E-09 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 1.17E-10 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 6.06E-14 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 1.20E-06 | 100%            | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.39E-07 | 28%             | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.38E-10 | <1%             | N               |
| Ruthenium-106   |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 1.32E-05 | 100%            | Y               |
| Air to Humans (Immersion)                                     | 4.41E-09 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 1.09E-12 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 5.62E-12 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 1.11E-05 | 84%             | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.14E-06 | 24%             | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.28E-08 | <1%             | N               |
| Strontium-89  |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 1.01E-06 | 28%             | Y               |
| Air to Humans (Immersion)                                     | 1.67E-10 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 5.22E-11 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 7.62E-10 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 3.56E-06 | 100%            | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.51E-07 | 4%              | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.74E-06 | 49%             | Y               |
| Strontium-90  |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 6.08E-06 | 12%             | Y               |
| Air to Humans (Immersion)                                     | 3.19E-10 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 7.61E-10 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.11E-08 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 5.19E-05 | 100%            | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 2.20E-06 | 4%              | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.53E-05 | 49%             | Y               |

TABLE D-1: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN AIR

8/25/93

| Technetium-99   |          |                 |                 |
|---|----------|-----------------|-----------------|
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 2.03E-07 | 11%             | Y               |
| Air to Humans (Immersion)                                     | 8.41E-12 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 2.16E-10 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 7.94E-10 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 5.19E-07 | 29%             | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 6.23E-07 | 34%             | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.81E-06 | 100%            | Y               |
|   |          |                 |                 |
| Thorium-232   |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 4.36E-02 | 100%            | Y               |
| Air to Humans (Immersion)                                     | 3.61E-12 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 3.31E-10 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 8.62E-10 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 1.13E-03 | 3%              | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 9.55E-07 | <1%             | N               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.96E-06 | <1%             | N               |
|   |          |                 |                 |
| Uranium-234/235   |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 3.55E-03 | 100%            | Y               |
| Air to Humans (Immersion)                                     | 2.93E-09 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 1.01E-09 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 5.88E-09 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 1.04E-04 | 3%              | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 2.93E-06 | <1%             | N               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.34E-05 | <1%             | N               |
|   |          |                 |                 |
| Uranium-238   |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 3.24E-03 | 100%            | Y               |
| Air to Humans (Immersion)                                     | 2.04E-12 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 8.99E-10 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 5.20E-09 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 9.19E-05 | 3%              | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 2.60E-06 | <1%             | N               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.19E-05 | <1%             | N               |

TABLE D-1: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN AIR

8/25/93

| Xenon-133   |          |                 |                 |
|---|----------|-----------------|-----------------|
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
|   | 0        | <1%             | N               |
| Air to Humans (Inhalation)                                    | 6.81E-10 | 100%            | Y               |
| Air to Humans (Immersion)                                     | 0        | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 0        | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 0        | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 0        | <1%             | N               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 0        | <1%             | N               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 0        | <1%             | N               |
| Zirconium-95  |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
|   | 7.39E-07 | 45%             | Y               |
| Air to Humans (Inhalation)                                    | 2.23E-08 | 1%              | Y               |
| Air to Humans (Immersion)                                     | 4.39E-10 | <1%             | N               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 7.49E-12 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.63E-06 | 100%            | Y               |
| Air to Vegetables to Humans (Ingestion)                       | 1.27E-06 | 78%             | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.71E-08 | 1%              | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   |          |                 |                 |

TABLE D-2: WITHIN-MEDIUM COMPARISONS-- CHEMICALS IN AIR

8/25/93

| Arsenic (Noncarcinogenic)                                     |              |                            |                        |
|---|--------------|----------------------------|------------------------|
| Pathway   | Hazard Index | Percent of Largest Pathway | Retain Pathway? Yes/No |
| Air to Humans (Inhalation)                                    | 3.57E+02     | 7%                         | Y                      |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 5.11E-01     | <1%                        | N                      |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 4.96E-02     | <1%                        | N                      |
| Air to Vegetables to Humans (Ingestion)                       | 5.23E+03     | 100%                       | Y                      |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.48E+03     | 28%                        | Y                      |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.13E+02     | 2%                         | Y                      |
| Arsenic (Carcinogenic)  |              |                            |                        |
| Pathway   | Risk         | Percent of Largest Pathway | Retain Pathway? Yes/No |
| Air to Humans (Inhalation)                                    | 5.36E+00     | 100%                       | Y                      |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 2.68E-04     | <1%                        | N                      |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.60E-05     | <1%                        | N                      |
| Air to Vegetables to Humans (Ingestion)                       | 2.74E+00     | 51%                        | Y                      |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 7.76E-01     | 14%                        | Y                      |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 5.93E-02     | 1%                         | Y                      |
| Beryllium   |              |                            |                        |
| Pathway   | Risk         | Percent of Largest Pathway | Retain Pathway? Yes/No |
| Air to Humans (Inhalation)                                    | 9.00E-01     | 13%                        | Y                      |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 3.30E-04     | <1%                        | N                      |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 9.39E-07     | <1%                        | N                      |
| Air to Vegetables to Humans (Ingestion)                       | 6.74E+00     | 100%                       | Y                      |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 9.53E-01     | 14%                        | Y                      |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.14E-03     | <1%                        | N                      |
| Chromium (III)  |              |                            |                        |
| Pathway   | Hazard Index | Percent of Largest Pathway | Retain Pathway? Yes/No |
| Air to Humans (Inhalation)                                    | 1.07E-01     | 5%                         | Y                      |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 7.06E-04     | <1%                        | N                      |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.64E-04     | <1%                        | N                      |
| Air to Vegetables to Humans (Ingestion)                       | 1.57E+00     | 77%                        | Y                      |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 2.04E+00     | 100%                       | Y                      |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 6.02E-01     | 30%                        | Y                      |
| Chromium (VI) (Noncarcinogenic)                               |              |                            |                        |
| Pathway   | Hazard Index | Percent of Largest Pathway | Retain Pathway? Yes/No |
| Air to Humans (Inhalation)                                    | NA           | NA                         | NA                     |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 1.41E-01     | <1%                        | N                      |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 5.28E-02     | <1%                        | N                      |
| Air to Vegetables to Humans (Ingestion)                       | 3.14E+02     | 77%                        | Y                      |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 4.08E+02     | 100%                       | Y                      |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.20E+02     | 29%                        | Y                      |

TABLE D-2: WITHIN-MEDIUM COMPARISONS-- CHEMICALS IN AIR

8/25/93

| Chromium (VI) (Carcinogenic)                                  |          |                 |                 |
|---|----------|-----------------|-----------------|
|   |          | Percent of      | Retain Pathway? |
| Pathway   | Risk     | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 4.50E+00 | 100%            | Y               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | NA       | NA              | NA              |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | NA       | NA              | NA              |
| Air to Vegetables to Humans (Ingestion)                       | NA       | NA              | NA              |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | NA       | NA              | NA              |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | NA       | NA              | NA              |
| Lead  |          |                 |                 |
|   | Hazard   | Percent of      | Retain Pathway? |
| Pathway   | Index    | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 7.65E+01 | 7%              | Y               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 2.19E-02 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 4.46E-02 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 1.12E+03 | 100%            | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 6.33E+01 | 6%              | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.02E+02 | 9%              | Y               |
| Mercury   |          |                 |                 |
|   | Hazard   | Percent of      | Retain Pathway? |
| Pathway   | Index    | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 3.57E+02 | 2%              | Y               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 6.90E+00 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 3.76E-03 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 5.23E+03 | 26%             | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.99E+04 | 100%            | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 8.57E+00 | <1%             | N               |
| Nickel  |          |                 |                 |
|   | Hazard   | Percent of      | Retain Pathway? |
| Pathway   | Index    | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 5.36E+00 | 7%              | Y               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 7.67E-03 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.20E-02 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 7.84E+01 | 100%            | Y               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 2.22E+01 | 28%             | Y               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.73E+01 | 35%             | Y               |
| Carbon Tetrachloride  |          |                 |                 |
|   | Risk     | Percent of      | Retain Pathway? |
| Pathway   |          | Largest Pathway | Yes/No          |
| Air to Humans (Inhalation)                                    | 5.68E-03 | 100%            | Y               |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 1.10E-07 | <1%             | N               |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.09E-07 | <1%             | N               |
| Air to Vegetables to Humans (Ingestion)                       | 1.72E-06 | <1%             | N               |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.38E-10 | <1%             | N               |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.08E-10 | <1%             | N               |

TABLE D-2: WITHIN-MEDIUM COMPARISONS-- CHEMICALS IN AIR

8/25/93

| Methylene Chloride  |                 |                               |                           |
|---|-----------------|-------------------------------|---------------------------|
| Pathway   | Risk            | Percent of<br>Largest Pathway | Retain Pathway?<br>Yes/No |
| Air to Humans (Inhalation)                                    | 1.82E-04        | 100%                          | Y                         |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 2.59E-10        | <1%                           | N                         |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.52E-10        | <1%                           | N                         |
| Air to Vegetables to Humans (Ingestion)                       | 1.87E-07        | <1%                           | N                         |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 6.10E-13        | <1%                           | N                         |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 4.69E-13        | <1%                           | N                         |
| Polychlorinated Biphenyls (PCBs)                              |                 |                               |                           |
| Pathway   | Risk            | Percent of<br>Largest Pathway | Retain Pathway?<br>Yes/No |
| Air to Humans (Inhalation)                                    | 8.25E-01        | <1%                           | N                         |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 2.95E-02        | <1%                           | N                         |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.85E-02        | <1%                           | N                         |
| Air to Vegetables to Humans (Ingestion)                       | 1.21E+01        | 14%                           | Y                         |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 8.53E+01        | 100%                          | Y                         |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 4.21E+01        | 49%                           | Y                         |
| Tetrachloroethylene   |                 |                               |                           |
| Pathway   | Risk            | Percent of<br>Largest Pathway | Retain Pathway?<br>Yes/No |
| Air to Humans (Inhalation)                                    | 2.14E-04        | 100%                          | Y                         |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 1.53E-09        | <1%                           | N                         |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.54E-09        | <1%                           | N                         |
| Air to Vegetables to Humans (Ingestion)                       | 9.14E-08        | <1%                           | N                         |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 6.64E-12        | <1%                           | N                         |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 5.24E-12        | <1%                           | N                         |
| 1,1,1-Trichloroethane   |                 |                               |                           |
| Pathway   | Hazard<br>Index | Percent of<br>Largest Pathway | Retain Pathway?<br>Yes/No |
| Air to Humans (Inhalation)                                    | 3.57E-01        | 100%                          | Y                         |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 2.02E-06        | <1%                           | N                         |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.00E-06        | <1%                           | N                         |
| Air to Vegetables to Humans (Ingestion)                       | 5.09E-05        | <1%                           | N                         |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 2.92E-09        | <1%                           | N                         |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.28E-09        | <1%                           | N                         |
| Trichloroethylene   |                 |                               |                           |
| Pathway   | Risk            | Percent of<br>Largest Pathway | Retain Pathway?<br>Yes/No |
| Air to Humans (Inhalation)                                    | 6.43E-04        | 100%                          | Y                         |
| Air to Livestock/Game (Beef) to Humans (Ingestion)            | 2.76E-09        | <1%                           | N                         |
| Air to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.74E-09        | <1%                           | N                         |
| Air to Vegetables to Humans (Ingestion)                       | 8.38E-08        | <1%                           | N                         |
| Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.65E-12        | <1%                           | N                         |
| Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.85E-12        | <1%                           | N                         |

TABLE D-3: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN SOIL/SEDIMENT

8/25/93

| Barium-140   |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 6.39E-15 | <1%             | N               |
| Soil to Air to Humans (Immersion)                              | 3.74E-15 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 7.77E-13 | 8%              | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 4.51E-14 | <1%             | N               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 4.38E-13 | 4%              | Y               |
| Soil to Vegetables to Humans (Ingestion)                       | 9.94E-12 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.64E-13 | 5%              | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.46E-12 | 44%             | Y               |
| Soil to Humans (Ground Exposure)                               | 6.21E-12 | 62%             | Y               |
| Cerium-144   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 6.58E-13 | 20%             | Y               |
| Soil to Air to Humans (Immersion)                              | 8.97E-17 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 1.96E-12 | 60%             | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 8.79E-13 | 27%             | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.89E-13 | 6%              | Y               |
| Soil to Vegetables to Humans (Ingestion)                       | 3.29E-12 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.92E-13 | 6%              | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 3.79E-14 | 1%              | Y               |
| Soil to Humans (Ground Exposure)                               | 4.04E-13 | 12%             | Y               |
| Cesium-137   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 5.66E-14 | <1%             | N               |
| Soil to Air to Humans (Immersion)                              | 7.18E-16 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 4.39E-12 | 2%              | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 5.25E-11 | 23%             | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 5.03E-11 | 22%             | Y               |
| Soil to Vegetables to Humans (Ingestion)                       | 2.28E-10 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.78E-10 | 78%             | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.56E-10 | 68%             | Y               |
| Soil to Humans (Ground Exposure)                               | 1.34E-12 | <1%             | N               |
| Cobalt-60  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 2.70E-13 | <1%             | N               |
| Soil to Air to Humans (Immersion)                              | 3.21E-15 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 2.36E-12 | 2%              | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.37E-11 | 14%             | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.11E-11 | 12%             | Y               |
| Soil to Vegetables to Humans (Ingestion)                       | 9.45E-11 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 9.99E-13 | 1%              | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 7.37E-13 | <1%             | N               |
| Soil to Humans (Ground Exposure)                               | 5.18E-12 | 5%              | Y               |

TABLE D-3: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN SOIL/SEDIMENT

8/25/93

| Iodine-129   |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 2.63E-13 | <1%             | N               |
| Soil to Air to Humans (Immersion)                              | 1.05E-17 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 2.16E-11 | 1%              | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 9.31E-11 | 6%              | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 3.45E-10 | 23%             | Y               |
| Soil to Vegetables to Humans (Ingestion)                       | 1.47E-09 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 4.07E-10 | 28%             | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.38E-09 | 94%             | Y               |
| Soil to Humans (Ground Exposure)                               | 5.07E-14 | <1%             | N               |
| Iodine-131   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 5.40E-14 | <1%             | N               |
| Soil to Air to Humans (Immersion)                              | 4.74E-16 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 4.39E-12 | 1%              | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.89E-11 | 6%              | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 7.01E-11 | 24%             | Y               |
| Soil to Vegetables to Humans (Ingestion)                       | 2.98E-10 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 8.26E-11 | 28%             | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.80E-10 | 94%             | Y               |
| Soil to Humans (Ground Exposure)                               | 9.33E-13 | <1%             | N               |
| Iodine-133   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 9.88E-15 | <1%             | N               |
| Soil to Air to Humans (Immersion)                              | 7.66E-16 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 9.12E-13 | 1%              | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 3.93E-12 | 6%              | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.46E-11 | 24%             | Y               |
| Soil to Vegetables to Humans (Ingestion)                       | 6.20E-11 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.72E-11 | 28%             | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 5.82E-11 | 94%             | Y               |
| Soil to Humans (Ground Exposure)                               | 1.48E-12 | 2%              | Y               |
| Lanthanum-140  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 7.90E-15 | <1%             | N               |
| Soil to Air to Humans (Immersion)                              | 3.05E-15 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 7.09E-13 | 14%             | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.27E-13 | 3%              | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.29E-14 | <1%             | N               |
| Soil to Vegetables to Humans (Ingestion)                       | 2.41E-12 | 48%             | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.09E-14 | <1%             | N               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 5.08E-15 | <1%             | N               |
| Soil to Humans (Ground Exposure)                               | 4.97E-12 | 100%            | Y               |

TABLE D-3: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN SOIL/SEDIMENT

8/25/93

| Neptunium-237  |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 4.74E-08 | 100%            | Y               |
| Soil to Air to Humans (Immersion)                              | 2.24E-14 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 1.52E-10 | <1%             | N               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 5.00E-12 | <1%             | N               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.23E-12 | <1%             | N               |
| Soil to Vegetables to Humans (Ingestion)                       | 3.04E-08 | 64%             | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 5.22E-13 | <1%             | N               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.17E-13 | <1%             | N               |
| Soil to Humans (Ground Exposure)                               | 3.64E-13 | <1%             | N               |
| Niobium-95   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 1.12E-14 | <1%             | N               |
| Soil to Air to Humans (Immersion)                              | 9.83E-16 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 2.30E-13 | <1%             | N               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 3.43E-11 | 100%            | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 7.41E-12 | 22%             | Y               |
| Soil to Vegetables to Humans (Ingestion)                       | 9.18E-12 | 27%             | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.75E-12 | 5%              | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 3.46E-13 | 1%              | Y               |
| Soil to Humans (Ground Exposure)                               | 1.77E-12 | 5%              | Y               |
| Plutonium-238  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 7.24E-10 | 100%            | Y               |
| Soil to Air to Humans (Immersion)                              | 1.15E-19 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 2.97E-10 | 41%             | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.78E-13 | <1%             | N               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 4.79E-14 | <1%             | N               |
| Soil to Vegetables to Humans (Ingestion)                       | 2.67E-10 | 37%             | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.88E-15 | <1%             | N               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 9.58E-16 | <1%             | N               |
| Soil to Humans (Ground Exposure)                               | 2.09E-15 | <1%             | N               |
| Plutonium-239/240  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 7.90E-10 | 100%            | Y               |
| Soil to Air to Humans (Immersion)                              | 1.04E-19 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 3.27E-10 | 41%             | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.96E-13 | <1%             | N               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 5.28E-14 | <1%             | N               |
| Soil to Vegetables to Humans (Ingestion)                       | 2.95E-10 | 37%             | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 4.28E-15 | <1%             | N               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.06E-15 | <1%             | N               |
| Soil to Humans (Ground Exposure)                               | 9.16E-16 | <1%             | N               |

TABLE D-3: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN SOIL/SEDIMENT

8/25/93

| Plutonium-241   |          |                 |                 |
|---|----------|-----------------|-----------------|
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                              | 1.51E-11 | 100%            | Y               |
| Soil to Air to Humans (Immersion)                               | 3.12E-21 | <1%             | N               |
| Soil to Humans (Ingestion)                                      | 6.41E-12 | 42%             | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)             | 3.84E-15 | <1%             | N               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)               | 1.03E-15 | <1%             | N               |
| Soil to Vegetables to Humans (Ingestion)                        | 5.77E-12 | 38%             | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 8.38E-17 | <1%             | N               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 2.07E-17 | <1%             | N               |
| Soil to Humans (Ground Exposure)                                | 9.08E-18 | <1%             | N               |
| Protactinium-233  |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                              | 1.51E-14 | 1%              | Y               |
| Soil to Air to Humans (Immersion)                               | 2.66E-16 | <1%             | N               |
| Soil to Humans (Ingestion)                                      | 3.00E-13 | 20%             | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)             | 1.80E-15 | <1%             | N               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)               | 2.42E-15 | <1%             | N               |
| Soil to Vegetables to Humans (Ingestion)                        | 1.50E-12 | 100%            | Y               |
| Soil to Pasture to Livestock/ Game (Beef) to Humans (Ingestion) | 4.80E-18 | <1%             | N               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 5.92E-18 | <1%             | N               |
| Soil to Humans (Ground Exposure)                                | 5.39E-13 | 36%             | Y               |
| Ruthenium-103   |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                              | 1.65E-14 | <1%             | N               |
| Soil to Air to Humans (Immersion)                               | 5.98E-16 | <1%             | N               |
| Soil to Humans (Ingestion)                                      | 2.73E-13 | 4%              | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)             | 3.27E-13 | 5%              | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)               | 1.46E-16 | <1%             | N               |
| Soil to Vegetables to Humans (Ingestion)                        | 7.11E-12 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 7.15E-13 | 10%             | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 2.91E-16 | <1%             | N               |
| Soil to Humans (Ground Exposure)                                | 1.14E-12 | 16%             | Y               |
| Ruthenium-106   |          |                 |                 |
|   | Dose     | Percent of      | Retain Pathway? |
| Pathway   | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                              | 8.56E-13 | 1%              | Y               |
| Soil to Air to Humans (Immersion)                               | 5.98E-16 | <1%             | N               |
| Soil to Humans (Ingestion)                                      | 2.53E-12 | 4%              | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)             | 3.03E-12 | 5%              | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)               | 1.35E-15 | <1%             | N               |
| Soil to Vegetables to Humans (Ingestion)                        | 6.58E-11 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 6.62E-12 | 10%             | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 2.70E-15 | <1%             | N               |
| Soil to Humans (Ground Exposure)                                | 8.23E-13 | 1%              | Y               |

TABLE D-3: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN SOIL/SEDIMENT

8/25/93

| Strontium-89   |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 6.58E-14 | <1%             | N               |
| Soil to Air to Humans (Immersion)                              | 1.08E-17 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 8.10E-13 | <1%             | N               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.45E-13 | <1%             | N               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.83E-12 | 1%              | Y               |
| Soil to Vegetables to Humans (Ingestion)                       | 1.78E-10 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.88E-13 | <1%             | N               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 4.47E-12 | 3%              | Y               |
| Soil to Humans (Ground Exposure)                               | 1.33E-13 | <1%             | N               |
| Strontium-90   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 3.95E-13 | <1%             | N               |
| Soil to Air to Humans (Immersion)                              | 2.07E-17 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 1.18E-11 | <1%             | N               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 2.12E-12 | <1%             | N               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.67E-11 | 1%              | Y               |
| Soil to Vegetables to Humans (Ingestion)                       | 2.60E-09 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.71E-11 | 1%              | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 4.27E-10 | 16%             | Y               |
| Soil to Humans (Ground Exposure)                               | 2.41E-13 | <1%             | N               |
| Technetium-99  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 1.32E-14 | <1%             | N               |
| Soil to Air to Humans (Immersion)                              | 5.47E-19 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 1.18E-11 | <1%             | N               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 6.01E-11 | <1%             | N               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.91E-10 | <1%             | N               |
| Soil to Vegetables to Humans (Ingestion)                       | 1.51E-08 | 38%             | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.39E-08 | 35%             | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 4.02E-08 | 100%            | Y               |
| Soil to Humans (Ground Exposure)                               | 1.42E-18 | <1%             | N               |
| Thorium-232  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 2.83E-09 | 100%            | Y               |
| Soil to Air to Humans (Immersion)                              | 2.34E-19 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 2.57E-10 | 9%              | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 9.21E-13 | <1%             | N               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.07E-12 | <1%             | N               |
| Soil to Vegetables to Humans (Ingestion)                       | 4.36E-10 | 15%             | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 8.05E-16 | <1%             | N               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.66E-15 | <1%             | N               |
| Soil to Humans (Ground Exposure)                               | 1.61E-15 | <1%             | N               |

TABLE D-3: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN SOIL/SEDIMENT

8/25/93

| Uranium-234/235  |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
|  | 2.30E-10 | 57%             | Y               |
| Soil to Air to Humans (Inhalation)                             | 1.90E-16 | <1%             | N               |
| Soil to Air to Humans (Immersion)                              | 2.36E-11 | 6%              | Y               |
| Soil to Humans (Ingestion)                                     | 2.83E-12 | <1%             | N               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.41E-11 | 4%              | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 4.02E-10 | 100%            | Y               |
| Soil to Vegetables to Humans (Ingestion)                       | 1.17E-13 | <1%             | N               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 5.33E-13 | <1%             | N               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 3.90E-13 | <1%             | N               |
| Soil to Humans (Ground Exposure)                               |          |                 |                 |
| Uranium-238  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
|  | 2.11E-10 | 59%             | Y               |
| Soil to Air to Humans (Inhalation)                             | 1.33E-19 | <1%             | N               |
| Soil to Air to Humans (Immersion)                              | 2.09E-11 | 6%              | Y               |
| Soil to Humans (Ingestion)                                     | 2.51E-12 | <1%             | N               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.25E-11 | 4%              | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 3.56E-10 | 100%            | Y               |
| Soil to Vegetables to Humans (Ingestion)                       | 1.03E-13 | <1%             | N               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 4.72E-13 | <1%             | N               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.57E-15 | <1%             | N               |
| Soil to Humans (Ground Exposure)                               |          |                 |                 |
| Zirconium-95   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
|  | 4.81E-14 | 2%              | Y               |
| Soil to Air to Humans (Inhalation)                             | 1.45E-15 | <1%             | N               |
| Soil to Air to Humans (Immersion)                              | 3.71E-13 | 14%             | Y               |
| Soil to Humans (Ingestion)                                     | 1.22E-12 | 47%             | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.80E-14 | <1%             | N               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.49E-12 | 57%             | Y               |
| Soil to Vegetables to Humans (Ingestion)                       | 6.23E-15 | <1%             | N               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 8.39E-17 | <1%             | N               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.62E-12 | 100%            | Y               |
| Soil to Humans (Ground Exposure)                               |          |                 |                 |

TABLE D-4: WITHIN-MEDIUM COMPARISONS-- CHEMICALS IN SOIL/SEDIMENT

8/25/93

| Arsenic (Noncarcinogenic)                                      |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Hazard   | Percent of      | Retain Pathway? |
| Pathway  | Index    | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 2.32E-05 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 1.19E-03 | 13%             | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.42E-03 | 15%             | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.19E-04 | 1%              | Y               |
| Soil to Vegetation to Humans (Ingestion)                       | 9.52E-03 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.38E-03 | 14%             | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.06E-04 | 1%              | Y               |
| Soil to Humans (Dermal Contact)                                | 6.90E-04 | 7%              | Y               |
| Arsenic (Carcinogenic)   |          |                 |                 |
|  | Risk     | Percent of      | Retain Pathway? |
| Pathway  |          | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 3.48E-07 | 7%              | Y               |
| Soil to Humans (Ingestion)                                     | 6.25E-07 | 13%             | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 7.48E-07 | 15%             | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 6.25E-08 | 1%              | Y               |
| Soil to Vegetation to Humans (Ingestion)                       | 5.00E-06 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 7.26E-07 | 15%             | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 5.56E-08 | 1%              | Y               |
| Soil to Humans (Dermal Contact)                                | 3.63E-07 | 7%              | Y               |
| Beryllium  |          |                 |                 |
|  | Risk     | Percent of      | Retain Pathway? |
| Pathway  |          | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 5.85E-08 | 2%              | Y               |
| Soil to Humans (Ingestion)                                     | 1.54E-06 | 50%             | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 9.19E-07 | 30%             | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.25E-09 | <1%             | N               |
| Soil to Vegetation to Humans (Ingestion)                       | 3.07E-06 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 2.23E-07 | 7%              | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 5.01E-10 | <1%             | N               |
| Soil to Humans (Dermal Contact)                                | 8.91E-07 | 29%             | Y               |
| Chromium (III)   |          |                 |                 |
|  | Hazard   | Percent of      | Retain Pathway? |
| Pathway  | Index    | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 6.97E-09 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 3.57E-07 | 18%             | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.97E-06 | 100%            | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 5.76E-07 | 29%             | Y               |
| Soil to Vegetation to Humans (Ingestion)                       | 5.71E-07 | 29%             | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.58E-07 | 18%             | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 9.60E-08 | 5%              | Y               |
| Soil to Humans (Dermal Contact)                                | 2.07E-07 | 11%             | Y               |

TABLE D-4: WITHIN-MEDIUM COMPARISONS-- CHEMICALS IN SOIL/SEDIMENT

8/25/93

| Chromium (VI) (Noncarcinogenic)                                |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Hazard   | Percent of      | Retain Pathway? |
| Pathway  | Index    | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | NA       | NA              | NA              |
| Soil to Humans (Ingestion)                                     | 7.14E-05 | 18%             | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 3.93E-04 | 100%            | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.27E-04 | 32%             | Y               |
| Soil to Vegetation to Humans (Ingestion)                       | 1.14E-04 | 29%             | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 7.16E-05 | 18%             | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.11E-05 | 5%              | Y               |
| Soil to Humans (Dermal Contact)                                | 4.14E-05 | 11%             | Y               |
| Chromium (VI) (Carcinogenic)                                   |          |                 |                 |
|  | Risk     | Percent of      | Retain Pathway? |
| Pathway  |          | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 2.93E-07 | 100%            | Y               |
| Soil to Humans (Ingestion)                                     | NA       | NA              | NA              |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | NA       | NA              | NA              |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | NA       | NA              | NA              |
| Soil to Vegetation to Humans (Ingestion)                       | NA       | NA              | NA              |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | NA       | NA              | NA              |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | NA       | NA              | NA              |
| Soil to Humans (Dermal Contact)                                | NA       | NA              | NA              |
| Lead   |          |                 |                 |
|  | Hazard   | Percent of      | Retain Pathway? |
| Pathway  | Index    | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 4.98E-06 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 2.55E-04 | 10%             | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 6.11E-05 | 2%              | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.07E-04 | 4%              | Y               |
| Soil to Vegetation to Humans (Ingestion)                       | 2.55E-03 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 6.67E-05 | 3%              | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.07E-04 | 4%              | Y               |
| Soil to Humans (Dermal Contact)                                | 1.48E-04 | 6%              | Y               |
| Mercury  |          |                 |                 |
|  | Hazard   | Percent of      | Retain Pathway? |
| Pathway  | Index    | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 2.32E-05 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 1.19E-03 | <1%             | N               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.92E-02 | 5%              | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 9.02E-06 | <1%             | N               |
| Soil to Vegetation to Humans (Ingestion)                       | 2.14E-01 | 51%             | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 4.20E-01 | 100%            | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.80E-04 | <1%             | N               |
| Soil to Humans (Dermal Contact)                                | 6.90E-04 | <1%             | N               |

TABLE D-4: WITHIN-MEDIUM COMPARISONS-- CHEMICALS IN SOIL/SEDIMENT

8/25/93

| Nickel   |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Hazard   | Percent of      | Retain Pathway? |
| Pathway  | Index    | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 3.48E-07 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 1.79E-05 | 8%              | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 2.14E-05 | 10%             | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.88E-05 | 13%             | Y               |
| Soil to Vegetation to Humans (Ingestion)                       | 2.14E-04 | 100%            | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.11E-05 | 15%             | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 3.84E-05 | 18%             | Y               |
| Soil to Humans (Dermal Contact)                                | 1.04E-05 | 5%              | Y               |
|  |          |                 |                 |
| Polychlorinated Biphenyls (PCBs)                               |          |                 |                 |
|  |          | Percent of      | Retain Pathway? |
| Pathway  | Risk     | Largest Pathway | Yes/No          |
| Soil to Air to Humans (Inhalation)                             | 5.36E-08 | <1%             | N               |
| Soil to Humans (Ingestion)                                     | 2.75E-06 | 3%              | Y               |
| Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 8.23E-05 | 100%            | Y               |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 4.44E-05 | 54%             | Y               |
| Soil to Vegetation to Humans (Ingestion)                       | 1.54E-05 | 19%             | Y               |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 5.59E-06 | 7%              | Y               |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.76E-06 | 3%              | Y               |
| Soil to Humans (Dermal Contact)                                | 1.60E-06 | 2%              | Y               |

TABLE D-5: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN SURFACE WATER

8/25/93

| Barium-140   |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 3.26E-08 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 5.83E-12 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 5.84E-11 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 2.80E-09 | 9%              | Y               |
| Water to Humans (Recreational-Immersion)             | 6.90E-10 | 2%              | Y               |
| Cerium-144   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 8.22E-08 | 37%             | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 1.14E-10 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.53E-11 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 2.20E-07 | 100%            | Y               |
| Water to Humans (Recreational-Immersion)             | 1.45E-11 | <1%             | N               |
| Cesium-137   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 1.84E-07 | <1%             | N               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 6.80E-09 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 6.70E-09 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 2.21E-05 | 100%            | Y               |
| Water to Humans (Recreational-Immersion)             | 1.32E-10 | <1%             | N               |
| Cobalt-60  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 9.93E-08 | 37%             | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 1.78E-09 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.47E-09 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 2.66E-07 | 100%            | Y               |
| Water to Humans (Recreational-Immersion)             | 5.94E-10 | <1%             | N               |
| Iodine-129   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 9.08E-07 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 1.20E-08 | 1%              | Y               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 4.60E-08 | 5%              | Y               |
| Water to Fish to Humans (Ingestion)                  | 8.56E-07 | 94%             | Y               |
| Water to Humans (Recreational-Immersion)             | 2.28E-12 | <1%             | N               |

TABLE D-5: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN SURFACE WATER

8/25/93

| Iodine-131   |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 1.84E-07 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 2.45E-09 | 1%              | Y               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 9.34E-09 | 5%              | Y               |
| Water to Fish to Humans (Ingestion)                  | 1.74E-07 | 95%             | Y               |
| Water to Humans (Recreational-Immersion)             | 8.77E-11 | <1%             | N               |
| Iodine-133   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 3.83E-08 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 5.08E-10 | 1%              | Y               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.94E-09 | 5%              | Y               |
| Water to Fish to Humans (Ingestion)                  | 3.61E-08 | 94%             | Y               |
| Water to Humans (Recreational-Immersion)             | 1.41E-10 | <1%             | N               |
| Lanthanum-140  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 2.98E-08 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 1.65E-11 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 3.05E-12 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 1.60E-08 | 54%             | Y               |
| Water to Humans (Recreational-Immersion)             | 5.62E-10 | 2%              | Y               |
| Neptunium-237  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 6.38E-06 | <1%             | N               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 6.47E-10 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.63E-10 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 1.37E-03 | 100%            | Y               |
| Water to Humans (Recreational-Immersion)             | 3.26E-11 | <1%             | N               |
| Niobium-95   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 9.64E-09 | <1%             | N               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 4.44E-09 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 9.87E-10 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 6.20E-06 | 100%            | Y               |
| Water to Humans (Recreational-Immersion)             | 1.80E-10 | <1%             | N               |

TABLE D-5: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN SURFACE WATER

8/25/93

| Plutonium-238  |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 1.25E-05 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 2.30E-11 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 6.39E-12 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 2.14E-06 | 17%             | Y               |
| Water to Humans (Recreational-Immersion)             | 2.49E-14 | <1%             | N               |
| Plutonium-239/240                                    |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 1.38E-05 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 2.54E-11 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 7.04E-12 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 2.36E-06 | 17%             | Y               |
| Water to Humans (Recreational-Immersion)             | 2.10E-14 | <1%             | N               |
| Plutonium-241  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 2.69E-07 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 4.97E-13 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.38E-13 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 4.62E-08 | 17%             | Y               |
| Water to Humans (Recreational-Immersion)             | 6.53E-16 | <1%             | N               |
| Protactinium-233                                     |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 1.26E-08 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 2.33E-13 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 3.23E-13 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 2.70E-09 | 21%             | Y               |
| Water to Humans (Recreational-Immersion)             | 5.01E-11 | <1%             | N               |
| Ruthenium-103  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 1.15E-08 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 4.24E-11 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.94E-14 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 4.68E-09 | 41%             | Y               |
| Water to Humans (Recreational-Immersion)             | 1.11E-10 | <1%             | N               |

TABLE D-5: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN SURFACE WATER

8/25/93

| Ruthenium-106  |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 1.06E-07 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 3.92E-10 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.80E-13 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 4.33E-08 | 41%             | Y               |
| Water to Humans (Recreational-Immersion)             | 5.06E-11 | <1%             | N               |
| Strontium-89   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 3.40E-08 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 1.88E-11 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.44E-10 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 2.04E-08 | 60%             | Y               |
| Water to Humans (Recreational-Immersion)             | 1.00E-12 | <1%             | N               |
| Strontium-90   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 4.96E-07 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 2.75E-10 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 3.56E-09 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 2.98E-07 | 60%             | Y               |
| Water to Humans (Recreational-Immersion)             | 1.88E-12 | <1%             | N               |
| Technetium-99  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 4.96E-09 | 60%             | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 7.78E-11 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.54E-10 | 3%              | Y               |
| Water to Fish to Humans (Ingestion)                  | 8.30E-09 | 100%            | Y               |
| Water to Humans (Recreational-Immersion)             | 4.90E-14 | <1%             | N               |
| Thorium-232  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 1.08E-05 | 58%             | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 1.19E-10 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.76E-10 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 1.85E-05 | 100%            | Y               |
| Water to Humans (Recreational-Immersion)             | 4.85E-14 | <1%             | N               |

TABLE D-5: WITHIN-MEDIUM COMPARISONS-- RADIONUCLIDES IN SURFACE WATER

8/25/93

| Uranium-234/235                                      |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 9.93E-07 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 3.66E-10 | < 1%            | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 3.05E-09 | < 1%            | N               |
| Water to Fish to Humans (Ingestion)                  | 1.60E-07 | 16%             | Y               |
| Water to Humans (Recreational-Immersion)             | 3.62E-11 | < 1%            | N               |
| Uranium-238  |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 8.79E-07 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 3.24E-10 | < 1%            | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.67E-09 | < 1%            | N               |
| Water to Fish to Humans (Ingestion)                  | 1.41E-07 | 16%             | Y               |
| Water to Humans (Recreational-Immersion)             | 2.82E-14 | < 1%            | N               |
| Zirconium-95   |          |                 |                 |
|  | Dose     | Percent of      | Retain Pathway? |
| Pathway  | (Sv/yr)  | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 1.56E-08 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 1.58E-10 | 1%              | Y               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.40E-12 | < 1%            | N               |
| Water to Fish to Humans (Ingestion)                  | 8.69E-10 | 6%              | Y               |
| Water to Humans (Recreational-Immersion)             | 2.66E-10 | 2%              | Y               |

TABLE D-6: WITHIN-MEDIUM COMPARISONS-- CHEMICALS IN SURFACE WATER

8/25/93

| Arsenic (Noncarcinogenic)                            |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Hazard   | Percent of      | Retain Pathway? |
| Pathway  | Index    | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 5.00E+01 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 1.84E-01 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.59E-02 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 4.71E+01 | 94%             | Y               |
| Water to Humans (Recreational-Dermal Contact)        | 2.12E-02 | <1%             | N               |
| Arsenic (Carcinogenic)                               |          |                 |                 |
|  | Risk     | Percent of      | Retain Pathway? |
| Pathway  |          | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 2.63E-02 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 9.68E-05 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 8.33E-06 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 2.48E-02 | 94%             | Y               |
| Water to Humans (Recreational-Dermal Contact)        | 1.11E-05 | <1%             | N               |
| Beryllium  |          |                 |                 |
|  | Risk     | Percent of      | Retain Pathway? |
| Pathway  |          | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 6.45E-02 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 1.19E-04 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 3.01E-07 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 2.63E-02 | 41%             | Y               |
| Water to Humans (Recreational-Dermal Contact)        | 6.13E-05 | <1%             | N               |
| Chromium (III)                                       |          |                 |                 |
|  | Hazard   | Percent of      | Retain Pathway? |
| Pathway  | Index    | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 1.50E-02 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 2.54E-04 | 2%              | Y               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 8.45E-05 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 5.14E-03 | 34%             | Y               |
| Water to Humans (Recreational-Dermal Contact)        | 8.31E-06 | <1%             | N               |
| Chromium (VI)  |          |                 |                 |
|  | Hazard   | Percent of      | Retain Pathway? |
| Pathway  | Index    | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 3.00E+00 | 100%            | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 5.09E-02 | 2%              | Y               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.69E-02 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 1.03E+00 | 34%             | Y               |
| Water to Humans (Recreational-Dermal Contact)        | 1.66E-03 | <1%             | N               |

TABLE D-6: WITHIN-MEDIUM COMPARISONS-- CHEMICALS IN SURFACE WATER

8/25/93

| Lead   |          |                 |                 |
|--|----------|-----------------|-----------------|
|  | Hazard   | Percent of      | Retain Pathway? |
| Pathway  | Index    | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 1.07E+01 | 95%             | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 7.90E-03 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.43E-02 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 1.13E+01 | 100%            | Y               |
| Water to Humans (Recreational-Dermal Contact)        | 7.89E-04 | <1%             | N               |
| Mercury  |          |                 |                 |
|  | Hazard   | Percent of      | Retain Pathway? |
| Pathway  | Index    | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 5.00E+01 | <1%             | N               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 2.49E+00 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.20E-03 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 5.89E+03 | 100%            | Y               |
| Water to Humans (Recreational-Dermal Contact)        | 4.05E-03 | <1%             | N               |
| Nickel   |          |                 |                 |
|  | Hazard   | Percent of      | Retain Pathway? |
| Pathway  | Index    | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 7.50E-01 | 99%             | Y               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 2.77E-03 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 3.84E-03 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 7.55E-01 | 100%            | Y               |
| Water to Humans (Recreational-Dermal Contact)        | 3.87E-04 | <1%             | N               |
| Polychlorinated Biphenyls (PCBs)                     |          |                 |                 |
|  | Risk     | Percent of      | Retain Pathway? |
| Pathway  |          | Largest Pathway | Yes/No          |
| Water to Humans (Ingestion)                          | 1.16E-01 | <1%             | N               |
| Water to Livestock/Game (Beef) to Humans (Ingestion) | 1.06E-02 | <1%             | N               |
| Water to Dairy Cattle (Milk) to Humans (Ingestion)   | 5.91E-03 | <1%             | N               |
| Water to Fish to Humans (Ingestion)                  | 2.48E+02 | 100%            | Y               |
| Water to Humans (Recreational-Dermal Contact)        | 1.17E-03 | <1%             | N               |

**APPENDIX E**

**SOURCE TERM ESTIMATES FOR X-10**

## APPENDIX E

### SOURCE TERM ESTIMATES FOR X-10

Estimates of quantities of radionuclides released to the air or available for release as a result of historical X-10 operations have been prepared for the following areas:

- Radioactive Lanthanum (RaLa) Processing
- Thorex Processing of Short-Decay Irradiated Thorium
- Chemical Separation of Plutonium from Clinton Pile Fuel
- Graphite Reactor Fuel Slug Ruptures
- Argon-41 from Graphite Reactor Cooling Air
- Tritium from Isotope Processing Programs

Each of these areas is discussed in this section, and estimated peak annual release quantities, emission rates, and predicted air concentrations for 18 radionuclides that have been assembled to support the screening process are presented in Table 5-1.

#### Emissions from Radioactive Lanthanum Separation Operations

The quantities of radionuclides that were available for release from ORNL processing of reactor fuel for separation of radioactive lanthanum (RaLa processing) were estimated based on the RaLa production information summarized in the Task 1 & 2 report and some assumptions and simple calculations. Table 2-7 in the Task 1 & 2 report presents data concerning the ORNL RaLa runs, including run dates, numbers of fuel slugs processed, curies of barium dissolved, curies (Ci) of barium shipped, and yield of the separation process. Complete information in all of these areas is not currently available for each RaLa run. In order to support the screening process, values for missing data were estimated based on the following relationships, which have been characterized based on the considerable data that are available:

- curies dissolved per slug
- curies shipped per slug
- recovery efficiency (Ci shipped ÷ Ci dissolved)

Values of these relationships were used to estimate the numbers of slugs processed and/or curies dissolved for RaLa runs for which such data have not yet been located. An average value of one of the above relationships, calculated over a period near in time and similar in nature of operations to each run with missing data, was used to fill in missing values. This similarity of operations is important because the curie content of the slugs used in RaLa processing increased significantly as supply shifted from ORNL graphite reactor slugs to four-inch Hanford slugs and later included eight-inch Hanford slugs.

With the estimates in place, the magnitude of ORNL RaLa processing over the period from 1944 to 1956 can be summarized as follows:

|                             |           |
|-----------------------------|-----------|
| Number of Slugs Processed:  | 34,000    |
| Curies of Barium Dissolved: | 1,300,000 |
| Curies of Barium Shipped:   | 560,000   |

The quantities of barium shipped were measured near the time of final separation of lanthanum, and therefore do not include a significant contribution from lanthanum-140.

The amounts of the selected fission products that were available in each graphite reactor slug used for RaLa processing in 1947 were estimated based on a neutron flux of  $1 \times 10^{12}$  neutrons/cm<sup>2</sup>-sec, an irradiation period of 40 days, and a cooling period of 1 day after removal from the reactor. The fission product content of each slug was estimated using the following equation:

$$A_i = (1 \times 10^{12} \text{ n/cm}^2\text{-sec})(577 \times 10^{-24} \text{ cm}^2)(N)(\text{yield}_i)(1 - e^{-\lambda_i t_{\text{irr}}})(e^{-\lambda_i t_{\text{clg}}})(2.703 \times 10^{-11} \text{ Ci/atom-sec})$$

where:

|  |   |   |
|--|---|---|
| $A_i$  | = | activity of radionuclide i in each fuel slug (Ci)     |
| $1 \times 10^{12} \text{ n/cm}^2\text{-sec}$ | = | maximum graphite reactor flux                         |
| $577 \times 10^{-24}$                        | = | fission cross section for uranium-235                 |
| N  | = | number of U-235 atoms per slug                        |
| $\text{yield}_i$                             | = | fission yield of radionuclide i for uranium-235       |
| $\lambda_i$                                  | = | decay constant of radionuclide i (sec <sup>-1</sup> ) |
| $t_{\text{irr}}$                             | = | irradiation time in reactor (sec)                     |
| $t_{\text{clg}}$                             | = | cooling time after removal from reactor (sec)         |
| $2.703 \times 10^{-11} \text{ Ci/atom-sec}$  | = | conversion from atoms/sec to curies                   |

A cross section is a probability that a certain reaction will occur between a nucleus and an incident particle or photon; in this case, the probability that an incident neutron will cause a U-235 atom to fission. The radioactivity content of each slug was multiplied times an estimated 9300 slugs processed in 1947 to estimate the total radionuclide inventory in processed fuel for that year.

Release fractions were applied to radionuclide inventories to estimate quantities released. The following release fractions were used:

|                               |      |
|-------------------------------|------|
| • Noble Gases                 | 100% |
| • Iodine                      | 80%  |
| • Particulates (i.e., others) | 0.1% |

The noble gas release fraction of 100% is based on the nonreactive nature of xenon and krypton. The release fraction for iodine is based on analyses of iodine release fractions at the Hanford plant performed as part of the Hanford dose reconstruction project. The release fraction for

particulate radionuclides is based on measured particulate emissions from RaLa processing at the Idaho Chemical Processing Plant during 1957 compared to the estimated radionuclide inventories in the materials testing reactor (MTR) fuel used as the barium source at that plant.

The plutonium content of the graphite reactor slugs in 1947 was estimated based on a plutonium formation rate of 36.5 micrograms per kilowatt-hour of reactor exposure obtained from graphite reactor operations reports. The fission rate corresponding to the neutron flux stated earlier was converted to a reactor exposure over 40 days (in kilowatt-hours) and multiplied times the 36.5 microgram Pu/kW-hr value to yield the micrograms of plutonium formed per slug over 40 days of exposure. A specific activity value of 0.0613 Ci/g was used to convert that mass to its curie equivalent. A release fraction of 0.1% was applied to estimate plutonium emissions.

Uranium emissions were estimated based on 2.6 pounds of natural uranium per slug, an isotopic composition of 99.276% uranium-238 and 0.71% uranium-235, and specific activity values of  $3.3 \times 10^{-7}$  Ci/g for uranium-238 and  $2.14 \times 10^{-6}$  Ci/g for uranium-235. A release fraction of 0.1% was applied to the quantities of the uranium isotopes to estimate releases to the atmosphere. Release estimates for 1947 are shown in Table E-1.

Radionuclide emissions for Oak Ridge RaLa processing of Hanford slugs during 1952 were estimated using the same method as above, with the following differences:

- a fission rate of  $1.26 \times 10^{14}$  fissions/sec-slug was calculated based on a power level of 2.25 watts/gram
- reactor irradiation time was 80 days
- cooling time was 5 days
- slug mass was 1800 grams
- an estimated total of 1300 slugs were dissolved

Release estimates for RaLa processing in 1952 are show in Table E-2.

### **Emissions from Thorex Short-Decay Runs**

Quantities of radionuclides available in the processing of short-decayed (20-60 days of decay) irradiated thorium that occurred in 1956 and 1957 were estimated based on documented characteristics of the material that was dissolved. Quantities of thorium dissolved in the four short-decay runs are documented by McDuffee (1957) and McDuffee and Yarbrow (1958). A 1957 memorandum by W.L. Albrecht documented the activities of protactinium-233 (Pa-233) and fission products in thorium receiving irradiation of the extent documented for the short-decay feed material. Data derived from the Albrecht memo are shown in Table E-3. Pa-233, an activation product of thorium-232 and the parent of uranium-233, was by far the most prominent radionuclide present. After 30 days of decay, each kilogram of irradiated thorium metal that was processed contained over 14,000 curies of Pa-233.

Quantities of Pa-233 and fission products available for each of the 14 dissolving batches of Thorex Runs HD-19, SD-1, SD-2, and SD-3 were estimated by multiplying the quantity of thorium metal dissolved in each batch by the curie content of each kilogram of metal based on the Albrecht data. Reductions were made in the quantities estimated to have been available for

TABLE E-1

ESTIMATED EMISSIONS FROM X-10 RaLa PROCESSING  
OF X-10 SLUGS IN 1947

| Nuclide | Half-Life<br>(seconds)   | Decay Constant<br>(sec <sup>-1</sup> ) | Fission<br>Yield      | Ci/slug at<br>time t  | Total Ci<br>Available | Release<br>Fraction | Release<br>Total (Ci) |
|---------|--------------------------|--|-----------------------|-----------------------|-----------------------|---------------------|-----------------------|
| I-131   | $6.96 \times 10^{+5}$    | $9.96 \times 10^{-7}$                  | $2.90 \times 10^{-2}$ | $8.63 \times 10^{+0}$ | $8.03 \times 10^{+4}$ | 80%                 | $6.42 \times 10^{+4}$ |
| I-132   | $8.14 \times 10^{+3}$    | $8.52 \times 10^{-5}$                  | $4.40 \times 10^{-2}$ | $9.39 \times 10^{-3}$ | $8.73 \times 10^{+1}$ | 80%                 | $6.98 \times 10^{+1}$ |
| I-133   | $7.31 \times 10^{+4}$    | $9.48 \times 10^{-6}$                  | $6.50 \times 10^{-2}$ | $9.60 \times 10^{+0}$ | $8.93 \times 10^{+4}$ | 80%                 | $7.14 \times 10^{+4}$ |
| I-129   | $5.36 \times 10^{+14}$   | $1.29 \times 10^{-15}$                 | $1.00 \times 10^{-2}$ | $1.50 \times 10^{-8}$ | $1.39 \times 10^4$    | 80%                 | $1.11 \times 10^4$    |
| Ce-144  | $2.45 \times 10^{+7}$    | $2.82 \times 10^{-8}$                  | $6.10 \times 10^{-2}$ | $1.90 \times 10^{+0}$ | $1.76 \times 10^{+4}$ | 0.1%                | $1.76 \times 10^{+1}$ |
| Cs-137  | $9.46 \times 10^{+8}$    | $7.32 \times 10^{-10}$                 | $5.90 \times 10^{-2}$ | $5.00 \times 10^{-2}$ | $4.65 \times 10^{+2}$ | 0.1%                | $4.65 \times 10^{-1}$ |
| Kr-85   | $3.39 \times 10^{+8}$    | $2.04 \times 10^{-9}$                  | $3.00 \times 10^{-3}$ | $7.07 \times 10^{-3}$ | $6.58 \times 10^{+1}$ | 100%                | $6.58 \times 10^{+1}$ |
| Xe-133  | $4.55 \times 10^{+5}$    | $1.52 \times 10^{-6}$                  | $6.50 \times 10^{-2}$ | $1.90 \times 10^{+1}$ | $1.77 \times 10^{+5}$ | 100%                | $1.77 \times 10^{+5}$ |
| Zr-95   | $5.67 \times 10^{+6}$    | $1.22 \times 10^{-7}$                  | $6.40 \times 10^{-2}$ | $7.31 \times 10^{+0}$ | $6.80 \times 10^{+4}$ | 0.1%                | $6.80 \times 10^{+1}$ |
| Nb-95   | $3.02 \times 10^{+6}$    | $2.29 \times 10^{-7}$                  | $6.40 \times 10^{-2}$ | $1.15 \times 10^{+1}$ | $1.07 \times 10^{+5}$ | 0.1%                | $1.07 \times 10^{+2}$ |
| Ru-103  | $3.41 \times 10^{+6}$    | $2.03 \times 10^{-7}$                  | $2.90 \times 10^{-2}$ | $4.82 \times 10^{+0}$ | $4.48 \times 10^{+4}$ | 0.1%                | $4.48 \times 10^{+1}$ |
| Ru-106  | $3.18 \times 10^{+7}$    | $2.18 \times 10^{-8}$                  | $3.80 \times 10^{-3}$ | $9.22 \times 10^{-2}$ | $8.58 \times 10^{+2}$ | 0.1%                | $8.58 \times 10^{-1}$ |
| Sr-89   | $4.55 \times 10^{+6}$    | $1.52 \times 10^{-7}$                  | $4.80 \times 10^{-2}$ | $6.49 \times 10^{+0}$ | $6.04 \times 10^{+4}$ | 0.1%                | $6.04 \times 10^{+1}$ |
| Sr-90   | $8.74 \times 10^{+8}$    | $7.93 \times 10^{-10}$                 | $5.80 \times 10^{-2}$ | $5.32 \times 10^{-2}$ | $4.95 \times 10^{+2}$ | 0.1%                | $4.95 \times 10^{-1}$ |
| Ba-140  | $1.11 \times 10^{+6}$    | $6.27 \times 10^{-7}$                  | $6.30 \times 10^{-2}$ | $1.77 \times 10^{+1}$ | $1.65 \times 10^{+5}$ | 0.1%                | $1.65 \times 10^{+2}$ |
| La-140  | $1.45 \times 10^{+5}$    | $4.79 \times 10^{-6}$                  | $6.30 \times 10^{-2}$ | $1.40 \times 10^{+1}$ | $1.30 \times 10^{+5}$ | 0.1%                | $1.30 \times 10^{+2}$ |
| Pu      | $7.69 \times 10^{+11}$ * | $9.01 \times 10^{-13}$ *               | NA                    | $8.54 \times 10^{-4}$ | $7.94 \times 10^{+0}$ | 0.1%                | $7.94 \times 10^{-3}$ |
| U-235   | $2.24 \times 10^{+16}$   | $3.10 \times 10^{-17}$                 | NA                    | $1.79 \times 10^{-5}$ | $1.66 \times 10^{-1}$ | 0.1%                | $1.66 \times 10^{-4}$ |
| U-238   | $1.42 \times 10^{+17}$   | $4.87 \times 10^{-18}$                 | NA                    | $3.90 \times 10^{-4}$ | $3.63 \times 10^{+0}$ | 0.1%                | $3.63 \times 10^{-3}$ |

NA = Not Applicable

\* Value is for plutonium-239

TABLE E-2

ESTIMATED EMISSIONS FROM X-10 RaLa PROCESSING  
OF HANFORD SLUGS IN 1952

| Nuclide | Half-Life<br>(seconds)   | Decay Constant<br>(sec <sup>-1</sup> ) | Fission<br>Yield      | Ci/slug at<br>time t   | Total Ci<br>Available  | Release<br>Fraction | Release<br>Total (Ci)  |
|---------|--------------------------|--|-----------------------|------------------------|------------------------|---------------------|------------------------|
| I-131   | $6.96 \times 10^{+5}$    | $9.96 \times 10^{-7}$                  | $2.90 \times 10^{-2}$ | $6.41 \times 10^{+1}$  | $8.34 \times 10^{+4}$  | 80%                 | $6.67 \times 10^{+4}$  |
| I-132   | $8.14 \times 10^{+3}$    | $8.52 \times 10^{-5}$                  | $4.40 \times 10^{-2}$ | $1.57 \times 10^{-14}$ | $2.04 \times 10^{+11}$ | 80%                 | $1.63 \times 10^{-11}$ |
| I-133   | $7.31 \times 10^{+4}$    | $9.48 \times 10^{-6}$                  | $6.50 \times 10^{-2}$ | $3.68 \times 10^{+0}$  | $4.79 \times 10^{+3}$  | 80%                 | $3.83 \times 10^{+3}$  |
| I-129   | $5.36 \times 10^{+14}$   | $1.29 \times 10^{-15}$                 | $1.00 \times 10^{-2}$ | $3.04 \times 10^{-7}$  | $3.95 \times 10^{-4}$  | 80%                 | $3.16 \times 10^{-4}$  |
| Ce-144  | $2.45 \times 10^{+7}$    | $2.82 \times 10^{-8}$                  | $6.10 \times 10^{-2}$ | $3.64 \times 10^{+1}$  | $4.73 \times 10^{+4}$  | 0.1%                | $4.73 \times 10^{+1}$  |
| Cs-137  | $9.46 \times 10^{+8}$    | $7.32 \times 10^{-10}$                 | $5.90 \times 10^{-2}$ | $1.01 \times 10^{+0}$  | $1.32 \times 10^{+3}$  | 0.1%                | $1.32 \times 10^{+0}$  |
| Kr-85   | $3.39 \times 10^{+8}$    | $2.04 \times 10^{-9}$                  | $3.00 \times 10^{-3}$ | $1.43 \times 10^{-1}$  | $1.86 \times 10^{+2}$  | 100%                | $1.86 \times 10^{+2}$  |
| Xe-133  | $4.55 \times 10^{+5}$    | $1.52 \times 10^{-6}$                  | $6.50 \times 10^{-2}$ | $1.15 \times 10^{+2}$  | $1.49 \times 10^{+5}$  | 100%                | $1.49 \times 10^{+5}$  |
| Zr-95   | $5.67 \times 10^{+6}$    | $1.22 \times 10^{-7}$                  | $6.40 \times 10^{-2}$ | $1.18 \times 10^{+2}$  | $1.53 \times 10^{+5}$  | 0.1%                | $1.53 \times 10^{+2}$  |
| Nb-95   | $3.02 \times 10^{+6}$    | $2.29 \times 10^{-7}$                  | $6.40 \times 10^{-2}$ | $1.57 \times 10^{+2}$  | $2.04 \times 10^{+5}$  | 0.1%                | $2.04 \times 10^{+2}$  |
| Ru-103  | $3.41 \times 10^{+6}$    | $2.03 \times 10^{-7}$                  | $2.90 \times 10^{-2}$ | $6.82 \times 10^{+1}$  | $8.87 \times 10^{+4}$  | 0.1%                | $8.87 \times 10^{+1}$  |
| Ru-106  | $3.18 \times 10^{+7}$    | $2.18 \times 10^{-8}$                  | $3.80 \times 10^{-3}$ | $1.79 \times 10^{+0}$  | $2.33 \times 10^{+3}$  | 0.1%                | $2.33 \times 10^{+0}$  |
| Sr-89   | $4.55 \times 10^{+6}$    | $1.52 \times 10^{-7}$                  | $4.80 \times 10^{-2}$ | $9.96 \times 10^{+1}$  | $1.29 \times 10^{+5}$  | 0.1%                | $1.29 \times 10^{+2}$  |
| Sr-90   | $8.74 \times 10^{+8}$    | $7.93 \times 10^{-10}$                 | $5.80 \times 10^{-2}$ | $1.08 \times 10^{+0}$  | $1.40 \times 10^{+3}$  | 0.1%                | $1.40 \times 10^{+0}$  |
| Ba-140  | $1.11 \times 10^{+6}$    | $6.27 \times 10^{-7}$                  | $6.30 \times 10^{-2}$ | $1.62 \times 10^{+2}$  | $2.10 \times 10^{+5}$  | 0.1%                | $2.10 \times 10^{+2}$  |
| La-140  | $1.45 \times 10^{+5}$    | $4.79 \times 10^{-6}$                  | $6.30 \times 10^{-2}$ | $2.71 \times 10^{+1}$  | $3.53 \times 10^{+4}$  | 0.1%                | $3.53 \times 10^{+1}$  |
| Pu      | $7.69 \times 10^{+11}$ * | $9.01 \times 10^{-13}$ *               | NA                    | $1.74 \times 10^{-2}$  | $2.26 \times 10^{+1}$  | 0.1%                | $2.26 \times 10^{+2}$  |
| U-235   | $2.24 \times 10^{+16}$   | $3.10 \times 10^{-17}$                 | NA                    | $2.73 \times 10^{-5}$  | $3.55 \times 10^{+2}$  | 0.1%                | $3.55 \times 10^{-5}$  |
| U-238   | $1.42 \times 10^{+17}$   | $4.87 \times 10^{-18}$                 | NA                    | $5.95 \times 10^{-4}$  | $7.74 \times 10^{-1}$  | 0.1%                | $7.74 \times 10^{-4}$  |

NA = Not Applicable

\* Value is for plutonium-239

TABLE E-3

FISSION PRODUCT AND PROTACTINIUM-233  
CONTENT OF SHORT-DECAY IRRADIATED THORIUM

| Radionuclide           | Ci per kg of Thorium after 30 d of Decay |
|------------------------|--|
| Total Fission Products | 340                                      |
| Kr-85                  | 0.12                                     |
| Zr-95                  | 72                                       |
| Nb-95                  | 68                                       |
| Ru-103                 | 9.0                                      |
| Ru-106                 | 0.90                                     |
| I-131                  | 5.0                                      |
| I-132 (Te-132)         | 0.17                                     |
| Xe-133                 | 3.1                                      |
| Ba-140/La-140          | 54                                       |
| Ce-141                 | 54                                       |
| Ce-144                 | 14                                       |
| Pa-233                 | 14,000                                   |

Reference: Albrecht, 1957.

batch HD-19-A to account for an irradiation level of 3300 grams Mass-233 per metric ton of thorium instead of the 4000 g/t value that was the basis of the Albrecht data and for a decay period of 109 days instead of 30. Reductions were made in the quantities estimated to have been available for batches HD-19-B and -C to account for irradiation levels of 1910 grams Mass-233 per metric ton of thorium instead of the 4000 g/t value that was the basis of the Albrecht data.

Quantities of uranium-233 that were contained in the dissolved metal were estimated by multiplying the kilograms of uranium reported to have been dissolved in each batch by 9.48, the number of curies of U-233 per kilogram of U-233.

Release fractions of 100%, 80% and 0.1% were applied to noble gases, iodine and particulates, respectively. Estimated quantities of radionuclides that were released in the course of the Thorex short-decay processing of thorium metal are shown in Table E-4. Available data appear to indicate that calendar year 1957, due to processing of short-decay thorium in the Thorex pilot plant, was the period of peak airborne emissions of Pa-233 from the Oak Ridge Reservation.

#### **Emissions from Chemical Separation of Plutonium from Clinton Pile Fuel**

Estimates of quantities of plutonium, uranium, and fission products available in the course of early processing of graphite reactor fuel slugs for recovery of fissionable plutonium were prepared based on material processing rates, estimated process efficiencies, and rates of production of plutonium and fission products in the natural uranium fuel slugs.

The chemical processing pilot plant operated full-scale from January 1944 until production ended in January 1945 (Jones, 1985). The bismuth phosphate process was used to recover 326.4 grams of plutonium (Johnson and Schaffer, 1992). The efficiency of separation of plutonium from fission products was improved from 40% to 90% (Jones, 1985). Taking the average plutonium recovery efficiency to be 65% (the midpoint of 40% and 90%), the total amount of plutonium processed was estimated to have been  $326.4 \div 0.65 = 502$  grams. Based on a specific activity of 0.0613 Ci/g, this corresponds to 30.8 curies of plutonium.

Given that the pile first went critical on November 4th, 1943 and that chemical processing involved one-third ton of uranium per day by late January 1944 (Thompson, 1963), it appears that decay periods for the slugs processed early in the campaign could not have been very long. A semi-monthly progress report issued in August 1944 indicated that slugs involved in recent dissolvings had been approximately 60 days old (Leverett, 1944). A decay period of 30 days was selected for the purposes of screening calculations.

The fission rate per ton of uranium processed was estimated based on a neutron flux of  $5 \times 10^{11}$  neutrons/cm<sup>2</sup>-sec. The radionuclide content of each ton of uranium processed was estimated using the equation given in the beginning of this appendix, with that fission rate substituted for the first three terms on the right hand side, an irradiation time of 40 days, and a cooling period of 30 days. These quantities were multiplied times 0.3 ton per day processed times 365 days to yield the totals of each radionuclide processed.

TABLE E-4

**ESTIMATED RADIONUCLIDE EMISSIONS  
ORNL THOREX SHORT-DECAY RUNS  
(July 1956 through November 1957)**

| Batch                | Metal Dissolved<br>(kilograms) |       | Activation Products Available (Ci) |                       |
|----------------------|--------------------------------|-------|------------------------------------|-----------------------|
|                      | Th                             | U     | U-233                              | Pa-233                |
| HD-19-A              | 239.3                          | 0.79  | $7.49 \times 10^{+0}$              | $3.75 \times 10^{+5}$ |
| HD-19-B              | 351.8                          | 0.673 | $6.38 \times 10^{+0}$              | $2.42 \times 10^{+6}$ |
| HD-19-C              | 30.8                           | 0.059 | $5.59 \times 10^{-1}$              | $2.12 \times 10^{+5}$ |
| SD-1-A               | 382.7                          | 0.926 | $8.81 \times 10^{+0}$              | $5.52 \times 10^{+6}$ |
| SD-1-B               | 335.7                          | 0.422 | $4.00 \times 10^{+0}$              | $4.84 \times 10^{+6}$ |
| SD-1-C               | 16.3                           | 0.025 | $2.37 \times 10^{-1}$              | $2.35 \times 10^{+5}$ |
| SD-2-A               | 438.2                          | 1.481 | $1.40 \times 10^{+1}$              | $6.32 \times 10^{+6}$ |
| SD-2-B               | 261.7                          | 0.783 | $7.42 \times 10^{+0}$              | $3.77 \times 10^{+6}$ |
| SD-2-C               | 264.3                          | 8.38  | $7.94 \times 10^{+0}$              | $3.81 \times 10^{+6}$ |
| SD-2-D               | 331.4                          | 9.15  | $8.67 \times 10^{+0}$              | $4.78 \times 10^{+6}$ |
| SD-2-E               | 161.6                          | 0.502 | $4.76 \times 10^{+0}$              | $2.33 \times 10^{+6}$ |
| SD-3-A               | 324                            | 0.834 | $7.91 \times 10^{+0}$              | $4.67 \times 10^{+6}$ |
| SD-3-B               | 301.4                          | 0.768 | $7.28 \times 10^{+0}$              | $4.34 \times 10^{+6}$ |
| SD-3-C               | 129.1                          | 0.331 | $3.14 \times 10^{+0}$              | $1.86 \times 10^{+6}$ |
| 1956 Total           | 622                            | 1.52  | $1.44 \times 10^{+1}$              | $3.01 \times 10^{+6}$ |
| 1957 Total           | 2,946                          | 7.83  | $7.42 \times 10^{+1}$              | $4.25 \times 10^{+7}$ |
| TOTAL                | 3,568                          | 9.35  | $8.86 \times 10^{+1}$              | $4.55 \times 10^{+7}$ |
| Release Fraction     |                                |       | 0.1%                               | 0.1%                  |
| 1957 Emissions (Ci): |                                |       | $7.42 \times 10^{-2}$              | $4.25 \times 10^{+4}$ |

TABLE E-4  
(CONTINUED)

ESTIMATED RADIONUCLIDE EMISSIONS  
ORNL THOREX SHORT-DECAY RUNS  
(July 1956 through November 1957)

| Batch                | Fission Products Available (Ci) |                         |                         |                         |                         |                         |                         |                         |                         |                         |  |  |  |
|----------------------|---------------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|--|--|--|
|                      | Zr-95                           | Nb-95                   | Ba/La-140               | Ce-141                  | Ce-144                  | Ru-103                  | I-131                   | Xe-133                  | Ru-106                  | Kr-85                   |  |  |  |
| HD-19-A              | 6.18 x 10 <sup>+3</sup>         | 2.79 x 10 <sup>+3</sup> | 1.48 x 10 <sup>+2</sup> | 1.98 x 10 <sup>+3</sup> | 2.20 x 10 <sup>+3</sup> | 4.45 x 10 <sup>+2</sup> | 1.09 x 10 <sup>+0</sup> | 1.89 x 10 <sup>+2</sup> | 1.53 x 10 <sup>+2</sup> | 2.28 x 10 <sup>+1</sup> |  |  |  |
| HD-19-B              | 1.21 x 10 <sup>+4</sup>         | 1.14 x 10 <sup>+4</sup> | 9.08 x 10 <sup>+3</sup> | 9.08 x 10 <sup>+3</sup> | 2.27 x 10 <sup>+3</sup> | 1.51 x 10 <sup>+3</sup> | 8.32 x 10 <sup>+2</sup> | 5.22 x 10 <sup>+2</sup> | 1.51 x 10 <sup>+2</sup> | 1.97 x 10 <sup>+1</sup> |  |  |  |
| HD-19-C              | 1.06 x 10 <sup>+3</sup>         | 9.94 x 10 <sup>+2</sup> | 7.95 x 10 <sup>+2</sup> | 7.95 x 10 <sup>+2</sup> | 1.99 x 10 <sup>+2</sup> | 1.32 x 10 <sup>+2</sup> | 7.29 x 10 <sup>+1</sup> | 4.57 x 10 <sup>+1</sup> | 1.32 x 10 <sup>+1</sup> | 1.72 x 10 <sup>+0</sup> |  |  |  |
| SD-1-A               | 2.76 x 10 <sup>+4</sup>         | 2.59 x 10 <sup>+4</sup> | 2.07 x 10 <sup>+4</sup> | 2.07 x 10 <sup>+4</sup> | 5.17 x 10 <sup>+3</sup> | 3.45 x 10 <sup>+3</sup> | 1.90 x 10 <sup>+3</sup> | 1.19 x 10 <sup>+3</sup> | 3.45 x 10 <sup>+2</sup> | 4.48 x 10 <sup>+1</sup> |  |  |  |
| SD-1-B               | 2.42 x 10 <sup>+4</sup>         | 2.27 x 10 <sup>+4</sup> | 1.81 x 10 <sup>+4</sup> | 1.81 x 10 <sup>+4</sup> | 4.54 x 10 <sup>+3</sup> | 3.02 x 10 <sup>+3</sup> | 1.66 x 10 <sup>+3</sup> | 1.04 x 10 <sup>+3</sup> | 3.02 x 10 <sup>+2</sup> | 3.93 x 10 <sup>+1</sup> |  |  |  |
| SD-1-C               | 1.17 x 10 <sup>+3</sup>         | 1.10 x 10 <sup>+3</sup> | 8.81 x 10 <sup>+2</sup> | 8.81 x 10 <sup>+2</sup> | 2.20 x 10 <sup>+2</sup> | 1.47 x 10 <sup>+2</sup> | 8.08 x 10 <sup>+1</sup> | 5.07 x 10 <sup>+1</sup> | 1.47 x 10 <sup>+1</sup> | 1.91 x 10 <sup>+0</sup> |  |  |  |
| SD-2-A               | 3.16 x 10 <sup>+4</sup>         | 2.96 x 10 <sup>+4</sup> | 2.37 x 10 <sup>+4</sup> | 2.37 x 10 <sup>+4</sup> | 5.92 x 10 <sup>+3</sup> | 3.95 x 10 <sup>+3</sup> | 2.17 x 10 <sup>+3</sup> | 1.36 x 10 <sup>+3</sup> | 3.95 x 10 <sup>+2</sup> | 5.13 x 10 <sup>+1</sup> |  |  |  |
| SD-2-B               | 1.89 x 10 <sup>+4</sup>         | 1.77 x 10 <sup>+4</sup> | 1.41 x 10 <sup>+4</sup> | 1.41 x 10 <sup>+4</sup> | 3.54 x 10 <sup>+3</sup> | 2.36 x 10 <sup>+3</sup> | 1.30 x 10 <sup>+3</sup> | 8.13 x 10 <sup>+2</sup> | 2.36 x 10 <sup>+2</sup> | 3.06 x 10 <sup>+1</sup> |  |  |  |
| SD-2-C               | 1.90 x 10 <sup>+4</sup>         | 1.79 x 10 <sup>+4</sup> | 1.43 x 10 <sup>+4</sup> | 1.43 x 10 <sup>+4</sup> | 3.57 x 10 <sup>+3</sup> | 2.38 x 10 <sup>+3</sup> | 1.31 x 10 <sup>+3</sup> | 8.21 x 10 <sup>+2</sup> | 2.38 x 10 <sup>+2</sup> | 3.10 x 10 <sup>+1</sup> |  |  |  |
| SD-2-D               | 2.39 x 10 <sup>+4</sup>         | 2.24 x 10 <sup>+4</sup> | 1.79 x 10 <sup>+4</sup> | 1.79 x 10 <sup>+4</sup> | 4.48 x 10 <sup>+3</sup> | 2.99 x 10 <sup>+3</sup> | 1.64 x 10 <sup>+3</sup> | 1.03 x 10 <sup>+3</sup> | 2.99 x 10 <sup>+2</sup> | 3.88 x 10 <sup>+1</sup> |  |  |  |
| SD-2-E               | 1.16 x 10 <sup>+4</sup>         | 1.09 x 10 <sup>+4</sup> | 8.74 x 10 <sup>+3</sup> | 8.74 x 10 <sup>+3</sup> | 2.18 x 10 <sup>+3</sup> | 1.46 x 10 <sup>+3</sup> | 8.01 x 10 <sup>+2</sup> | 5.02 x 10 <sup>+2</sup> | 1.46 x 10 <sup>+2</sup> | 1.89 x 10 <sup>+1</sup> |  |  |  |
| SD-3-A               | 2.34 x 10 <sup>+4</sup>         | 2.19 x 10 <sup>+4</sup> | 1.75 x 10 <sup>+4</sup> | 1.75 x 10 <sup>+4</sup> | 4.38 x 10 <sup>+3</sup> | 2.92 x 10 <sup>+3</sup> | 1.61 x 10 <sup>+3</sup> | 1.01 x 10 <sup>+3</sup> | 2.92 x 10 <sup>+2</sup> | 3.79 x 10 <sup>+1</sup> |  |  |  |
| SD-3-B               | 2.17 x 10 <sup>+4</sup>         | 2.04 x 10 <sup>+4</sup> | 1.63 x 10 <sup>+4</sup> | 1.63 x 10 <sup>+4</sup> | 4.07 x 10 <sup>+3</sup> | 2.72 x 10 <sup>+3</sup> | 1.49 x 10 <sup>+3</sup> | 9.37 x 10 <sup>+2</sup> | 2.72 x 10 <sup>+2</sup> | 3.53 x 10 <sup>+1</sup> |  |  |  |
| SD-3-C               | 9.30 x 10 <sup>+3</sup>         | 8.72 x 10 <sup>+3</sup> | 6.98 x 10 <sup>+3</sup> | 6.98 x 10 <sup>+3</sup> | 1.74 x 10 <sup>+3</sup> | 1.16 x 10 <sup>+3</sup> | 6.40 x 10 <sup>+2</sup> | 4.01 x 10 <sup>+2</sup> | 1.16 x 10 <sup>+2</sup> | 1.51 x 10 <sup>+1</sup> |  |  |  |
| 1956 Total           | 1.93 x 10 <sup>+4</sup>         | 1.51 x 10 <sup>+4</sup> | 1.00 x 10 <sup>+4</sup> | 1.19 x 10 <sup>+4</sup> | 4.67 x 10 <sup>+3</sup> | 2.09 x 10 <sup>+3</sup> | 9.06 x 10 <sup>+2</sup> | 5.68 x 10 <sup>+2</sup> | 3.18 x 10 <sup>+2</sup> | 4.42 x 10 <sup>+1</sup> |  |  |  |
| 1957 Total           | 2.12 x 10 <sup>+5</sup>         | 1.99 x 10 <sup>+5</sup> | 1.59 x 10 <sup>+5</sup> | 1.59 x 10 <sup>+5</sup> | 3.98 x 10 <sup>+4</sup> | 2.65 x 10 <sup>+4</sup> | 1.46 x 10 <sup>+4</sup> | 9.16 x 10 <sup>+3</sup> | 2.65 x 10 <sup>+3</sup> | 3.45 x 10 <sup>+2</sup> |  |  |  |
| TOTAL                | 2.32 x 10 <sup>+5</sup>         | 2.14 x 10 <sup>+5</sup> | 1.69 x 10 <sup>+5</sup> | 1.71 x 10 <sup>+5</sup> | 4.45 x 10 <sup>+4</sup> | 2.86 x 10 <sup>+4</sup> | 1.55 x 10 <sup>+4</sup> | 9.73 x 10 <sup>+3</sup> | 2.97 x 10 <sup>+3</sup> | 3.89 x 10 <sup>+2</sup> |  |  |  |
| Release Fraction     | 0.1%                            | 0.1%                    | 0.1%                    | 0.1%                    | 0.1%                    | 0.1%                    | 80%                     | 100%                    | 0.1%                    | 100%                    |  |  |  |
| 1957 Emissions (Ci): | 2.12 x 10 <sup>+2</sup>         | 1.99 x 10 <sup>+2</sup> | 1.59 x 10 <sup>+2</sup> | 1.59 x 10 <sup>+2</sup> | 3.98 x 10 <sup>+1</sup> | 2.65 x 10 <sup>+1</sup> | 1.17 x 10 <sup>+4</sup> | 9.16 x 10 <sup>+3</sup> | 2.65 x 10 <sup>+0</sup> | 3.45 x 10 <sup>+2</sup> |  |  |  |

The amount of uranium available was estimated to be 0.3 tons per day times 365 days, or 219,000 pounds. This amount of natural uranium was estimated to be 0.71% U-235 and 99.28% U-238 by weight, yielding totals of 1.5 and 210 curies of uranium-235 and uranium-238 available, respectively.

Release fractions of 100%, 80%, and 0.1% were applied to inventories of noble gases, iodine, and particulates available, respectively, to estimate quantities released to the atmosphere. Estimated quantities of radionuclides that were released in the course of pilot plant chemical separation of plutonium are shown in Table E-5. Available data appear to indicate that calendar year 1944, due to processing of graphite reactor fuel for chemical separation of plutonium, was the period of peak airborne emissions of iodine-129, cerium-144, cesium-137, zirconium-95, niobium-95, ruthenium-103, ruthenium-106, strontium-89, strontium-90, plutonium, uranium-235, and uranium-238 from the Oak Ridge Reservation.

### **Emissions from Graphite Reactor Fuel Slug Ruptures**

The quantities of uranium, plutonium, and fission products released as a result of ruptures of the aluminum cans which encased graphite reactor fuel slugs were estimated. The natural uranium metal that comprised these slugs oxidized upon contact with air, and uranium oxide particles and liberated fission products in pile exhaust air went unfiltered from 1944 to 1948. Fifty slug rupture events from 1944 through 1948 were documented by Cagle and Emlet in 1948. Data available concerning the slugs that ruptured include position in the reactor (row, position in row, radial coordinate), date charged to the reactor, date ruptured, total age in days, accumulated kilowatt-hours of exposure, and temperature zone.

The average neutron flux in the graphite reactor was reportedly  $5.0 \times 10^{11}$  neutrons per cubic centimeter per second, and each fuel slug contained approximately 1175 grams of natural uranium metal (Rupp and Cox, 1955). With natural uranium being 0.71% U-235 by weight, each slug contained  $2.15 \times 10^{22}$  U-235 atoms. Based on a U-235 fission cross-section of 577 barns ( $577 \times 10^{-24}$  cm<sup>2</sup>), the average graphite reactor neutron flux resulted in  $6.2 \times 10^{12}$  fissions per second in each slug.

The fission product content of each slug that ruptured was estimated based on the fission rate derived above and the length of time the slug had spent in the reactor. The age of each slug, in hours, was estimated by dividing the reported accumulated kilowatt-hours of reactor exposure by 3500 kilowatts, the average reactor power level. The fission product content of the slug at the time of rupture was then calculated based on the fission rate, the fission yield of each fission product nuclide, and the rates of decay of each fission product after it was formed using the equation shown earlier in this appendix. All slug rupture events were assumed to have involved single slugs, except for the events of November 30, 1947 and August 25, 1948, which involved 13 and 5 slugs, respectively (Cagle and Emlet, 1948). Reports indicate that "much" of the released uranium oxide fell to the water-filled canal below the reactor air outlet (Emlet, 1947; Cagle and Emlet, 1948). No data or information was located to support a release fraction for particulates from slug ruptures. For the purposes of screening calculations, 10% of the particulate fission product activities present in each slug at the time of rupture were assumed to be released when the uranium oxidized based on professional judgement. Release fractions of 100% and 80% were applied to noble gas and iodine inventories, respectively.

TABLE E-5

ESTIMATED RADIONUCLIDE EMISSIONS  
CLINTON LABORATORIES CHEMICAL SEPARATION OF PLUTONIUM

| Nuclide | Half-Life (seconds)       | Decay Constant (sec <sup>-1</sup> ) | Fission Yield | Ci/Ton at End of Cooling | Total Ci Processed       | Release Fraction | Release Total (Ci)       |
|---------|---------------------------|-------------------------------------|---------------|--------------------------|--------------------------|------------------|--------------------------|
| I-131   | 6.96 x 10 <sup>+5</sup>   | 9.96 x 10 <sup>-7</sup>             | 0.029         | 2.70 x 10 <sup>+2</sup>  | 2.95 x 10 <sup>+4</sup>  | 80%              | 2.36 x 10 <sup>+4</sup>  |
| I-132   | 8.14 x 10 <sup>+3</sup>   | 8.38 x 10 <sup>-5</sup>             | 0.044         | 2.73 x 10 <sup>-91</sup> | 2.99 x 10 <sup>-89</sup> | 80%              | 2.39 x 10 <sup>-89</sup> |
| I-133   | 7.31 x 10 <sup>+4</sup>   | 9.48 x 10 <sup>-6</sup>             | 0.065         | 1.75 x 10 <sup>-7</sup>  | 1.91 x 10 <sup>-5</sup>  | 80%              | 1.53 x 10 <sup>-5</sup>  |
| I-129   | 5.36 x 10 <sup>+14</sup>  | 1.27 x 10 <sup>-15</sup>            | 0.010         | 5.58 x 10 <sup>-6</sup>  | 6.11 x 10 <sup>-4</sup>  | 80%              | 4.89 x 10 <sup>-4</sup>  |
| Ce-144  | 2.45 x 10 <sup>+7</sup>   | 2.78 x 10 <sup>-8</sup>             | 0.061         | 6.60 x 10 <sup>+2</sup>  | 7.23 x 10 <sup>+4</sup>  | 0.1%             | 7.23 x 10 <sup>+1</sup>  |
| Cs-137  | 9.46 x 10 <sup>+8</sup>   | 7.20 x 10 <sup>-10</sup>            | 0.059         | 1.86 x 10 <sup>+1</sup>  | 2.04 x 10 <sup>+3</sup>  | 0.1%             | 2.04 x 10 <sup>+0</sup>  |
| Kr-85   | 3.39 x 10 <sup>+8</sup>   | 2.01 x 10 <sup>-9</sup>             | 0.003         | 2.62 x 10 <sup>+0</sup>  | 2.87 x 10 <sup>+2</sup>  | 100%             | 2.87 x 10 <sup>+2</sup>  |
| Xe-133  | 4.55 x 10 <sup>+5</sup>   | 1.50 x 10 <sup>-6</sup>             | 0.065         | 1.70 x 10 <sup>+2</sup>  | 1.86 x 10 <sup>+4</sup>  | 100%             | 1.86 x 10 <sup>+4</sup>  |
| Zr-95   | 5.67 x 10 <sup>+6</sup>   | 1.20 x 10 <sup>-7</sup>             | 0.064         | 2.02 x 10 <sup>+3</sup>  | 2.22 x 10 <sup>+5</sup>  | 0.1%             | 2.22 x 10 <sup>+2</sup>  |
| Nb-95   | 3.02 x 10 <sup>+6</sup>   | 2.25 x 10 <sup>-7</sup>             | 0.064         | 2.45 x 10 <sup>+3</sup>  | 2.69 x 10 <sup>+5</sup>  | 0.1%             | 2.69 x 10 <sup>+2</sup>  |
| Ru-103  | 3.41 x 10 <sup>+6</sup>   | 2.03 x 10 <sup>-7</sup>             | 0.029         | 1.10 x 10 <sup>+3</sup>  | 1.20 x 10 <sup>+5</sup>  | 0.1%             | 1.20 x 10 <sup>+2</sup>  |
| Ru-106  | 3.18 x 10 <sup>+7</sup>   | 2.14 x 10 <sup>-8</sup>             | 0.004         | 3.26 x 10 <sup>+1</sup>  | 3.57 x 10 <sup>+3</sup>  | 0.1%             | 3.57 x 10 <sup>+0</sup>  |
| Sr-89   | 4.55 x 10 <sup>+6</sup>   | 1.50 x 10 <sup>-7</sup>             | 0.048         | 1.67 x 10 <sup>+3</sup>  | 1.83 x 10 <sup>+5</sup>  | 0.1%             | 1.83 x 10 <sup>+2</sup>  |
| Sr-90   | 8.74 x 10 <sup>+8</sup>   | 7.80 x 10 <sup>-10</sup>            | 0.058         | 1.98 x 10 <sup>+1</sup>  | 2.17 x 10 <sup>+3</sup>  | 0.1%             | 2.17 x 10 <sup>+0</sup>  |
| Ba-140  | 1.11 x 10 <sup>+6</sup>   | 6.16 x 10 <sup>-7</sup>             | 0.063         | 1.43 x 10 <sup>+3</sup>  | 1.56 x 10 <sup>+5</sup>  | 0.1%             | 1.56 x 10 <sup>+2</sup>  |
| La-140  | 1.45 x 10 <sup>+5</sup>   | 4.71 x 10 <sup>-6</sup>             | 0.063         | 4.02 x 10 <sup>-2</sup>  | 4.40 x 10 <sup>+0</sup>  | 0.1%             | 4.40 x 10 <sup>-3</sup>  |
| Pu      | 7.69 x 10 <sup>+11*</sup> | 9.01 x 10 <sup>-13*</sup>           | NA            | NA                       | 3.08 x 10 <sup>+1</sup>  | 0.1%             | 3.08 x 10 <sup>-2</sup>  |
| U-235   | 2.24 x 10 <sup>+16</sup>  | 3.10 x 10 <sup>-17</sup>            | NA            | NA                       | 1.51 x 10 <sup>+9</sup>  | 0.1%             | 1.51 x 10 <sup>-3</sup>  |
| U-238   | 1.42 x 10 <sup>+17</sup>  | 4.87 x 10 <sup>-18</sup>            | NA            | NA                       | 2.11 x 10 <sup>+2</sup>  | 0.1%             | 2.11 x 10 <sup>-1</sup>  |

NA = Not Applicable

\* Value is for plutonium-239

Quantities of plutonium available from the ruptured slugs were estimated based on there being an average of 60.5 grams of plutonium present per ton in uranium irradiated for 1000 days or more (Emlet, 1947). This concentration applied to the mass of uranium liberated from ruptured slugs yielded an estimate of plutonium available from each event. Quantities of uranium available were estimated based on the number of slugs that ruptured and the mass (2.6 pounds) and composition of the natural uranium (0.71% U-235 and 99.276% U-238) that each slug contained.

With the multiple-slug ruptures in November, 1947 appears to be the year in which emissions from ruptured slugs would have been the greatest. In November 1948, the graphite reactor filter house went into operation. While slug ruptures continued past 1948 (there were 41 in 1956 (Seagren and Cox, 1957)), emissions of particulate radionuclides were substantially decreased by the filters, and non-filterable emissions do not appear to have approached the magnitude of other operations which are being evaluated in the screening process.

Estimated quantities of radionuclides that were released from slug ruptures in the graphite reactor in 1947 are shown in Table E-6. Available data appear to indicate that slug ruptures were not the most significant airborne emission source for any of the identified radionuclides. Ten of the radionuclides included in the assessment of slug rupture emissions could be elevated to roughly the magnitude of the current most significant airborne emission source of the nuclide in question if the particulate release fraction were to increase significantly from the 10% used in the screening calculations. The following values of particulate release fraction would be required for emissions of the identified radionuclides from graphite reactor slug ruptures in 1947 to rival the most significant emissions of that nuclide:

|               |      |
|---------------|------|
| cesium-137    | 15%  |
| strontium-90  | 15%  |
| plutonium     | 26%  |
| ruthenium-106 | 30%  |
| cerium-144    | 34%  |
| lanthanum-140 | 50%  |
| barium-140    | 81%  |
| zirconium-95  | 89%  |
| strontium-89  | 96%  |
| niobium-95    | 100% |

#### **Emissions of Argon-41 in Graphite Reactor Cooling Air**

Ar-41 was created by neutron activation of stable argon-40 in graphite reactor cooling air. The release rate of Ar-41 from the graphite reactor stack was estimated to be 470 curies per day when the pile was operated at a power level of 3.6 megawatts (Morgan, 1949). The graphite reactor operated from November 1943 to November 1963, and annual emissions are not likely to have varied significantly from the corresponding annual emission of 172,000 curies.

TABLE E-6

ESTIMATED RELEASES FROM OAK RIDGE GRAPHITE REACTOR SLUG RUPTURES

| Date                          | KWh in Rx            | Slugs Rel'd | I-131                | I-133                | I-129                 | Ce-144               | Cs-137               | Kr-85                 | Xe-133               | Zr-95                | Nb-95                |
|-------------------------------|----------------------|-------------|----------------------|----------------------|-----------------------|----------------------|----------------------|-----------------------|----------------------|----------------------|----------------------|
| Feb-47                        | $6.8 \times 10^{+7}$ | 1           | 4.86                 | 10.89                | $1.51 \times 10^{-7}$ | 8.80                 | 0.49                 | $6.69 \times 10^2$    | 10.89                | 10.72                | 10.72                |
| Feb-47                        | $2.6 \times 10^{+7}$ | 1           | 4.86                 | 10.89                | $5.79 \times 10^{-8}$ | 5.42                 | 0.19                 | $2.67 \times 10^2$    | 10.89                | 10.32                | 10.70                |
| Apr-47                        | $9.4 \times 10^{+5}$ | 1           | 3.01                 | 10.89                | $2.09 \times 10^{-9}$ | 0.28                 | 0.01                 | $9.92 \times 10^4$    | 8.39                 | 1.19                 | 2.13                 |
| Aug-47                        | $5.6 \times 10^{+6}$ | 1           | 4.84                 | 10.89                | $1.26 \times 10^{-8}$ | 1.54                 | 0.04                 | $5.92 \times 10^3$    | 10.89                | 5.44                 | 7.89                 |
| Oct-47                        | $9.0 \times 10^{+7}$ | 1           | 4.86                 | 10.89                | $1.99 \times 10^{-7}$ | 9.46                 | 0.64                 | $8.62 \times 10^2$    | 10.89                | 10.72                | 10.72                |
| Oct-47                        | $1.2 \times 10^{+7}$ | 1           | 4.86                 | 10.89                | $2.57 \times 10^{-8}$ | 2.91                 | 0.09                 | $1.20 \times 10^2$    | 10.89                | 8.20                 | 10.02                |
| Nov-47                        | $9.5 \times 10^{+7}$ | 1           | 4.86                 | 10.89                | $2.11 \times 10^{-7}$ | 9.57                 | 0.68                 | $9.06 \times 10^2$    | 10.89                | 10.72                | 10.72                |
| Nov-47                        | $9.3 \times 10^{+7}$ | 1           | 4.86                 | 10.89                | $2.08 \times 10^{-7}$ | 9.54                 | 0.67                 | $8.94 \times 10^2$    | 10.89                | 10.72                | 10.72                |
| Nov-47                        | $9.4 \times 10^{+7}$ | 13          | 63.17                | 141.59               | $2.71 \times 10^{-6}$ | 124.12               | 8.76                 | $1.17 \times 10^{+0}$ | 141.59               | 139.42               | 139.42               |
| Dec-47                        | $9.2 \times 10^{+7}$ | 1           | 4.86                 | 10.89                | $2.05 \times 10^{-7}$ | 9.52                 | 0.66                 | $8.86 \times 10^2$    | 10.89                | 10.72                | 10.72                |
| Dec-47                        | $9.2 \times 10^{+7}$ | 1           | 4.86                 | 10.89                | $2.04 \times 10^{-7}$ | 9.51                 | 0.66                 | $8.82 \times 10^2$    | 10.89                | 10.72                | 10.72                |
| Dec-47                        | $9.2 \times 10^{+7}$ | 1           | 4.86                 | 10.89                | $2.04 \times 10^{-7}$ | 9.51                 | 0.66                 | $8.82 \times 10^2$    | 10.89                | 10.72                | 10.72                |
| Dec-47                        | $9.6 \times 10^{+7}$ | 1           | 4.86                 | 10.89                | $2.13 \times 10^{-7}$ | 9.59                 | 0.69                 | $9.17 \times 10^2$    | 10.89                | 10.72                | 10.72                |
| Total Liberated in 1947 (Ci): |                      |             | 119.62               | 272.30               | $4.40 \times 10^{-6}$ | 209.77               | 14.25                | 1.90                  | 269.79               | 250.37               | 255.95               |
| Release Fraction:             |                      |             | 80%                  | 80%                  | 80%                   | 10%                  | 10%                  | 100%                  | 100%                 | 10%                  | 10%                  |
| 1947 Release Total (Ci):      |                      |             | $9.6 \times 10^{+1}$ | $2.2 \times 10^{+2}$ | $3.5 \times 10^{-6}$  | $2.1 \times 10^{+1}$ | $1.4 \times 10^{+0}$ | $1.9 \times 10^{+0}$  | $2.7 \times 10^{+2}$ | $2.5 \times 10^{+1}$ | $2.6 \times 10^{+1}$ |

TABLE E-6  
(CONTINUED)

ESTIMATED RELEASES FROM OAK RIDGE GRAPHITE REACTOR SLUG RUPTURES

| Date                          | KWh in Rx              | Slugs Rel'd | Ru-103 | Ru-106                 | Sr-89                  | Sr-90                  | Ba-140                 | La-140                 | U-235                   | U-238                   | Pu                      |
|-------------------------------|------------------------|-------------|--------|------------------------|------------------------|------------------------|------------------------|------------------------|-------------------------|-------------------------|-------------------------|
| Feb-47                        | 6.8 x 10 <sup>+7</sup> | 1           | 4.86   | 0.49                   | 8.04                   | 0.53                   | 10.56                  | 10.56                  | 1.79 x 10 <sup>-5</sup> | 3.88 x 10 <sup>-4</sup> | 4.82 x 10 <sup>-3</sup> |
| Feb-47                        | 2.6 x 10 <sup>+7</sup> | 1           | 4.84   | 0.28                   | 7.91                   | 0.20                   | 10.56                  | 10.56                  | 1.79 x 10 <sup>-5</sup> | 3.88 x 10 <sup>-4</sup> | 4.82 x 10 <sup>-3</sup> |
| Apr-47                        | 9.4 x 10 <sup>+5</sup> | 1           | 0.87   | 0.01                   | 1.10                   | 0.01                   | 4.80                   | 10.45                  | 1.79 x 10 <sup>-5</sup> | 3.88 x 10 <sup>-4</sup> | 4.82 x 10 <sup>-3</sup> |
| Aug-47                        | 5.6 x 10 <sup>+6</sup> | 1           | 3.35   | 0.07                   | 4.72                   | 0.04                   | 10.28                  | 10.56                  | 1.79 x 10 <sup>-5</sup> | 3.88 x 10 <sup>-4</sup> | 4.82 x 10 <sup>-3</sup> |
| Oct-47                        | 9.0 x 10 <sup>+7</sup> | 1           | 4.86   | 0.55                   | 8.04                   | 0.68                   | 10.56                  | 10.56                  | 1.79 x 10 <sup>-5</sup> | 3.88 x 10 <sup>-4</sup> | 4.82 x 10 <sup>-3</sup> |
| Oct-47                        | 1.2 x 10 <sup>+7</sup> | 1           | 4.46   | 0.14                   | 6.72                   | 0.09                   | 10.56                  | 10.56                  | 1.79 x 10 <sup>-5</sup> | 3.88 x 10 <sup>-4</sup> | 4.82 x 10 <sup>-3</sup> |
| Nov-47                        | 9.5 x 10 <sup>+7</sup> | 1           | 4.86   | 0.56                   | 8.04                   | 0.72                   | 10.56                  | 10.56                  | 1.79 x 10 <sup>-5</sup> | 3.88 x 10 <sup>-4</sup> | 4.82 x 10 <sup>-3</sup> |
| Nov-47                        | 9.3 x 10 <sup>+7</sup> | 1           | 4.86   | 0.56                   | 8.04                   | 0.71                   | 10.56                  | 10.56                  | 1.79 x 10 <sup>-5</sup> | 3.88 x 10 <sup>-4</sup> | 4.82 x 10 <sup>-3</sup> |
| Nov-47                        | 9.4 x 10 <sup>+7</sup> | 13          | 63.2   | 7.23                   | 104.56                 | 9.30                   | 137.24                 | 137.24                 | 2.32 x 10 <sup>-4</sup> | 5.05 x 10 <sup>-3</sup> | 6.27 x 10 <sup>-2</sup> |
| Dec-47                        | 9.2 x 10 <sup>+7</sup> | 1           | 4.86   | 0.55                   | 8.04                   | 0.71                   | 10.56                  | 10.56                  | 1.79 x 10 <sup>-5</sup> | 3.88 x 10 <sup>-4</sup> | 4.82 x 10 <sup>-3</sup> |
| Dec-47                        | 9.2 x 10 <sup>+7</sup> | 1           | 4.86   | 0.55                   | 8.04                   | 0.70                   | 10.56                  | 10.56                  | 1.79 x 10 <sup>-5</sup> | 3.88 x 10 <sup>-4</sup> | 4.82 x 10 <sup>-3</sup> |
| Dec-47                        | 9.2 x 10 <sup>+7</sup> | 1           | 4.86   | 0.55                   | 8.04                   | 0.70                   | 10.56                  | 10.56                  | 1.79 x 10 <sup>-5</sup> | 3.88 x 10 <sup>-4</sup> | 4.82 x 10 <sup>-3</sup> |
| Dec-47                        | 9.6 x 10 <sup>+7</sup> | 1           | 4.86   | 0.56                   | 8.04                   | 0.73                   | 10.56                  | 10.56                  | 1.79 x 10 <sup>-5</sup> | 3.88 x 10 <sup>-4</sup> | 4.82 x 10 <sup>-3</sup> |
| Total Liberated in 1947 (Ci): |                        |             | 115.58 | 12.11                  | 189.35                 | 15.13                  | 257.88                 | 263.82                 | 4.46 x 10 <sup>-4</sup> | 9.71 x 10 <sup>-3</sup> | 1.21 x 10 <sup>-1</sup> |
| Release Fraction:             |                        |             | 10%    | 10%                    | 10%                    | 10%                    | 10%                    | 10%                    | 10%                     | 10%                     | 10%                     |
| 1947 Release Total (Ci):      |                        |             | 11.56  | 1.2 x 10 <sup>+0</sup> | 1.9 x 10 <sup>+1</sup> | 1.5 x 10 <sup>+0</sup> | 2.6 x 10 <sup>+1</sup> | 2.6 x 10 <sup>+1</sup> | 4.5 x 10 <sup>-5</sup>  | 9.7 x 10 <sup>-4</sup>  | 1.2 x 10 <sup>-2</sup>  |

## Emissions of Tritium from Isotope Processing Programs

While airborne tritium was likely emitted to some extent from ORNL reactor and fuel processing operations, available data indicate that the most significant source of airborne tritium emissions was the handling of tritium that was received from Savannah River, purified, and repackaged for commercial distribution. Documented quantities of tritium shipped from ORNL provide indication of trends of quantities of the nuclide that were processed. According to Isotope Division reports, under 50,000 Ci were shipped each year 1952 through 1958; 1971 shipments totaled 220,000 Ci; shipments in 1986 topped a million curies; and shipments peaked at 2.4 million curies in 1987.

Reporting of airborne tritium emissions from ORNL began in 1972. Like quantities shipped, the reported airborne effluents peaked in 1987. Reported quantities of tritium shipped annually from ORNL and quantities reported to have been released in ORNL airborne effluents are depicted in Figure E-1. Because the information that has been reviewed does not identify any sources of airborne tritium emissions in the 1950s through 1960s that likely approached the magnitude of reported emissions from isotope processing during the 1980s, the peak annual tritium emission of 44,000 curies reported for 1987 was used for screening calculations.

### REFERENCES

Bradshaw and Cottrell, 1954. Bradshaw, R.L. and W.D. Cottrell. "A Study of the Contribution of the RaLa Process to Atmospheric Contamination at ORNL." ORNL Central Files No. 54-11-86. November 1, 1954.

Cagle and Emler, 1948. Cagle, C.D., and L.B. Emler. "Slug Ruptures in the Oak Ridge National Laboratory Pile." Operations Division. Report ORNL-170. October 13, 1948.

Emler, 1947. Emler, L.B. "Ruptured Slug— Clinton Pile." ORNL Central Files Number 47-12-391. December 10, 1947.

Johnson and Schaffer, 1992. Johnson, Leland, and Daniel Schaffer. *Oak Ridge National Laboratory, The First Fifty Years (Draft)*. July 29, 1992.

Jones, 1985. Jones, Vincent C. *United States Army in World War II; Special Studies; Manhattan: The Army and the Atomic Bomb*. Center for Military History, U. S. Army. 1985.

Leverett, 1944. Leverett, M.C. "Engineering Development Section Semimonthly Report for Period Ending August 15, 1944." Clinton Laboratories Report M-CE-1887. August, 1944.

McDuffee, 1957. McDuffee, W.T. "Thorex Pilot Plant Run HD-19 Summary." ORNL Central Files No. 57-4-1. April 30, 1957.

McDuffee and Yarbrow, 1958. McDuffee, W.T. and O.O. Yarbrow. "Thorex Pilot Plant: Short-Decay Processing Run Summary, Runs SD-1, 2 and 3." ORNL Central Files No. 58-6-1. June 30, 1958.

Morgan, 1949. Morgan, K.Z. "Air Contamination." Letter to Dr. Stuart McLain, Argonne National Laboratory. ORNL Central Files Number CF 49-11-134. November 9, 1949.

Reynolds et al., 1946. Reynolds, S.A., W.A. Rodger, and E.J. Witkowski. "Distribution of  $I^{131}$  in Wastes from the  $Ba^{140}$  Process." ORNL Report MonN-133. July 9, 1946.

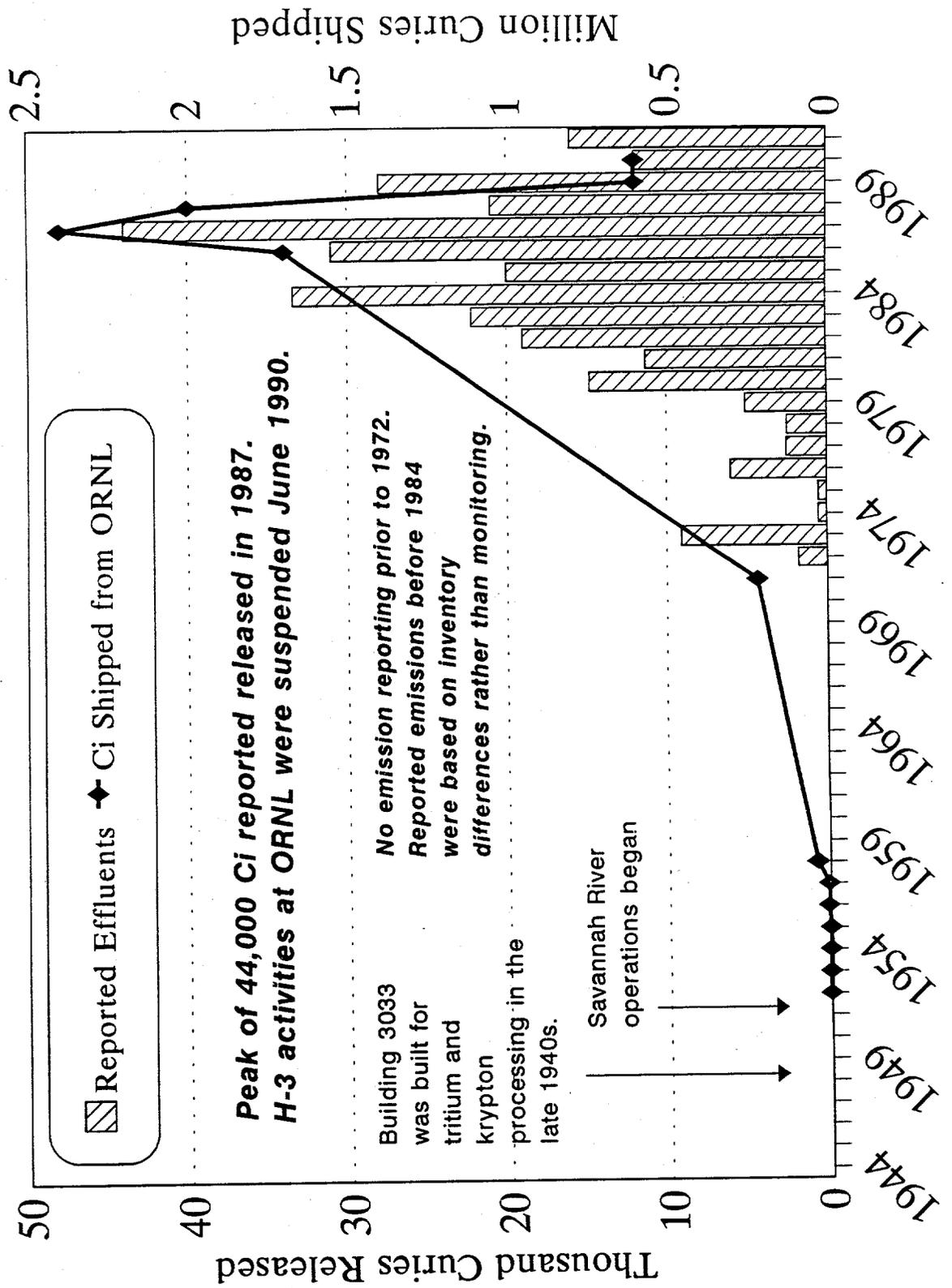
Rupp and Cox, 1955. Rupp, A.F. and J.A. Cox. "Operation of the ORNL Graphite Reactor and the Low-Intensity Test Reactor — 1954." Report ORNL-1866. September 16, 1955.

Seagren and Cox, 1957. Seagren, H.E. and J.A. Cox. "Operation of the ORNL Graphite Reactor and of the Low-Intensity Test Reactor and Preoperation Activities at the Research Reactor; Annual Report for 1956." Operations Division. Report ORNL-2286. July 25, 1957.

Thompson, 1963. Thompson, W.E., Jr. *History of the Oak Ridge National Laboratory 1943-1963, First Rough Draft*. ORNL Central Files No. 63-8-75. August 23, 1963.

Yarbro, 1958. Yarbro, O.O. "Activity Fall-out Resulting from Short-Decay Processing." ORNL Central Files No. 58-2-149. February 27, 1958.

FIGURE E-1  
X-10 TRITIUM AIR EMISSIONS AND SHIPMENTS



**APPENDIX F**

**SOURCE TERM ESTIMATES FOR K-25**

## APPENDIX F

### SOURCE TERM ESTIMATES FOR K-25

This appendix describes the analyses and/or calculations performed to determine airborne source terms for materials released from K-25. Source terms for several materials were taken directly from existing documents, as described in Section 5.1.2 of the main text, and are not discussed here. For the remaining materials, the calculations are described below.

#### Uranium-234/235 and Uranium-238

The highest annual release of uranium from K-25 occurred in 1958, but was reported in terms of total activity (1.80 Ci) and total quantity (2711 kg), not in terms of specific isotopes. Using the information provided in the Radionuclide Release Report for 1958 and estimated specific activity values, the series of algebraic equations shown below was solved to determine the percentages of total K-25 emissions that were released as uranium-235 and uranium-238. Specific activity values were assumed to be equal to those for enriched uranium processed at Y-12 used in Appendix G calculations. These values correspond to mass-per-curie values of 15.8 kg/Ci for uranium-234/235 and 2780 kg/Ci for uranium-238. Because the gaseous diffusion plant enriched uranium to assays greater than 90 percent uranium-235 prior to 1964 (MMES, 1986), it is reasonable to base screening estimates of K-25 releases during 1958 on published gross emission data for that year and the isotopic composition specified by these values.

$$1.80 \text{ Ci} = \frac{x \text{ kg U-235}}{15.8 \text{ kg/Ci}} + \frac{y \text{ kg U-238}}{2780 \text{ kg/Ci}} \text{ is the same as } 1.8 = \frac{x}{15.8} + \frac{y}{2780}$$

(Equation 1)

$$2711 \text{ kg} = x \text{ kg U-235} + y \text{ kg U-238} \text{ is the same as } 2711 = x + y$$

(Equation 2)

#### Step 1 Rearrange Equation 1

$$15.8 * 1.8 = \left( \frac{x}{15.8} + \frac{y}{2780} \right) * 15.8$$

$$28.4 = x + \frac{15.8}{2780}y$$

or

$$-28.4 = -x - \frac{15.8}{2780}y \quad (\text{Equation 1a})$$

Step 2 Sum Equation 1a and Equation 2

$$\begin{array}{r} -28.4 = -x - \frac{15.8}{2780}y \\ + \quad 2711 = x + y \\ \hline 2682.6 = 0.9943 y \\ \text{or} \\ 2698 \text{ kg} = y \end{array}$$

Step 3 Solve for "x"

*If y = 2698 kg, then x =*

$$2711 \text{ kg} = x \text{ kg} + 2698 \text{ kg}$$

$$13 \text{ kg} = x$$

Step 4 Calculate source terms

$$\text{Uranium-234/235: } \frac{13 \text{ kg}}{15.8 \text{ kg/Ci}} = 0.82 \text{ Ci}$$

$$\text{Uranium-238: } \frac{2698 \text{ kg}}{2780 \text{ kg/Ci}} = 0.97 \text{ Ci}$$

## Nickel

Information regarding the use of nickel sulfate at K-25 was retrieved from the stores inventory for fiscal years 1982 and 1983 (Adams, 1993). Based on the amount of nickel sulfate that was ordered and distributed in these two years, it appears that approximately 4000 pounds of nickel were used each year. Although these inventories should capture all of the nickel sulfate ordered through the stores department, it will not capture any nickel sulfate ordered by a division directly

from the manufacturer. The amount of nickel sulfate that may have been ordered directly from a manufacturer is not known, however, it is expected to be small compared to the amount ordered through the stores department during the early 1980s. It was during this period that K-25 was upgrading the diffusion cascade, and the amount of nickel ordered in 1982 and 1983 should be representative of a high-activity period. A search of the stores inventories for fiscal years 1979 and 1980 revealed no purchasing or distributing activity for nickel sulfate. The other nickel compounds ordered or distributed during 1982 and 1983 were nickel electroplating solutions, which are not expected to be a source of airborne releases. For the purpose of this screening analysis, the maximum amount of nickel released is assumed to have been 4,000 pounds, or 1,800 kg, during 1982-1983.

### Carbon Tetrachloride

Carbon tetrachloride was used at K-25 in the late 1940s and early 1950s. Information regarding the amount of carbon tetrachloride used during this period was obtained from Site Quarterly Progress Reports and from an interview with a current plant employee. The progress reports for the third and fourth quarters of 1949 indicate that 9,155 and 7,000 gallons of carbon tetrachloride were recovered through distillation during these periods, respectively (LeGeay, 1993). Based on the opinion of a current plant employee, this amount of carbon tetrachloride was accumulated from 1946 to 1949. When the plant began to run out of clean carbon tetrachloride, they distilled what had accumulated over the previous years. This distilled carbon tetrachloride lasted until about 1952. It is unknown what percentage of the total the recovered 16,155 gallons represents; however, it would appear that this amount of carbon tetrachloride was used between the end of 1949 and sometime in 1952. For the purpose of this screening analysis, it is assumed that approximately one-third of 16,155 gallons, or about 5,400 gallons, was used annually during this period. This amount was used in the calculation of predicted maximum average annual air concentrations off-site. All 5,400 gallons are assumed to have been released to the atmosphere.

### Trichloroethylene

Information regarding the usage of trichloroethylene at K-25 was found during the review of the Site Quarterly Progress Reports as part of Tasks 1 and 2. Between June 30, 1950 and June 30, 1951,  $475 \pm 77$  gallons per month were used (UCC, 1951). It is not known whether this is the largest amount ever used at the plant. For the purpose of this screening analysis, it is assumed that the upper end of the suggested range (i.e.,  $475 + 77$  or approximately 550 gallons) was used each month during this period. This is equal to approximately 6,600 gallons over a twelve-month period. It is assumed that all 6,600 gallons were released to the atmosphere. This amount was used in the calculation of predicted maximum annual air concentrations off-site.

## REFERENCES

Adams, 1993. Adams, John. K-25 Selective Activity Reports. March 1993.

Legeay, 1993. Legeay, Gus. Interview and telephone conversation notes with Gus Legeay. March 1993.

MMES, 1986. Martin Marietta Energy Systems, Inc. Oak Ridge Gaseous Diffusion Plant Historical Radionuclide Release Report. Prepared by A.C. Lay and J.G. Rogers for the U.S. Department of Energy. K/HS-95. February 28, 1986.

UCC, 1951. Union Carbide Corporation. K-25 Plant Quarterly Progress Reports for Fourth Fiscal Quarter April 1 - June 30, 1951. Document No. K-640.

**APPENDIX G**

**SOURCE TERM ESTIMATES FOR Y-12**

## APPENDIX G

### SOURCE TERM ESTIMATES FOR Y-12

This appendix describes the analyses and/or calculations performed to determine airborne source terms for materials released from Y-12. Source terms for several materials were taken directly from existing documents, as described in Section 5.1.3 of the main text, and are not discussed here. For the remaining materials, the calculations are described below.

#### Uranium-234/235 and Uranium-238

Information on airborne release estimates of uranium-234/235 and uranium-238 was obtained from several sources. The U.S. Department of Energy's Historical Radionuclide Releases from Current DOE Oak Ridge Operations Office Facilities (USDOE, 1988a; hereafter the Radionuclide Release Report) and an update provided by Martin Marietta Energy Systems, Inc (MMES, 1991a) provide airborne release estimates from 1944 to 1989, with the exception of 1948-1952, for which data were not available. Additional information was located in another historical radionuclide release report (Owings, 1986), a report on uranium losses from the late 1950s (Griffith, 1957), the Y-12 Plant Radioactive Effluent Reports for CY 1985-1991 (MMES, 1985-1990, 1991b, and 1992) and the U.S. DOE's Annual Environmental Reports for 1985 through 1991 (U.S. DOE, 1985-1987, 1988b, and 1989-1992). Information from all of these sources was used to generate natural uranium, uranium-234/235, and uranium-238 release estimates shown in Table G-1. This table presents both measured and estimated annual releases, in kg, that are then combined into a total activity release estimate, in curies.

Based on the information gathered as part of Tasks 1 & 2, the largest reported annual release occurred in 1956. Since this information is incomplete, it is important to bear in mind that additional information gathered in any later stages of the health studies may indicate that the highest releases occurred in another year. During this year, a total of approximately 13 kg or 0.83 Ci of uranium-234/235 and a total of approximately 30 kg or 0.012 Ci of uranium-238 were released into the atmosphere. However, the largest amount released was in the form of natural uranium, which consists of approximately 0.71% uranium-234/235 and approximately 99.29% uranium-238 by weight. Based on a release estimate of 3363 kg natural uranium, an additional 24 kg of uranium-234/235 (i.e., 0.71% \* 3363 kg) and 3339 kg of uranium-238 (i.e., 99.29% \* 3363 kg) were released. Using these release estimates and the specific activity of each isotope, an estimate of the total activity released during 1956 was calculated using the following equation:

$$\text{Activity Released (Ci)} = \text{Total Released (kg)} * \text{Specific Activity (Ci/kg)}$$

The specific activity of Y-12 enriched uranium (uranium-234 and uranium-235) is 0.063 Ci/kg. Assuming a total of 37 kg of uranium 234/235 were released during 1956 (i.e., 13 kg + 24 kg), this corresponds to approximately 2.3 Ci. For uranium-238, the specific activity is 0.00036 Ci/kg. Assuming a total of 3369 kg uranium-238 were released (i.e., 30 kg + 3339 kg), this corresponds to approximately 1.2 Ci.

**Table G-1: Airborne Uranium Release Estimates for Y-12**

| Year | Measured $^{234}\text{U}/^{235}\text{U}$ (kg) | Estimated $^{234}\text{U}/^{235}\text{U}$ (kg) | Total Activity—Measured & Estimated $^{234}\text{U}/^{235}\text{U}$ (Ci) <sup>a</sup> | Measured Depleted $^{238}\text{U}$ (kg) | Estimated Depleted $^{238}\text{U}$ (kg) | Total Activity—Measured & Estimated Depleted $^{238}\text{U}$ (Ci) <sup>b</sup> | Estimated Natural Uranium (kg) |
|------|---|--|---|---|--|---|--------------------------------|
| 1944 | 0.27  | 0.1  | 0.023   | ND                                      | ND                                       | ND  | 55                             |
| 1945 | 0.27  | 0.1  | 0.023   | ND                                      | ND                                       | ND  | 102                            |
| 1946 | 0.27  | 0.21   | 0.030   | ND                                      | ND                                       | ND  | 102                            |
| 1947 | 0.27  | ND   | 0.017   | ND                                      | ND                                       | ND  | 55                             |
| 1948 | 0.27  | 0.11   | 0.024   | ND                                      | ND                                       | ND  | 650                            |
| 1949 | 0.27  | 0.11   | 0.024   | ND                                      | ND                                       | ND  | 650                            |
| 1950 | 0.27  | 0.11   | 0.024   | ND                                      | ND                                       | ND  | 650                            |
| 1951 | 0.27  | 0.11   | 0.024   | ND                                      | ND                                       | ND  | 650                            |
| 1952 | 0.27  | 0.11   | 0.024   | ND                                      | ND                                       | ND  | 650                            |
| 1953 | 0.40  | ND   | 0.025   | ND                                      | 30                                       | 0.011   | 683                            |
| 1954 | 0.40  | 2  | 0.15  | ND                                      | 30                                       | 0.011   | 3763                           |
| 1955 | 0.40  | 2  | 0.15  | ND                                      | 30                                       | 0.011   | 3763                           |
| 1956 | 11.16   | 2  | 0.83  | ND                                      | 30                                       | 0.011   | 3363                           |
| 1957 | 9.16  | 2  | 0.71  | ND                                      | 30                                       | 0.011   | ND                             |
| 1958 | 8.95  | 2  | 0.69  | ND                                      | 30                                       | 0.011   | ND                             |
| 1959 | 28.53   | 2  | 1.9   | ND                                      | 90                                       | 0.032   | ND                             |
| 1960 | 7.11  | 2  | 0.57  | ND                                      | 90                                       | 0.032   | ND                             |
| 1961 | 7.11  | 2  | 0.57  | ND                                      | 100                                      | 0.036   | ND                             |
| 1962 | 1.90  | 2  | 0.25  | ND                                      | 90                                       | 0.032   | ND                             |
| 1963 | 11.06   | 2  | 0.82  | ND                                      | 90                                       | 0.032   | ND                             |

Table G-1: Airborne Uranium Release Estimates for Y-12 (Continued)

| Year | Measured $^{234}\text{U}/^{235}\text{U}$ (kg) | Estimated $^{234}\text{U}/^{235}\text{U}$ (kg) | Total Activity—Measured & Estimated $^{234}\text{U}/^{235}\text{U}$ (Ci) <sup>a</sup> | Measured Depleted $^{238}\text{U}$ (kg) | Estimated Depleted $^{238}\text{U}$ (kg) | Total Activity—Measured & Estimated Depleted $^{238}\text{U}$ (Ci) <sup>b</sup> | Estimated Natural Uranium (kg) |
|------|---|--|---|---|--|---|--------------------------------|
| 1964 | 9.48  | 2  | 0.72  | 68.49                                   | 90                                       | 0.057   | ND                             |
| 1965 | 6.32  | ND   | 0.40  | 35.14                                   | 240                                      | 0.099   | ND                             |
| 1966 | 7.11  | ND   | 0.45  | ND                                      | 205                                      | 0.074   | ND                             |
| 1967 | 7.11  | ND   | 0.45  | ND                                      | 205                                      | 0.074   | ND                             |
| 1968 | 5.53  | ND   | 0.35  | ND                                      | 205                                      | 0.074   | ND                             |
| 1969 | 5.53  | ND   | 0.35  | 12.00                                   | 205                                      | 0.078   | ND                             |
| 1970 | 6.32  | ND   | 0.40  | 12.00                                   | 241                                      | 0.091   | ND                             |
| 1971 | 0.79  | ND   | 0.050   | 84.38                                   | 205                                      | 0.10  | ND                             |
| 1972 | 0.16  | ND   | 0.01  | 6.74                                    | 215                                      | 0.080   | ND                             |
| 1973 | 0.16  | ND   | 0.089   | 0.71                                    | 205                                      | 0.074   | ND                             |
| 1974 | 1.42  | ND   | 0.09  | 0.67                                    | 205                                      | 0.074   | ND                             |
| 1975 | 1.74  | ND   | 0.11  | 2.36                                    | 205                                      | 0.075   | ND                             |
| 1976 | 1.74  | ND   | 0.11  | ND                                      | 205                                      | 0.074   | ND                             |
| 1977 | 0.95  | ND   | 0.060   | ND                                      | 205                                      | 0.074   | ND                             |
| 1978 | 0.16  | ND   | 0.010   | ND                                      | 205                                      | 0.074   | ND                             |
| 1979 | 0.95  | ND   | 0.060   | ND                                      | 205                                      | 0.074   | ND                             |
| 1980 | 2.53  | ND   | 0.16  | ND                                      | 215                                      | 0.077   | ND                             |
| 1981 | 1.90  | ND   | 0.12  | ND                                      | 205                                      | 0.074   | ND                             |
| 1982 | 1.74  | ND   | 0.11  | 0.14                                    | 205                                      | 0.074   | ND                             |

**Table G-1: Airborne Uranium Release Estimates for Y-12 (Continued)**

| Year | Measured $^{234}\text{U}/^{235}\text{U}$ (kg) | Estimated $^{234}\text{U}/^{235}\text{U}$ (kg) | Total Activity—Measured & Estimated $^{234}\text{U}/^{235}\text{U}$ (Ci) <sup>a</sup> | Measured Depleted $^{238}\text{U}$ (kg) | Estimated Depleted $^{238}\text{U}$ (kg) | Total Activity—Measured & Estimated Depleted $^{238}\text{U}$ (Ci) <sup>b</sup> | Estimated Natural Uranium (kg) |
|------|---|--|---|---|--|---|--------------------------------|
| 1983 | 1.90  | ND   | 0.12  | 1.49                                    | 205                                      | 0.074   | ND                             |
| 1984 | 1.54  | ND   | 0.10  | 2.01                                    | 325                                      | 0.12  | ND                             |
| 1985 | 1.12  | ND   | 0.071   | ND                                      | 190                                      | 0.068   | ND                             |
| 1986 | 1.24  | ND   | 0.078   | ND                                      | 211                                      | 0.076   | ND                             |
| 1987 | 1.6   | ND   | 0.10  | ND                                      | 115                                      | 0.041   | ND                             |
| 1988 | 1.6   | ND   | 0.10  | ND                                      | 46                                       | 0.017   | ND                             |
| 1989 | 1.9   | ND   | 0.12  | ND                                      | 42                                       | 0.015   | ND                             |
| 1990 | 1.3   | ND   | 0.082   | ND                                      | 19.6                                     | 0.0071  | ND                             |
| 1991 | 0.6   | 0.3  | 0.057   | ND                                      | 22.6                                     | 0.0081  | ND                             |

ND No data located

a Assuming a specific activity of Y-12 enriched uranium (uranium-234 and uranium-235) of 0.063 Ci/kg.

b Assuming a specific activity of uranium-238 of 0.00036 Ci/kg.

c Assuming 0.71 % of natural uranium by weight is uranium-234/235 with a specific activity of 0.063 Ci/kg, and 99.29% is uranium-238 with a specific activity of 0.00036 Ci/kg.

Source: Griffith, 1957; Owings, 1986

## REFERENCES

Griffith, 1957. Griffith, W.L. "Uranium Losses from the Y-12 Plant to the Environment." Report Y-B92-13. 1957 (approximate year). (Deleted Revision)—Sanitized document from classified version.

MMES, 1985. Martin Marietta Energy Systems, Inc. Y-12 Plant Radioactive Effluent Report for CY 1984 (U). Report No. Y/TS-93, Part 1. First Quarter, 1985. Not For Public Distribution: Restricted Data-Confidential.

MMES, 1986. Martin Marietta Energy Systems, Inc. Y-12 Plant Radioactive Effluent Report for CY 1985 (U). Report No. Y/TS-93, Part 2. First Quarter, 1986. Not For Public Distribution: Restricted Data-Confidential.

MMES, 1987. Martin Marietta Energy Systems, Inc. Y-12 Plant Radioactive Effluent Report for CY 1986 (U). Report No. Y/TS-93, Part 3. First Quarter, 1987. Not For Public Distribution: Restricted Data-Confidential.

MMES, 1988. Martin Marietta Energy Systems, Inc. Y-12 Plant Radioactive Effluent Report for CY 1987 (U). Report No. Y/TS-93, Part 4. First Quarter, 1988. Not For Public Distribution: Restricted Data-Confidential.

MMES, 1989. Martin Marietta Energy Systems, Inc. Y-12 Plant Radioactive Effluent Report for CY 1988 (U). Report No. Y/TS-93, Part 5. First Quarter, 1989. Not For Public Distribution: Restricted Data-Confidential.

MMES, 1990. Martin Marietta Energy Systems, Inc. Y-12 Plant Radioactive Effluent Report for CY 1989 (U). Report No. Y/TS-93, Part 6. First Quarter, 1990. Not For Public Distribution: Restricted Data-Confidential.

MMES, 1991b. Martin Marietta Energy Systems, Inc. "Historical Radionuclide Release Report Update." Internal correspondence from T.R. Butz to M.E. Mitchell dated January 18, 1991.

MMES, 1991b. Martin Marietta Energy Systems, Inc. Y-12 Plant Radioactive Effluent Report for CY 1990 (U). Report No. Y/TS-93, Part 7. First Quarter, 1991. Not For Public Distribution: Restricted Data-Confidential.

MMES, 1992. Martin Marietta Energy Systems, Inc. Y-12 Plant Radioactive Effluent Report for CY 1991 (U). Report No. Y/TS-93, Part 8. First Quarter, 1992. Not For Public Distribution: Restricted Data-Confidential.

Owings, 1986. Owings, E. Oak Ridge Y-12 Plant Historical Uranium and Radionuclide Release Report. Report Y/DG-17723. May, 1986.

USDOE, 1985. United States Department of Energy. Environmental Surveillance of the U.S. Department of Energy Oak Ridge Reservation and Surrounding Environs during 1985. Report ORNL-6271. May, 1992.

USDOE, 1986. United States Department of Energy. Environmental Surveillance of the U.S. Department of Energy Oak Ridge Reservation and Surrounding Environs during 1986. Report ES/ESH-1/V2. February, 1992.

USDOE, 1987. United States Department of Energy. Environmental Surveillance of the U.S. Department of Energy Oak Ridge Reservation and Surrounding Environs during 1987. Report ES/ESH-4/V1. April, 1988.

USDOE, 1988a. U.S. Department of Energy. Historical Radionuclide Releases from Current DOE Oak Ridge Operations Office Facilities. Report OR-890. May 1988.

USDOE, 1988b. United States Department of Energy. Oak Ridge Reservation Environmental Report for 1988. Report ES/ESH-8/V1. May, 1989.

USDOE, 1989. United States Department of Energy. Oak Ridge Reservation Environmental Report for 1989. Report ES/ESH-13/V1. October, 1990.

USDOE, 1990. United States Department of Energy. Oak Ridge Reservation Environmental Report for 1990. Report ES/ESH-18/V1. September, 1991.

USDOE, 1991. United States Department of Energy. Oak Ridge Reservation Environmental Report for 1991. Report ES/ESH-22/V1. October, 1992.

**APPENDIX H**

**ENVIRONMENTAL MONITORING DATA FROM  
SURFACE WATER BODIES ASSEMBLED  
FOR PATHWAY EVALUATION**

**IMPORTANT NOTICE**

All of the environmental monitoring data presented in this appendix have been excerpted from the identified source documents. It was not possible during the Phase I study to independently verify the quality of these data. The values as presented as they appear in the source documents. No attempt was made to evaluate whether the numbers of significant figures provided are appropriate. Considerable data validation efforts would likely be necessary prior to use of these data as a basis for estimation of historical exposures or health risks.

## APPENDIX H

### ENVIRONMENTAL MONITORING DATA FROM SURFACE WATER BODIES ASSEMBLED FOR PATHWAY EVALUATION

This appendix presents the surface water sampling data assembled for use in exposure pathway evaluation. This information was gathered from a review of approximately 100 documents describing environmental sampling on or near the Oak Ridge Reservation. Data from three general locations are included: at or just downstream of the confluence of Poplar Creek with the Clinch River (for the K-25 facility evaluation), at or just downstream of White Oak Creek with the Clinch River (for the X-10 facility evaluation), and in East Fork Poplar Creek at or near the City of Oak Ridge (for the Y-12 facility evaluation). These data are presented in Tables H-1, H-2, and H-3, respectively. For each contaminant for which data were located, the maximum value measured during a given sampling program at a given location is recorded.

#### REFERENCES

- Ashwood et al., 1986. Ashwood, T.L., C.R. Olsen, I.L. Larsen, and P.D. Lowry. "Sediment Contamination in Streams Surrounding the Oak Ridge Gaseous Diffusion Plant." Report ORNL/TM-9791. May 1986. ChemRisk Repository No. 166.
- Cook et al., 1992. Cook, R.B., S.M. Adams, J.J. Beauchamp, M.S. Bevelhimer, B.G. Blaylock, C.C. Brandt, C.J. Ford, M.L. Frank, M.J. Gentry, S.K. Holladay, L.A. Hook, D.A. Levine, R.C. Longman, C.W. McGinn, J.L. Skiles, G.W. Suter, and L.F. Williams. "Phase 1 Data Summary Report for the Clinch River Remedial Investigation: Health Risk and Ecological Risk Screening Assessment." Environmental Sciences Division. Report ORNL/ER-155. December 1992.
- Cottrell, 1960. Cottrell, W.D. "Radioactivity in Silt of the Clinch and Tennessee Rivers." Report ORNL-2847. June 7, 1960. ChemRisk Repository No. 143.
- Cowser and Synder, 1966. Cowser, K.E. and W.S. Snyder. Safety Analysis of Radionuclide Release to the Clinch River. Supplement No. 3 to Status Report No. 5 on Clinch River Study. Progress Report No. 3 (Final) of Subcommittee on Safety Evaluation." Report ORNL-3721, Suppl. 3. May 1966. ChemRisk Repository No. 149.
- Hibbitts, 1984. Hibbitts, H.W. "Transmittal of Environmental Sampling Data for Mercury." February - December, 1984. ChemRisk Repository No. 536.
- Hoffman et al., 1980. Hoffman, F.O., J.W. Huckabee, D.M. Lucas, C.T. Garten, Jr., T.G. Scott, R.L. Walker, P.S. Gouge, and C.V. Holmes. "Sampling of Technetium-99 in Vegetation and Soils in the Vicinity of Operating Gaseous Diffusion Facilities." ORNL Environmental Sciences Division. Report ORNL/TM-7386.

Loar et al., 1981. Loar, J.M., F.A. Burkhardt, G.F. Cada, J.W. Huckabee, J.T. Kitchings, K.D. Kumar, A.M. Sasson, J.A. Solomon, and J.D. Story. "Ecological Studies in the Biotic Communities in the Vicinity of the Oak Ridge Gaseous Diffusion Plant." Environmental Sciences Division. Report ORNL/TM-6714. October 1981. ChemRisk Repository No. 250.

Long, 1979. Long, L.W. "Clinch River and Poplar Creek Bottom Sediments Data Special Sampling Program 1979 Only." K-25 Compliance and Environmental Policy Document Center Report No. 00490. April 10, 1979. ChemRisk Repository No. 615.

MMES, 1984. Martin Marietta Energy Systems. "Environmental Monitoring Report. United States Department of Energy, Oak Ridge Facilities. Calendar Year 1983." Report Y/UB-19. ChemRisk Repository No. 954.

MMES, 1985. Martin Marietta Energy Systems. "Environmental Monitoring Report. United States Department of Energy, Oak Ridge Facilities. Calendar Year 1984." Report ORNL-6209. ChemRisk Repository No. 955.

MMES, 1986. Martin Marietta Energy Systems. "Environmental Surveillance of the Oak Ridge Reservations and Surrounding Environs During 1985." Report ORNL-6271. ChemRisk Repository No. 199.

MMES, 1987. Martin Marietta Energy Systems. Environmental Surveillance of the U.S. Department of Energy Oak Ridge Reservation and Surrounding Environs During 1986. Report ES/ESH-1/V1.

MMES, 1988. Martin Marietta Energy Systems. "Environmental Surveillance of the U.S. Department of Energy Oak Ridge Reservations and Surrounding Environs During 1987. Volume 1: Narrative, Summary, and Conclusions." Report ES/ESH-4/V1. ChemRisk Repository No. 370.

MMES, 1989. Martin Marietta Energy Systems. "Oak Ridge Reservation Environmental Report for 1988. Volume 1: Narrative, Summary, and Conclusions." Report ES/ESH-8/V1. ChemRisk Repository No. 254.

Morton, 1965. Morton, R.J. (ed.). "Status Report No. 5 on Clinch River Study, Clinch River Study Steering Committee." Health Physics Division. Report ORNL-3721. October 1965. ChemRisk Repository No. 149.

Oakes et al., 1982. Oakes, T.W., W.F. Ohnesorge, J.S. Eldridge, T.G. Scott, D.W. Parsons, H.M. Hubbard, O.M. Sealand, K.E. Shank, and L.D. Eyman. "Technical Background Information for the Environmental and Safety Report, Vol. 5: The 1977 Clinch River Sediment Survey--Data Presentation." Report ORNL-5878. November 1982. ChemRisk Repository No. 157.

Reece, J. 1974. Preliminary aquatic survey of East Fork Poplar Creek and Bear Creek, 1974. United States Atomic Energy Commission, Oak Ridge Operations. September 20, 1974.

TVA, 1985a. Tennessee Valley Authority. "Instream Contaminant Study, Task 1: Water Sampling and Analysis." Office of Natural Resources and Economic Development, Knoxville, Tennessee. April 1985. ChemRisk Repository No. 840.

TVA, 1985b. Tennessee Valley Authority. "Instream Contaminant Study, Task 2: Sediment Characterization, Volume II- Appendices." Office of Natural Resources and Economic Development, Knoxville, Tennessee. January 1985. ChemRisk Repository No. 842.

TVA, 1985c. Tennessee Valley Authority. "Instream Contaminant Study, Task 4: Fish Sampling and Analysis." Office of Natural Resources and Economic Development, Knoxville, Tennessee. April 1985. ChemRisk Repository No. 844.

TVA, 1990. Tennessee Valley Authority. "Results of Fish Tissue Screening Studies from Sites in the Tennessee and Cumberland Rivers in 1988." Office of Water Resources, Chattanooga, Tennessee. TVA/WR/AB--90/7. May 1989. ChemRisk Repository No. 846.

TVA, 1991. Tennessee Valley Authority. "Results of Sediment and Water Sampling for Inorganic, Organic, and Radionuclide Analysis at Recreation Areas and Water Intakes--Norris, Melton Hill, and Watts Bar Lakes: Data Report." Water Quality Department. ChemRisk Repository No. 852.

UCC, 1961. Union Carbide Corporation. "Applied Health Physics Annual Report for 1960." Report ORNL-3159. ChemRisk Repository No. 542

UCC, 1962. Union Carbide Corporation. "Applied Health Physics Annual Report for 1961." Report ORNL-3284. ChemRisk Repository No. 543.

UCC, 1963. Union Carbide Corporation. "Applied Health Physics Annual Report for 1962." Report ORNL-3490. ChemRisk Repository No. 544.

UCC, 1964. Union Carbide Corporation. "Applied Health Physics Annual Report for 1963." Report ORNL-3665. ChemRisk Repository No. 545.

UCC, 1965. Union Carbide Corporation. "Applied Health Physics Annual Report for 1964." Report ORNL-3820. ChemRisk Repository No. 546.

UCC, 1966. Union Carbide Corporation. "Applied Health Physics Annual Report for 1965." Report ORNL-3969. ChemRisk Repository No. 547.

UCC, 1967. Union Carbide Corporation. "Applied Health Physics Annual Report for 1966." Report ORNL-4146. ChemRisk Repository No. 548.

UCC, 1968. Union Carbide Corporation. "Applied Health Physics Annual Report for 1967." Report ORNL-4286. ChemRisk Repository No. 549.

UCC, 1969. Union Carbide Corporation. "Applied Health Physics Annual Report for 1968." Report ORNL-4423. ChemRisk Repository No. 550.

UCC, 1970. Union Carbide Corporation. "Applied Health Physics Annual Report for 1969." Report ORNL-4563. ChemRisk Repository No. 551.

UCC, 1971. Union Carbide Corporation. "Applied Health Physics Annual Report for 1970." Report ORNL-4690. ChemRisk Repository No. 552.

UCC, 1972. Union Carbide Corporation. "Environmental Monitoring Report, United States Atomic Energy Commission, Oak Ridge Facilities. Calendar Year 1971." Report UCC-ND-221. ChemRisk Repository No. 942.

UCC, 1973. Union Carbide Corporation. "Environmental Monitoring Report, United States Atomic Energy Commission, Oak Ridge Facilities. Calendar Year 1972." Report UCC-ND-244. ChemRisk Repository No. 943.

UCC, 1974. Union Carbide Corporation. "Environmental Monitoring Report, United States Atomic Energy Commission, Oak Ridge Facilities. Calendar Year 1973." Report UCC-ND-280. ChemRisk Repository No. 944.

UCC, 1975. Union Carbide Corporation. "Environmental Monitoring Report, United States Energy Research and Development Administration, Oak Ridge Facilities. Calendar Year 1974." Report UCC-ND-302. ChemRisk Repository No. 945.

UCC, 1976. Union Carbide Corporation. "Environmental Monitoring Report, United States Energy Research and Development Administration, Oak Ridge Facilities. Calendar Year 1975." Report Y/UB-4. ChemRisk Repository No. 946.

UCC, 1977. Union Carbide Corporation. "Environmental Monitoring Report, United States Energy Research and Development Administration, Oak Ridge Facilities. Calendar Year 1976." Report Y/UB-6. ChemRisk Repository No. 947.

UCC, 1978. Union Carbide Corporation. "Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities. Calendar Year 1977." Report Y/UB-8. ChemRisk Repository No. 948.

UCC, 1979. Union Carbide Corporation. "Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities. Calendar Year 1978." Report Y/UB-10. ChemRisk Repository No. 949.

UCC, 1980. Union Carbide Corporation. "Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities. Calendar Year 1979." Report Y/UB-13. ChemRisk Repository No. 950.

UCC, 1981. Union Carbide Corporation. "Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities. Calendar Year 1980." Report Y/UB-15. ChemRisk Repository No. 951.

UCC, 1982. Union Carbide Corporation. "Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities. Calendar Year 1981." Report Y/UB-16. ChemRisk Repository No. 952.

UCC, 1983a. Union Carbide Corporation. "Environmental Monitoring Report, United States Department of Energy, Oak Ridge Facilities. Calendar Year 1982." Report Y/UB-18. ChemRisk Repository No. 953.

UCC, 1983b. Union Carbide Corporation. "Mercury at Y-12 Plant: A Study of Mercury Use at the Y-12 Plant, Accountability, and Impacts on Y-12 Workers and the Environment- 1950 to 1983." Compiled by the 1983 Mercury Task Force. Report Y/EX-24. August 18, 1983. ChemRisk Repository No.

Van Winkle, et al., 1982. W. Van Winkle, R.W. Counts, J.G. Dorsey, J.W. Elwood, V.W. Lowe, Jr., R. McElhaney, S.D. Schlotzhauer, F.G. Taylor, Jr., and R.R. Turner. (1982). "Mercury Contamination in East Fork Poplar Creek and Bear Creek." Report ORNL/TM-8894. February 1984. ChemRisk Repository No. 171.

TABLE H-1: ENVIRONMENTAL SAMPLES AT OR DOWNSTREAM OF THE CONFLUENCE OF THE CLUNCH RIVER AND POPLAR CREEK (K-25 SITE)

| Media | Chemical or Radionuclide | Date    | Location | Study             | Number of Samples | Maximum Value | Units        | Species (Fish)     | Comments                        |
|-------|--------------------------|---------|----------|-------------------|-------------------|---------------|--------------|--------------------|---------------------------------|
| Fish  | Arsenic                  | 1984    | CRM 11.0 | TVA, 1985c        | 30                | 0.4           | mg/kg        | NA                 |                                 |
| Fish  | Arsenic                  | 1989-90 | CRM 9.5  | Cook et al., 1992 | 12                | 0.15          | mg/kg (wet)  | NA                 |                                 |
| Fish  | Beryllium                | 1989-90 | CRM 9.5  | Cook et al., 1992 | 12                | <0.003        | mg/kg (wet)  | NA                 |                                 |
| Fish  | Chromium                 | 1977    | CRM 11.5 | Loar et al., 1981 | 28                | 0.33          | mg/kg (wet)  | Shad               |                                 |
| Fish  | Chromium                 | 1977    | CRM 10.5 | Loar et al., 1981 | 55                | 0.92          | mg/kg (wet)  | Shad               |                                 |
| Fish  | Chromium                 | 1984    | CRM 11.0 | TVA, 1985c        | 30                | 0.14          | mg/kg (wet)  | Bass               |                                 |
| Fish  | Lead                     | 1977    | CRM 11.5 | Loar et al., 1981 | 28                | 0.31          | mg/kg (wet)  | Shad               |                                 |
| Fish  | Lead                     | 1977    | CRM 10.5 | Loar et al., 1981 | 55                | 0.31          | mg/kg (wet)  | Lepomis            |                                 |
| Fish  | Nickel                   | 1977    | CRM 11.5 | Loar et al., 1981 | 28                | 1.2           | mg/kg (wet)  | Lepomis            |                                 |
| Fish  | Nickel                   | 1977    | CRM 10.5 | Loar et al., 1981 | 55                | 0.9           | mg/kg (wet)  | Lepomis            |                                 |
| Fish  | Nickel                   | 1984    | CRM 11.0 | TVA, 1985c        | 30                | 1             | mg/kg (wet)  | Smallmouth Buffalo |                                 |
| Fish  | PCBs                     | 1977    | PCM 0.5  | Loar et al., 1981 | 50                | 6             | mg/kg (wet)  | NA                 |                                 |
| Fish  | PCBs                     | 1977    | CRM 11.5 | Loar et al., 1981 | 19                | 0.4           | mg/kg (wet)  | NA                 |                                 |
| Fish  | PCBs                     | 1977    | CRM 10.5 | Loar et al., 1981 | 25                | 0.5           | mg/kg (wet)  | NA                 |                                 |
| Fish  | PCBs                     | 1984    | CRM 11.0 | TVA, 1985c        | 70                | 1.2           | mg/kg (wet)  | NA                 |                                 |
| Fish  | PCBs                     | 1984    | CRM 12.0 | MMS, 1985         | 200               | 12            | mg/kg (wet)  | Carp               |                                 |
| Fish  | PCBs                     | 1985    | CRM 12.0 | MMS, 1986         | 34                | 1.4           | mg/kg (wet)  | Carp               |                                 |
| Fish  | PCBs                     | 1988    | CRM 2.1  | TVA, 1990         | 10                | 4.6           | mg/kg (wet)  | NA                 |                                 |
| Fish  | PCBs                     | 1989-90 | CRM 9.5  | Cook et al., 1992 | 16                | 2.1           | mg/kg (wet)  | NA                 |                                 |
| Fish  | Pu-238                   | 1978    | CRM 12.0 | UCC, 1979         | 5                 | 0.22          | pCi/kg (wet) | Shad               | Five composites of 10 fish each |
| Fish  | Pu-238                   | 1979    | CRM 12.0 | UCC, 1980         | 5                 | 0.88          | pCi/kg (wet) | Bluegill           | Five composites of 10 fish each |
| Fish  | Pu-238                   | 1980    | CRM 12.0 | UCC, 1981         | 5                 | 0.12          | pCi/kg (wet) | Bluegill           | Five composites of 10 fish each |
| Fish  | Pu-238                   | 1981    | CRM 12.0 | UCC, 1982         | 5                 | 0.1           | pCi/kg (wet) | Bluegill           | Five composites of 10 fish each |
| Fish  | Pu-238                   | 1982    | CRM 12.0 | UCC, 1983a        | 5                 | 0.024         | pCi/kg (wet) | Shad               | Five composites of 10 fish each |
| Fish  | Pu-238                   | 1983    | CRM 12.0 | MMS, 1984         | 5                 | 0.15          | pCi/kg (wet) | Bluegill           | Five composites of 10 fish each |
| Fish  | Pu-238                   | 1984    | CRM 12.0 | MMS, 1985         | 5                 | 0.23          | pCi/kg (wet) | Shad               | Five composites of 10 fish each |
| Fish  | Pu-238                   | 1985    | CRM 12.0 | MMS, 1986         | 5                 | 0.02          | pCi/kg (wet) | Bluegill           | Five composites of 10 fish each |
| Fish  | Pu-239                   | 1976    | CRM 12.0 | UCC, 1977         | 1                 | 0.29          | pCi/kg (wet) | shad               | Five composites of 10 fish each |
| Fish  | Pu-239                   | 1977    | CRM 12.0 | UCC, 1978         | 2                 | 0.82          | pCi/kg (wet) | shad               | Five composites of 10 fish each |
| Fish  | Pu-239                   | 1978    | CRM 12.0 | UCC, 1979         | 5                 | 0.16          | pCi/kg (wet) | Shad               | Five composites of 10 fish each |
| Fish  | Pu-239                   | 1979    | CRM 12.0 | UCC, 1980         | 5                 | 0.88          | pCi/kg (wet) | Bluegill           | Five composites of 10 fish each |
| Fish  | Pu-239                   | 1980    | CRM 12.0 | UCC, 1981         | 5                 | 0.17          | pCi/kg (wet) | Shad               | Five composites of 10 fish each |
| Fish  | Pu-239                   | 1981    | CRM 12.0 | UCC, 1982         | 5                 | 0.081         | pCi/kg (wet) | Bluegill           | Five composites of 10 fish each |
| Fish  | Pu-239                   | 1982    | CRM 12.0 | UCC, 1983a        | 5                 | 0.027         | pCi/kg (wet) | Bluegill           | Five composites of 10 fish each |
| Fish  | Pu-239                   | 1983    | CRM 12.0 | MMS, 1984         | 5                 | 0.83          | pCi/kg (wet) | Bluegill           | Five composites of 10 fish each |
| Fish  | Pu-239                   | 1984    | CRM 12.0 | MMS, 1985         | 5                 | 1.5           | pCi/kg (wet) | Shad               | Five composites of 10 fish each |
| Fish  | Pu-239                   | 1985    | CRM 12.0 | MMS, 1986         | 5                 | 0.055         | pCi/kg (wet) | Bluegill           | Five composites of 10 fish each |
| Fish  | Tc-99                    | 1984    | PCM 0.2  | TVA, 1985c        | 4                 | 490           | pCi/kg (wet) | NA                 | One composite of 10 fish        |
| Fish  | U-234                    | 1983    | CRM 12.0 | MMS, 1984         | 1                 | 3.1           | pCi/kg (wet) | Shad               | One composite of 10 fish        |
| Fish  | U-234                    | 1984    | CRM 12.0 | MMS, 1985         | 1                 | 53            | pCi/kg (wet) | Shad               | One composite of 10 fish        |
| Fish  | U-234                    | 1985    | CRM 12.0 | MMS, 1986         | 1                 | 5.1           | pCi/kg (wet) | Bluegill           | One composite of 10 fish        |
| Fish  | U-235                    | 1978    | CRM 12.0 | UCC, 1979         | 1                 | 0.48          | pCi/kg (wet) | Crappie            | One composite of 10 fish        |
| Fish  | U-235                    | 1979    | CRM 12.0 | UCC, 1980         | 1                 | 8.5           | pCi/kg (wet) | Shad               | One composite of 10 fish        |
| Fish  | U-235                    | 1980    | CRM 12.0 | UCC, 1981         | 1                 | 0.75          | pCi/kg (wet) | Shad               | One composite of 10 fish        |
| Fish  | U-235                    | 1981    | CRM 12.0 | UCC, 1982         | 1                 | 2.23          | pCi/kg (wet) | Bluegill           | One composite of 10 fish        |
| Fish  | U-235                    | 1982    | CRM 12.0 | UCC, 1983a        | 1                 | 0.024         | pCi/kg (wet) | Shad               | One composite of 10 fish        |
| Fish  | U-235                    | 1983    | CRM 12.0 | MMS, 1984         | 1                 | 0.14          | pCi/kg (wet) | Bluegill           | One composite of 10 fish        |
| Fish  | U-235                    | 1984    | CRM 12.0 | MMS, 1985         | 1                 | 2.5           | pCi/kg (wet) | Shad               | One composite of 10 fish        |
| Fish  | U-235                    | 1985    | CRM 12.0 | MMS, 1986         | 1                 | 0.49          | pCi/kg (wet) | Bluegill           | One composite of 10 fish        |
| Fish  | U-238                    | 1983    | CRM 12.0 | MMS, 1984         | 1                 | 2.2           | pCi/kg (wet) | Shad               | One composite of 10 fish        |
| Fish  | U-238                    | 1984    | CRM 12.0 | MMS, 1985         | 1                 | 30            | pCi/kg (wet) | Shad               | One composite of 10 fish        |
| Fish  | U-238                    | 1985    | CRM 12.0 | MMS, 1986         | 1                 | 2.8           | pCi/kg (wet) | Bluegill           | One composite of 10 fish        |

TABLE H-1: ENVIRONMENTAL SAMPLES AT OR DOWNSTREAM OF THE CONFLUENCE OF THE CLINCH RIVER AND POPLAR CREEK (K-25 SITE)

| Media    | Chemical or Radionuclide | Date    | Location       | Study                | Number of Samples | Maximum Value | Units       | Species (Fish) | Comments             |
|----------|--------------------------|---------|----------------|----------------------|-------------------|---------------|-------------|----------------|----------------------|
| Sediment | Arsenic                  | 1989-90 | CRM 0.0 - 12   | Cook et al., 1992    | 52                | 20.3          | mg/kg       | N/A            |                      |
| Sediment | Arsenic                  | 1984    | CRM 10         | TVA, 1985b           | 1                 | 5.1           | mg/kg (dry) | N/A            |                      |
| Sediment | Beryllium                | 1989-90 | CRM 0.0 - 12   | Cook et al., 1992    | 52                | 1.6           | mg/kg       | N/A            |                      |
| Sediment | Chromium                 | 1977    | CRM 11.0       | UCC, 1978            | 2                 | 87            | mg/kg (dry) | N/A            |                      |
| Sediment | Chromium                 | 1978    | CRM 11.0       | UCC, 1979            | 2                 | 57            | mg/kg (dry) | N/A            |                      |
| Sediment | Chromium                 | 1979    | CRM 11.0       | UCC, 1980            | 2                 | 244           | mg/kg (dry) | N/A            |                      |
| Sediment | Chromium                 | 1980    | CRM 11.0       | UCC, 1981            | 2                 | 14            | mg/kg (dry) | N/A            |                      |
| Sediment | Chromium                 | 1981    | CRM 11.0       | UCC, 1982            | 2                 | 108           | mg/kg (dry) | N/A            |                      |
| Sediment | Chromium                 | 1982    | CRM 11.0       | UCC, 1983a           | 2                 | 26            | mg/kg (dry) | N/A            |                      |
| Sediment | Chromium                 | 1983    | CRM 11.0       | MMEs, 1984           | 2                 | 9             | mg/kg (dry) | N/A            |                      |
| Sediment | Chromium                 | 1984    | CRM 10.0       | MMEs, 1985           | 1                 | 30            | mg/kg (dry) | N/A            |                      |
| Sediment | Chromium                 | 1985    | CRM 11.0       | MMEs, 1985           | 2                 | 30            | mg/kg (dry) | N/A            |                      |
| Sediment | Chromium                 | 1985    | CRM 11.0       | MMEs, 1986           | 3                 | 19            | mg/kg (dry) | N/A            |                      |
| Sediment | Chromium                 | 1989-90 | CRM 0.0 - 12   | Cook et al., 1992    | 52                | 47.7          | mg/kg (dry) | N/A            |                      |
| Sediment | Lead                     | 1977    | CRM 11.0       | UCC, 1978            | 2                 | 38            | mg/kg (dry) | N/A            |                      |
| Sediment | Lead                     | 1978    | CRM 11.0       | UCC, 1979            | 2                 | 35            | mg/kg (dry) | N/A            |                      |
| Sediment | Lead                     | 1979    | CRM 11.0       | UCC, 1980            | 2                 | 37            | mg/kg (dry) | N/A            |                      |
| Sediment | Lead                     | 1980    | CRM 11.0       | UCC, 1981            | 4                 | <12           | mg/kg (dry) | N/A            |                      |
| Sediment | Lead                     | 1981    | CRM 11.0       | UCC, 1982            | 2                 | 31            | mg/kg (dry) | N/A            |                      |
| Sediment | Lead                     | 1982    | CRM 11.0       | UCC, 1983a           | 2                 | 17            | mg/kg (dry) | N/A            |                      |
| Sediment | Lead                     | 1983    | CRM 11.0       | MMEs, 1984           | 2                 | 18            | mg/kg (dry) | N/A            |                      |
| Sediment | Lead                     | 1984    | CRM 10.0       | MMEs, 1985           | 1                 | 14            | mg/kg (dry) | N/A            |                      |
| Sediment | Lead                     | 1984    | CRM 11.0       | MMEs, 1985           | 2                 | 29            | mg/kg (dry) | N/A            |                      |
| Sediment | Lead                     | 1985    | CRM 11.0       | MMEs, 1986           | 3                 | 20            | mg/kg (dry) | N/A            |                      |
| Sediment | Lead                     | 1989-90 | CRM 0.0 - 12   | Cook et al., 1992    | 52                | 37.6          | mg/kg (dry) | N/A            |                      |
| Sediment | Nickel                   | 1977    | CRM 11.0       | UCC, 1978            | 2                 | 55            | mg/kg (dry) | N/A            |                      |
| Sediment | Nickel                   | 1978    | CRM 11.0       | UCC, 1979            | 2                 | 50            | mg/kg (dry) | N/A            |                      |
| Sediment | Nickel                   | 1979    | CRM 11.0       | UCC, 1980            | 2                 | 26            | mg/kg (dry) | N/A            |                      |
| Sediment | Nickel                   | 1980    | CRM 11.0       | UCC, 1981            | 2                 | 14            | mg/kg (dry) | N/A            |                      |
| Sediment | Nickel                   | 1981    | CRM 11.0       | UCC, 1982            | 2                 | 71            | mg/kg (dry) | N/A            |                      |
| Sediment | Nickel                   | 1982    | CRM 11.0       | UCC, 1983a           | 2                 | 23            | mg/kg (dry) | N/A            |                      |
| Sediment | Nickel                   | 1983    | CRM 11.0       | MMEs, 1984           | 2                 | 18            | mg/kg (dry) | N/A            |                      |
| Sediment | Nickel                   | 1984    | CRM 10.0       | TVA, 1985b           | 1                 | 14            | mg/kg (dry) | N/A            |                      |
| Sediment | Nickel                   | 1984    | CRM 11.0       | MMEs, 1985           | 2                 | 22            | mg/kg (dry) | N/A            |                      |
| Sediment | Nickel                   | 1985    | CRM 11.0       | MMEs, 1986           | 3                 | 28            | mg/kg (dry) | N/A            |                      |
| Sediment | Nickel                   | 1989-90 | CRM 0.0 - 12   | Cook et al., 1992    | 52                | 57.7          | mg/kg (dry) | N/A            |                      |
| Sediment | PCBs                     | 1979    | CRM 12         | Long, 1979           | 1                 | <0.1          | mg/kg (dry) | N/A            |                      |
| Sediment | PCBs                     | 7/12/84 | CRM 10.0       | TVA, 1985b           | 7                 | <0.1          | mg/kg (dry) | N/A            |                      |
| Sediment | Pu-238                   | 1977    | CRM 12         | Oakes et al., 1982   | 1                 | <0.0005       | pCi/g (dry) | N/A            | Top 3 inches of core |
| Sediment | Pu-238                   | 1977    | CRM 11.5       | Oakes et al., 1982   | 2                 | 0.03          | pCi/g (dry) | N/A            | Top 3 inches of core |
| Sediment | Pu-238                   | 1977    | CRM 11.0       | Oakes et al., 1982   | 4                 | 0.06          | pCi/g (dry) | N/A            | Top 3 inches of core |
| Sediment | Pu-238                   | 1984    | CRM 11.0       | MMEs, 1985           | 1                 | 0.0038        | pCi/g (dry) | N/A            |                      |
| Sediment | Pu-238                   | 1989-90 | CRM 0.0 - 12   | Cook et al., 1992    | 18                | 0.07          | pCi/g (dry) | N/A            |                      |
| Sediment | Pu-239                   | 1984    | CRM 11.0       | MMEs, 1985           | 1                 | 0.035         | pCi/g (dry) | N/A            |                      |
| Sediment | Pu-239                   | 1984    | CRM 10.0       | TVA, 1985b           | 2                 | 0.31          | pCi/g (dry) | N/A            |                      |
| Sediment | Pu-239,240               | 1977    | CRM 12         | Oakes et al., 1982   | 1                 | <0.0005       | pCi/g (dry) | N/A            | Top 3 inches of core |
| Sediment | Pu-239,240               | 1977    | CRM 11.5       | Oakes et al., 1982   | 2                 | 0.55          | pCi/g (dry) | N/A            | Top 3 inches of core |
| Sediment | Pu-239,240               | 1977    | CRM 11.0       | Oakes et al., 1982   | 4                 | 0.9           | pCi/g (dry) | N/A            | Top 3 inches of core |
| Sediment | Pu-239,240               | 1989-90 | CRM 0.0 - 12   | Cook et al., 1992    | 18                | 1.57          | pCi/g (dry) | N/A            |                      |
| Soil     | Tc-99                    | 1979    | K-25 Perimeter | Hoffman et al., 1980 | 9                 | 1.7           | pCi/g (dry) | N/A            |                      |
| Sediment | U-234                    | 1983    | CRM 12.0       | MMEs, 1984           | NA                | 3             | pCi/g (dry) | N/A            |                      |
| Sediment | U-234                    | 1984    | CRM 11.0       | MMEs, 1985           | 1                 | 3             | pCi/g (dry) | N/A            |                      |
| Sediment | U-234                    | 1989-90 | CRM 0 to 12    | Cook et al., 1992    | 18                | 5.47          | pCi/g (dry) | N/A            |                      |

TABLE H-1: ENVIRONMENTAL SAMPLES AT OR DOWNSTREAM OF THE CONFLUENCE OF THE CLINCH RIVER AND POPLAR CREEK (K-25 SITE)

| Media    | Chemical or Radionuclide | Date    | Location     | Study             | Number of Samples | Maximum Value | Units       | Species (Fish) | Comments |
|----------|--------------------------|---------|--------------|-------------------|-------------------|---------------|-------------|----------------|----------|
| Sediment | U-238                    | 1989-90 | CRM 0 to 12  | Cook et al., 1992 | 18                | 0.69          | pCi/g (dry) | N/A            |          |
| Sediment | U-235                    | 1989-90 | CRM 0 to 12  | Cook et al., 1992 | 18                | 4.03          | pCi/g (dry) | N/A            |          |
| Sediment | Uranium                  | 1977    | CRM 11.0     | UCC, 1978         | 2                 | 1.4           | mg/kg (dry) | N/A            |          |
| Sediment | Uranium                  | 1978    | CRM 11.0     | UCC, 1979         | 2                 | 8             | mg/kg (dry) | N/A            |          |
| Sediment | Uranium                  | 1979    | CRM 11.0     | UCC, 1980         | 2                 | 1             | mg/kg (dry) | N/A            |          |
| Sediment | Uranium                  | 1980    | CRM 11.0     | UCC, 1981         | 2                 | 1             | mg/kg (dry) | N/A            |          |
| Sediment | Uranium                  | 1981    | CRM 11.0     | UCC, 1982         | 2                 | 11            | mg/kg (dry) | N/A            |          |
| Sediment | Uranium                  | 1982    | CRM 11.0     | UCC, 1983a        | 2                 | 1             | mg/kg (dry) | N/A            |          |
| Sediment | Uranium                  | 1983    | CRM 11.0     | MMES, 1984        | 2                 | 1             | mg/kg (dry) | N/A            |          |
| Sediment | Uranium                  | 1984    | CRM 11.0     | MMES, 1985        | 2                 | 1             | mg/kg (dry) | N/A            |          |
| Sediment | Uranium                  | 1985    | CRM 11.0     | MMES, 1986        | 6                 | 2.1           | mg/kg (dry) | N/A            |          |
| Sediment | Uranium                  | 7/12/84 | CRM 10.0     | TVA, 1985b        | 2                 | 2.2           | mg/kg (dry) | N/A            |          |
|          |                          |         |              |                   |                   |               |             |                |          |
| Water    | Arsenic                  | 1977-78 | CRM 11.6     | Loar et al., 1981 | NA                | 0.02          | mg/L        | N/A            |          |
| Water    | Beryllium                | 1984    | CRM 6.8      | TVA, 1985a        | 1                 | <0.001        | mg/L        | N/A            |          |
| Water    | Beryllium                | 1989-90 | CRM 0.0 - 12 | Cook et al., 1992 | 2                 | <0.0039       | mg/L        | N/A            |          |
| Water    | Chromium                 | 1971    | CRM 11.0     | UCC, 1972         | 2                 | <0.004        | mg/L        | N/A            |          |
| Water    | Chromium                 | 1972    | CRM 11.0     | UCC, 1973         | 12                | 0.06          | mg/L        | N/A            |          |
| Water    | Chromium                 | 1973    | CRM 11.0     | UCC, 1974         | 11                | 0.05          | mg/L        | N/A            |          |
| Water    | Chromium                 | 1974    | CRM 11.0     | UCC, 1975         | 12                | 0.02          | mg/L        | N/A            |          |
| Water    | Chromium                 | 1975    | CRM 11.0     | UCC, 1976         | 12                | 0.2           | mg/L        | N/A            |          |
| Water    | Chromium                 | 1976    | CRM 11.0     | UCC, 1977         | 12                | 0.05          | mg/L        | N/A            |          |
| Water    | Chromium                 | 1977    | CRM 11.0     | UCC, 1978         | 12                | 0.02          | mg/L        | N/A            |          |
| Water    | Chromium                 | 1978    | CRM 11.0     | UCC, 1979         | 12                | 0.01          | mg/L        | N/A            |          |
| Water    | Chromium                 | 1979    | CRM 11.0     | UCC, 1980         | 12                | 0.02          | mg/L        | N/A            |          |
| Water    | Chromium                 | 1980    | CRM 11.0     | UCC, 1981         | 12                | 0.03          | mg/L        | N/A            |          |
| Water    | Chromium                 | 1981    | CRM 11.0     | UCC, 1982         | 12                | <0.01         | mg/L        | N/A            |          |
| Water    | Chromium                 | 1982    | CRM 11.0     | UCC, 1983a        | 12                | 0.03          | mg/L        | N/A            |          |
| Water    | Chromium                 | 1983    | CRM 11.0     | MMES, 1984        | 12                | 0.03          | mg/L        | N/A            |          |
| Water    | Chromium                 | 1984    | CRM 6.8      | TVA, 1985a        | 1                 | <0.001        | mg/L        | N/A            |          |
| Water    | Chromium                 | 1984    | CRM 11.0     | MMES, 1985        | 12                | <0.01         | mg/L        | N/A            |          |
| Water    | Chromium                 | 1985    | CRM 11.0     | MMES, 1986        | 11                | 0.02          | mg/L        | N/A            |          |
| Water    | Chromium                 | 1985    | CRM 11.0     | UCC, 1974         | 12                | <0.02         | mg/L        | N/A            |          |
| Water    | Lead                     | 1973    | CRM 11.0     | UCC, 1975         | 12                | 0.03          | mg/L        | N/A            |          |
| Water    | Lead                     | 1974    | CRM 11.0     | UCC, 1976         | 12                | 0.25          | mg/L        | N/A            |          |
| Water    | Lead                     | 1975    | CRM 11.0     | UCC, 1977         | 12                | 0.02          | mg/L        | N/A            |          |
| Water    | Lead                     | 1976    | CRM 11.0     | UCC, 1978         | 12                | 0.02          | mg/L        | N/A            |          |
| Water    | Lead                     | 1977    | CRM 11.0     | UCC, 1979         | 12                | <0.01         | mg/L        | N/A            |          |
| Water    | Lead                     | 1978    | CRM 11.0     | UCC, 1980         | 12                | <0.01         | mg/L        | N/A            |          |
| Water    | Lead                     | 1979    | CRM 11.0     | UCC, 1981         | 12                | <0.01         | mg/L        | N/A            |          |
| Water    | Lead                     | 1980    | CRM 11.0     | UCC, 1982         | 12                | <0.01         | mg/L        | N/A            |          |
| Water    | Lead                     | 1981    | CRM 11.0     | UCC, 1983a        | 12                | 0.02          | mg/L        | N/A            |          |
| Water    | Lead                     | 1982    | CRM 11.0     | MMES, 1984        | 12                | <0.01         | mg/L        | N/A            |          |
| Water    | Lead                     | 1983    | CRM 11.0     | MMES, 1985        | 1                 | <0.001        | mg/L        | N/A            |          |
| Water    | Lead                     | 1984    | CRM 6.8      | TVA, 1985a        | 1                 | 0.006         | mg/L        | N/A            |          |
| Water    | Lead                     | 1984    | CRM 11.0     | MMES, 1986        | 12                | 0.01          | mg/L        | N/A            |          |
| Water    | Lead                     | 1985    | CRM 11.0     | MMES, 1986        | 11                | 0.01          | mg/L        | N/A            |          |
| Water    | Lead                     | 1989-90 | CRM 0.0 - 12 | Cook et al., 1992 | 3                 | <0.0015       | mg/L        | N/A            |          |
| Water    | Nickel                   | 1975    | CRM 11.0     | UCC, 1978         | 12                | 0.1           | mg/L        | N/A            |          |
| Water    | Nickel                   | 1976    | CRM 11.0     | UCC, 1977         | 12                | 0.05          | mg/L        | N/A            |          |
| Water    | Nickel                   | 1977    | CRM 11.0     | UCC, 1978         | 12                | 0.03          | mg/L        | N/A            |          |
| Water    | Nickel                   | 1978    | CRM 11.0     | UCC, 1979         | 12                | 0.01          | mg/L        | N/A            |          |
| Water    | Nickel                   | 1979    | CRM 11.0     | UCC, 1980         | 12                | 0.03          | mg/L        | N/A            |          |
| Water    | Nickel                   | 1980    | CRM 11.0     | UCC, 1981         | 12                | 0.2           | mg/L        | N/A            |          |

TABLE H-1: ENVIRONMENTAL SAMPLES AT OR DOWNSTREAM OF THE CONFLUENCE OF THE CLINCH RIVER AND POPLAR CREEK (K-25 SITE)

| Media | Chemical or Radionuclide | Date    | Location | Study             | Number of Samples | Maximum Value | Units | Species (Fish) | Comments |
|-------|--------------------------|---------|----------|-------------------|-------------------|---------------|-------|----------------|----------|
| Water | Nickel                   | 1981    | CRM 11.0 | UCC, 1982         | 12                | <0.01         | mg/L  | N/A            |          |
| Water | Nickel                   | 1982    | CRM 11.0 | UCC, 1983a        | 12                | 0.02          | mg/L  | N/A            |          |
| Water | Nickel                   | 1983    | CRM 11.0 | MMES, 1984        | 12                | 0.031         | mg/L  | N/A            |          |
| Water | Nickel                   | 1984    | CRM 6.8  | TVA, 1985a        | 1                 | 0.021         | mg/L  | N/A            |          |
| Water | Nickel                   | 1984    | CRM 11.0 | MMES, 1985        | 12                | 0.15          | mg/L  | N/A            |          |
| Water | Nickel                   | 1985    | CRM 11.0 | MMES, 1986        | 11                | 0.06          | mg/L  | N/A            |          |
| Water | PCBs                     | 1989-90 | CRM 9.5  | Cook et al., 1992 | 7                 | <0.001        | mg/L  | N/A            |          |
| Water | Tc-99                    | 5/30/84 | CRM 6.8  | TVA, 1985a        | 1                 | 0.73          | pCi/L | N/A            | Baseflow |
| Water | Uranium                  | 1971    | CRM 12   | UCC, 1972         | 4                 | 6             | pCi/L | N/A            |          |
| Water | Uranium                  | 1972    | CRM 12   | UCC, 1973         | 12                | 5             | pCi/L | N/A            |          |
| Water | Uranium                  | 1973    | CRM 12   | UCC, 1974         | 12                | 5             | pCi/L | N/A            |          |
| Water | Uranium                  | 1974    | CRM 12   | UCC, 1975         | 11                | 7             | pCi/L | N/A            |          |
| Water | Uranium                  | 1975    | CRM 12   | UCC, 1976         | 12                | 14            | pCi/L | N/A            |          |
| Water | Uranium                  | 1976    | CRM 12   | UCC, 1977         | 12                | 17            | pCi/L | N/A            |          |
| Water | Uranium                  | 1977    | CRM 12   | UCC, 1978         | 12                | 7             | pCi/L | N/A            |          |
| Water | Uranium                  | 1978    | CRM 12   | UCC, 1979         | 12                | 21            | pCi/L | N/A            |          |
| Water | Uranium                  | 1979    | CRM 12   | UCC, 1980         | 12                | 8             | pCi/L | N/A            |          |
| Water | Uranium                  | 1980    | CRM 12   | UCC, 1981         | 12                | 5             | pCi/L | N/A            |          |
| Water | Uranium                  | 1981    | CRM 12   | UCC, 1982         | 12                | 4             | pCi/L | N/A            |          |
| Water | Uranium                  | 1982    | CRM 12   | UCC, 1983a        | 12                | 4             | pCi/L | N/A            |          |
| Water | Uranium                  | 1983    | CRM 12   | MMES, 1984        | 12                | 8.1           | pCi/L | N/A            |          |
| Water | Uranium                  | 1984    | CRM 12   | MMES, 1985        | 12                | 7.4           | pCi/L | N/A            |          |
| Water | Uranium                  | 1985    | CRM 12   | MMES, 1986        | 12                | 8.1           | pCi/L | N/A            |          |

NA = Information not available  
 N/A = Not applicable

TABLE H-2: ENVIRONMENTAL SAMPLES AT OR DOWNSTREAM OF THE CONFLUENCE OF THE CLINCH RIVER AND WHITE OAK CREEK (X-10 SITE)

| Media | Chemical or Radionuclide | Date    | Location     | Study             | Number of Samples | Maximum Value | Units          | Species (Fish) | Comments                             |
|-------|--------------------------|---------|--------------|-------------------|-------------------|---------------|----------------|----------------|--------------------------------------|
| Fish  | Co-60                    | 1960-62 | Clinch River | Morton, 1965      | 22                | 120           | pCi/kg (wet)   | carpsucker     | Concentration represents annual avg. |
| Fish  | Co-60                    | 1975    | CRM 14.5     | UCC, 1976         | 1                 | 45            | pCi/kg (wet)   | NA             | One composite of 10 fish             |
| Fish  | Co-60                    | 1976    | CRM 20       | UCC, 1977         | 1                 | 67.4          | pCi/kg (wet)   | NA             | One composite of 10 fish             |
| Fish  | Co-60                    | 1977    | CRM 20.8     | UCC, 1978         | 1                 | <217          | pCi/kg (wet)   | NA             | One composite of 10 fish             |
| Fish  | Co-60                    | 1978    | CRM 20.8     | UCC, 1979         | 4                 | 79.2          | pCi/kg (wet)   | blue gill      | Avg of quarterly composites of 10    |
| Fish  | Co-60                    | 1979    | CRM 20.8     | UCC, 1980         | 4                 | 92            | pCi/kg (wet)   | blue gill      | Avg of quarterly composites of 10    |
| Fish  | Co-60                    | 1980    | CRM 20.8     | UCC, 1981         | 4                 | 59            | pCi/kg (wet)   | blue gill      | Avg of quarterly composites of 10    |
| Fish  | Co-60                    | 1981    | CRM 20.8     | UCC, 1982         | 4                 | 140           | pCi/kg (wet)   | blue gill      | Avg of quarterly composites of 10    |
| Fish  | Co-60                    | 1982    | CRM 20.8     | UCC, 1983a        | 4                 | 41            | pCi/kg (wet)   | shad           | Avg of quarterly composites of 10    |
| Fish  | Co-60                    | 1983    | CRM 20.8     | MMES, 1984        | 4                 | 110           | pCi/kg (wet)   | blue gill      | Avg of quarterly composites of 10    |
| Fish  | Co-60                    | 1984    | CRM 20.8     | MMES, 1985        | 4                 | 24            | pCi/kg (wet)   | catfish        | Avg of quarterly composites of 10    |
| Fish  | Co-60                    | 1985    | CRM 20.8     | MMES, 1986        | NA                | 14            | pCi/kg (wet)   | bluegill       | All samples were composites          |
| Fish  | Co-60                    | 1988    | CRM 20.8     | MMES, 1987        | 6                 | 0.24          | pCi/g (ash wt) | bluegill       | All samples were composites          |
| Fish  | Co-60                    | 1989-90 | CRM 20.8     | Cook et al., 1992 | 21                | <700          | pCi/kg (wet)   | NA             |                                      |
| Fish  | Co-60                    | 1989-90 | CRM 14.7     | Cook et al., 1992 | 6                 | <430          | pCi/kg (wet)   | NA             |                                      |
| Fish  | Cs-137                   | 1960-62 | Clinch River | Morton, 1965      | 122               | 1200          | pCi/kg (wet)   | carpsucker     | Concentration represents annual avg. |
| Fish  | Cs-137                   | 1965    | Clinch River | UCC, 1966         | NA                | 199           | pCi/kg (wet)   | NA             |                                      |
| Fish  | Cs-137                   | 1966    | Clinch River | UCC, 1967         | NA                | 1453          | pCi/kg (wet)   | NA             |                                      |
| Fish  | Cs-137                   | 1967    | Clinch River | UCC, 1968         | NA                | 402           | pCi/kg (wet)   | NA             |                                      |
| Fish  | Cs-137                   | 1968    | Clinch River | UCC, 1969         | NA                | 559           | pCi/kg (wet)   | NA             |                                      |
| Fish  | Cs-137                   | 1971    | Clinch River | UCC, 1972         | 1                 | 343           | pCi/kg (wet)   | NA             |                                      |
| Fish  | Cs-137                   | 1972    | Clinch River | UCC, 1973         | 1                 | 185           | pCi/kg (wet)   | NA             | One composite of 10 fish             |
| Fish  | Cs-137                   | 1973    | Clinch River | UCC, 1974         | 1                 | 1500          | pCi/kg (wet)   | NA             | One composite of 10 fish             |
| Fish  | Cs-137                   | 1974    | Clinch River | UCC, 1975         | 1                 | 187           | pCi/kg (wet)   | NA             | One composite of 10 fish             |
| Fish  | Cs-137                   | 1975    | CRM 14.5     | UCC, 1976         | 1                 | 30            | pCi/kg (wet)   | NA             | One composite of 10 fish             |
| Fish  | Cs-137                   | 1976    | CRM 20       | UCC, 1977         | 1                 | 3417          | pCi/kg (wet)   | NA             | One composite of 10 fish             |
| Fish  | Cs-137                   | 1977    | CRM 20.8     | UCC, 1978         | 1                 | 5397          | pCi/kg (wet)   | NA             | One composite of 10 fish             |
| Fish  | Cs-137                   | 1978    | CRM 20.8     | UCC, 1979         | 4                 | 10287         | pCi/kg (wet)   | blue gill      | Avg of quarterly composites of 10    |
| Fish  | Cs-137                   | 1979    | CRM 20.8     | UCC, 1980         | 4                 | 3955          | pCi/kg (wet)   | blue gill      | Avg of quarterly composites of 10    |
| Fish  | Cs-137                   | 1980    | CRM 20.8     | UCC, 1981         | 4                 | 1289          | pCi/kg (wet)   | blue gill      | Avg of quarterly composites of 10    |
| Fish  | Cs-137                   | 1981    | CRM 20.8     | UCC, 1982         | 4                 | 1371          | pCi/kg (wet)   | blue gill      | Avg of quarterly composites of 10    |
| Fish  | Cs-137                   | 1982    | CRM 20.8     | UCC, 1983a        | 4                 | 1100          | pCi/kg (wet)   | blue gill      | Avg of quarterly composites of 10    |
| Fish  | Cs-137                   | 1983    | CRM 20.8     | MMES, 1984        | 4                 | 2100          | pCi/kg (wet)   | shad           | Avg of quarterly composites of 10    |
| Fish  | Cs-137                   | 1984    | CRM 20.8     | MMES, 1985        | 4                 | 1300          | pCi/kg (wet)   | blue gill      | Avg of quarterly composites of 10    |
| Fish  | Cs-137                   | 1985    | CRM 20.8     | MMES, 1986        | NA                | 1200          | pCi/kg (wet)   | blue gill      | All samples were composites          |
| Fish  | Cs-137                   | 1988    | CRM 20.8     | MMES, 1989        | 6                 | 18            | pCi/g (ash wt) | bluegill       | All samples were composites          |
| Fish  | Cs-137                   | 1989-90 | CRM 20.6     | Cook et al., 1992 | 21                | 2310          | pCi/kg (wet)   | NA             |                                      |
| Fish  | Cs-137                   | 1989-90 | CRM 14.7     | Cook et al., 1992 | 6                 | <320          | pCi/kg (wet)   | NA             |                                      |
| Fish  | Pu-238                   | 1978    | CRM 20.8     | UCC, 1979         | 4                 | 0.01          | pCi/kg (wet)   | Bluegill       | Composites of 10 samples each        |
| Fish  | Pu-238                   | 1979    | CRM 20.8     | UCC, 1980         | 5                 | 0.88          | pCi/kg (wet)   | Bluegill       | Composites of 10 samples each        |
| Fish  | Pu-238                   | 1980    | CRM 20.8     | UCC, 1981         | 5                 | 0.12          | pCi/kg (wet)   | Bluegill       | Composites of 10 samples each        |
| Fish  | Pu-238                   | 1981    | CRM 20.8     | UCC, 1982         | 5                 | 0.073         | pCi/kg (wet)   | Shad           | Composites of 10 samples each        |
| Fish  | Pu-238                   | 1982    | CRM 20.8     | UCC, 1983a        | 5                 | 0.17          | pCi/kg (wet)   | Shad           | Composites of 10 samples each        |
| Fish  | Pu-238                   | 1983    | CRM 20.8     | MMES, 1984        | 4                 | <0.13         | pCi/kg (wet)   | Shad           | Composites of 10 samples each        |
| Fish  | Pu-238                   | 1984    | CRM 20.8     | MMES, 1985        | 6                 | 0.41          | pCi/kg (wet)   | Catfish        | Composites of 10 samples each        |
| Fish  | Pu-238                   | 1985    | CRM 20.8     | MMES, 1986        | 6                 | 0.012         | pCi/kg (wet)   | Catfish        | Composites of 10 samples each        |
| Fish  | Pu-239                   | 1976    | CRM 20       | UCC, 1977         | 3                 | 0.27          | pCi/kg (wet)   | Bluegill       | Composites of 10 samples each        |
| Fish  | Pu-239                   | 1977    | CRM 20       | UCC, 1978         | 3                 | 0.086         | pCi/kg (wet)   | Shad           | Composites of 10 samples each        |
| Fish  | Pu-239                   | 1978    | CRM 20.8     | UCC, 1979         | 5                 | 0.02          | pCi/kg (wet)   | Bluegill       | Composites of 10 samples each        |
| Fish  | Pu-239                   | 1979    | CRM 20.8     | UCC, 1980         | 4                 | 0.88          | pCi/kg (wet)   | Bluegill       | Composites of 10 samples each        |
| Fish  | Pu-239                   | 1980    | CRM 20.8     | UCC, 1981         | 5                 | 0.17          | pCi/kg (wet)   | Shad           | Composites of 10 samples each        |
| Fish  | Pu-239                   | 1981    | CRM 20.8     | UCC, 1982         | 5                 | 0.17          | pCi/kg (wet)   | Shad           | Composites of 10 samples each        |
| Fish  | Pu-239                   | 1982    | CRM 20.8     | UCC, 1983a        | 5                 | 0.57          | pCi/kg (wet)   | Shad           | Composites of 10 samples each        |

TABLE H-2: ENVIRONMENTAL SAMPLES AT OR DOWNSTREAM OF THE CONFLUENCE OF THE CLINCH RIVER AND WHITE OAK CREEK (X-10 SITE)

| Media | Chemical or Radionuclide | Date    | Location     | Study             | Number of Samples | Maximum Value | Units           | Species (Fish) | Comments                             |
|-------|--------------------------|---------|--------------|-------------------|-------------------|---------------|-----------------|----------------|--------------------------------------|
| Fish  | Pu-239                   | 1983    | CRM 20.8     | MMES, 1984        | 3                 | <0.21         | pCi/kg (wet)    | Bass           | Composites of 10 samples each        |
| Fish  | Pu-239                   | 1984    | CRM 20.8     | MMES, 1985        | 6                 | 0.13          | pCi/kg (wet)    | Catfish        | Composites of 10 samples each        |
| Fish  | Pu-239                   | 1985    | CRM 20.8     | MMES, 1986        | 6                 | 0.069         | pCi/kg (wet)    | Carp           | Composites of 10 samples each        |
| Fish  | Ru-106                   | 1960-62 | Clinch River | Morton, 1965      | 69                | 170           | pCi/kg (wet)    | Carp           | Concentration represents annual avg. |
| Fish  | Ru-106                   | 1965    | Clinch River | UCC, 1966         | NA                | 6487          | pCi/kg (wet)    | NA             |                                      |
| Fish  | Ru-106                   | 1966    | Clinch River | UCC, 1967         | NA                | 513           | pCi/kg (wet)    | NA             |                                      |
| Fish  | Ru-106                   | 1967    | Clinch River | UCC, 1968         | NA                | 122           | pCi/kg (wet)    | NA             |                                      |
| Fish  | Ru-106                   | 1968    | Clinch River | UCC, 1969         | NA                | ND            | pCi/kg (wet)    | NA             |                                      |
| Fish  | Ru-106                   | 1971    | Clinch River | UCC, 1972         | 1                 | <315          | pCi/kg (wet)    | NA             | One composite of 10 fish             |
| Fish  | Ru-106                   | 1975    | CRM 14.5     | UCC, 1976         | 1                 | 230           | pCi/kg (wet)    | NA             | One composite of 10 fish             |
| Fish  | Ru-106                   | 1976    | CRM 20       | UCC, 1977         | 1                 | 302           | pCi/kg (wet)    | NA             | One composite of 10 fish             |
| Fish  | Sr-90                    | 1960-62 | Clinch River | Morton, 1965      | 18                | 540           | pCi/kg (wet)    | carpsucker     | Concentration represents annual avg. |
| Fish  | Sr-90                    | 1965    | Clinch River | UCC, 1966         | NA                | 32            | pCi/kg (wet)    | NA             |                                      |
| Fish  | Sr-90                    | 1966    | Clinch River | UCC, 1967         | NA                | 2028          | pCi/kg (wet)    | NA             |                                      |
| Fish  | Sr-90                    | 1967    | Clinch River | UCC, 1968         | NA                | 118           | pCi/kg (wet)    | NA             |                                      |
| Fish  | Sr-90                    | 1968    | Clinch River | UCC, 1969         | NA                | 473           | pCi/kg (wet)    | NA             |                                      |
| Fish  | Sr-90                    | 1971    | Clinch River | UCC, 1972         | 1                 | 135           | pCi/kg (wet)    | NA             | One composite of 10 fish             |
| Fish  | Sr-90                    | 1972    | Clinch River | UCC, 1973         | 1                 | 62            | pCi/kg (wet)    | NA             | One composite of 10 fish             |
| Fish  | Sr-90                    | 1973    | Clinch River | UCC, 1974         | 1                 | 140           | pCi/kg (wet)    | NA             | One composite of 10 fish             |
| Fish  | Sr-90                    | 1974    | Clinch River | UCC, 1975         | 1                 | 52            | pCi/kg (wet)    | NA             | One composite of 10 fish             |
| Fish  | Sr-90                    | 1975    | CRM 14.5     | UCC, 1976         | 1                 | 220           | pCi/kg (wet)    | NA             | One composite of 10 fish             |
| Fish  | Sr-90                    | 1976    | CRM 20       | UCC, 1977         | 1                 | 1100          | pCi/kg (wet)    | NA             | One composite of 10 fish             |
| Fish  | Sr-90                    | 1977    | CRM 20.8     | UCC, 1978         | 1                 | 815           | pCi/kg (wet)    | NA             | One composite of 10 fish             |
| Fish  | Sr-90                    | 1978    | CRM 20.8     | UCC, 1979         | 4                 | 128           | pCi/kg (wet)    | blue gill      | avg of quarterly composites of 10    |
| Fish  | Sr-90                    | 1979    | CRM 20.8     | UCC, 1980         | 4                 | 255           | pCi/kg (wet)    | blue gill      | avg of quarterly composites of 10    |
| Fish  | Sr-90                    | 1980    | CRM 20.8     | UCC, 1981         | 4                 | 391           | pCi/kg (wet)    | blue gill      | avg of quarterly composites of 10    |
| Fish  | Sr-90                    | 1981    | CRM 20.8     | UCC, 1982         | 4                 | 172.5         | pCi/kg (wet)    | blue gill      | avg of quarterly composites of 10    |
| Fish  | Sr-90                    | 1982    | CRM 20.8     | UCC, 1983a        | 4                 | 69            | pCi/kg (wet)    | blue gill      | avg of quarterly composites of 10    |
| Fish  | Sr-90                    | 1983    | CRM 20.8     | MMES, 1984        | 4                 | 160           | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | Sr-90                    | 1984    | CRM 20.8     | MMES, 1985        | 4                 | 96            | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | Sr-90                    | 1985    | CRM 20.8     | MMES, 1986        | 4                 | 120           | pCi/kg (wet)    | bluegill       | avg of quarterly composites of 10    |
| Fish  | Sr-90                    | 1989-90 | CRM 14.7     | Cook et al., 1992 | 6                 | 700           | pCi/kg (wet)    | NA             |                                      |
| Fish  | Total Sr                 | 1988    | CRM 20.8     | MMES, 1989        | 6                 | 1.2           | pCi/g (fish wt) | bluegill       | Composites                           |
| Fish  | U-234                    | 1978    | CRM 20.8     | UCC, 1979         | 4                 | 5.06          | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-234                    | 1979    | CRM 20.8     | UCC, 1980         | 4                 | 3.3           | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-234                    | 1980    | CRM 20.8     | UCC, 1981         | 4                 | 3.7           | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-234                    | 1981    | CRM 20.8     | UCC, 1982         | 4                 | 5.92          | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-234                    | 1982    | CRM 20.8     | UCC, 1983a        | 4                 | 5.5           | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-234                    | 1983    | CRM 20.8     | MMES, 1984        | 4                 | 3.5           | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-234                    | 1984    | CRM 20.8     | MMES, 1985        | 4                 | 4.5           | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-234                    | 1985    | CRM 20.8     | MMES, 1986        | 4                 | 2.7           | pCi/kg (wet)    | bluegill       | avg of quarterly composites of 10    |
| Fish  | U-235                    | 1978    | CRM 20.8     | UCC, 1979         | 4                 | 0.23          | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-235                    | 1979    | CRM 20.8     | UCC, 1980         | 4                 | 0.27          | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-235                    | 1980    | CRM 20.8     | UCC, 1981         | 4                 | 0.44          | pCi/kg (wet)    | blue gill      | avg of quarterly composites of 10    |
| Fish  | U-235                    | 1981    | CRM 20.8     | UCC, 1982         | 4                 | 0.5           | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-235                    | 1982    | CRM 20.8     | UCC, 1983a        | 4                 | 0.58          | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-235                    | 1983    | CRM 20.8     | MMES, 1984        | 4                 | 0.098         | pCi/kg (wet)    | carp           | avg of quarterly composites of 10    |
| Fish  | U-235                    | 1984    | CRM 20.8     | MMES, 1985        | 4                 | 0.89          | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-235                    | 1985    | CRM 20.8     | MMES, 1986        | 4                 | 0.35          | pCi/kg (wet)    | bluegill       | avg of quarterly composites of 10    |
| Fish  | U-238                    | 1978    | CRM 20.8     | UCC, 1979         | 4                 | 3.33          | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-238                    | 1979    | CRM 20.8     | UCC, 1980         | 4                 | 2.1           | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-238                    | 1980    | CRM 20.8     | UCC, 1981         | 4                 | 2.4           | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |
| Fish  | U-238                    | 1981    | CRM 20.8     | UCC, 1982         | 4                 | 3.72          | pCi/kg (wet)    | shad           | avg of quarterly composites of 10    |

TABLE H-2: ENVIRONMENTAL SAMPLES AT OR DOWNSTREAM OF THE CONFLUENCE OF THE CLINCH RIVER AND WHITE OAK CREEK (X-10 SITE)

| Media    | Chemical or Radionuclide | Date | Location | Study          | Number of Samples | Maximum Value | Units        | Species (Fish) | Comments                          |
|----------|--------------------------|------|----------|----------------|-------------------|---------------|--------------|----------------|-----------------------------------|
| Fish     | U-238                    | 1982 | CRM 20.8 | UCC, 1983a     | 4                 | 3.5           | pCi/kg (wet) | shad           | avg of quarterly composites of 10 |
| Fish     | U-238                    | 1983 | CRM 20.8 | MMES, 1984     | 4                 | 2.2           | pCi/kg (wet) | shad           | avg of quarterly composites of 10 |
| Fish     | U-238                    | 1984 | CRM 20.8 | MMES, 1985     | 4                 | 3.5           | pCi/kg (wet) | catfish        | avg of quarterly composites of 10 |
| Fish     | U-238                    | 1985 | CRM 20.8 | MMES, 1986     | NA                | 1.1           | pCi/kg (wet) | bluegill       |                                   |
| Fish     | Zr-Nb-95                 | 1976 | CRM 20   | UCC, 1977      | 1                 | 112           | pCi/kg (wet) | NA             | One composite of 10 fish          |
| Sediment | Ce-144                   | 1954 | CRM 19.1 | Cottrell, 1960 | 1                 | 5             | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1954 | CRM 16.3 | Cottrell, 1960 | 1                 | 8             | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1954 | CRM 15.2 | Cottrell, 1960 | 1                 | 7             | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1954 | CRM 14.0 | Cottrell, 1960 | 1                 | 8             | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1955 | CRM 19.1 | Cottrell, 1960 | 1                 | 6             | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1955 | CRM 16.3 | Cottrell, 1960 | 1                 | 21            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1955 | CRM 15.2 | Cottrell, 1960 | 1                 | 32            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1955 | CRM 14.0 | Cottrell, 1960 | 1                 | 22            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1956 | CRM 19.1 | Cottrell, 1960 | 1                 | 24            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1956 | CRM 16.3 | Cottrell, 1960 | 1                 | 37            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1956 | CRM 15.2 | Cottrell, 1960 | 1                 | 58            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1956 | CRM 14.0 | Cottrell, 1960 | 1                 | 20            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1957 | CRM 19.1 | Cottrell, 1960 | 1                 | 33            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1957 | CRM 16.3 | Cottrell, 1960 | 1                 | 12            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1957 | CRM 15.2 | Cottrell, 1960 | 1                 | 9             | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1957 | CRM 14.0 | Cottrell, 1960 | 1                 | 7             | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1958 | CRM 19.1 | Cottrell, 1960 | 1                 | 7             | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1958 | CRM 16.3 | Cottrell, 1960 | 1                 | 20            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1958 | CRM 15.2 | Cottrell, 1960 | 1                 | 22            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1958 | CRM 14.0 | Cottrell, 1960 | 1                 | 43            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1961 | CRM 20.7 | UCC, 1962      | NA                | 3.6           | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1962 | CRM 19.1 | UCC, 1963      | NA                | 3.8           | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1963 | CRM 19.1 | UCC, 1964      | NA                | 0.9           | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1964 | CRM 19.1 | UCC, 1965      | NA                | 6.6           | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1965 | CRM 16.3 | UCC, 1966      | NA                | 2.6           | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1966 | CRM 16.3 | UCC, 1967      | NA                | 1.2           | pCi/g (dry)  | N/A            |                                   |
| Sediment | Ce-144                   | 1967 | CRM 20.7 | UCC, 1968      | NA                | 12            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1954 | CRM 19.1 | Cottrell, 1960 | 1                 | 11            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1954 | CRM 16.3 | Cottrell, 1960 | 1                 | 19            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1954 | CRM 15.2 | Cottrell, 1960 | 1                 | 19            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1954 | CRM 14.0 | Cottrell, 1960 | 1                 | 19            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1955 | CRM 19.1 | Cottrell, 1960 | 1                 | 18            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1955 | CRM 16.3 | Cottrell, 1960 | 1                 | 23            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1955 | CRM 15.2 | Cottrell, 1960 | 1                 | 26            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1955 | CRM 14.0 | Cottrell, 1960 | 1                 | 39            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1956 | CRM 19.1 | Cottrell, 1960 | 1                 | 59            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1956 | CRM 16.3 | Cottrell, 1960 | 1                 | 29            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1956 | CRM 15.2 | Cottrell, 1960 | 1                 | 30            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1956 | CRM 14.0 | Cottrell, 1960 | 1                 | 15            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1957 | CRM 19.1 | Cottrell, 1960 | 1                 | 14            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1957 | CRM 16.3 | Cottrell, 1960 | 1                 | 17            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1957 | CRM 15.2 | Cottrell, 1960 | 1                 | 4             | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1957 | CRM 14.0 | Cottrell, 1960 | 1                 | 21            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1958 | CRM 19.1 | Cottrell, 1960 | 1                 | 9             | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1958 | CRM 16.3 | Cottrell, 1960 | 1                 | 16            | pCi/g (dry)  | N/A            |                                   |
| Sediment | Co-60                    | 1958 | CRM 15.2 | Cottrell, 1960 | 1                 |               |              |                |                                   |
| Sediment | Co-60                    | 1958 | CRM 14.0 | Cottrell, 1960 | 1                 |               |              |                |                                   |

TABLE H-2: ENVIRONMENTAL SAMPLES AT OR DOWNSTREAM OF THE CONFLUENCE OF THE CLINCH RIVER AND WHITE OAK CREEK (X-10 SITE)

| Media    | Chemical or Radionuclide | Date    | Location               | Study                | Number of Samples | Maximum Value | Units       | Species (Fish) | Comments                       |
|----------|--------------------------|---------|------------------------|----------------------|-------------------|---------------|-------------|----------------|--------------------------------|
| Sediment | Co-60                    | 1960    | CRM 19.1               | UCC, 1961            | NA                | 8.2           | pCi/g (dry) | N/A            |                                |
| Sediment | Co-60                    | 1961    | CRM 19.1               | UCC, 1962            | NA                | 5.9           | pCi/g (dry) | N/A            |                                |
| Sediment | Co-60                    | 1961    | CRM 20.7               | UCC, 1962            | NA                | 13            | pCi/g (dry) | N/A            |                                |
| Sediment | Co-60                    | 1962    | CRM 19.1               | UCC, 1963            | NA                | 0.7           | pCi/g (dry) | N/A            |                                |
| Sediment | Co-60                    | 1963    | CRM 19.1               | UCC, 1964            | NA                | 1.9           | pCi/g (dry) | N/A            |                                |
| Sediment | Co-60                    | 1964    | CRM 19.1               | UCC, 1965            | NA                | 5.1           | pCi/g (dry) | N/A            |                                |
| Sediment | Co-60                    | 1965    | CRM 16.3               | UCC, 1966            | NA                | 8.1           | pCi/g (dry) | N/A            |                                |
| Sediment | Co-60                    | 1966    | CRM 20.7               | UCC, 1967            | NA                | 68            | pCi/g (dry) | N/A            |                                |
| Sediment | Co-60                    | 1967    | CRM 20.7               | UCC, 1968            | NA                | 0.8           | pCi/g (dry) | N/A            |                                |
| Sediment | Co-60                    | Jun-77  | CRM 20.8               | Oakes et al., 1982   | 5                 | 0.8           | pCi/g (dry) | N/A            |                                |
| Sediment | Co-60                    | Jul-77  | CRM 20.8               | Oakes et al., 1982   | 18                | 0.8           | pCi/g (dry) | N/A            |                                |
| Sediment | Co-60                    | 7/24/84 | CRM 18.3               | TVA, 1985b           | 1                 | 1.2           | pCi/g (dry) | N/A            |                                |
| Sediment | Co-60                    | 1984    | CRM 20.8               | MMES, 1985           | NA                | 0.49          | pCi/g (dry) | N/A            |                                |
| Sediment | Co-60                    | 1985    | near K-25 Water Intake | Ashwood et al., 1986 | 7                 | 1.94          | pCi/g (dry) | N/A            |                                |
| Sediment | Co-60                    | 1989-90 | PC to MH Dam           | Cook et al., 1992    | 51                | 0.75          | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-137                   | 1961    | CRM 20.7               | UCC, 1962            | NA                | 95            | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-137                   | 1962    | CRM 19.1               | UCC, 1963            | NA                | 5.2           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-137                   | 1963    | CRM 19.1               | UCC, 1964            | NA                | 2.9           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-137                   | 1964    | CRM 19.1               | UCC, 1965            | NA                | 69            | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-137                   | 1965    | CRM 16.3               | UCC, 1966            | NA                | 145           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-137                   | 1966    | CRM 16.3               | UCC, 1967            | NA                | 26            | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-137                   | 1967    | CRM 20.7               | UCC, 1968            | NA                | 660           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-137                   | Jun-77  | CRM 20.8               | Oakes et al., 1982   | 5                 | 43.8          | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-137                   | Jul-77  | CRM 20.8               | Oakes et al., 1982   | 18                | 35.7          | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-137                   | 7/24/84 | CRM 18.3               | TVA, 1985b           | NA                | 167           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-137                   | 1984    | CRM 20.8               | MMES, 1985           | NA                | 5.7           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-137                   | 1985    | near K-25 Water Intake | Ashwood et al., 1986 | 7                 | 14.3          | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-137                   | 1989-90 | PC to MH Dam           | Cook et al., 1992    | 58                | 106.01        | pCi/g (dry) | N/A            | USAEC Intake                   |
| Sediment | Cs-137                   | 1990    | CRM 13                 | TVA, 1991            | 1                 | 23.74         | pCi/g       | N/A            |                                |
| Sediment | Cs-137                   | 1990    | CRM 17                 | TVA, 1991            | 1                 | 0.19          | pCi/g       | N/A            | Beech-Soaring Eagle Campground |
| Sediment | Cs-Ba-137                | 1960    | CRM 19.1               | UCC, 1961            | NA                | 64            | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1961    | CRM 19.1               | UCC, 1962            | NA                | 41            | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1954    | CRM 19.1               | Cottrell, 1960       | 1                 | 12            | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1954    | CRM 16.3               | Cottrell, 1960       | 1                 | 27            | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1954    | CRM 15.2               | Cottrell, 1960       | 1                 | 22            | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1954    | CRM 14.0               | Cottrell, 1960       | 1                 | 24            | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1955    | CRM 19.1               | Cottrell, 1960       | 1                 | 7             | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1955    | CRM 16.3               | Cottrell, 1960       | 1                 | 22            | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1955    | CRM 15.2               | Cottrell, 1960       | 1                 | 34            | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1955    | CRM 14.0               | Cottrell, 1960       | 1                 | 29            | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1956    | CRM 19.1               | Cottrell, 1960       | 1                 | 116           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1956    | CRM 16.3               | Cottrell, 1960       | 1                 | 208           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1956    | CRM 15.2               | Cottrell, 1960       | 1                 | 268           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1956    | CRM 14.0               | Cottrell, 1960       | 1                 | 115           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1957    | CRM 19.1               | Cottrell, 1960       | 1                 | 528           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1957    | CRM 16.3               | Cottrell, 1960       | 1                 | 177           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1957    | CRM 15.2               | Cottrell, 1960       | 1                 | 119           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1957    | CRM 14.0               | Cottrell, 1960       | 1                 | 184           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1958    | CRM 19.1               | Cottrell, 1960       | 1                 | 44            | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1958    | CRM 16.3               | Cottrell, 1960       | 1                 | 223           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1958    | CRM 15.2               | Cottrell, 1960       | 1                 | 146           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Ba-137                | 1958    | CRM 14.0               | Cottrell, 1960       | 1                 | 298           | pCi/g (dry) | N/A            |                                |
| Sediment | Cs-Pr-144                | 1960    | CRM 19.1               | UCC, 1961            | NA                | 9             | pCi/g (dry) | N/A            |                                |

TABLE H-2: ENVIRONMENTAL SAMPLES AT OR DOWNSTREAM OF THE CONFLUENCE OF THE CLUNCH RIVER AND WHITE OAK CREEK (X-10 SITE)

| Media    | Chemical or Radionuclide | Date    | Location | Study          | Number of Samples | Maximum Value | Units       | Species (Fish) | Comments                        |
|----------|--------------------------|---------|----------|----------------|-------------------|---------------|-------------|----------------|---------------------------------|
| Sediment | Cs-Pr-144                | 1961    | CRM 19.1 | UCC, 1962      | NA                | 2.7           | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-103-106               | 1961    | CRM 20.7 | UCC, 1962      | NA                | 85            | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-103-106               | 1962    | CRM 19.1 | UCC, 1963      | NA                | 6.1           | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-103-106               | 1963    | CRM 19.1 | UCC, 1964      | NA                | 4.4           | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-103-106               | 1964    | CRM 19.1 | UCC, 1965      | NA                | 15            | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-103-106               | 1965    | CRM 16.3 | UCC, 1966      | NA                | 2.1           | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-103-106               | 1966    | CRM 16.3 | UCC, 1967      | NA                | 4.2           | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-103-106               | 1967    | CRM 20.7 | UCC, 1968      | NA                | 0.83          | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1954    | CRM 19.1 | Cottrell, 1960 | 1                 | 8             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1954    | CRM 16.3 | Cottrell, 1960 | 1                 | 5             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1954    | CRM 15.2 | Cottrell, 1960 | 1                 | 5             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1954    | CRM 14.0 | Cottrell, 1960 | 1                 | 6             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1955    | CRM 19.1 | Cottrell, 1960 | 1                 |               | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1955    | CRM 16.3 | Cottrell, 1960 | 1                 | 4             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1955    | CRM 15.2 | Cottrell, 1960 | 1                 |               | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1955    | CRM 14.0 | Cottrell, 1960 | 1                 | 4             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1956    | CRM 19.1 | Cottrell, 1960 | 1                 | 4             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1956    | CRM 16.3 | Cottrell, 1960 | 1                 | 5             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1956    | CRM 15.2 | Cottrell, 1960 | 1                 | 8             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1956    | CRM 14.0 | Cottrell, 1960 | 1                 | 11            | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1956    | CRM 19.1 | Cottrell, 1960 | 1                 | 6             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1957    | CRM 16.3 | Cottrell, 1960 | 1                 | 14            | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1957    | CRM 15.2 | Cottrell, 1960 | 1                 | 6             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1957    | CRM 14.0 | Cottrell, 1960 | 1                 | 3             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1957    | CRM 19.1 | Cottrell, 1960 | 1                 | 4             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1958    | CRM 16.3 | Cottrell, 1960 | 1                 | 3             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1958    | CRM 15.2 | Cottrell, 1960 | 1                 | 7             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1958    | CRM 14.0 | Cottrell, 1960 | 1                 | 6             | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-106                   | 1960    | CRM 19.1 | UCC, 1961      | NA                | 16            | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-Rh-106                | 1960    | CRM 19.1 | UCC, 1962      | NA                | 27            | pCi/g (dry) | N/A            |                                 |
| Sediment | Ru-Rh-106                | 1961    | CRM 18.3 | TVA, 1985b     | 2                 | 95            | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-89                    | 7/27/84 | CRM 13   | TVA, 1991      | 1                 | 1             | pCi/g       | N/A            | USAEC Intake                    |
| Sediment | Sr-89                    | 1990    | CRM 17   | TVA, 1991      | 1                 | <0.54         | pCi/g       | N/A            | Beach- Soaring Eagle Campground |
| Sediment | Sr-90                    | 1954    | CRM 19.1 | Cottrell, 1960 | 1                 | 5             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1954    | CRM 16.3 | Cottrell, 1960 | 1                 | 5             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1954    | CRM 15.2 | Cottrell, 1960 | 1                 | 5             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1954    | CRM 14.0 | Cottrell, 1960 | 1                 | 5             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1955    | CRM 16.3 | Cottrell, 1960 | 1                 | 4             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1955    | CRM 14.0 | Cottrell, 1960 | 1                 | 4             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1956    | CRM 19.1 | Cottrell, 1960 | 1                 | 4             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1956    | CRM 16.3 | Cottrell, 1960 | 1                 | 7             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1956    | CRM 15.2 | Cottrell, 1960 | 1                 | 9             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1956    | CRM 14.0 | Cottrell, 1960 | 1                 | 4             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1957    | CRM 19.1 | Cottrell, 1960 | 1                 | 3             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1957    | CRM 16.3 | Cottrell, 1960 | 1                 | 5             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1957    | CRM 15.2 | Cottrell, 1960 | 1                 | 5             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1957    | CRM 14.0 | Cottrell, 1960 | 1                 | 3             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1958    | CRM 19.1 | Cottrell, 1960 | 1                 | 2             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1958    | CRM 16.3 | Cottrell, 1960 | 1                 | 6             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1958    | CRM 15.2 | Cottrell, 1960 | 1                 | 6             | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1958    | CRM 14.0 | Cottrell, 1960 | 1                 | 11            | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1960    | CRM 19.1 | UCC, 1961      | NA                | 0.7           | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1961    | CRM 19.1 | UCC, 1962      | NA                | 1             | pCi/g (dry) | N/A            |                                 |

TABLE H-2: ENVIRONMENTAL SAMPLES AT OR DOWNSTREAM OF THE CONFLUENCE OF THE CLINCH RIVER AND WHITE OAK CREEK (X-10 SITE)

| Media    | Chemical or Radionuclide | Date    | Location               | Study                   | Number of Samples | Maximum Value | Units       | Species (Fish) | Comments                        |
|----------|--------------------------|---------|------------------------|-------------------------|-------------------|---------------|-------------|----------------|---------------------------------|
| Sediment | Sr-90                    | 1961    | CRM 20.7               | UCC, 1962               | NA                | 0.86          | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1962    | CRM 19.1               | UCC, 1963               | NA                | 0.41          | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1963    | CRM 19.1               | UCC, 1964               | NA                | 0.74          | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1964    | CRM 19.1               | UCC, 1965               | NA                | 0.72          | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1965    | CRM 16.3               | UCC, 1966               | NA                | 1.2           | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1966    | CRM 16.3               | UCC, 1967               | NA                | 0.63          | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1967    | CRM 20.7               | UCC, 1968               | NA                | 2.4           | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1984    | CRM 20.8               | MMES, 1985              | NA                | 0.7           | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 7/24/84 | CRM 18.3               | TVA, 1985b              | 1                 | 1.8           | pCi/g (dry) | N/A            |                                 |
| Sediment | Sr-90                    | 1989-90 | PC to MH Dam           | Cook et al., 1992       | 28                | 1.25          | pCi/g (dry) | N/A            | USAEC Intake                    |
| Sediment | Sr-90                    | 1990    | CRM 13                 | TVA, 1991               | 1                 | <0.17         | pCi/g       | N/A            | Beach- Soaring Eagle Campground |
| Sediment | Sr-90                    | 1990    | CRM 17                 | TVA, 1991               | 1                 | <0.43         | pCi/g       | N/A            |                                 |
| Sediment | U-234                    | 1984    | CRM 20.8               | MMES, 1985              | NA                | 0.15          | pCi/g (dry) | N/A            |                                 |
| Sediment | U-234                    | 1989-90 | PC to MH Dam           | Cook et al., 1992       | 28                | 1.99          | pCi/g (dry) | N/A            | USAEC Intake                    |
| Sediment | U-234                    | 1990    | CRM 13                 | TVA, 1991               | 1                 | <0.024        | pCi/g       | N/A            | Beach- Soaring Eagle Campground |
| Sediment | U-234                    | 1990    | CRM 17                 | TVA, 1991               | 1                 | <0.053        | pCi/g (dry) | N/A            |                                 |
| Sediment | U-235                    | 1985    | near K-25 Water Intake | Ashwood et al., 1986    | 7                 | <0.2          | pCi/g (dry) | N/A            |                                 |
| Sediment | U-235                    | 1989-90 | PC to MH Dam           | Cook et al., 1992       | 28                | 0.11          | pCi/g (dry) | N/A            |                                 |
| Sediment | U-235                    | 1990    | CRM 13                 | TVA, 1991               | 1                 | <0.021        | pCi/g       | N/A            | USAEC Intake                    |
| Sediment | U-235                    | 1990    | CRM 17                 | TVA, 1991               | 1                 | <0.038        | pCi/g (dry) | N/A            | Beach- Soaring Eagle Campground |
| Sediment | U-238                    | 1985    | near K-25 Water Intake | Ashwood et al., 1986    | 7                 | <2.8          | pCi/g (dry) | N/A            |                                 |
| Sediment | U-238                    | 1989-90 | PC to MH Dam           | Cook et al., 1992       | 28                | 1.83          | pCi/g (dry) | N/A            |                                 |
| Sediment | U-238                    | 1990    | CRM 13                 | TVA, 1991               | 1                 | <0.022        | pCi/g       | N/A            | USAEC Intake                    |
| Sediment | U-238                    | 1990    | CRM 17                 | TVA, 1991               | 1                 | <0.026        | pCi/g       | N/A            | Beach- Soaring Eagle Campground |
| Sediment | Uranium                  | 7/24/84 | CRM 18.3               | TVA, 1985b              | 1                 | 1.6           | pCi/g (dry) | N/A            |                                 |
| Sediment | Zr-Nb-95                 | 1960    | CRM 19.1               | UCC, 1961               | NA                | 1             | pCi/g (dry) | N/A            |                                 |
| Sediment | Zr-Nb-95                 | 1961    | CRM 19.1               | UCC, 1962               | NA                | 1.4           | pCi/g (dry) | N/A            |                                 |
| Sediment | Zr-95-Nb-95              | 1961    | CRM 20.7               | UCC, 1962               | NA                | 1.5           | pCi/g (dry) | N/A            |                                 |
| Sediment | Zr-95-Nb-95              | 1962    | CRM 19.1               | UCC, 1963               | NA                | 6.2           | pCi/g (dry) | N/A            |                                 |
| Sediment | Zr-95-Nb-95              | 1963    | CRM 19.1               | UCC, 1964               | NA                | 0.9           | pCi/g (dry) | N/A            |                                 |
| Sediment | Zr-95-Nb-95              | 1964    | CRM 19.1               | UCC, 1965               | NA                | 0.68          | pCi/g (dry) | N/A            |                                 |
| Sediment | Zr-95-Nb-95              | 1965    | CRM 16.3               | UCC, 1966               | NA                | ND            | pCi/g (dry) | N/A            |                                 |
| Sediment | Zr-95-Nb-95              | 1966    | CRM 16.3               | UCC, 1967               | NA                | 0.27          | pCi/g (dry) | N/A            |                                 |
| Sediment | Zr-95-Nb-95              | 1967    | CRM 20.7               | UCC, 1968               | NA                | 1.9           | pCi/g (dry) | N/A            |                                 |
| Water    | Ce-144                   | 1960    | CRM 20.8               | UCC, 1961               | NA                | 4.2           | pCi/L       | N/A            | Calculated value                |
| Water    | Ce-144                   | 1961    | CRM 20.8               | UCC, 1962               | NA                | 0.8           | pCi/L       | N/A            | Calculated value                |
| Water    | Ce-144                   | 1962    | CRM 20.8               | UCC, 1963               | NA                | 0.2           | pCi/L       | N/A            | Calculated value                |
| Water    | Ce-144                   | 1963    | CRM 20.8               | UCC, 1964               | NA                | 0.2           | pCi/L       | N/A            | Calculated value                |
| Water    | Ce-144                   | 1964    | CRM 20.8               | UCC, 1965               | NA                | 0.7           | pCi/L       | N/A            | Calculated value                |
| Water    | Ce-144                   | 1965    | CRM 20.8               | UCC, 1966               | NA                | 0.1           | pCi/L       | N/A            | Calculated value                |
| Water    | Ce-144                   | 1966    | CRM 20.8               | UCC, 1967               | NA                | 0.3           | pCi/L       | N/A            | Calculated value                |
| Water    | Ce-144                   | 1967    | CRM 20.8               | UCC, 1968               | NA                | <0.1          | pCi/L       | N/A            | Calculated value                |
| Water    | Ce-144                   | 1968    | CRM 20.8               | UCC, 1969               | NA                | <0.1          | pCi/L       | N/A            | Calculated value                |
| Water    | Ce-144                   | 1969    | CRM 20.8               | UCC, 1970               | NA                | <0.1          | pCi/L       | N/A            | Calculated value                |
| Water    | Ce-144                   | 1970    | CRM 20.8               | UCC, 1971               | NA                | <0.1          | pCi/L       | N/A            | Calculated value                |
| Water    | Ce-144                   | 1971    | CRM 20.8               | UCC, 1972               | 12                | <0.10         | pCi/L       | N/A            | Calculated value                |
| Water    | Ce-144                   | 1971    | CRM 14.5               | UCC, 1972               | 4                 | 0.7           | pCi/L       | N/A            |                                 |
| Water    | Ce-60                    | 1960    | CRM 20.8               | UCC, 1961               | NA                | 13            | pCi/L       | N/A            | Calculated value                |
| Water    | Co-60                    | 1961    | CRM 20.8               | UCC, 1962               | NA                | 6             | pCi/L       | N/A            | Calculated value                |
| Water    | Co-60                    | 1962    | CRM 14.6               | Cowser and Snyder, 1966 | 93                | 20            | pCi/L       | N/A            | Calculated value                |
| Water    | Co-60                    | 1962    | CRM 20.8               | UCC, 1963               | NA                | 1.8           | pCi/L       | N/A            | Calculated value                |
| Water    | Co-60                    | 1963    | CRM 20.8               | UCC, 1964               | NA                | 2.5           | pCi/L       | N/A            | Calculated value                |

TABLE H-2: ENVIRONMENTAL SAMPLES AT OR DOWNSTREAM OF THE CONFLUENCE OF THE CLINCH RIVER AND WHITE OAK CREEK (X-10 SITE)

| Media | Chemical or Radionuclide | Date    | Location     | Study                   | Number of Samples | Maximum Value | Units | Species (Fish) | Comments         |
|-------|--------------------------|---------|--------------|-------------------------|-------------------|---------------|-------|----------------|------------------|
| Water | Co-60                    | 1964    | CRM 20.8     | UCC, 1965               | NA                | 3             | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1965    | CRM 20.8     | UCC, 1966               | NA                | 1.7           | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1966    | CRM 20.8     | UCC, 1967               | NA                | 2.1           | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1967    | CRM 20.8     | UCC, 1968               | NA                | <0.1          | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1968    | CRM 20.8     | UCC, 1969               | NA                | 0.2           | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1969    | CRM 20.8     | UCC, 1970               | NA                | 0.3           | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1970    | CRM 20.8     | UCC, 1971               | NA                | 0.1           | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1971    | CRM 20.8     | UCC, 1972               | 12                | 0.5           | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1971    | CRM 14.5     | UCC, 1972               | 4                 | 0.9           | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1978    | CRM 14.5     | UCC, 1979               | 4                 | 0.27          | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1979    | CRM 14.5     | UCC, 1980               | 4                 | 0.11          | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1980    | CRM 14.5     | UCC, 1981               | 4                 | 0.41          | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1981    | CRM 14.5     | UCC, 1982               | 4                 | 0.14          | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1982    | CRM 14.5     | UCC, 1983a              | 4                 | 1.6           | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1983    | CRM 14.5     | MMES, 1984              | 4                 | 0.24          | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1984    | CRM 14.5     | MMES, 1985              | 4                 | <0.54         | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 5/31/84 | WOCM 0.4     | TVA, 1985a              | 2                 | 19            | pCi/L | N/A            | baseflow         |
| Water | Co-60                    | 1985    | CRM 20.8     | MMES, 1986              | 52                | 170           | pCi/L | N/A            | Calculated value |
| Water | Co-60                    | 1989-90 | PC to MH Dam | Cook et al., 1992       | 3                 | <0.29         | pCi/L | N/A            | evaporate        |
| Water | Cs-137                   | 1960    | CRM 20.8     | UCC, 1961               | NA                | 6.3           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1961    | CRM 20.8     | UCC, 1962               | NA                | 3.2           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1962    | CRM 14.6     | Cowser and Snyder, 1966 | 92                | 21            | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1962    | CRM 20.8     | UCC, 1963               | NA                | 0.9           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1963    | CRM 20.8     | UCC, 1964               | NA                | 0.9           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1964    | CRM 20.8     | UCC, 1965               | NA                | 1             | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1965    | CRM 20.8     | UCC, 1966               | NA                | 0.3           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1966    | CRM 20.8     | UCC, 1967               | NA                | 0.5           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1967    | CRM 20.8     | UCC, 1968               | NA                | 0.2           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1968    | CRM 20.8     | UCC, 1969               | NA                | 0.2           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1968    | CRM 20.8     | UCC, 1970               | NA                | 0.4           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1970    | CRM 20.8     | UCC, 1971               | NA                | 0.2           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1971    | CRM 20.8     | UCC, 1972               | 12                | 0.6           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1971    | CRM 14.5     | UCC, 1972               | 4                 | 2             | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1972    | CRM 20.8     | UCC, 1973               | 12                | 0.4           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1972    | CRM 14.5     | UCC, 1973               | 4                 | 1.1           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1973    | CRM 20.8     | UCC, 1974               | 12                | 0.9           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1973    | CRM 14.5     | UCC, 1974               | 4                 | 0.7           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1974    | CRM 20.8     | UCC, 1975               | 12                | 0.43          | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1974    | CRM 14.5     | UCC, 1975               | 4                 | 0.05          | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1975    | CRM 20.8     | UCC, 1976               | 12                | 0.17          | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1975    | CRM 14.5     | UCC, 1976               | 4                 | 0.14          | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1976    | CRM 20.8     | UCC, 1977               | 12                | 0.2           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1976    | CRM 14.5     | UCC, 1977               | 4                 | 0.05          | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1977    | CRM 20.8     | UCC, 1978               | 12                | 0.26          | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1977    | CRM 14.5     | UCC, 1978               | 4                 | 0.05          | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1977    | CRM 14.5     | UCC, 1979               | 4                 | 3.18          | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1979    | CRM 14.5     | UCC, 1980               | 4                 | 0.05          | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1980    | CRM 14.5     | UCC, 1981               | 4                 | 0.18          | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1981    | CRM 14.5     | UCC, 1982               | 4                 | 0.22          | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1982    | CRM 14.5     | UCC, 1983a              | 4                 | 1.9           | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1983    | CRM 14.5     | MMES, 1984              | 4                 | 0.51          | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 1984    | CRM 14.5     | MMES, 1985              | 4                 | <0.54         | pCi/L | N/A            | Calculated value |
| Water | Cs-137                   | 5/31/84 | WOCM 0.4     | TVA, 1985a              | 2                 | 68            | pCi/L | N/A            | baseflow         |

TABLE H-2: ENVIRONMENTAL SAMPLES AT OR DOWNSTREAM OF THE CONFLUENCE OF THE CLUNCH RIVER AND WHITE OAK CREEK (X-10 SITE)

| Media | Chemical or Radionuclide | Date    | Location     | Study                   | Number of Samples | Maximum Value | Units | Species (Fish) | Comments         |
|-------|--------------------------|---------|--------------|-------------------------|-------------------|---------------|-------|----------------|------------------|
| Water | Cs-137                   | 1985    | CRM 20.8     | MMES, 1986              | 52                | 1500          | pCi/L | N/A            |                  |
| Water | Cs-137                   | 1989-90 | PC to MH Dam | Cook et al., 1992       | 2                 | <0.16         | pCi/L | N/A            | evaporate        |
| Water | Ru-103-106               | 1960    | CRM 20.8     | UCC, 1961               | NA                | 2.2           | pCi/L | N/A            | Calculated value |
| Water | Ru-103-106               | 1961    | CRM 20.8     | UCC, 1962               | NA                | 360           | pCi/L | N/A            | Calculated value |
| Water | Ru-103-106               | 1962    | CRM 20.8     | UCC, 1963               | NA                | 210           | pCi/L | N/A            | Calculated value |
| Water | Ru-103-106               | 1963    | CRM 20.8     | UCC, 1964               | NA                | 48            | pCi/L | N/A            | Calculated value |
| Water | Ru-103-106               | 1964    | CRM 20.8     | UCC, 1965               | NA                | 25            | pCi/L | N/A            | Calculated value |
| Water | Ru-103-106               | 1965    | CRM 20.8     | UCC, 1966               | NA                | 7.9           | pCi/L | N/A            | Calculated value |
| Water | Ru-103-106               | 1966    | CRM 20.8     | UCC, 1967               | NA                | 8.1           | pCi/L | N/A            | Calculated value |
| Water | Ru-103-106               | 1967    | CRM 20.8     | UCC, 1968               | NA                | 0.3           | pCi/L | N/A            | Calculated value |
| Water | Ru-103-106               | 1968    | CRM 20.8     | UCC, 1969               | NA                | 1.1           | pCi/L | N/A            | Calculated value |
| Water | Ru-103-106               | 1969    | CRM 20.8     | UCC, 1970               | NA                | 0.4           | pCi/L | N/A            | Calculated value |
| Water | Ru-103-106               | 1970    | CRM 20.8     | UCC, 1971               | NA                | 0.2           | pCi/L | N/A            | Calculated value |
| Water | Ru-106, 103              | 1971    | CRM 20.8     | UCC, 1972               | 12                | 0.3           | pCi/L | N/A            | Calculated value |
| Water | Ru-106, 103              | 1971    | CRM 14.5     | UCC, 1972               | 4                 | 4.8           | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1962    | CRM 14.6     | Cowser and Snyder, 1966 | 93                | 769           | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1972    | CRM 20.8     | UCC, 1973               | 12                | 0.3           | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1972    | CRM 14.5     | UCC, 1973               | 4                 | 1.2           | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1973    | CRM 20.8     | UCC, 1974               | 12                | 0.2           | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1973    | CRM 14.5     | UCC, 1974               | 4                 | 0.9           | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1974    | CRM 20.8     | UCC, 1975               | 12                | 0.17          | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1974    | CRM 14.5     | UCC, 1975               | 4                 | 0.14          | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1975    | CRM 20.8     | UCC, 1976               | 12                | 0.09          | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1975    | CRM 14.5     | UCC, 1976               | 4                 | 0.18          | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1976    | CRM 20.8     | UCC, 1977               | 12                | 0.08          | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1976    | CRM 14.5     | UCC, 1977               | 4                 | 0.23          | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1977    | CRM 20.8     | UCC, 1978               | 12                | 0.15          | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1977    | CRM 14.5     | UCC, 1978               | 4                 | 0.23          | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1978    | CRM 20.8     | UCC, 1979               | 4                 | 1.82          | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1978    | CRM 14.5     | UCC, 1979               | 4                 | 0.14          | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1979    | CRM 20.8     | UCC, 1980               | 4                 | 0.27          | pCi/L | N/A            | Calculated value |
| Water | Ru-106                   | 1980    | CRM 14.5     | UCC, 1981               | 4                 | 0.27          | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1960    | CRM 20.8     | UCC, 1961               | NA                | 7.2           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1961    | CRM 20.8     | UCC, 1962               | NA                | 5.6           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1962    | CRM 14.6     | Cowser and Snyder, 1966 | 64                | 11.61         | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1962    | CRM 20.8     | UCC, 1963               | NA                | 1.5           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1963    | CRM 20.8     | UCC, 1964               | NA                | 1.4           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1964    | CRM 20.8     | UCC, 1965               | NA                | 1.4           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1965    | CRM 20.8     | UCC, 1966               | NA                | 0.6           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1966    | CRM 20.8     | UCC, 1967               | NA                | 0.9           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1967    | CRM 20.8     | UCC, 1968               | NA                | 0.6           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1968    | CRM 20.8     | UCC, 1969               | NA                | 0.6           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1969    | CRM 20.8     | UCC, 1970               | NA                | 0.9           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1970    | CRM 20.8     | UCC, 1971               | NA                | 0.6           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1971    | CRM 20.8     | UCC, 1972               | 12                | 1.8           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1971    | CRM 14.5     | UCC, 1972               | 4                 | 2.7           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1972    | CRM 20.8     | UCC, 1973               | 12                | 1.6           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1972    | CRM 14.5     | UCC, 1973               | 4                 | 2.1           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1973    | CRM 20.8     | UCC, 1974               | 12                | 1.7           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1973    | CRM 14.5     | UCC, 1974               | 4                 | 1.8           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1974    | CRM 20.8     | UCC, 1975               | 12                | 1.6           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1974    | CRM 14.5     | UCC, 1975               | 4                 | 1.09          | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1975    | CRM 20.8     | UCC, 1976               | 12                | 2.42          | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1975    | CRM 14.5     | UCC, 1976               | 4                 | 1.32          | pCi/L | N/A            | Calculated value |

TABLE H-2: ENVIRONMENTAL SAMPLES AT OR DOWNSTREAM OF THE CONFLUENCE OF THE CLINCH RIVER AND WHITE OAK CREEK (X-10 SITE)

| Media | Chemical or Radionuclide | Date    | Location          | Study             | Number of Samples | Maximum Value | Units | Species (Fish) | Comments         |
|-------|--------------------------|---------|-------------------|-------------------|-------------------|---------------|-------|----------------|------------------|
| Water | Sr-90                    | 1976    | CRM 20.8          | UCC, 1977         | 12                | 2.6           | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1976    | CRM 14.5          | UCC, 1977         | 4                 | 0.36          | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1977    | CRM 20.8          | UCC, 1978         | 12                | 1.85          | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1977    | CRM 14.5          | UCC, 1978         | 4                 | 0.36          | pCi/L | N/A            | Calculated value |
| Water | Sr-90                    | 1978    | CRM 14.5          | UCC, 1979         | 4                 | 0.18          | pCi/L | N/A            |                  |
| Water | Sr-90                    | 1979    | CRM 14.5          | UCC, 1980         | 4                 | 0.68          | pCi/L | N/A            |                  |
| Water | Sr-90                    | 1980    | CRM 14.5          | UCC, 1981         | 4                 | 1.82          | pCi/L | N/A            |                  |
| Water | Sr-90                    | 1981    | CRM 14.5          | UCC, 1982         | 4                 | 2.97          | pCi/L | N/A            |                  |
| Water | Sr-90                    | 1982    | CRM 14.5          | UCC, 1983a        | 4                 | 4.6           | pCi/L | N/A            |                  |
| Water | Sr-90                    | 1983    | CRM 14.5          | MMES, 1984        | 4                 | 4.9           | pCi/L | N/A            |                  |
| Water | Sr-90                    | 1984    | CRM 14.5          | MMES, 1985        | 4                 | 2.2           | pCi/L | N/A            |                  |
| Water | Sr-90                    | 1985    | CRM 20.8          | MMES, 1986        | 52                | 350           | pCi/L | N/A            |                  |
| Water | Sr-90                    | 1989-90 | PC to MH Dam      | Cook et al., 1992 | 2                 | <0.10         | pCi/L | N/A            | water            |
| Water | Tritium                  | 1970    | CRM 20.8          | UCC, 1971         | NA                | 1360          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1971    | CRM 20.8          | UCC, 1972         | 12                | 5160          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1971    | CRM 14.5          | UCC, 1972         | 4                 | 6580          | pCi/L | N/A            |                  |
| Water | Tritium                  | 1972    | CRM 20.8          | UCC, 1973         | 12                | 2720          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1972    | CRM 14.5          | UCC, 1973         | 4                 | 3290          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1973    | CRM 20.8          | UCC, 1974         | 12                | 4248          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1973    | CRM 14.5          | UCC, 1974         | 4                 | 3100          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1974    | CRM 20.8          | UCC, 1975         | 12                | 3260          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1974    | CRM 14.5          | UCC, 1975         | 4                 | 2410          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1975    | CRM 20.8          | UCC, 1976         | 12                | 6000          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1975    | CRM 14.5          | UCC, 1976         | 4                 | 4100          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1976    | CRM 20.8          | UCC, 1977         | 12                | 4000          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1976    | CRM 14.5          | UCC, 1977         | 4                 | 3500          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1977    | CRM 20.8          | UCC, 1978         | 12                | 4400          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1977    | CRM 14.5          | UCC, 1978         | 4                 | 3050          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1978    | CRM 14.5          | UCC, 1979         | 4                 | 3600          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1979    | CRM 14.5          | UCC, 1980         | 4                 | 2200          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1980    | CRM 14.5          | UCC, 1981         | 4                 | 3233          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1981    | CRM 14.5          | UCC, 1982         | 4                 | 3620          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1982    | CRM 14.5          | UCC, 1983a        | 4                 | 7800          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1983    | CRM 14.5          | MMES, 1984        | 4                 | 8400          | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 1984    | CRM 14.5          | MMES, 1985        | 4                 | 17000         | pCi/L | N/A            | Calculated value |
| Water | Tritium                  | 5/31/84 | CRM 15.0          | TVA, 1985a        | 1                 | 500           | pCi/L | N/A            | baseflow         |
| Water | Tritium                  | 5/31/84 | WOCM 0.4          | TVA, 1985a        | 2                 | 544000        | pCi/L | N/A            | baseflow         |
| Water | Tritium                  | 1985    | CRM 20.8          | MMES, 1986        | 52                | 350000        | pCi/L | N/A            | baseflow         |
| Water | Tritium                  | 1990    | CRM 13            | TVA 1991          | 1                 | 481.00        | pCi/L | N/A            | baseflow         |
| Water | Tritium                  | 1990    | CRM 17            | TVA 1991          | 1                 | 827.00        | pCi/L | N/A            | baseflow         |
| Water | U-234                    | 1985    | CRM 14.5          | MMES, 1986        | 3                 | 0.13          | pCi/L | N/A            |                  |
| Water | U-235                    | 1985    | CRM 14.5          | MMES, 1986        | 3                 | 0.004         | pCi/L | N/A            |                  |
| Water | U-238                    | 1985    | CRM 14.5          | MMES, 1986        | 3                 | 0.00016       | pCi/L | N/A            |                  |
| Water | Uranium                  | 1973    | K-25 Water Intake | UCC, 1974         | 12                | 5             | pCi/L | N/A            |                  |
| Water | Uranium                  | 1974    | K-25 Water Intake | UCC, 1975         | 11                | 10            | pCi/L | N/A            |                  |
| Water | Uranium                  | 1975    | K-25 Water Intake | UCC, 1976         | 12                | 7             | pCi/L | N/A            |                  |
| Water | Uranium                  | 1976    | K-25 Water Intake | UCC, 1977         | 12                | 20            | pCi/L | N/A            |                  |
| Water | Uranium                  | 1977    | K-25 Water Intake | UCC, 1978         | 12                | 15            | pCi/L | N/A            |                  |
| Water | Uranium                  | 1978    | K-25 Water Intake | UCC, 1979         | 12                | 0.4           | pCi/L | N/A            |                  |
| Water | Uranium                  | 1979    | CRM 14.5          | UCC, 1980         | 12                | 5             | pCi/L | N/A            |                  |
| Water | Uranium                  | 1980    | CRM 14.5          | UCC, 1981         | 12                | 1             | pCi/L | N/A            |                  |
| Water | Uranium                  | 1981    | CRM 14.5          | UCC, 1982         | 12                | 3             | pCi/L | N/A            |                  |
| Water | Uranium                  | 1982    | CRM 14.5          | UCC, 1983a        | 12                | 6             | pCi/L | N/A            |                  |



TABLE H-3: ENVIRONMENTAL SAMPLES IN EAST FORK POPLAR CREEK (Y-12 SITE)

| Media    | Chemical or Radionuclide | Date     | Location                     | Study                     | Number of Samples | Maximum Value | Units       | Species (Fish)  | Comments   |
|----------|--------------------------|----------|------------------------------|---------------------------|-------------------|---------------|-------------|-----------------|--|
| Fish     | Beryllium                | 1984     | EFPCM 13.8                   | TVA, 1985c                | 10                | <0.100        | mg/kg (wet) | NA              |  |
| Fish     | Beryllium                | 1984     | EFPCM 13.8                   | TVA, 1985c                | 5                 | <0.10         | mg/kg (wet) | NA              |  |
| Fish     | Chromium                 | 1984     | EFPCM 8.8                    | TVA, 1985c                | 23                | 0.14          | mg/kg (wet) | Bluegill        |  |
| Fish     | Chromium                 | 1984     | EFPCM 13.8                   | TVA, 1985c                | 10                | 0.13          | mg/kg (wet) | Largemouth Bass |  |
| Fish     | Lead                     | 1984     | EFPCM 13.8                   | TVA, 1985c                | 10                | 0.12          | mg/kg (wet) | Carp            |  |
| Fish     | Lead                     | 1984     | EFPCM 13.8                   | TVA, 1985c                | 5                 | 0.23          | mg/kg (wet) | Bluegill        |  |
| Fish     | Mercury                  | 1970     | NHP Outfall                  | UCC, 1983b                | 12                | 1.3           | mg/kg (wet) | NA              |  |
| Fish     | Mercury                  | 1982     | EFPCM 14.1                   | Van Winkle et al., 1982   | 11                | 2.7           | mg/kg (wet) | NA              |  |
| Fish     | Mercury                  | 1984     | EFPCM 13.8                   | TVA, 1985c                | 5                 | 1.1           | mg/kg (wet) | NA              |  |
| Fish     | Mercury                  | 1984     | EFPCM 8.8                    | TVA, 1985c                | 23                | 1.4           | mg/kg (wet) | redbreast       |  |
| Fish     | Mercury                  | 1984     | EFPCM 13.8                   | TVA, 1985c                | 10                | 1.5           | mg/kg (wet) | Largemouth Bass |  |
| Fish     | PCBs                     | 1984     | EFPCM 8.8                    | TVA, 1985c                | 70                | <0.100        | mg/kg (wet) | NA              |  |
| Fish     | PCBs                     | 1984     | EFPCM 13.8                   | TVA, 1985c                | 42                | 1.7           | mg/kg (wet) | NA              |  |
| Fish     | Tc-99                    | 1984     | EFPCM 13.8                   | TVA, 1985c                | 5                 | 1.4           | pCi/g (wet) | Carp            |  |
| Sediment | Chromium                 | 1984     | EFPCM 13.66                  | TVA, 1985b                | 2                 | 62            | mg/kg (dry) | N/A             |  |
| Sediment | Chromium                 | 1984     | EFPCM 13.71                  | TVA, 1985b                | 1                 | 43            | mg/kg (dry) | N/A             |  |
| Sediment | Chromium                 | 1984     | EFPCM 13.74                  | TVA, 1985b                | 1                 | 24            | mg/kg (dry) | N/A             |  |
| Sediment | Lead                     | 1984     | EFPCM 13.66                  | TVA, 1985b                | 2                 | 84            | mg/kg (dry) | N/A             |  |
| Sediment | Lead                     | 1984     | EFPCM 13.71                  | TVA, 1985b                | 1                 | 78            | mg/kg (dry) | N/A             |  |
| Sediment | Lead                     | 1984     | EFPCM 13.74                  | TVA, 1985b                | 1                 | 36            | mg/kg (dry) | N/A             |  |
| Sediment | Mercury                  | 1974     | apx. EFPCM 10.5              | Reece, 1974               | 3                 | 16            | mg/kg (dry) | N/A             |  |
| Sediment | Mercury                  | 1982     | EFPCM 13.8                   | Van Winkle et al., 1982   | 1                 | 127           | mg/kg (dry) | N/A             |  |
| Sediment | Mercury                  | 1984     | EFPCM 13.66                  | TVA, 1985b                | 2                 | 63            | mg/kg (dry) | N/A             |  |
| Sediment | Mercury                  | 1984     | EFPCM 13.71                  | TVA, 1985b                | 1                 | 44            | mg/kg (dry) | N/A             |  |
| Sediment | Mercury                  | 1984     | EFPCM 13.74                  | TVA, 1985b                | 1                 | 29            | mg/kg (dry) | N/A             |  |
| Sediment | Mercury                  | 1984     | EFPCM next to Jefferson Ave. | Hibbitts, 1984            | 2                 | 45            | mg/kg (dry) | N/A             |  |
| Sediment | Mercury                  | 1984     | EFPC at OR Turnpike          | Hibbitts, 1984            | 2                 | 110           | mg/kg (dry) | N/A             |  |
| Sediment | Mercury                  | 1984     | EFPC (Scarboro)              | Hibbitts, 1984            | 10                | 24            | mg/kg (dry) | N/A             |  |
| Sediment | PCB                      | 1984     | EFPCM 13.66                  | TVA, 1985b                | 7                 | 1.2           | mg/kg (dry) | N/A             |  |
| Sediment | PCB                      | 1984     | EFPCM 13.71                  | TVA, 1985b                | 7                 | <0.100        | mg/kg (dry) | N/A             |  |
| Sediment | PCB                      | 1984     | EFPCM 13.74                  | TVA, 1985b                | 7                 | 0.6           | mg/kg (dry) | N/A             |  |
| Sediment | Pu-238                   | 1984     | EFPCM 13.71                  | TVA, 1985b                | 1                 | 0.013         | pCi/g (dry) | N/A             |  |
| Sediment | Pu-238                   | 1984     | EFPCM 13.74                  | TVA, 1985b                | 1                 | 0.008         | pCi/g (dry) | N/A             |  |
| Sediment | U-235                    | 1984     | EFPCM 13.66                  | TVA, 1985b                | 1                 | 0.8           | pCi/g (dry) | N/A             |  |
| Sediment | U-235                    | 1984     | EFPCM 13.71                  | TVA, 1985b                | 1                 | 1.2           | pCi/g (dry) | N/A             |  |
| Sediment | U-235                    | 1984     | EFPCM 13.74                  | TVA, 1985b                | 1                 | 0.42          | pCi/g (dry) | N/A             |  |
| Sediment | Uranium                  | 1984     | EFPCM 13.66                  | TVA, 1985b                | 1                 | 26            | mg/kg (dry) | N/A             |  |
| Sediment | Uranium                  | 1984     | EFPCM 13.71                  | TVA, 1985b                | 1                 | 90            | mg/kg (dry) | N/A             |  |
| Sediment | Uranium                  | 1984     | EFPCM 13.74                  | TVA, 1985b                | 1                 | 18            | mg/kg (dry) | N/A             |  |
| Soil     | Beryllium                | 1983     | EFPC floodplain              | Hibbitts, 1984            | 3                 | 1.15          | mg/kg       | N/A             | Jefferson Jr. High                               |
| Soil     | Chromium                 | 1984     | EFPC floodplain              | Hibbitts, 1984            | 68                | 100           | mg/kg       | N/A             | Civic Center                                     |
| Soil     | Chromium                 | 1984     | EFPC floodplain              | Hibbitts, 1984            | 17                | 110           | mg/kg       | N/A             | Southfield Apartments                            |
| Soil     | Chromium                 | 1984     | EFPC floodplain              | Hibbitts, 1984            | 28                | 100           | mg/kg       | N/A             | Carrighan Towers                                 |
| Soil     | Chromium                 | 1984     | EFPC floodplain              | Hibbitts, 1984            | 13                | 220           | mg/kg       | N/A             | Parcel 564 (apx. EFPCM 12.5-13)                  |
| Soil     | Lead                     | 1983     | EFPC floodplain              | Hibbitts, 1984            | 3                 | 104           | mg/kg       | N/A             | Jefferson Jr. High                               |
| Soil     | Lead                     | 1984     | EFPC floodplain              | Hibbitts, 1984            | 68                | 115           | mg/kg       | N/A             | Civic Center                                     |
| Soil     | Lead                     | 1984     | EFPC floodplain              | Hibbitts, 1984            | 17                | 100           | mg/kg       | N/A             | Southfield Apartments                            |
| Soil     | Lead                     | 1984     | EFPC floodplain              | Hibbitts, 1984            | 13                | 120           | mg/kg       | N/A             | Carrighan Towers                                 |
| Soil     | Lead                     | 1984     | EFPC floodplain              | Hibbitts, 1984            | 28                | 260           | mg/kg       | N/A             | Parcel 564 (apx. EFPCM 12.5-13)                  |
| Soil     | Mercury                  | 1984     | EFPC floodplain              | Hibbitts, 1984            | 68                | 510           | mg/kg       | N/A             | Civic Center                                     |
| Soil     | Mercury                  | 1984     | EFPC floodplain              | Hibbitts, 1984            | 17                | 430           | mg/kg       | N/A             | Southfield Apartments                            |
| Soil     | Mercury                  | 1984     | EFPC floodplain              | Hibbitts, 1984            | 13                | 510           | mg/kg       | N/A             | Carrighan Towers                                 |
| Soil     | Mercury                  | 1984     | EFPC floodplain              | Hibbitts, 1984            | 28                | 2100          | mg/kg       | N/A             | Parcel 564 (apx. EFPCM 12.5-13)                  |
| Soil     | Mercury                  | 1983-198 | EFPC floodplain              | MES, 1984; 1985; 1986; 19 | 3000+             | 650           | mg/kg       | N/A             | Measured in Robertsville Area of Oak Ridge, 1985 |

TABLE H-3: ENVIRONMENTAL SAMPLES IN EAST FORK POPLAR CREEK (Y-12 SITE)

| Media | Chemical or Radionuclide | Date | Location        | Study          | Number of Samples | Maximum |       | Species (Fish) | Comments                        |
|-------|--------------------------|------|-----------------|----------------|-------------------|---------|-------|----------------|---------------------------------|
|       |                          |      |                 |                |                   | Value   | Units |                |                                 |
| Soil  | Radionuclide             | 1983 | EFPC floodplain | Hibbitts, 1984 | 3                 | 3.4     | mg/kg | N/A            | Jefferson Jr High               |
| Soil  | PCBs                     | 1984 | EFPC floodplain | Hibbitts, 1984 | 70                | 6.8     | mg/kg | N/A            |                                 |
| Soil  | PCBs                     | 1984 | EFPC floodplain | Hibbitts, 1984 | 7                 | 10      | pCi/g | N/A            | Parcel 564 (bpx. EFPCM 12.5-13) |
| Soil  | Th-232                   | 1983 | EFPC floodplain | Hibbitts, 1984 | 3                 | <18     | mg/kg | N/A            | Jefferson Jr High               |
| Soil  | Thorium                  | 1984 | EFPC floodplain | Hibbitts, 1984 | 68                | 29      | mg/kg | N/A            | Civic Center                    |
| Soil  | Thorium                  | 1984 | EFPC floodplain | Hibbitts, 1984 | 17                | 30      | mg/kg | N/A            | Southfield Apartments           |
| Soil  | Thorium                  | 1984 | EFPC floodplain | Hibbitts, 1984 | 13                | 33      | mg/kg | N/A            | Carrihan Towers                 |
| Soil  | Thorium                  | 1984 | EFPC floodplain | Hibbitts, 1984 | 28                | 100     | mg/kg | N/A            | Parcel 564 (bpx. EFPCM 12.5-13) |
| Soil  | U-235                    | 1984 | EFPC floodplain | Hibbitts, 1984 | 7                 | 5.9     | pCi/g | N/A            | Parcel 564 (bpx. EFPCM 12.5-13) |
| Soil  | U-238                    | 1984 | EFPC floodplain | Hibbitts, 1984 | 7                 | 50      | pCi/g | N/A            | Jefferson Jr High               |
| Soil  | Uranium                  | 1983 | EFPC floodplain | Hibbitts, 1984 | 3                 | <90     | mg/kg | N/A            | Civic Center                    |
| Soil  | Uranium                  | 1984 | EFPC floodplain | Hibbitts, 1984 | 68                | 48      | mg/kg | N/A            | Southfield Apartments           |
| Soil  | Uranium                  | 1984 | EFPC floodplain | Hibbitts, 1984 | 17                | 57      | mg/kg | N/A            | Carrihan Towers                 |
| Soil  | Uranium                  | 1984 | EFPC floodplain | Hibbitts, 1984 | 13                | 56      | mg/kg | N/A            | Parcel 564 (bpx. EFPCM 12.5-13) |
| Soil  | Uranium                  | 1984 | EFPC floodplain | Hibbitts, 1984 | 28                | 220     | mg/kg | N/A            | Parcel 564 (bpx. EFPCM 12.5-13) |
| Water | Beryllium                | 1984 | EFPCM 14.36     | TVA, 1985a     | 1                 | <0.001  | mg/L  | N/A            |                                 |
| Water | Beryllium                | 1985 | NHP Outfall     | MMEs, 1986     | 12                | <0.0005 | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1971 | NHP Outfall     | UCC, 1972      | 7                 | 0.55    | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1972 | NHP Outfall     | UCC, 1973      | 12                | 0.34    | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1973 | NHP Outfall     | UCC, 1974      | 12                | 0.27    | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1974 | NHP Outfall     | UCC, 1975      | 12                | 0.05    | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1975 | NHP Outfall     | UCC, 1976      | 12                | 0.01    | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1976 | NHP Outfall     | UCC, 1977      | 12                | <0.01   | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1977 | NHP Outfall     | UCC, 1978      | 12                | 0.09    | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1978 | NHP Outfall     | UCC, 1979      | 12                | 0.05    | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1979 | NHP Outfall     | UCC, 1980      | 12                | <0.01   | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1980 | NHP Outfall     | UCC, 1981      | 12                | <0.01   | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1981 | NHP Outfall     | UCC, 1982      | 12                | 0.01    | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1982 | NHP Outfall     | UCC, 1983a     | 12                | 0.01    | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1983 | NHP Outfall     | MMEs, 1984     | 12                | 0.01    | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1984 | EFPCM 14.36     | TVA, 1985a     | 1                 | 0.002   | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1984 | NHP Outfall     | MMEs, 1985     | 12                | <0.01   | mg/L  | N/A            |                                 |
| Water | Chromium                 | 1985 | NHP Outfall     | MMEs, 1986     | 12                | 0.03    | mg/L  | N/A            |                                 |
| Water | Lead                     | 1971 | NHP Outfall     | UCC, 1972      | 12                | 0.4     | mg/L  | N/A            |                                 |
| Water | Lead                     | 1972 | NHP Outfall     | UCC, 1973      | 12                | 0.025   | mg/L  | N/A            |                                 |
| Water | Lead                     | 1973 | NHP Outfall     | UCC, 1974      | 12                | 0.03    | mg/L  | N/A            |                                 |
| Water | Lead                     | 1974 | NHP Outfall     | UCC, 1975      | 12                | 0.4     | mg/L  | N/A            |                                 |
| Water | Lead                     | 1975 | NHP Outfall     | UCC, 1976      | 12                | 0.03    | mg/L  | N/A            |                                 |
| Water | Lead                     | 1976 | NHP Outfall     | UCC, 1977      | 12                | 0.02    | mg/L  | N/A            |                                 |
| Water | Lead                     | 1977 | NHP Outfall     | UCC, 1978      | 12                | 0.01    | mg/L  | N/A            |                                 |
| Water | Lead                     | 1978 | NHP Outfall     | UCC, 1979      | 12                | <0.01   | mg/L  | N/A            |                                 |
| Water | Lead                     | 1979 | NHP Outfall     | UCC, 1980      | 12                | <0.01   | mg/L  | N/A            |                                 |
| Water | Lead                     | 1980 | NHP Outfall     | UCC, 1981      | 12                | 0.03    | mg/L  | N/A            |                                 |
| Water | Lead                     | 1981 | NHP Outfall     | UCC, 1982      | 12                | <0.01   | mg/L  | N/A            |                                 |
| Water | Lead                     | 1982 | NHP Outfall     | UCC, 1983a     | 12                | <0.01   | mg/L  | N/A            |                                 |
| Water | Lead                     | 1983 | NHP Outfall     | MMEs, 1984     | 12                | 0.002   | mg/L  | N/A            |                                 |
| Water | Lead                     | 1984 | EFPCM 14.36     | TVA, 1985a     | 1                 | 0.03    | mg/L  | N/A            |                                 |
| Water | Lead                     | 1984 | NHP Outfall     | MMEs, 1985     | 12                | <0.01   | mg/L  | N/A            |                                 |
| Water | Lead                     | 1985 | NHP Outfall     | MMEs, 1986     | 12                | 0.007   | mg/L  | N/A            |                                 |
| Water | Mercury                  | 1971 | NHP Outfall     | UCC, 1972      | 9                 | 0.0009  | mg/L  | N/A            |                                 |
| Water | Mercury                  | 1972 | NHP Outfall     | UCC, 1973      | 12                | 0.001   | mg/L  | N/A            |                                 |
| Water | Mercury                  | 1973 | NHP Outfall     | UCC, 1974      | 12                | <0.0005 | mg/L  | N/A            |                                 |
| Water | Mercury                  | 1974 | NHP Outfall     | UCC, 1975      | 12                | 0.0009  | mg/L  | N/A            |                                 |
| Water | Mercury                  | 1975 | NHP Outfall     | UCC, 1976      | 12                | 0.0008  | mg/L  | N/A            |                                 |
| Water | Mercury                  | 1976 | NHP Outfall     | UCC, 1977      | 12                | 0.0008  | mg/L  | N/A            |                                 |

TABLE H-3: ENVIRONMENTAL SAMPLES IN EAST FORK POPLAR CREEK (Y-12 SITE)

| Media | Chemical or Radionuclide | Date     | Location    | Study      | Number of Samples | Maximum Value | Units | Species (Fish) | Comments                              |
|-------|--------------------------|----------|-------------|------------|-------------------|---------------|-------|----------------|---------------------------------------|
| Water | Mercury                  | 1977     | NHP Outfall | UCC, 1978  | 12                | 0.003         | mg/L  | N/A            |                                       |
| Water | Mercury                  | 1978     | NHP Outfall | UCC, 1979  | 12                | 0.002         | mg/L  | N/A            |                                       |
| Water | Mercury                  | 1979     | NHP Outfall | UCC, 1980  | 12                | 0.004         | mg/L  | N/A            |                                       |
| Water | Mercury                  | 1980     | NHP Outfall | UCC, 1981  | 12                | 0.003         | mg/L  | N/A            |                                       |
| Water | Mercury                  | 1981     | NHP Outfall | UCC, 1982  | 12                | 0.002         | mg/L  | N/A            |                                       |
| Water | Mercury                  | 1982     | NHP Outfall | UCC, 1983a | 12                | 0.007         | mg/L  | N/A            |                                       |
| Water | Mercury                  | 1983     | NHP Outfall | MMES, 1984 | 12                | 0.025         | mg/L  | N/A            |                                       |
| Water | Mercury                  | 1984     | NHP Outfall | MMES, 1985 | 12                | 0.0038        | mg/L  | N/A            |                                       |
| Water | Mercury                  | 10/23/84 | EFPCM 10.0  | TVA, 1985a | 7                 | 0.007         | mg/L  | N/A            | Stormflow- Total                      |
| Water | Mercury                  | 11/10/84 | EFPCM 10.0  | TVA, 1985a | 7                 | 0.024         | mg/L  | N/A            | Stormflow- Total                      |
| Water | Mercury                  | 5/31/84  | EFPCM 14.36 | TVA, 1985a | 1                 | 0.0066        | mg/L  | N/A            | Stormflow- Total                      |
| Water | Mercury                  | 10/22/84 | EFPCM 14.36 | TVA, 1985a | 6                 | 0.011         | mg/L  | N/A            | Stormflow- Total                      |
| Water | Mercury                  | 11/10/84 | EFPCM 14.36 | TVA, 1985a | 7                 | 0.026         | mg/L  | N/A            | Stormflow- Total                      |
| Water | Mercury                  | 1985     | near PC     | MMES, 1986 | 12                | 0.0039        | mg/L  | N/A            |                                       |
| Water | Mercury                  | 1985     | NHP Outfall | MMES, 1986 | 12                | 0.008         | mg/L  | N/A            |                                       |
| Water | PCBs                     | 5/31/84  | EFPCM 14.36 | TVA, 1985a | 1                 | <0.0001       | mg/L  | N/A            |                                       |
| Water | Tritium                  | 1984     | EFPCM 14.36 | TVA, 1985a | 12                | 400           | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1971     | NHP Outfall | UCC, 1972  | 12                | 400           | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1972     | NHP Outfall | UCC, 1973  | 12                | 1000          | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1973     | NHP Outfall | UCC, 1974  | 11                | 200           | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1974     | NHP Outfall | UCC, 1975  | 12                | 146           | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1975     | NHP Outfall | UCC, 1976  | 12                | 7             | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1976     | NHP Outfall | UCC, 1977  | 12                | 95            | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1977     | NHP Outfall | UCC, 1978  | 12                | 38            | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1978     | NHP Outfall | UCC, 1979  | 12                | 19            | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1979     | NHP Outfall | UCC, 1980  | 12                | 16            | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1980     | NHP Outfall | UCC, 1981  | 12                | 69            | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1981     | NHP Outfall | UCC, 1982  | 12                | 150           | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1982     | NHP Outfall | UCC, 1983a | 12                | 41            | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1983     | NHP Outfall | MMES, 1984 | 12                | 37            | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1984     | NHP Outfall | MMES, 1985 | 12                | 170           | pCi/L | N/A            |                                       |
| Water | Uranium                  | 1985     | near PC     | MMES, 1986 | 12                | 0.268         | mg/L  | N/A            | 1.2% U-235 (max), 0.76 % U-235 (avg.) |

N/A = Information not available  
N/A = Not applicable

**APPENDIX I**  
**BETWEEN-MEDIA COMPARISON SUMMARY SHEETS**

## APPENDIX I

### BETWEEN-MEDIA COMPARISON SUMMARY SHEETS

This appendix summarizes the results of the between-media exposure pathway comparisons for each of the chemicals and radionuclides evaluated in Tasks 3 & 4 and the associated exposure pathways for each contaminant that were determined to be important (i.e., contribute to exposure) in the within-medium comparison. The objective of the between-media comparisons is to evaluate the relative importance of exposure pathways across media.

The exposure pathway equations and exposure parameters described previously for the within-medium comparisons are also used in this between-media evaluation. However, instead of a unit concentration, representative concentrations of a contaminant in all relevant environmental media for which information was available are used. For the purposes of this assessment, these representative concentrations are based on preliminary effluent data summarized in Task 1 and environmental monitoring data summarized in Task 2. The representative concentrations correspond to maximum, single-year releases from each of the three facilities on the ORR (for air pathways) and maximum reported concentrations in surface water soil/sediment, and fish at or near each of the three surface water locations of interest (for surface water and soil/sediment pathways).

Health hazards (e.g., cancer risks or hazard indices) associated with exposures to the representative contaminant concentrations that correspond to releases from each of the three facilities are shown in Tables I-1 through I-3. Health hazards are summed for each medium, and the medium with the highest hazard is identified as the "benchmark" to which risks associated with other media for that contaminant are compared. The ratio of each medium to the benchmark value is calculated to show the relative importance of each medium. In addition, the health hazards for all important pathways for a contaminant are summed to give a total health hazard associated with the contaminant due to releases from a given facility. These values are used to rank the radionuclides, carcinogenic chemicals, and noncarcinogenic chemicals with respect to potential off-site health impacts from maximum, single-year releases or maximum, yearly environmental measurements.

TABLE I-1: BETWEEN-MEDIA COMPARISONS-- K-25 SITE SUMMARY

| Material                              | Pathway  | Dose (Sv/yr)                 | Conversion (Risk/Sv) | Risk (1 Year) | % Importance |
|---------------------------------------|--|------------------------------|----------------------|---------------|--------------|
| <b>Radionuclides</b><br>Plutonium-238 | Surface Water to Fish to Humans (Ingestion)                    | 2.35E-07                     | 7.3%                 | 1.72E-08      |              |
|                                       |  | Total Risk (Surface Water) = |                      | 1.72E-08      | 100%         |
|                                       | Soil to Air to Humans (Inhalation)                             | 5.07E-08                     | 7.3%                 | 3.70E-09      |              |
|                                       | Soil to Humans (Ingestion)                                     | 2.08E-08                     | 7.3%                 | 1.52E-09      |              |
|                                       | Soil to Vegetables to Humans (Ingestion)                       | 1.87E-08                     | 7.3%                 | 1.37E-09      |              |
|                                       |  | Total Risk (Soil) =          |                      | 6.58E-09      | 38%          |
|                                       |  | Total Risk =                 |                      | 2.37E-08      |              |
| Plutonium-239/240                     | Surface Water to Fish to Humans (Ingestion)                    | 2.59E-07                     | 7.3%                 | 1.89E-08      |              |
|                                       |  | Total Risk (Surface Water) = |                      | 1.89E-08      | 12%          |
|                                       | Soil to Air to Humans (Inhalation)                             | 1.24E-06                     | 7.3%                 | 9.05E-08      |              |
|                                       | Soil to Humans (Ingestion)                                     | 5.14E-07                     | 7.3%                 | 3.75E-08      |              |
|                                       | Soil to Vegetables to Humans (Ingestion)                       | 4.63E-07                     | 7.3%                 | 3.38E-08      |              |
|                                       |  | Total Risk (Soil) =          |                      | 1.62E-07      | 100%         |
|                                       |  | Total Risk =                 |                      | 1.81E-07      |              |
| Technetium-99                         | Air to Humans (Inhalation)                                     | 1.15E-08                     | 7.3%                 | 8.40E-10      |              |
|                                       | Air to Vegetables to Humans (Ingestion)                        | 2.96E-08                     | 7.3%                 | 2.16E-09      |              |
|                                       | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 3.55E-08                     | 7.3%                 | 2.59E-09      |              |
|                                       | Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 1.03E-07                     | 7.3%                 | 7.52E-09      |              |
|                                       |  | Total Risk (Air) =           |                      | 1.31E-08      | < 1%         |
|                                       | Surface Water to Humans (Ingestion)                            | 3.62E-09                     | 7.3%                 | 2.64E-10      |              |
|                                       | Surface Water to Dairy Cattle (Milk) to Humans (Ingestion)     | 1.86E-10                     | 7.3%                 | 1.36E-11      |              |
|                                       | Surface Water to Fish to Humans (Ingestion)                    | 5.21E-08                     | 7.3%                 | 3.80E-09      |              |
|                                       |  | Total Risk (Surface Water) = |                      | 4.08E-09      | < 1%         |
|                                       |  | Total Risk =                 |                      | 1.88E-06      |              |
|                                       | Soil to Vegetables to Humans (Ingestion)                       | 2.57E-05                     | 7.3%                 | 1.72E-06      |              |
|                                       | Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 2.36E-05                     | 7.3%                 | 1.72E-06      |              |
|                                       | Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 6.84E-05                     | 7.3%                 | 4.99E-06      |              |
|                                       |  | Total Risk (Soil) =          |                      | 8.59E-06      | 100%         |
|                                       |  | Total Risk =                 |                      | 8.61E-06      |              |

TABLE I-1: BETWEEN-MEDIA COMPARISONS-- K-25 SITE SUMMARY

| Material                         | Pathway  | Dose (Sv/yr)               | Conversion (Risk/Sv)                | Risk (1 year)   | % Importance |
|----------------------------------|--|----------------------------|-------------------------------------|-----------------|--------------|
| <b>Radionuclides (continued)</b> |  |                            |                                     |                 |              |
| Uranium-234/235                  | Air to Humans (Inhalation)                                     | 2.41E-05                   | 7.3%                                | 1.76E-06        |              |
|                                  | Air to Vegetables to Humans (Ingestion)                        | 7.06E-07                   | 7.3%                                | 5.15E-08        |              |
|                                  |  |                            | <b>Total Risk (Air) =</b>           | <b>1.81E-06</b> | <b>100%</b>  |
|                                  | Surface Water to Humans (Ingestion)                            | 2.08E-05                   | 7.3%                                | 1.52E-06        |              |
|                                  | Surface Water to Fish to Humans (Ingestion)                    | 1.19E-06                   | 7.3%                                | 8.69E-08        |              |
|                                  |  |                            | <b>Total Risk (Surface Water) =</b> | <b>1.61E-06</b> | <b>89%</b>   |
|                                  | Soil to Air to Humans (Inhalation)                             | 1.43E-07                   | 7.3%                                | 1.04E-08        |              |
|                                  | Soil to Humans (Ingestion)                                     | 1.47E-08                   | 7.3%                                | 1.07E-09        |              |
|                                  | Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 8.74E-09                   | 7.3%                                | 6.38E-10        |              |
|                                  | Soil to Vegetables to Humans (Ingestion)                       | 2.49E-07                   | 7.3%                                | 1.82E-08        |              |
|                                  |  | <b>Total Risk (Soil) =</b> | <b>3.03E-08</b>                     | <b>2%</b>       |              |
|                                  |  | <b>Total Risk =</b>        | <b>3.45E-06</b>                     |                 |              |
| Uranium-238                      | Air to Humans (Inhalation)                                     | 2.63E-05                   | 7.3%                                | 1.92E-06        |              |
|                                  | Air to Vegetables to Humans (Ingestion)                        | 7.44E-07                   | 7.3%                                | 5.43E-08        |              |
|                                  |  |                            | <b>Total Risk (Air) =</b>           | <b>1.97E-06</b> | <b>100%</b>  |
|                                  | Surface Water to Humans (Ingestion)                            | 1.85E-05                   | 7.3%                                | 1.35E-06        |              |
|                                  | Surface Water to Fish to Humans (Ingestion)                    | 5.65E-07                   | 7.3%                                | 4.12E-08        |              |
|                                  |  |                            | <b>Total Risk (Surface Water) =</b> | <b>1.39E-06</b> | <b>70%</b>   |
|                                  | Soil to Air to Humans (Inhalation)                             | 8.43E-07                   | 7.3%                                | 6.15E-08        |              |
|                                  | Soil to Humans (Ingestion)                                     | 8.37E-08                   | 7.3%                                | 6.11E-09        |              |
|                                  | Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 5.00E-08                   | 7.3%                                | 3.65E-09        |              |
|                                  | Soil to Vegetables to Humans (Ingestion)                       | 1.42E-06                   | 7.3%                                | 1.04E-07        |              |
|                                  |  | <b>Total Risk (Soil) =</b> | <b>1.75E-07</b>                     | <b>9%</b>       |              |
|                                  |  | <b>Total Risk =</b>        | <b>3.54E-06</b>                     |                 |              |
| Material                         | Pathway  | Lifetime Risk              | Conversion (yr/lifetime)            | Risk (1 Year)   | % Importance |
| <b>Carcinogenic Chemicals</b>    |  |                            |                                     |                 |              |
| Beryllium                        | Soil to Air to Humans (Inhalation)                             | 9.36E-08                   | 70                                  | 1.34E-09        |              |
|                                  | Soil to Humans (Ingestion)                                     | 2.46E-06                   | 70                                  | 3.51E-08        |              |
|                                  | Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.47E-06                   | 70                                  | 2.10E-08        |              |
|                                  | Soil to Vegetables to Humans (Ingestion)                       | 4.91E-06                   | 70                                  | 7.01E-08        |              |
|                                  | Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.57E-07                   | 70                                  | 5.10E-09        |              |
|                                  | Soil to Humans (Dermal Contact)                                | 1.43E-06                   | 70                                  | 2.04E-08        |              |
|                                  |  | <b>Total Risk (Soil) =</b> | <b>1.53E-07</b>                     | <b>100%</b>     |              |
|                                  |  | <b>Total Risk =</b>        | <b>1.53E-07</b>                     |                 |              |

TABLE I-1: BETWEEN-MEDIA COMPARISONS-- K-25 SITE SUMMARY

| Material                                  | Pathway   | Lifetime Risk | Conversion (yr/lifetime)     | Risk (1 year)       | % Importance        |
|---|---|---------------|------------------------------|---------------------|---------------------|
| <b>Carcinogenic Chemicals (continued)</b> |   |               |                              |                     |                     |
| Carbon Tetrachloride                      | Air to Humans (Inhalation)                                    | 1.48E-06      | 70                           | 2.11E-08            |                     |
|   |   |               | Total Risk (Air) =           | 2.11E-08            | 100%                |
|   |   |               | Total Risk =                 | 2.11E-08            |                     |
| Methylene Chloride                        | Air to Humans (Inhalation)                                    | 8.02E-09      | 70                           | 1.15E-10            |                     |
|   |   |               | Total Risk (Air) =           | 1.15E-10            | 100%                |
|   |   |               | Total Risk =                 | 1.15E-10            |                     |
| PCBs                                      | Surface Water to Fish to Humans (Ingestion)                   | 2.97E-02      | 70                           | 4.24E-04            |                     |
|   |   |               | Total Risk (Surface Water) = | 4.24E-04            | 100%                |
|   |   |               | Total Risk =                 | 4.24E-04            |                     |
| Trichloroethylene                         | Air to Humans (Inhalation)                                    | 1.99E-07      | 70                           | 2.84E-09            |                     |
|   |   |               | Total Risk (Air) =           | 2.84E-09            | 100%                |
|   |   |               | Total Risk =                 | 2.84E-09            |                     |
| <b>Material</b>                           | <b>Pathway</b>  |               |                              | <b>Hazard Index</b> | <b>% Importance</b> |
| <b>Noncarcinogenic Chemicals</b>          |   |               |                              |                     |                     |
| Chromium (III)                            | Surface Water to Livestock/Game (Beef) to Humans (Ingestion)  |               |                              | 9.00E-04            |                     |
|   |   |               |                              | 1.53E-05            |                     |
|   |   |               |                              | 2.96E-04            |                     |
|   | Surface Water to Fish to Humans (Ingestion)                   |               |                              | 1.21E-03            | 100%                |
|   |   |               | 8.71E-05                     |                     |                     |
|   |   |               | 4.80E-04                     |                     |                     |
|   | Soil to Humans (Ingestion)                                    |               |                              | 1.55E-04            |                     |
|   |   |               | 1.39E-04                     |                     |                     |
|   |   |               | 8.73E-05                     |                     |                     |
|   | Soil to Livestock /Game (Beef) to Humans (Ingestion)          |               |                              | 2.58E-05            |                     |
|   |   |               | 5.05E-05                     |                     |                     |
|   |   |               | 1.02E-03                     | 85%                 |                     |
|   | Soil to Pasture to Livestock/Game (Beef to Humans (Ingestion) |               |                              | 2.24E-03            |                     |
|   |   |               | Total Hazard (Soil) =        |                     |                     |
|   | Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)  |               |                              |                     |                     |
|   |   |               | Total Hazard =               |                     |                     |
|   | Soil to Humans (Dermal Contact)                               |               |                              |                     |                     |
|   |   |               | Total Hazard =               |                     |                     |

TABLE I-1: BETWEEN-MEDIA COMPARISONS-- K-25 SITE SUMMARY

| Material   | Pathway   | Hazard Index    | % Importance |
|--|---|-----------------|--------------|
| <b>Noncarcinogenic Chemicals (continued)</b>                   |   |                 |              |
| Nickel   | Air to Humans (Inhalation)                                    | 8.04E-05        |              |
|  | Air to Vegetables to Humans (Ingestion)                       | 1.18E-03        |              |
|  | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.32E-04        |              |
|  | Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 4.10E-04        |              |
|  | <b>Total Hazard (Air) =</b>                                   | <b>2.00E-03</b> | <b>1%</b>    |
|  | Surface Water to Humans (Ingestion)                           | 1.50E-01        |              |
|  | Surface Water to Fish to Humans (Ingestion)                   | 1.93E-02        |              |
|  | <b>Total Hazard (Surface Water) =</b>                         | <b>1.69E-01</b> | <b>100%</b>  |
|  | Soil to Humans (Ingestion)                                    | 1.04E-03        |              |
|  | Soil to Livestock/Game (Beef) to Humans (Ingestion)           | 1.24E-03        |              |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.67E-03  |                 |              |
| Soil To Vegetables to Humans (Ingestion)                       | 1.24E-02  |                 |              |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.80E-03  |                 |              |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.23E-03  |                 |              |
| Soil to Humans (Dermal Contact)                                | 6.01E-04  |                 |              |
| <b>Total Hazard (Soil) =</b>                                   | <b>2.10E-02</b>   | <b>12%</b>      |              |
| <b>Total Hazard =</b>  | <b>1.92E-01</b>   |                 |              |
| 1,1,1-Trichloroethane  | Air to Humans (Inhalation)                                    | 2.93E-03        |              |
|  | <b>Total Hazard (Air) =</b>                                   | <b>2.93E-03</b> | <b>100%</b>  |
|  | <b>Total Hazard =</b>   | <b>2.93E-03</b> |              |

TABLE I-2: BETWEEN-MEDIA COMPARISONS-- X-10 SITE SUMMARY

| Material             | Pathway  | Dose (Sv/yr)                 | Conversion (Risk/Sv) | Risk (1 year) | % Importance |
|----------------------|--|------------------------------|----------------------|---------------|--------------|
| <b>Radionuclides</b> | Air to Humans (Immersion)                                      | 1.36E-06                     | 7.3%                 | 9.93E-08      | 100%         |
|                      |  |                              | Total Risk (Air) =   | 9.93E-08      |              |
|                      |  |                              | Total Risk =         | 9.93E-08      |              |
| <b>Barium-140</b>    | Air to Humans (Inhalation)                                     | 2.26E-08                     | 7.3%                 | 1.65E-09      |              |
|                      | Air to Humans (Immersion)                                      | 1.32E-08                     | 7.3%                 | 9.64E-10      |              |
|                      | Air to Vegetables to Humans (Ingestion)                        | 7.84E-07                     | 7.3%                 | 5.72E-08      |              |
|                      | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 1.07E-08                     | 7.3%                 | 7.81E-10      |              |
|                      | Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 9.57E-08                     | 7.3%                 | 6.99E-09      |              |
|                      |  | Total Risk (Air) =           |                      | 6.76E-08      | 100%         |
|                      | Total Risk =   |                              | 6.76E-08             |               |              |
| <b>Cerium-144</b>    | Air to Humans (Inhalation)                                     | 1.32E-06                     | 7.3%                 | 9.64E-08      |              |
|                      | Air to Vegetables to Humans (Ingestion)                        | 1.12E-06                     | 7.3%                 | 8.18E-08      |              |
|                      | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 1.18E-07                     | 7.3%                 | 8.61E-09      |              |
|                      | Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 2.34E-08                     | 7.3%                 | 1.71E-09      |              |
|                      | Water to Humans (Ingestion)                                    | 3.45E-07                     | 7.3%                 | 2.52E-08      |              |
|                      | Water to Fish to Humans (Ingestion)                            | 9.25E-07                     | 7.3%                 | 6.75E-08      |              |
|                      |  | Total Risk (Surface Water) = |                      | 9.27E-08      | 49%          |
|                      | Soil to Air to Humans (Inhalation)                             | 4.48E-08                     | 7.3%                 | 3.27E-09      |              |
|                      | Soil to Humans (Ingestion)                                     | 1.33E-07                     | 7.3%                 | 9.71E-09      |              |
|                      | Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 5.98E-08                     | 7.3%                 | 4.37E-09      |              |
|                      | Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.29E-08                     | 7.3%                 | 9.42E-10      |              |
|                      | Soil to Vegetation to Humans (Ingestion)                       | 2.24E-07                     | 7.3%                 | 1.64E-08      |              |
|                      | Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.31E-08                     | 7.3%                 | 9.56E-10      |              |
|                      | Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 2.58E-09                     | 7.3%                 | 1.88E-10      |              |
|                      | Soil to Humans (Ground Exposure)                               | 2.75E-08                     | 7.3%                 | 2.01E-09      |              |
|                      |  | Total Risk (Soil) =          |                      | 3.78E-08      | 20%          |
|                      | Total Risk =   |                              | 3.19E-07             |               |              |

TABLE I-2: BETWEEN-MEDIA COMPARISONS-- X-10 SITE SUMMARY

| Material   | Pathway  | Dose (Sv/yr)                 | Conversion (Risk/Sv) | Risk (1 year) | % Importance |
|--|--|------------------------------|----------------------|---------------|--------------|
| <b>Radionuclides (continued)</b><br>Cesium-137                 | Air to Humans (Inhalation)                                     | 3.05E-09                     | 7.3%                 | 2.23E-10      |              |
|  | Air to Vegetables to Humans (Ingestion)                        | 6.74E-08                     | 7.3%                 | 4.92E-09      |              |
|  | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 1.91E-07                     | 7.3%                 | 1.39E-08      |              |
|  | Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 1.67E-07                     | 7.3%                 | 1.22E-08      |              |
|  |  | Total Risk (Air) =           |                      | 3.13E-08      | <1%          |
|  | Water to Humans (Ingestion)                                    | 2.77E-04                     | 7.3%                 | 2.02E-05      |              |
|  | Water to Fish to Humans (Ingestion)                            | 3.95E-05                     | 7.3%                 | 2.88E-06      |              |
|  |  | Total Risk (Surface Water) = |                      | 2.31E-05      | 71%          |
|  | Soil to Humans (Ingestion)                                     | 2.90E-06                     | 7.3%                 | 2.12E-07      |              |
|  | Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 3.47E-05                     | 7.3%                 | 2.53E-06      |              |
| Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 3.32E-05   | 7.3%                         | 2.42E-06             |               |              |
| Soil to Vegetation to Humans (Ingestion)                       | 1.51E-04   | 7.3%                         | 1.10E-05             |               |              |
| Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.18E-04   | 7.3%                         | 8.61E-06             |               |              |
| Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.03E-04   | 7.3%                         | 7.52E-06             |               |              |
|  | Total Risk (Soil) =  |                              | 3.23E-05             | 100%          |              |
|  | Total Risk =   |                              | 5.55E-05             |               |              |
| Cobalt-60  | Water to Humans (Ingestion)                                    | 1.69E-05                     | 7.3%                 | 1.23E-06      |              |
|  | Water to Fish to Humans (Ingestion)                            | 2.98E-07                     | 7.3%                 | 2.18E-08      |              |
|  |  | Total Risk (Surface Water) = |                      | 1.26E-06      | 100%         |
|  | Soil to Humans (Ingestion)                                     | 1.39E-07                     | 7.3%                 | 1.01E-08      |              |
|  | Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 8.09E-07                     | 7.3%                 | 5.91E-08      |              |
|  | Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 6.52E-07                     | 7.3%                 | 4.76E-08      |              |
|  | Soil to Vegetation to Humans (Ingestion)                       | 5.58E-06                     | 7.3%                 | 4.07E-07      |              |
|  | Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 5.89E-08                     | 7.3%                 | 4.30E-09      |              |
|  | Soil to Humans (Ground Exposure)                               | 4.35E-08                     | 7.3%                 | 3.18E-09      |              |
|  |  | Total Risk (Soil) =          |                      | 5.32E-07      | 42%          |
|  | Total Risk =   |                              | 1.79E-06             |               |              |
| Iodine-129   | Air to Vegetables to Humans (Ingestion)                        | 2.39E-10                     | 7.3%                 | 1.74E-11      |              |
|  | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 2.43E-10                     | 7.3%                 | 1.77E-11      |              |
|  | Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 8.24E-10                     | 7.3%                 | 6.02E-11      |              |
|  |  | Total Risk (Air) =           |                      | 9.53E-11      | 100%         |
|  | Total Risk =   |                              | 9.53E-11             |               |              |
| Iodine-131   | Air to Vegetables to Humans (Ingestion)                        | 8.15E-03                     | 7.3%                 | 5.95E-04      |              |
|  | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 1.16E-03                     | 7.3%                 | 8.47E-05      |              |
|  | Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 3.94E-03                     | 7.3%                 | 2.88E-04      |              |
|  | Total Risk (Air) =   |                              | 9.67E-04             | 100%          |              |
|  | Total Risk =   |                              | 9.67E-04             |               |              |

TABLE I-2: BETWEEN-MEDIA COMPARISONS-- X-10 SITE SUMMARY

| Material                         | Pathway  | Dose (Sv/yr) | Conversion (Risk/Sv)                         | Risk (1 year)        | % importance |
|----------------------------------|--|--------------|--|----------------------|--------------|
| <b>Radionuclides (continued)</b> |  |              |  |                      |              |
| Iodine-133                       | Air to Vegetables to Humans (Ingestion)                        | 1.49E-03     | 7.3%   | 1.09E-04             |              |
|                                  | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 1.51E-03     | 7.3%   | 1.10E-04             |              |
|                                  | Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 5.13E-03     | 7.3%   | 3.74E-04             |              |
|                                  |  |              | Total Risk (Air) =<br>Total Risk =           | 5.93E-04<br>5.93E-04 | 100%         |
| Krypton-85                       | Air to Humans (Immersion)                                      | 6.18E-11     | 7.3%   | 4.51E-12             |              |
|                                  |  |              | Total Risk (Air) =<br>Total Risk =           | 4.51E-12<br>4.51E-12 | 100%         |
| Lanthanum-140                    | Air to Humans (Inhalation)                                     | 2.80E-08     | 7.3%   | 2.04E-09             |              |
|                                  | Air to Humans (Immersion)                                      | 1.08E-08     | 7.3%   | 7.88E-10             |              |
|                                  | Air to Vegetables to Humans (Ingestion)                        | 7.16E-07     | 7.3%   | 5.23E-08             |              |
|                                  | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 3.04E-08     | 7.3%   | 2.22E-09             |              |
|                                  | Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 9.99E-09     | 7.3%   | 7.29E-10             |              |
|                                  |  |              | Total Risk (Air) =<br>Total Risk =           | 5.80E-08<br>5.80E-08 | 100%         |
| Niobium-95                       | Air to Vegetables to Humans (Ingestion)                        | 1.35E-06     | 7.3%   | 9.86E-08             |              |
|                                  | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 4.78E-05     | 7.3%   | 3.49E-06             |              |
|                                  | Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 9.44E-06     | 7.3%   | 6.89E-07             |              |
|                                  |  |              | Total Risk (Air) =                           | 4.28E-06             | 100%         |
|                                  | Water to Humans (Ingestion)                                    | 4.34E-09     | 7.3%   | 3.17E-10             |              |
|                                  | Water to Fish to Humans (Ingestion)                            | 1.16E-08     | 7.3%   | 8.47E-10             |              |
|                                  |  |              | Total Risk (Surface Water) =                 | 1.16E-09             | <1%          |
|                                  | Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.06E-07     | 7.3%   | 7.74E-09             |              |
|                                  | Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.30E-08     | 7.3%   | 1.68E-09             |              |
|                                  | Soil to Vegetation to Humans (Ingestion)                       | 2.85E-08     | 7.3%   | 2.08E-09             |              |
| Plutonium-238                    | Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 5.43E-09     | 7.3%   | 3.96E-10             |              |
|                                  | Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.07E-09     | 7.3%   | 7.81E-11             |              |
|                                  | Soil to Humans (Ground Exposure)                               | 5.50E-09     | 7.3%   | 4.02E-10             |              |
|                                  |  |              | Total Risk (Soil) =<br>Total Risk =          | 1.24E-08<br>4.29E-06 | <1%          |
| Plutonium-238                    | Water to Fish to Humans (Ingestion)                            | 2.35E-07     | 7.3%   | 1.72E-08             |              |
|                                  |  |              | Total Risk (Surface Water) =<br>Total Risk = | 1.72E-08<br>1.72E-08 | 100%         |

TABLE I-2: BETWEEN-MEDIA COMPARISONS-- X-10 SITE SUMMARY

| Material  | Pathway  | Dose (Sv/yr)                 | Conversion (Risk/Sv)         | Risk (1 year) | % Importance |
|---|--|------------------------------|------------------------------|---------------|--------------|
| <i>Radionuclides (continued)</i><br>Plutonium-239 | Air to Humans (Inhalation)                                     | 6.56E-07                     | 7.3%                         | 4.79E-08      |              |
|   | Air to Vegetables to Humans (Ingestion)                        | 7.76E-08                     | 7.3%                         | 5.66E-09      |              |
|   |  |                              | Total Risk (Air) =           | 5.36E-08      | 100%         |
|   | Water to Fish to Humans (Ingestion)                            | 2.59E-07                     | 7.3%                         | 1.89E-08      | 35%          |
|   |  | Total Risk (Surface Water) = | 1.89E-08                     |               |              |
|   |  | Total Risk =                 | 7.25E-08                     |               |              |
| Protactinium-233                                  | Air to Humans (Inhalation)                                     | 1.79E-05                     | 7.3%                         | 1.31E-06      |              |
|   | Air to Vegetables to Humans (Ingestion)                        | 1.02E-04                     | 7.3%                         | 7.45E-06      |              |
|   |  |                              | Total Risk (Air) =           | 8.75E-06      | 100%         |
|   |  |                              | Total Risk =                 | 8.75E-06      |              |
| Ruthenium-103                                     | Air to Humans (Inhalation)                                     | 5.32E-08                     | 7.3%                         | 3.88E-09      |              |
|   | Air to Vegetables to Humans (Ingestion)                        | 2.52E-07                     | 7.3%                         | 1.84E-08      |              |
|   | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 7.13E-08                     | 7.3%                         | 5.20E-09      |              |
|   |  |                              | Total Risk (Air) =           | 2.76E-08      | 13%          |
|   | Water to Humans (Ingestion)                                    | 2.07E-06                     | 7.3%                         | 1.51E-07      |              |
|   | Water to Fish to Humans (Ingestion)                            | 8.42E-07                     | 7.3%                         | 6.15E-08      |              |
|   |  |                              | Total Risk (Surface Water) = | 2.13E-07      | 100%         |
|   |  |                              | Total Risk =                 | 8.61E-10      |              |
|   |  |                              |                              | 1.03E-09      |              |
|   |  |                              |                              | 2.23E-08      |              |
| Ruthenium-106                                     | Soil to Humans (Ingestion)                                     | 1.18E-08                     | 7.3%                         | 8.61E-10      |              |
|   | Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.41E-08                     | 7.3%                         | 1.03E-09      |              |
|   | Soil to Vegetation to Humans (Ingestion)                       | 3.06E-07                     | 7.3%                         | 2.23E-08      |              |
|   | Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.07E-08                     | 7.3%                         | 2.24E-09      |              |
|   | Soil to Humans (Ground Exposure)                               | 4.90E-08                     | 7.3%                         | 3.58E-09      |              |
|   |  |                              | Total Risk (Soil) =          | 3.00E-08      | 14%          |
|   |  |                              | Total Risk =                 | 2.70E-07      |              |
|   |  |                              |                              | 5.86E-09      |              |
|   |  |                              |                              | 4.95E-09      |              |
|   |  |                              |                              | 1.40E-09      |              |
|   |  | Total Risk (Air) =           | 1.22E-08                     | <1%           |              |
|   |  |                              | 5.98E-06                     |               |              |
|   |  |                              | 1.08E-06                     |               |              |
|   |  | Total Risk (Surface Water) = | 7.06E-06                     | 100%          |              |
|   |  |                              | 5.93E-09                     |               |              |
|   |  |                              | 1.76E-08                     |               |              |
|   |  |                              | 2.10E-08                     |               |              |
|   |  |                              | 4.56E-07                     |               |              |
|   |  |                              | 4.59E-08                     |               |              |
|   |  |                              | 5.71E-09                     |               |              |
|   |  | Total Risk (Soil) =          | 5.52E-07                     | 8%            |              |
|   |  | Total Risk =                 | 7.62E-06                     |               |              |

TABLE I-2: BETWEEN-MEDIA COMPARISONS-- X-10 SITE SUMMARY

| Material                         | Pathway  | Dose (Sv/yr)                 | Conversion (Risk/Sv) | Risk (1 Year) | % Importance |
|----------------------------------|--|------------------------------|----------------------|---------------|--------------|
| <b>Radionuclides (continued)</b> |  |                              |                      |               |              |
| Strontium-89                     | Air to Humans (Inhalation)                                     | 3.14E-07                     | 7.3%                 | 2.29E-08      |              |
|                                  | Air to Vegetables to Humans (Ingestion)                        | 1.10E-06                     | 7.3%                 | 8.03E-08      |              |
|                                  | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 4.68E-08                     | 7.3%                 | 3.42E-09      |              |
|                                  | Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 5.39E-07                     | 7.3%                 | 3.93E-08      |              |
|                                  |  | Total Risk (Air) =           |                      | 1.46E-07      | 100%         |
|                                  | Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 1.83E-09                     | 7.3%                 | 1.34E-10      |              |
|                                  | Soil to Vegetation to Humans (Ingestion)                       | 1.78E-07                     | 7.3%                 | 1.30E-08      |              |
|                                  | Soil to Pasture to Dairy Cattle (Milk) to Humans               | 4.47E-09                     | 7.3%                 | 3.26E-10      |              |
|                                  |  | Total Risk (Soil) =          |                      | 1.35E-08      | 9%           |
|                                  |  | Total Risk =                 |                      | 1.59E-07      |              |
| Strontium-90                     | Air to Humans (Inhalation)                                     | 2.37E-08                     | 7.3%                 | 1.73E-09      |              |
|                                  | Air to Vegetables to Humans (Ingestion)                        | 2.02E-07                     | 7.3%                 | 1.47E-08      |              |
|                                  | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 8.58E-09                     | 7.3%                 | 6.26E-10      |              |
|                                  | Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)    | 9.88E-08                     | 7.3%                 | 7.21E-09      |              |
|                                  |  | Total Risk (Air) =           |                      | 2.43E-08      | <1%          |
|                                  | Water to Human (Ingestion)                                     | 1.74E-04                     | 7.3%                 | 1.27E-05      |              |
|                                  | Water to Fish to Humans (Ingestion)                            | 1.17E-05                     | 7.3%                 | 8.54E-07      |              |
|                                  |  | Total Risk (Surface Water) = |                      | 1.36E-05      | 100%         |
|                                  | Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.93E-07                     | 7.3%                 | 2.14E-08      |              |
|                                  | Soil to Vegetation to Humans (Ingestion)                       | 2.86E-05                     | 7.3%                 | 2.09E-06      |              |
| Tritium                          | Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 4.08E-07                     | 7.3%                 | 2.98E-08      |              |
|                                  | Soil to Pasture to Dairy Cattle (Milk) to Humans               | 4.70E-06                     | 7.3%                 | 3.43E-07      |              |
|                                  |  | Total Risk (Soil) =          |                      | 2.48E-06      | 18%          |
|                                  |  | Total Risk =                 |                      | 1.61E-05      |              |
|                                  |  |                              |                      |               |              |
|                                  |  |                              |                      |               |              |
|                                  |  |                              |                      |               |              |
|                                  |  |                              |                      |               |              |
|                                  |  |                              |                      |               |              |
|                                  |  |                              |                      |               |              |
| Uranium-234/235                  | Air to Humans (Inhalation)                                     | 9.22E-09                     | 7.3%                 | 6.73E-10      |              |
|                                  | Air to Vegetables to Humans (Ingestion)                        | 2.70E-10                     | 7.3%                 | 1.97E-11      |              |
|                                  |  | Total Risk (Air) =           |                      | 6.93E-10      | <1%          |
|                                  | Water to Humans (Ingestion)                                    | 1.99E-05                     | 7.3%                 | 1.45E-06      |              |
|                                  | Water to Fish to Humans (Ingestion)                            | 1.36E-07                     | 7.3%                 | 9.93E-09      |              |
|                                  |  | Total Risk (Surface Water) = |                      | 1.46E-06      | 100%         |
|                                  | Soil to Air to Humans (Inhalation)                             | 4.84E-07                     | 7.3%                 | 3.53E-08      |              |
|                                  | Soil to Humans (Ingestion)                                     | 4.96E-08                     | 7.3%                 | 3.62E-09      |              |
|                                  | Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 2.96E-08                     | 7.3%                 | 2.16E-09      |              |
|                                  | Soil to Vegetation to Humans (Ingestion)                       | 8.44E-07                     | 7.3%                 | 6.16E-08      |              |
|                                  | Total Risk (Soil) =  |                              | 1.03E-07             | 7%            |              |
|                                  | Total Risk =   |                              | 1.57E-06             |               |              |

TABLE I-2: BETWEEN-MEDIA COMPARISONS-- X-10 SITE SUMMARY

| Material  | Pathway   | Dose (S/yr)                  | Conversion (Risk/Sv)         | Risk (1 year) | % Importance |
|---|---|------------------------------|------------------------------|---------------|--------------|
| <b>Radionuclides (continued)</b>                    | Air to Humans (Inhalation)                                    | 1.20E-06                     | 7.3%                         | 8.76E-08      |              |
|   | Air to Vegetables to Humans (Ingestion)                       | 3.40E-08                     | 7.3%                         | 2.48E-09      |              |
|   |   |                              | Total Risk (Air) =           | 9.01E-08      | 7%           |
|   | Water to Humans (Ingestion)                                   | 1.76E-05                     | 7.3%                         | 1.28E-06      |              |
|   | Water to Fish to Humans (Ingestion)                           | 6.97E-08                     | 7.3%                         | 5.09E-09      |              |
|   |   |                              | Total Risk (Surface Water) = | 1.29E-06      | 100%         |
|   | Soil to Air to Humans (Inhalation)                            | 3.79E-07                     | 7.3%                         | 2.77E-08      |              |
|   | Soil to Humans (Ingestion)                                    | 3.77E-08                     | 7.3%                         | 2.75E-09      |              |
|   | Soil to Dairy Cattle (Milk) to Humans (Ingestion)             | 2.25E-08                     | 7.3%                         | 1.64E-09      |              |
|   | Soil to Vegetation to Humans (Ingestion)                      | 6.51E-07                     | 7.3%                         | 4.75E-08      |              |
|   |   | Total Risk (Soil) =          | 7.96E-08                     | 6%            |              |
|   |   | Total Risk =                 | 1.46E-06                     |               |              |
| <b>Xenon-133</b>                                    | Air to Humans (Immersion)                                     | 2.11E-07                     | 7.3%                         | 1.54E-08      |              |
|   |   |                              | Total Risk (Air) =           | 1.54E-08      | 100%         |
|   |   |                              | Total Risk =                 | 1.54E-08      |              |
| <b>Zirconium-95</b>                                 | Air to Humans (Inhalation)                                    | 2.88E-07                     | 7.3%                         | 2.10E-08      |              |
|   | Air to Humans (Immersion)                                     | 8.71E-09                     | 7.3%                         | 6.36E-10      |              |
|   | Air to Vegetables to Humans (Ingestion)                       | 6.36E-07                     | 7.3%                         | 4.64E-08      |              |
|   | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 4.94E-07                     | 7.3%                         | 3.61E-08      |              |
|   | Air to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 6.65E-09                     | 7.3%                         | 4.85E-10      |              |
|   |   |                              | Total Risk (Air) =           | 1.05E-07      | 100%         |
|   | Water to Humans (Ingestion)                                   | 7.02E-09                     | 7.3%                         | 5.12E-10      |              |
|   | Water to Livestock/Game (Beef) to Humans (Ingestion)          | 7.12E-11                     | 7.3%                         | 5.20E-12      |              |
|   | Water to Fish to Humans (Ingestion)                           | 1.87E-08                     | 7.3%                         | 1.37E-09      |              |
|   | Water to Humans (Recreational-- Immersion)                    | 1.20E-10                     | 7.3%                         | 8.76E-12      |              |
|   |   | Total Risk (Surface Water) = | 1.89E-09                     | 2%            |              |
| Soil to Air to Humans (Inhalation)                  | 1.49E-10  | 7.3%                         | 1.09E-11                     |               |              |
| Soil to Humans (Ingestion)                          | 1.15E-09  | 7.3%                         | 8.40E-11                     |               |              |
| Soil to Livestock/Game (Beef) to Humans (Ingestion) | 3.79E-09  | 7.3%                         | 2.77E-10                     |               |              |
| Soil to Vegetation to Humans (Ingestion)            | 4.61E-09  | 7.3%                         | 3.37E-10                     |               |              |
| Soil to Humans (Ground Exposure)                    | 8.13E-09  | 7.3%                         | 5.93E-10                     |               |              |
|   |   | Total Risk (Soil) =          | 1.30E-09                     | 1%            |              |
|   |   | Total Risk =                 | 1.08E-07                     |               |              |

TABLE I-3: BETWEEN-MEDIA COMPARISONS-- Y-12 SITE SUMMARY

| Material                              | Pathway   | Dose (Sv/yr)                                       | Conversion (Risk/Sv) | Risk (1 year)        | % Importance |
|---------------------------------------|---|--|----------------------|----------------------|--------------|
| <b>Radionuclides</b><br>Plutonium-238 | Soil to Air to Humans (Inhalation)                | 9.42E-09   | 7.3%                 | 6.88E-10             |              |
|                                       | Soil to Humans (Ingestion)                        | 3.86E-09   | 7.3%                 | 2.82E-10             |              |
|                                       | Soil to Vegetables to Humans (Ingestion)          | 3.48E-09   | 7.3%                 | 2.54E-10             |              |
|                                       |   | Total Risk (Soil) =<br>Total Risk =                |                      | 1.22E-09<br>1.22E-09 |              |
| Technetium-99                         | Surface Water to Fish to Humans (Ingestion)       | 1.49E-07   | 7.3%                 | 1.09E-08             |              |
|                                       |   | Total Risk (Surface Water) =<br>Total Risk =       |                      | 1.09E-08<br>1.09E-08 | 100%         |
| Thorium-232                           | Soil to Air to Humans (Inhalation)                | 2.83E-05   | 7.3%                 | 2.07E-06             |              |
|                                       | Soil to Humans (Ingestion)                        | 2.57E-06   | 7.3%                 | 1.88E-07             |              |
|                                       | Soil to Vegetables to Humans (Ingestion)          | 4.36E-06   | 7.3%                 | 3.18E-07             |              |
|                                       |   | Total Risk (Soil) =<br>Total Risk =                |                      | 2.57E-06<br>2.57E-06 | 100%         |
| Uranium-234/235                       | Air to Humans (Inhalation)                        | 8.51E-05   | 7.3%                 | 6.21E-06             |              |
|                                       | Air to Vegetables to Humans (Ingestion)           | 2.49E-06   | 7.3%                 | 1.82E-07             |              |
|                                       |   |  |                      | 6.39E-06             | 55%          |
|                                       |   | Total Risk (Air) =<br>Total Risk (Surface Water) = |                      | 1.17E-05<br>1.17E-05 | 100%         |
| Uranium-238                           | Surface Water to Fish to Humans (Ingestion)       | 1.60E-04   | 7.3%                 | 9.93E-08             |              |
|                                       | Soil to Air to Humans (Inhalation)                | 1.36E-06   | 7.3%                 | 1.01E-08             |              |
|                                       | Soil to Humans (Ingestion)                        | 1.39E-07   | 7.3%                 | 6.07E-09             |              |
|                                       | Soil to Dairy Cattle (Milk) to Humans (Ingestion) | 8.32E-08   | 7.3%                 | 1.73E-07             |              |
|                                       | Soil to Vegetables to Humans (Ingestion)          | 2.37E-06   | 7.3%                 | 2.89E-07             |              |
|                                       |   | Total Risk (Soil) =<br>Total Risk =                |                      | 1.84E-05             | 2%           |
| Uranium-238                           | Air to Humans (Inhalation)                        | 4.21E-05   | 7.3%                 | 3.07E-06             |              |
|                                       | Air to Vegetables to Humans (Ingestion)           | 1.19E-06   | 7.3%                 | 8.69E-08             |              |
|                                       |   |  |                      | 3.16E-06             | 31%          |
|                                       |   | Total Risk (Air) =<br>Total Risk (Surface Water) = |                      | 1.03E-05<br>1.03E-05 | 100%         |
| Uranium-238                           | Surface Water to Fish to Humans (Ingestion)       | 1.41E-04   | 7.3%                 | 1.07E-06             |              |
|                                       | Soil to Air to Humans (Inhalation)                | 1.47E-05   | 7.3%                 | 1.07E-06             |              |
|                                       | Soil to Humans (Ingestion)                        | 1.47E-06   | 7.3%                 | 1.07E-07             |              |
|                                       | Soil to Dairy Cattle (Milk) to Humans (Ingestion) | 8.74E-07   | 7.3%                 | 6.38E-08             |              |
|                                       | Soil to Vegetables to Humans (Ingestion)          | 2.49E-05   | 7.3%                 | 1.82E-06             |              |
|                                       |   | Total Risk (Soil) =<br>Total Risk =                |                      | 3.06E-06<br>1.65E-05 | 30%          |

TABLE I-3: BETWEEN-MEDIA COMPARISONS-- Y-12 SITE SUMMARY

| Material                      | Pathway  | Lifetime Risk                | Conversion (yr/lifetime)            | Risk (1 year)                    | % Importance |
|-------------------------------|--|------------------------------|-------------------------------------|----------------------------------|--------------|
| <b>Carcinogenic Chemicals</b> |  |                              |                                     |                                  |              |
| Beryllium                     | Soil to Air to Humans (Inhalation)                             | 7.02E-08                     | 70                                  | 1.00E-09                         |              |
|                               | Soil to Humans (Ingestion)                                     | 1.84E-06                     | 70                                  | 2.63E-08                         |              |
|                               | Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 1.10E-06                     | 70                                  | 1.57E-08                         |              |
|                               | Soil to Vegetables to Humans (Ingestion)                       | 3.69E-06                     | 70                                  | 5.27E-08                         |              |
|                               | Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 2.68E-07                     | 70                                  | 3.83E-09                         |              |
|                               | Soil to Humans (Dermal Contact)                                | 1.07E-06                     | Total Risk (Soil) =<br>Total Risk = | 1.53E-08<br>1.15E-07<br>1.15E-07 | 100%         |
| Carbon Tetrachloride          | Air to Humans (Inhalation)                                     | 4.32E-05                     | 70                                  | 6.17E-07                         | 100%         |
|                               |  |                              | Total Risk (Air) =<br>Total Risk =  | 6.17E-07<br>6.17E-07             |              |
| Methylene Chloride            | Air to Humans (Inhalation)                                     | 2.55E-06                     | 70                                  | 3.64E-08                         | 100%         |
|                               |  |                              | Total Risk (Air) =<br>Total Risk =  | 3.64E-08<br>3.64E-08             |              |
|                               |  |                              |                                     |                                  |              |
| PCBs                          | Surface Water to Fish to Humans (Ingestion)                    | 4.21E-03                     | 70                                  | 6.01E-05                         | 100%         |
|                               |  | Total Risk (Surface Water) = | 6.01E-05                            | 6.01E-05                         |              |
|                               | Soil to Humans (Ingestion)                                     | 1.87E-05                     | 70                                  | 2.67E-07                         |              |
|                               | Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 5.60E-04                     | 70                                  | 8.00E-06                         |              |
|                               | Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 3.02E-04                     | 70                                  | 4.31E-06                         |              |
|                               | Soil to Vegetables to Humans (Ingestion)                       | 1.05E-04                     | 70                                  | 1.50E-06                         |              |
|                               | Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 3.80E-05                     | 70                                  | 5.43E-07                         |              |
|                               | Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 1.88E-05                     | 70                                  | 2.69E-07                         |              |
|                               | Soil to Humans (Dermal Contact)                                | 1.08E-05                     | 70                                  | 1.54E-07                         | 25%          |
|                               |  |                              | Total Risk (Soil) =<br>Total Risk = | 1.50E-05<br>7.52E-05             |              |
| Tetrachloroethylene           | Air to Humans (Inhalation)                                     | 1.56E-06                     | 70                                  | 2.23E-08                         | 100%         |
|                               |  |                              | Total Risk (Air) =<br>Total Risk =  | 2.23E-08<br>2.23E-08             |              |
|                               |  |                              |                                     |                                  |              |
| Trichloroethylene             | Air to Humans (Inhalation)                                     | 2.51E-10                     | 70                                  | 3.59E-12                         | 100%         |
|                               |  |                              | Total Risk (Air) =<br>Total Risk =  | 3.59E-12<br>3.59E-12             |              |
|                               |  |                              |                                     |                                  |              |

TABLE I-3: BETWEEN-MEDIA COMPARISONS-- Y-12 SITE SUMMARY

| Material   | Pathway  | Hazard Index                          | % Importance |
|--|--|---------------------------------------|--------------|
| <b>Noncarcinogenic Chemicals</b><br>Chromium (III) | Surface Water to Livestock/Game (Beef) to Humans (Ingestion)   | 1.40E-04                              |              |
|  | Surface Water to Fish to Humans (Ingestion)                    | 4.50E-05                              |              |
|  |  | <b>Total Hazard (Surface Water) =</b> |              |
|  | Soil to Humans (Ingestion)                                     | 1.85E-04                              | 20%          |
|  | Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 7.86E-05                              |              |
|  | Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 4.33E-04                              |              |
|  | Soil to Vegetables to Humans (Ingestion)                       | 1.39E-04                              |              |
|  | Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 1.26E-04                              |              |
|  | Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 7.87E-05                              |              |
|  | Soil to Humans (Dermal Contact)                                | 2.32E-05                              |              |
|  | <b>Total Hazard (Soil) =</b>                                   |                                       |              |
|  | <b>Total Hazard =</b>  |                                       |              |
|  |  |                                       | 100%         |
| Lead   | Surface Water to Fish to Humans (Ingestion)                    | 5.28E-02                              |              |
|  |  | 5.28E-02                              | 6%           |
|  |  | 6.63E-02                              |              |
|  | Soil to Humans (Ingestion)                                     | 1.59E-02                              |              |
|  | Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 2.78E-02                              |              |
|  | Soil to Dairy Cattle (Milk) to Humans (Ingestion)              | 6.63E-01                              |              |
|  | Soil to Vegetables to Humans (Ingestion)                       | 1.73E-02                              |              |
|  | Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 2.78E-02                              |              |
|  | Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)   | 3.85E-02                              |              |
|  | Soil to Humans (Dermal Contact)                                | 8.57E-01                              |              |
|  | <b>Total Hazard (Soil) =</b>                                   |                                       |              |
|  | <b>Total Hazard =</b>  |                                       |              |
|  |  |                                       | 100%         |
| Mercury  | Air to Humans (Inhalation)                                     | 8.22E-03                              |              |
|  | Air to Vegetables to Humans (Ingestion)                        | 1.20E-01                              |              |
|  | Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion)  | 4.59E-01                              |              |
|  |  | <b>Total Hazard (Air) =</b>           |              |
|  | Surface Water to Fish to Humans (Ingestion)                    | 5.87E-01                              | <1%          |
|  |  | 2.89E+00                              | <1%          |
|  |  | 2.89E+00                              |              |
|  | Soil to Livestock/Game (Beef) to Humans (Ingestion)            | 4.04E+01                              |              |
|  | Soil to Vegetables to Humans (Ingestion)                       | 4.50E+02                              |              |
|  | Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion) | 8.82E+02                              |              |
|  | <b>Total Hazard (Soil) =</b>                                   |                                       |              |
|  | <b>Total Hazard =</b>  |                                       |              |
|  |  |                                       | 100%         |
| 1,1,1-Trichloroethane                              | Air to Humans (Inhalation)                                     | 1.37E+03                              |              |
|  |  | 1.38E+03                              |              |
|  |  | 3.18E-04                              |              |
|  | <b>Total Hazard (Air) =</b>                                    |                                       |              |
|  | <b>Total Hazard =</b>  |                                       |              |
|  |  |                                       | 100%         |



Tennessee Department of Health  
Authorization No. 343286 No. of Copies: 1,200  
This Public Document was promulgated at a cost of \$4.59 per copy. 8-93

Preparation and publication of this report were totally supported by grant number DE-FG-05-910R21981 awarded to the State of Tennessee by the U.S. Department of Energy. However, this support does not constitute an official endorsement from the Department of Energy of the views expressed in the report.