OAK RIDGE HEALTH STUDIES

PHASE 1 REPORT

Oak Ridge Health Agreement Steering Panel

VOLUME II - PART B
DOSE RECONSTRUCTION FEASIBLITY 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

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Volume II - Part B - Dose Reconstruction Feasibility Study

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

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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

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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

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

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
Radionuclides	
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
Nonradioactive Metals	
Lithium	Y-12 Lithium Separation and Enrichment
Organics	
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 μm. 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 (μm)	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 μm) 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^3, pCi/L, or pCi/kg).
U	=	Intake rate [breathing rate (m^3/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^3 for a radionuclide in air, 1 $\mu g/L$ 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 $(mg/kg\text{-}day)^{-1}$, 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, deliniates 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	$B_{(veg)}$ (unitless)	$B_{(pasture)}$ (unitless)	F_m (day/L)	F_f (day/kg)	BCF (pCi/kg)/(pCi/L) or (mg/kg)/(mg/L)	PC (cm/hr)
RADIONUCLIDES						
Argon-41	0.0 [a]	0.0 [a]	0.0 [a]	0.0 [a]	1.0 [b]	NA
Cerium-144	8.4×10^{-04} [c]	9.0×10^{-03} [c]	6.0×10^{-05} [c]	7.5×10^{-04} [a,c]	$1.25 \times 10^{+02}$ [d]	NA
Cesium-137	2.6×10^{-02} [c]	1.4×10^{-01} [c]	7.1×10^{-03} [c]	2.0×10^{-02} [a,c]	$5.6 \times 10^{+03}$ [d]	NA
Cobalt-60	2.0×10^{-02} [a]	3.0×10^{-03} [c]	2.9×10^{-03} [c]	9.7×10^{-03} [c]	$1.25 \times 10^{+02}$ [d]	NA
Iodine-129	3.4×10^{-02} [c]	1.8×10^{-01} [c]	9.9×10^{-03} [c]	7.2×10^{-03} [c]	$4.4 \times 10^{+01}$ [d]	NA
Iodine-131	3.4×10^{-02} [c]	1.8×10^{-01} [c]	9.9×10^{-03} [c]	7.2×10^{-03} [c]	$4.4 \times 10^{+01}$ [d]	NA
Iodine-133	3.4×10^{-02} [c]	1.8×10^{-01} [c]	9.9×10^{-03} [c]	7.2×10^{-03} [c]	$4.4 \times 10^{+01}$ [d]	NA
Krypton-85	0.0 [a]	0.0 [a]	0.0 [a]	0.0 [a]	1.0 [b]	NA
Lanthanum-140	1.7×10^{-03} [a]	1.0×10^{-02} [a]	2.0×10^{-05} [a]	3.0×10^{-04} [a]	$2.5 \times 10^{+01}$ [j]	NA
Neptunium-237	1.0×10^{-01} [a]	4.3×10^{-03} [a]	5.0×10^{-06} [a]	5.5×10^{-05} [a]	$1.0 \times 10^{+04}$ [b]	NA
Niobium-95	2.0×10^{-02} [a]	2.1×10^{-03} [a]	2.0×10^{-02} [a]	2.5×10^{-01} [a,c]	$3.0 \times 10^{+04}$ [b]	NA
Plutonium-238	4.5×10^{-04} [a]	9.0×10^{-04} [c]	1.0×10^{-07} [a,c]	1.0×10^{-06} [c]	8.0 [d]	NA
Plutonium-239/240	4.5×10^{-04} [a]	9.0×10^{-04} [c]	1.0×10^{-07} [a,c]	1.0×10^{-06} [c]	8.0 [d]	NA
Plutonium-241	4.5×10^{-04} [a]	9.0×10^{-04} [c]	1.0×10^{-07} [a,c]	1.0×10^{-06} [c]	8.0 [d]	NA
Protactinium-233	2.5×10^{-03} [a]	1.1×10^{-04} [a]	5.0×10^{-06} [a]	1.0×10^{-05} [a]	$1.0 \times 10^{+01}$ [b]	NA
Ruthenium-103	1.3×10^{-02} [c]	9.0×10^{-02} [c]	3.3×10^{-06} [c]	2.0×10^{-03} [a,c]	$1.9 \times 10^{+01}$ [d]	NA
Ruthenium-106	1.3×10^{-02} [c]	9.0×10^{-02} [c]	3.3×10^{-06} [c]	2.0×10^{-03} [a,c]	$1.9 \times 10^{+01}$ [d]	NA
Strontium-89	1.1×10^{-01} [c]	1.1×10^{-01} [a]	1.4×10^{-03} [c]	3.0×10^{-04} [a,c]	$2.8 \times 10^{+01}$ [d]	NA
Strontium-90	1.1×10^{-01} [c]	7.2×10^{-01} [c]	1.4×10^{-03} [c]	3.0×10^{-04} [a,c]	$2.8 \times 10^{+01}$ [d]	NA
Technetium-99	6.4×10^{-01} [a]	9.5 [a]	1.0×10^{-02} [a]	8.5×10^{-03} [a]	$7.8 \times 10^{+01}$ [d]	NA
Thorium-232	8.5×10^{-04} [a]	3.6×10^{-05} [a]	5.0×10^{-06} [a]	6.0×10^{-06} [a]	$8.0 \times 10^{+01}$ [d]	NA
Uranium-234/235	8.5×10^{-03} [a]	1.7×10^{-03} [a]	3.7×10^{-04} [c]	2.0×10^{-04} [a]	7.5 [d]	NA
Uranium-238	8.5×10^{-03} [a]	1.7×10^{-03} [a]	3.7×10^{-04} [c]	2.0×10^{-04} [a]	7.5 [d]	NA

TABLE 4-1

PHYSICAL CONSTANTS FOR CONTAMINANTS RELEASED FROM THE OAK RIDGE RESERVATION

Material	$B_{(veg)}$ (unitless)	$B_{(pasture)}$ (unitless)	F_m (day/L)	F_f (day/kg)	BCF (pCi/kg)/(pCi/L) or (mg/kg)/(mg/L)	PC (cm/hr)
Xenon-133	0.0 [a]	0.0 [a]	0.0 [a]	0.0 [a]	1.0 [b]	NA
Zirconium-95	2.0×10^{-03} [a]	2.1×10^{-04} [a]	3.0×10^{-05} [a,c]	5.5×10^{-03} [a]	2.6 [d]	NA
NONRADIOACTIVE METALS						
Arsenic	4.0×10^{-03} [e]	4.0×10^{-02} [a]	6.2×10^{-05} [e]	2.0×10^{-03} [e]	$4.4 \times 10^{+01}$ [f]	4.6×10^{-04} [g]
Beryllium	1.0×10^{-03} [e]	1.0×10^{-02} [a]	9.1×10^{-07} [c,e]	1.0×10^{-03} [e]	$1.9 \times 10^{+01}$ [f]	1.03×10^{-03} [g]
Chromium (III)	8.0×10^{-04} [e]	7.5×10^{-03} [a]	1.1×10^{-03} [c]	9.2×10^{-03} [c,e]	$1.6 \times 10^{+01}$ [f]	6.01×10^{-04} [g]
Chromium (VI)	8.0×10^{-04} [e]	7.5×10^{-03} [a]	1.1×10^{-05} [c]	9.2×10^{-03} [c,e]	$1.6 \times 10^{+01}$ [f]	6.01×10^{-04} [g]
Lead	5.0×10^{-03} [e]	4.5×10^{-02} [a]	2.6×10^{-04} [c,e]	4.0×10^{-04} [e]	$4.9 \times 10^{+01}$ [f]	7.98×10^{-05} [g]
Mercury	9.0×10^{-02} [e]	9.0×10^{-01} [a]	4.7×10^{-06} [c]	2.7×10^{-02} [e]	$5.5 \times 10^{+03}$ [f]	8.78×10^{-05} [g]
Nickel	6.0×10^{-03} [e]	6.0×10^{-02} [a]	1.0×10^{-03} [c,e]	2.0×10^{-03} [c,e]	$4.7 \times 10^{+01}$ [f]	5.6×10^{-04} [g]
ORGANIC						
Carbon Tetrachloride	NA	NA	3.5×10^{-06} [h]	1.1×10^{-05} [h]	$1.9 \times 10^{+01}$ [f]	NA
Methylene Chloride	NA	NA	1.4×10^{-07} [h]	4.5×10^{-07} [h]	NA	NA
Polychlorinated Biphenyls	2.8×10^{-03} [i]	2.8×10^{-03} [i]	1.0×10^{-02} [e]	5.0×10^{-02} [e]	$1.0 \times 10^{+05}$ [f]	1.1×10^{-02} [g]
Tetrachloroethylene	NA	NA	3.2×10^{-06} [h]	1.0×10^{-05} [h]	$1.1 \times 10^{+01}$ [f]	NA
1,1,1-Trichloroethane	NA	NA	2.5×10^{-06} [d]	7.9×10^{-06} [d]	5.6 [f]	NA
Trichloroethylene	NA	NA	1.9×10^{-06} [d]	6.0×10^{-06} [d]	$1.06 \times 10^{+01}$ [f]	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)
$B_{(veg)}$ = Concentration ratio for the transfer of a contaminant from dry soil to leafy vegetables (wet weight)
$B_{(pasture)}$ = Concentration ratio for the transfer of a contaminant from dry soil to pasture (dry weight)
F_m = Biotransfer factor from cattle intake to milk concentration
F_f = Biotransfer factor from cattle intake to meat concentration
BCF = Bioconcentration factor for fish
PC = Skin permeability constant

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TABLE 4-2

TOXICITY CRITERIA FOR CHEMICALS RELEASED FROM THE OAK RIDGE RESERVATION

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

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[a]

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

TABLE 4-3

COMMITTED EFFECTIVE DOSE EQUIVALENT FACTORS FOR INHALED AND INGESTED RADIONUCLIDES[a]

Nuclide	Adult Inhalation Committed Effective Dose Equivalent Factors (Sv/Bq inhaled)[b]	Adult Ingestion Committed Effective Dose Equivalent Factors (Sv/Bq ingested)
Xenon-133	NA	NA
Zirconium-95[c]	7.3×10^{-9} D	1.1×10^{-9}

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[a]

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

TABLE 4-4

EFFECTIVE DOSE EQUIVALENT RATE FACTORS FOR EXTERNAL EXPOSURE TO RADIONUCLIDES[a]

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

TABLE 4-4

EFFECTIVE DOSE EQUIVALENT RATE FACTORS FOR EXTERNAL EXPOSURE TO RADIONUCLIDES[a]

Radionuclide(s) *Bold values used in screening; others are intermediate values for parent-daughter chains.*	**Immersion in Contaminated Water** (Sv/y per Bq/cm^3)	**Immersion in Contaminated Air** (Sv/y per Bq/cm^3)	**Irradiation from Contaminated Ground Surface** (Sv/y per Bq/cm^2)
xenon-133	1.16×10^{-04}	4.91×10^{-02}	1.39×10^{-05}
yttrium-90	2.12×10^{-05}	1.99×10^{-02}	2.73×10^{-05}
zirconium-95	2.25×10^{-03}	1.04	2.05×10^{-04}
Zr-95 + Nb-95 daughter[k]	3.46×10^{-03}	1.61	3.15×10^{-04}

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 Ru-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

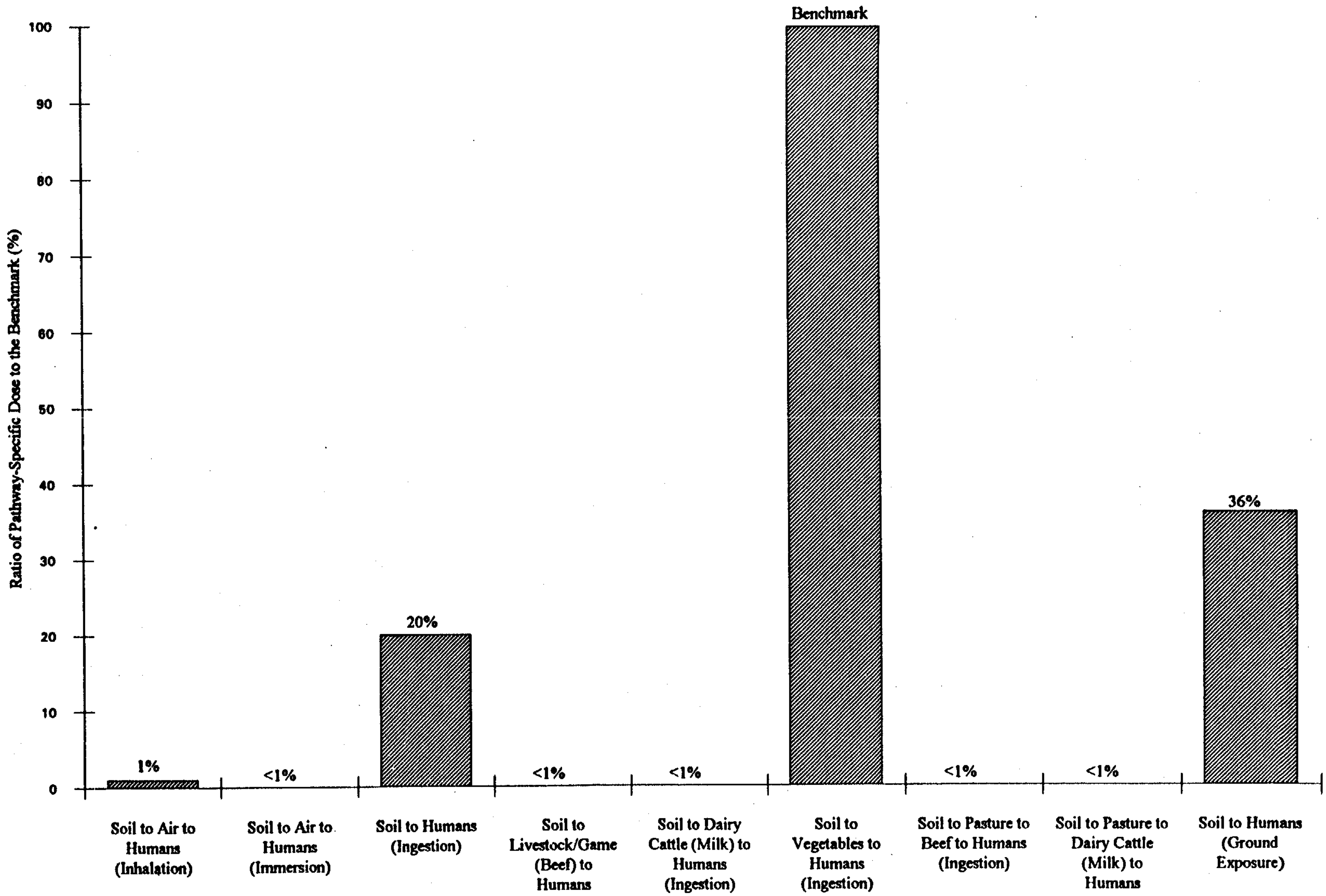

FIGURE 4-1
EVALUATION OF RELATIVE IMPORTANCE OF EXPOSURE PATHWAYS FOR PROTACTINIUM-233 IN SOIL/SEDIMENT

TABLE 4-5

COMPARISON OF COMPLETE EXPOSURE PATHWAYS WITHIN THE AIR MEDIUM

Pathway / Material	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)
RADIONUCLIDES							
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	✓	✓			■	✓	✓
NONRADIOACTIVE METALS							
Arsenic - (Carcinogenic)	■				✓	✓	✓
Arsenic - (Noncarcinogenic)	✓				■	✓	✓
Beryllium	✓				■	✓	
Chromium (III)	✓				✓	■	✓
Chromium (VI) - (Carcinogenic)	■						
Chromium (VI) - (Noncarcinogenic)					✓	■	✓
Lead	✓				■	✓	✓
Mercury	✓				✓	■	
Nickel	✓				■	✓	✓
ORGANICS							
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)
RADIONUCLIDES					
Barium-140	■			✓	✓
Cerium-144	✓			■	
Cesium-137				■	
Cobalt-60	✓			■	
Iodine-129	■	✓	✓	✓	
Iodine-131	■	✓	✓	✓	
Iodine-133	■	✓	✓	✓	
Lathanum-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)
NONRADIOACTIVE METALS					
Arsenic (Noncarcinogenic)	■			✓	
Arsenic (Carcinogenic)	■			✓	
Beryllium	■			✓	
Chromium (III)	■	✓		✓	
Chromium (VI)	■	✓		✓	
Lead	✓			■	
Mercury				■	
Nickel	✓			■	
ORGANICS					
Polychlorinated Biphenyls				■	

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

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TABLE 4-7

COMPARISON OF COMPLETE EXPOSURE PATHWAYS WITHIN THE SOIL/SEDIMENT MEDIUM

Pathway / Material	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)
RADIONUCLIDES									
Barium-140			✓		✓	■	✓	✓	✓
Cerium-144	✓		✓	✓	✓	■	✓	✓	✓
Cesium-137			✓	✓	✓	■	✓	✓	
Cobalt-60			✓	✓	✓	■	✓		✓
Iodine-129			✓	✓	✓	■	✓	✓	
Iodine-131			✓	✓	✓	■	✓	✓	
Iodine-133			✓	✓	✓	■	✓	✓	
Lathanium-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

Pathway Material	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	✓		✓	✓		✓			■
NONRADIOACTIVE METALS									
Arsenic (Noncarcinogenic)			✓	✓	✓	■	✓	✓	✓
Arsenic (Carcinogenic)	✓		✓	✓	✓	■	✓	✓	✓
Beryllium	✓		✓	✓		■	✓		✓
Chromium (III)			✓	■	✓	✓	✓	✓	✓
Chromium (VI) (Carcinogenic)	■								
Chromium (VI) (Noncarcinogenic)			✓	■	✓	✓	✓	✓	✓
Lead			✓	✓	✓	■	✓	✓	✓
Mercury				✓		✓	■		
Nickel			✓	✓	✓	■	✓	✓	✓
ORGANICS									
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 $(\chi/Q)^a$ (sec/m^3)	Predicted Air Concentration[a] (pCi/m^3)
Argon-41	170,000	1943-1963	5,400,000,000	1.0×10^{-8}	54
Barium-140	210[c]	1952	6,700,000	3.5×10^{-8}	0.23
Cerium-144	72[c]	1944	2,300,000	5.5×10^{-8}	0.13
Cesium-137	2.0[c]	1944	63,000	5.5×10^{-8}	0.0035
Cobalt-60	NA	NA	NA	NA	NA
Iodine-129	0.00049[d]	1944	16	5.5×10^{-8}	0.00000088
Iodine-131	67,000[d]	1952	2,100,000,000	3.5×10^{-8}	74
Iodine-133	71,000[d]	1947	2,300,000,000	5.5×10^{-8}	130
Krypton-85	350[b]	1957	11,000,000	5.5×10^{-8}	0.61
Lanthanum-140	130[c]	1947	4,100,000	5.5×10^{-8}	0.23
Niobium-95	270[c]	1944	8,600,000	5.5×10^{-8}	0.47
Plutonium-238	ND	ND	ND	NA	NA
Plutonium-239/240	0.031[c]	1944	980	5.5×10^{-8}	0.000054
Plutonium-241	ND	ND	ND	NA	NA
Protactinium-233	43,000[c]	1957	1,400,000,000	5.5×10^{-8}	77

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 (χ/Q)[a] (sec/m^3)	Predicted Air Concentration[a] (pCi/m^3)
Ruthenium-103	120[c]	1944	3,800,000	5.5×10^{-8}	0.21
Ruthenium-106	3.6[c]	1944	110,000	5.5×10^{-8}	0.0061
Strontium-89	180[c]	1944	5,700,000	5.5×10^{-8}	0.31
Strontium-90	2.2[c]	1944	70,000	5.5×10^{-8}	0.0039
Tritium	44,000	1987	1,400,000,000	3.5×10^{-8}	49
Uranium-234/235	0.0015[c]	1944	48	5.5×10^{-8}	0.0000026
Uranium-238	0.21[c]	1944	6,700	5.5×10^{-8}	0.00037
Xenon-133	180,000[b]	1947	5,700,000,000	5.5×10^{-8}	310
Zirconium-95	220[c]	1944	7,000,000	5.5×10^{-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 (χ/Q)[a] (sec/m^3)	Predicted Air Concentration[a] (pCi/m^3)
Neptunium-237	NA	NA	NA	NA	NA
Plutonium-239	NA	NA	NA	NA	NA
Technetium-99	6.8	1976	220,000	2.6×10^{-7}	0.057
Uranium-234/235	0.82	1958	26,000	2.6×10^{-7}	0.0068
Uranium-238	0.97	1958	31,000	2.6×10^{-7}	0.0081

Chemicals	Estimated Maximum Amount Released (kg/yr)	Year or Time Period of Maximum Release	Emission Rate (mg/sec)	Long-Term Dispersion Factor (χ/Q)[a] (sec/m^3)	Predicted Air Concentration[a] (mg/m^3)
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	2.6×10^{-7}	0.000015
Carbon Tetrachloride	32,000	1949 - 1952	1,000	2.6×10^{-7}	0.00026
Methylene Chloride	5,300	1983	170	2.6×10^{-7}	0.000044
Polychlorinated Biphenyls	ND	ND	ND	NA	NA
1,1,1-Trichloroethane	1,000,000	1980 - 1984	32,000	2.6×10^{-7}	0.0082
Trichloroethylene	37,000	mid 1951-mid 1952	1,200	2.6×10^{-7}	0.00031

NA = Not Applicable
ND = No Data
a 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 (χ/Q)[a] (sec/m^3)	Predicted Air Concentration[a] (pCi/m^3)
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	3.3×10^{-7}	0.024
Uranium-238	1.2	1956	38,000	3.3×10^{-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 (χ/Q)[a] (sec/m^3)	Predicted Air Concentration[a] (mg/m^3)
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	3.3×10^{-7}	0.000023
Carbon Tetrachloride	720,000	1944	23,000	3.3×10^{-7}	0.0076
Methylene Chloride	13,000	1982	410	3.3×10^{-7}	0.00014
Polychlorinated Biphenyls	ND	ND	ND	NA	NA
Tetrachloroethylene	690,000	1983	22,000	3.3×10^{-7}	0.0073
1,1,1-Trichloroethane	85,000	1982	2,700	3.3×10^{-7}	0.00089
Trichloroethylene	37	1980	1.2	3.3×10^{-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 (χ/Q) for each emission source at each plant. This factor is expressed in units of seconds per cubic meter (sec/m^3). For a given location, the predicted air concentration can be determined by multiplying the χ/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, χ/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 χ/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 χ/Q values. The average χ/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

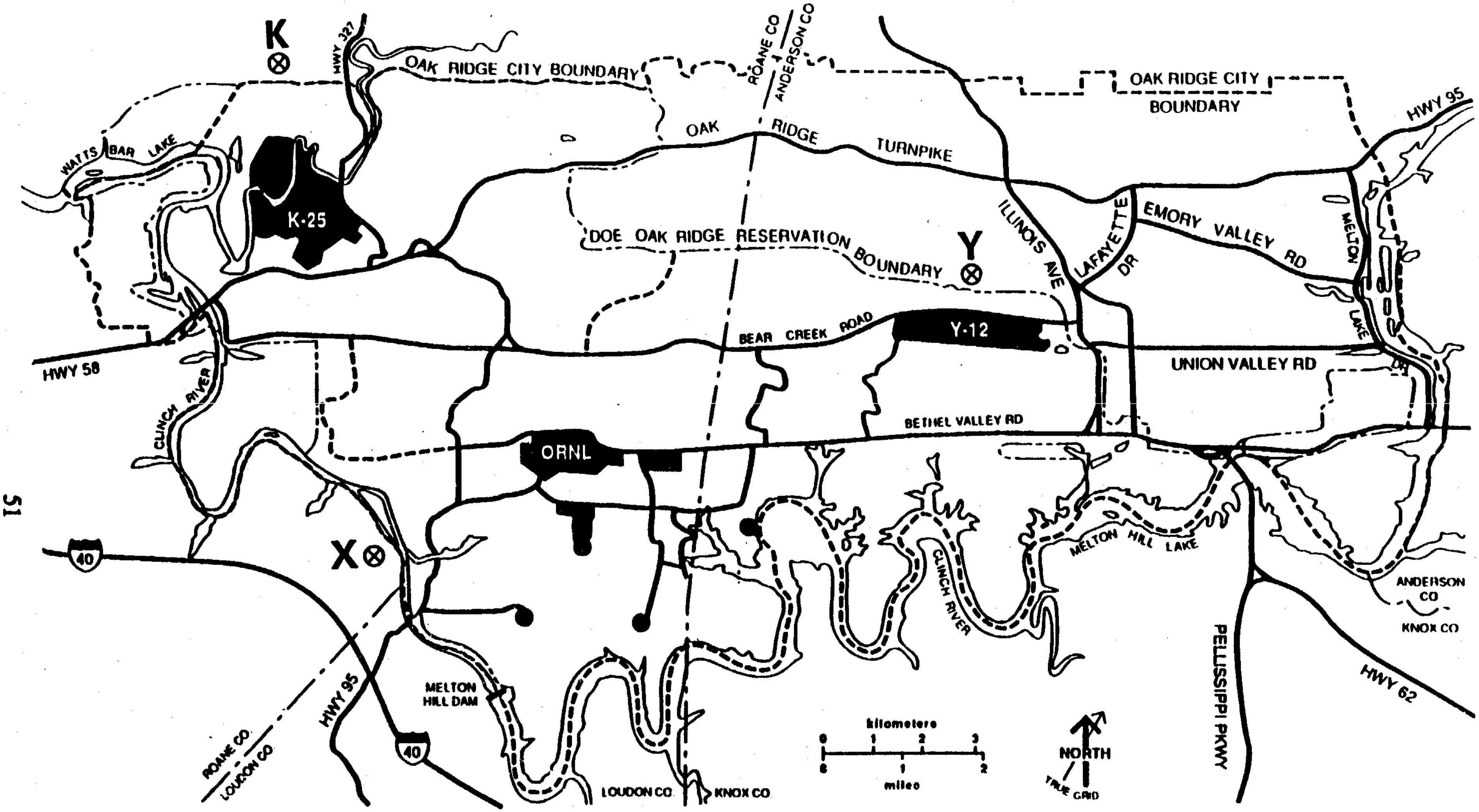
AIR DISPERSION MODEL INPUT PARAMETERS

Parameter	Value	Source/Rationale
X-10 CENTRAL STACK (BUILDING 3039)		
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)
X-10 CHEMICAL PROCESSING PLANT STACK (BUILDING 3020)		
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)
X-10 GRAPHITE REACTOR STACK		
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
K-25		
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)
Y-12		
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)



51

LEGEND

X Nearest resident to X-10

K Nearest resident to K-25

Y Nearest resident to Y-12

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

ChemRisk
A Division of McLaren/Hart

Rev. 08-31-93
OakRdg8-93/5-1

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; value for specific isotopes assumed to be the same as for total uranium.
Water	Uranium-238	21	pCi/L	1978	UCC, 1979	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)	0.06	mg/L	1972	UCC, 1973	Maximum reported value for total 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 fenceline 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[a]

Material	Air	Surface Water	Soil/Sediment
Radionuclides			
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[a]

Material	Air	Surface Water	Soil/Sediment
RADIONUCLIDES			
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%
CARCINOGENIC CHEMICALS			
Beryllium	ND	ND	■
Carbon Tetrachloride	■	NA	NA
Chromium(VI)	ND	ND	ND
Methylene Chloride	■	NA	NA
Polychlorinated Biphenyls	ND	■	ND
Trichloroethylene	■	NA	NA
NONCARCINOGENIC CHEMICALS			
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[a]

Material	Air	Surface Water	Soil/Sediment
RADIONUCLIDES			
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%
CARCINOGENIC CHEMICALS			
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
NONCARCINOGENIC CHEMICALS			
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[a]

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

TABLE 5-11

PRELIMINARY RANKING OF POTENTIAL HAZARDS[a]

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

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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 95×10^{-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^3), and

AH = absolute humidity (g_{water}/m^3_{air} or ml_{water}/m^3_{air}).

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 1×10^{-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 1.7×10^{-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 8×10^{-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).

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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 conjuction 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 conjuction with a risk conversion factor to estimate cancer risk.

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Air → Humans (Inhalation)

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

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

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^3 or pCi/m^3;

U_{air} = Average volume of air inhaled per day, m^3/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^3;

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^3/cm^3; and

DCF_{imm} = Effective dose equivalent rate factor for immersion in an infinite cloud, Sv - cm^3/Bq - year.

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^3 or pCi/m^3;
$Q_{air(b)}$	=	Daily inhalation rate of beef cattle, m^3/day; and
F_f	=	Biotransfer factor from cattle intake to meat concentration, (mg/kg)/(mg/day) or (pCi/kg)/(pCi/day).

Equation #2

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

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

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.

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^3 or pCi/m^3;

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

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

Equation #2

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

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

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.

Equation #1

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

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^3 or pCi/m^3;
$V_{D(veg)}$	=	Wet/Dry deposition velocity per unit mass of vegetation $[(m/day)/(kg/m^2)]$;
k_w	=	Weathering rate constant, day^{-1};
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

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

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

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.

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^3 or pCi/m^3;
R	=	Universal gas constant, atm-m^3/mole-°K;
T	=	Temperature, °K;
H	=	Henry's Law constant, atm-m^3/mole;
K_{ow}	=	Octanol-water partition coefficient, dimensionless;
Cf_1	=	Conversion factor, m^3/L; and
Cf_2	=	Conversion factor (density of water), L/kg.

Equation #2

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

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

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^3 or pCi/m^3;
$V_{D(past)}$	=	Wet/Dry deposition velocity per unit mass of vegetation $[(m/day)/(kg/m^2)]$;
k_w	=	Weathering rate constant, day^{-1}; 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.

Equation #3

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

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

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^3 or pCi/m^3;
R	=	Universal gas constant, atm-m^3/mole-°K;
T	=	Temperature, °K;
H	=	Henry's Law constant, atm-m^3/mole;
K_{ow}	=	Octanol-water partition coefficient, dimensionless;
Cf_1	=	Conversion factor, m^3/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

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

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

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.

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^3 or pCi/m^3;

$V_{D(past)}$ = Wet/Dry deposition velocity per unit mass of vegetation $[(m/day)/(kg/m^2)]$;

k_w = Weathering rate constant, day^{-1}; 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.

Equation #3

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

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

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.

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^3 or pCi/m^3;
R	=	Universal gas constant, atm-m^3/mole-°K;
T	=	Temperature, °K;
H	=	Henry's Law constant, atm-m^3/mole;
K_{ow}	=	Octanol-water partition coefficient, dimensionless;
Cf_1	=	Conversion factor, m^3/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.

Equation #3

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

$$I_{milk(past)} = C_{milk(past)} U_{milk} f_{cm}$$ (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)

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

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

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.

Equation #2

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

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

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

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

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

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

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

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

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.

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^3;
Cf_3	=	Conversion factor, days/hour; and
DCF_{imm}	=	Effective dose equivalent rate factor for immersion in contaminated water, Sv-cm^3/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

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

where:

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

Equation #2

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

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

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^3 or pCi/m^3;
U_{air}	=	Average volume of air inhaled per day, m^3/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.

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^3 or pCi/m^3;
A	=	Equilibrium concentration of contaminant on surface soil, mg/kg or pCi/kg;
M	=	Mass loading of particles in ambient air, mg/m^3;
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^3;
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^3/cm^3; and
$DCF_{(imm)}$	=	Effective dose equivalent rate factor for immersion in contaminated water, $Sv\text{-}cm^3/Bq\text{-}year$.

Air → Soil → Humans (Ingestion)

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

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

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

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

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

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.

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

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

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

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

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

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

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.

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_{bp} = Fraction of feed ingested by beef cattle that is pasture, dimensionless.

Equation #3

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

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

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.

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.

Equation #3

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

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

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^3;
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^2/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^3/cm^3.

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^2;
SL	=	Soil loading on skin, mg/cm^2-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
EXPOSURE PATHWAYS, GENERAL				
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
AIR EXPOSURE PATHWAYS				
Dry deposition velocity onto vegetation (iodine)	$V_{d\text{-iodine}}$	2	cm/sec	7
Dry deposition velocity onto vegetation (small particles)	$V_{d\text{-small particles}}$	0.1	cm/sec	7

APPENDIX C

EXPOSURE PARAMETERS

Parameter	Symbol	Value	Units	Reference
Dry deposition velocity onto vegetation (noble gases)	$V_{d\text{-noble gases}}$	1×10^{-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)	$V_{w\text{-iodine-small particles}}$	10	cm/sec	14
Wet deposition velocity (noble gases)	$V_{w\text{-noble gases}}$	0.01	cm/sec	Professional judgement
Biomass yield (vegetable crops)	Y_{veg}	2	kg/m^2 wet weight	11
Biomass yield (pasture)	Y_{past}	0.28	kg/m^2 wet weight	19
Total deposition onto vegetation (iodine)	$V_{D\text{-iodine}}$	1100 (veg) 7900 (past	$(m/day)/(kg/m^2)$	Footnote a
Total deposition onto vegetation (small particles)	$V_{D\text{-small particles}}$	385 (veg) 2570 (past)	$(m/day)/(kg/m^2)$	Footnote b
Total deposition onto vegetation (noble gases)	$V_{D\text{-noble gases}}$	0.35 (veg) 2.5 (past)	$(m/day)/(kg/m^2)$	Footnote c
Quantity of air inhaled per day	U(air)	20	m^3/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^3/day	6
Daily inhalation rate of dairy cattle	Qair(d)	150	m^3/day	2, 6
Weathering rate constant for vegetables	k_w	0.05	day-1	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-1	8

APPENDIX C

EXPOSURE PARAMETERS

Parameter	Symbol	Value	Units	Reference
Growth period or exposure period for pasture	T_g	30	day	17
WATER EXPOSURE PATHWAYS				
Daily intake of water by beef cattle	Qwater(b)	44	L/day	6
Daily intake of water by dairy cattle	Qwater(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^2	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
SOIL EXPOSURE PATHWAYS				
Mass loading of particles in ambient air	M	0.065	mg/m^3	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_{sc}	0.5	dimensionless	Professional judgement
Daily ingestion rate of soil by beef cattle	Qsoil(b)	0.34	kg/day	6
Fraction of soil ingested by beef cattle that is contaminated	f_{csb}	1	dimensionless	Professional judgement
Daily ingestion rate of soil by dairy cattle	Qsoil(d)	0.36	kg/day	6
Fraction of soil ingested by dairy cattle that is contaminated	f_{csd}	1	dimensionless	Professional judgement
Surface area of exposed skin (dermal contact to soil)	SA	5800	cm^2	20
Soil loading on skin	SL	0.5	mg/cm^2-day	20
Fraction of contaminant absorbed through skin (metals)	F_a	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^3	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

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

b

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

c

$$V_{D\text{-}noble\ gas} = \frac{V_{d\text{-}noble\ gas} \times 1-P_{rain} + V_{w\text{-}noble\ gases} \times P_{rain}}{Y_{noble\ gases}}$$

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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^3 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.

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 (Miik) 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

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

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

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

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

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

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

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

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			
		Percent of	Retain Pathway?
Pathway	Risk	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

Methylene Chloride			
		Percent of	Retain Pathway?
Pathway	Risk	Largest Pathway	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)			
		Percent of	Retain Pathway?
Pathway	Risk	Largest Pathway	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			
		Percent of	Retain Pathway?
Pathway	Risk	Largest Pathway	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			
	Hazard	Percent of	Retain Pathway?
Pathway	Index	Largest Pathway	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			
		Percent of	Retain Pathway?
Pathway	Risk	Largest Pathway	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

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

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

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

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

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

Uranium-234/235			
Pathway	Dose (Sv/yr)	Percent of Largest Pathway	Retain Pathway? Yes/No
Soil to Air to Humans (Inhalation)	2.30E-10	57%	Y
Soil to Air to Humans (Immersion)	1.90E-16	<1%	N
Soil to Humans (Ingestion)	2.36E-11	6%	Y
Soil to Livestock/Game (Beef) to Humans (Ingestion)	2.83E-12	<1%	N
Soil to Dairy Cattle (Milk) to Humans (Ingestion)	1.41E-11	4%	Y
Soil to Vegetables to Humans (Ingestion)	4.02E-10	100%	Y
Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion)	1.17E-13	<1%	N
Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)	5.33E-13	<1%	N
Soil to Humans (Ground Exposure)	3.90E-13	<1%	N

Uranium-238			
Pathway	Dose (Sv/yr)	Percent of Largest Pathway	Retain Pathway? Yes/No
Soil to Air to Humans (Inhalation)	2.11E-10	59%	Y
Soil to Air to Humans (Immersion)	1.33E-19	<1%	N
Soil to Humans (Ingestion)	2.09E-11	6%	Y
Soil to Livestock/Game (Beef) to Humans (Ingestion)	2.51E-12	<1%	N
Soil to Dairy Cattle (Milk) to Humans (Ingestion)	1.25E-11	4%	Y
Soil to Vegetables to Humans (Ingestion)	3.56E-10	100%	Y
Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion)	1.03E-13	<1%	N
Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)	4.72E-13	<1%	N
Soil to Humans (Ground Exposure)	1.57E-15	<1%	N

Zirconium-95			
Pathway	Dose (Sv/yr)	Percent of Largest Pathway	Retain Pathway? Yes/No
Soil to Air to Humans (Inhalation)	4.81E-14	2%	Y
Soil to Air to Humans (Immersion)	1.45E-15	<1%	N
Soil to Humans (Ingestion)	3.71E-13	14%	Y
Soil to Livestock/Game (Beef) to Humans (Ingestion)	1.22E-12	47%	Y
Soil to Dairy Cattle (Milk) to Humans (Ingestion)	1.80E-14	<1%	N
Soil to Vegetables to Humans (Ingestion)	1.49E-12	57%	Y
Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion)	6.23E-15	<1%	N
Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)	8.39E-17	<1%	N
Soil to Humans (Ground Exposure)	2.62E-12	100%	Y

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)			
		Percent of	Retain Pathway?
Pathway	Risk	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			
		Percent of	Retain Pathway?
Pathway	Risk	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

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)			
		Percent of	Retain Pathway?
Pathway	Risk	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

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

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

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

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

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

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

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)			
		Percent of	Retain Pathway?
Pathway	Risk	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			
		Percent of	Retain Pathway?
Pathway	Risk	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

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)			
		Percent of	Retain Pathway?
Pathway	Risk	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 x 10^{12} neutrons/cm^2-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:

$$A_i = (1\times10^{12}\ n/cm^2\text{-sec})(577\times10^{-24}cm^2)(N)(yield_i)(1-e^{-\lambda_i t_{irr}})(e^{-\lambda_i t_{clg}})(2.703\times10^{-11}\ Ci/atom\text{-sec})$$

where:

A_i	=	activity of radionuclide i in each fuel slug (Ci)
1 x 10^{12} n/cm^2-sec	=	maximum graphite reactor flux
577 x 10^{-24}	=	fission cross section for uranium-235
N	=	number of U-235 atoms per slug
$yield_i$	=	fission yield of radionuclide i for uranium-235
λ_i	=	decay constant of radionuclide i (sec^{-1})
t_{irr}	=	irradiation time in reactor (sec)
t_{clg}	=	cooling time after removal from reactor (sec)
2.703 x 10^{-11} 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 3.3×10^{-7} Ci/g for uranium-238 and 2.14×10^{-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 1.26×10^{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 Yarbro (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 (seconds)	Decay Constant (sec^{-1})	Fission Yield	Ci/slug at time t	Total Ci Available	Release Fraction	Release Total (Ci)
I-131	$6.96 \times 10^{+5}$	9.96×10^{-7}	2.90×10^{-2}	$8.63 \times 10^{+0}$	$8.03 \times 10^{+4}$	80%	$6.42 \times 10^{+4}$
I-132	$8.14 \times 10^{+3}$	8.52×10^{-5}	4.40×10^{-2}	9.39×10^{-3}	$8.73 \times 10^{+1}$	80%	$6.98 \times 10^{+1}$
I-133	$7.31 \times 10^{+4}$	9.48×10^{-6}	6.50×10^{-2}	$9.60 \times 10^{+0}$	$8.93 \times 10^{+4}$	80%	$7.14 \times 10^{+4}$
I-129	$5.36 \times 10^{+14}$	1.29×10^{-15}	1.00×10^{-2}	1.50×10^{-8}	1.39×10^{-4}	80%	1.11×10^{-4}
Ce-144	$2.45 \times 10^{+7}$	2.82×10^{-8}	6.10×10^{-2}	$1.90 \times 10^{+0}$	$1.76 \times 10^{+4}$	0.1%	$1.76 \times 10^{+1}$
Cs-137	$9.46 \times 10^{+8}$	7.32×10^{-10}	5.90×10^{-2}	5.00×10^{-2}	$4.65 \times 10^{+2}$	0.1%	4.65×10^{-1}
Kr-85	$3.39 \times 10^{+8}$	2.04×10^{-9}	3.00×10^{-3}	7.07×10^{-3}	$6.58 \times 10^{+1}$	100%	$6.58 \times 10^{+1}$
Xe-133	$4.55 \times 10^{+5}$	1.52×10^{-6}	6.50×10^{-2}	$1.90 \times 10^{+1}$	$1.77 \times 10^{+5}$	100%	$1.77 \times 10^{+5}$
Zr-95	$5.67 \times 10^{+6}$	1.22×10^{-7}	6.40×10^{-2}	$7.31 \times 10^{+0}$	$6.80 \times 10^{+4}$	0.1%	$6.80 \times 10^{+1}$
Nb-95	$3.02 \times 10^{+6}$	2.29×10^{-7}	6.40×10^{-2}	$1.15 \times 10^{+1}$	$1.07 \times 10^{+5}$	0.1%	$1.07 \times 10^{+2}$
Ru-103	$3.41 \times 10^{+6}$	2.03×10^{-7}	2.90×10^{-2}	$4.82 \times 10^{+0}$	$4.48 \times 10^{+4}$	0.1%	$4.48 \times 10^{+1}$
Ru-106	$3.18 \times 10^{+7}$	2.18×10^{-8}	3.80×10^{-3}	9.22×10^{-2}	$8.58 \times 10^{+2}$	0.1%	8.58×10^{-1}
Sr-89	$4.55 \times 10^{+6}$	1.52×10^{-7}	4.80×10^{-2}	$6.49 \times 10^{+0}$	$6.04 \times 10^{+4}$	0.1%	$6.04 \times 10^{+1}$
Sr-90	$8.74 \times 10^{+8}$	7.93×10^{-10}	5.80×10^{-2}	5.32×10^{-2}	$4.95 \times 10^{+2}$	0.1%	4.95×10^{-1}
Ba-140	$1.11 \times 10^{+6}$	6.27×10^{-7}	6.30×10^{-2}	$1.77 \times 10^{+1}$	$1.65 \times 10^{+5}$	0.1%	$1.65 \times 10^{+2}$
La-140	$1.45 \times 10^{+5}$	4.79×10^{-6}	6.30×10^{-2}	$1.40 \times 10^{+1}$	$1.30 \times 10^{+5}$	0.1%	$1.30 \times 10^{+2}$
Pu	$7.69 \times 10^{+11}$*	9.01×10^{-13}*	NA	8.54×10^{-4}	$7.94 \times 10^{+0}$	0.1%	7.94×10^{-3}
U-235	$2.24 \times 10^{+16}$	3.10×10^{-17}	NA	1.79×10^{-5}	1.66×10^{-1}	0.1%	1.66×10^{-4}
U-238	$1.42 \times 10^{+17}$	4.87×10^{-18}	NA	3.90×10^{-4}	$3.63 \times 10^{+0}$	0.1%	3.63×10^{-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 (seconds)	Decay Constant (sec^{-1})	Fission Yield	Ci/slug at time t	Total Ci Available	Release Fraction	Release Total (Ci)
I-131	$6.96 \times 10^{+5}$	9.96×10^{-7}	2.90×10^{-2}	$6.41 \times 10^{+1}$	$8.34 \times 10^{+4}$	80%	$6.67 \times 10^{+4}$
I-132	$8.14 \times 10^{+3}$	8.52×10^{-5}	4.40×10^{-2}	1.57×10^{-14}	$2.04 \times 10^{+11}$	80%	1.63×10^{-11}
I-133	$7.31 \times 10^{+4}$	9.48×10^{-6}	6.50×10^{-2}	$3.68 \times 10^{+0}$	$4.79 \times 10^{+3}$	80%	$3.83 \times 10^{+3}$
I-129	$5.36 \times 10^{+14}$	1.29×10^{-15}	1.00×10^{-2}	3.04×10^{-7}	3.95×10^{-4}	80%	3.16×10^{-4}
Ce-144	$2.45 \times 10^{+7}$	2.82×10^{-8}	6.10×10^{-2}	$3.64 \times 10^{+1}$	$4.73 \times 10^{+4}$	0.1%	$4.73 \times 10^{+1}$
Cs-137	$9.46 \times 10^{+8}$	7.32×10^{-10}	5.90×10^{-2}	$1.01 \times 10^{+0}$	$1.32 \times 10^{+3}$	0.1%	$1.32 \times 10^{+0}$
Kr-85	$3.39 \times 10^{+8}$	2.04×10^{-9}	3.00×10^{-3}	1.43×10^{-1}	$1.86 \times 10^{+2}$	100%	$1.86 \times 10^{+2}$
Xe-133	$4.55 \times 10^{+5}$	1.52×10^{-6}	6.50×10^{-2}	$1.15 \times 10^{+2}$	$1.49 \times 10^{+5}$	100%	$1.49 \times 10^{+5}$
Zr-95	$5.67 \times 10^{+6}$	1.22×10^{-7}	6.40×10^{-2}	$1.18 \times 10^{+2}$	$1.53 \times 10^{+5}$	0.1%	$1.53 \times 10^{+2}$
Nb-95	$3.02 \times 10^{+6}$	2.29×10^{-7}	6.40×10^{-2}	$1.57 \times 10^{+2}$	$2.04 \times 10^{+5}$	0.1%	$2.04 \times 10^{+2}$
Ru-103	$3.41 \times 10^{+6}$	2.03×10^{-7}	2.90×10^{-2}	$6.82 \times 10^{+1}$	$8.87 \times 10^{+4}$	0.1%	$8.87 \times 10^{+1}$
Ru-106	$3.18 \times 10^{+7}$	2.18×10^{-8}	3.80×10^{-3}	$1.79 \times 10^{+0}$	$2.33 \times 10^{+3}$	0.1%	$2.33 \times 10^{+0}$
Sr-89	$4.55 \times 10^{+6}$	1.52×10^{-7}	4.80×10^{-2}	$9.96 \times 10^{+1}$	$1.29 \times 10^{+5}$	0.1%	$1.29 \times 10^{+2}$
Sr-90	$8.74 \times 10^{+8}$	7.93×10^{-10}	5.80×10^{-2}	$1.08 \times 10^{+0}$	$1.40 \times 10^{+3}$	0.1%	$1.40 \times 10^{+0}$
Ba-140	$1.11 \times 10^{+6}$	6.27×10^{-7}	6.30×10^{-2}	$1.62 \times 10^{+2}$	$2.10 \times 10^{+5}$	0.1%	$2.10 \times 10^{+2}$
La-140	$1.45 \times 10^{+5}$	4.79×10^{-6}	6.30×10^{-2}	$2.71 \times 10^{+1}$	$3.53 \times 10^{+4}$	0.1%	$3.53 \times 10^{+1}$
Pu	$7.69 \times 10^{+11}$*	9.01×10^{-13}*	NA	1.74×10^{-2}	$2.26 \times 10^{+1}$	0.1%	2.26×10^{-2}
U-235	$2.24 \times 10^{+16}$	3.10×10^{-17}	NA	2.73×10^{-5}	3.55×10^{-2}	0.1%	3.55×10^{-5}
U-238	$1.42 \times 10^{+17}$	4.87×10^{-18}	NA	5.95×10^{-4}	7.74×10^{-1}	0.1%	7.74×10^{-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 5×10^{11} neutrons/cm^2-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 (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	5.59×10^{-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	2.37×10^{-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):			7.42×10^{-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	$6.18 \times 10^{+3}$	$2.79 \times 10^{+3}$	$1.48 \times 10^{+2}$	$1.98 \times 10^{+3}$	$2.20 \times 10^{+3}$	$4.45 \times 10^{+2}$	$1.09 \times 10^{+0}$	1.89×10^{2}	$1.53 \times 10^{+2}$	$2.28 \times 10^{+1}$
HD-19-B	$1.21 \times 10^{+4}$	$1.14 \times 10^{+4}$	$9.08 \times 10^{+3}$	$9.08 \times 10^{+3}$	$2.27 \times 10^{+3}$	$1.51 \times 10^{+3}$	$8.32 \times 10^{+2}$	$5.22 \times 10^{+2}$	$1.51 \times 10^{+2}$	$1.97 \times 10^{+1}$
HD-19-C	$1.06 \times 10^{+3}$	$9.94 \times 10^{+2}$	$7.95 \times 10^{+2}$	$7.95 \times 10^{+2}$	$1.99 \times 10^{+2}$	$1.32 \times 10^{+2}$	$7.29 \times 10^{+1}$	$4.57 \times 10^{+1}$	$1.32 \times 10^{+1}$	$1.72 \times 10^{+0}$
SD-1-A	$2.76 \times 10^{+4}$	$2.59 \times 10^{+4}$	$2.07 \times 10^{+4}$	$2.07 \times 10^{+4}$	$5.17 \times 10^{+3}$	$3.45 \times 10^{+3}$	$1.90 \times 10^{+3}$	$1.19 \times 10^{+3}$	$3.45 \times 10^{+2}$	$4.48 \times 10^{+1}$
SD-1-B	$2.42 \times 10^{+4}$	$2.27 \times 10^{+4}$	$1.81 \times 10^{+4}$	$1.81 \times 10^{+4}$	$4.54 \times 10^{+3}$	$3.02 \times 10^{+3}$	$1.66 \times 10^{+3}$	$1.04 \times 10^{+3}$	$3.02 \times 10^{+2}$	$3.93 \times 10^{+1}$
SD-1-C	$1.17 \times 10^{+3}$	$1.10 \times 10^{+3}$	$8.81 \times 10^{+2}$	$8.81 \times 10^{+2}$	$2.20 \times 10^{+2}$	$1.47 \times 10^{+2}$	$8.08 \times 10^{+1}$	$5.07 \times 10^{+1}$	$1.47 \times 10^{+1}$	$1.91 \times 10^{+0}$
SD-2-A	$3.16 \times 10^{+4}$	$2.96 \times 10^{+4}$	$2.37 \times 10^{+4}$	$2.37 \times 10^{+4}$	$5.92 \times 10^{+3}$	$3.95 \times 10^{+3}$	$2.17 \times 10^{+3}$	1.36×10^{3}	$3.95 \times 10^{+2}$	$5.13 \times 10^{+1}$
SD-2-B	$1.89 \times 10^{+4}$	$1.77 \times 10^{+4}$	$1.41 \times 10^{+4}$	$1.41 \times 10^{+4}$	$3.54 \times 10^{+3}$	$2.36 \times 10^{+3}$	$1.30 \times 10^{+3}$	$8.13 \times 10^{+3}$	$2.36 \times 10^{+2}$	$3.06 \times 10^{+1}$
SD-2-C	$1.90 \times 10^{+4}$	$1.79 \times 10^{+4}$	$1.43 \times 10^{+4}$	$1.43 \times 10^{+4}$	$3.57 \times 10^{+3}$	$2.38 \times 10^{+3}$	$1.31 \times 10^{+3}$	$8.21 \times 10^{+2}$	$2.38 \times 10^{+2}$	$3.10 \times 10^{+1}$
SD-2-D	$2.39 \times 10^{+4}$	$2.24 \times 10^{+4}$	$1.79 \times 10^{+4}$	$1.79 \times 10^{+4}$	$4.48 \times 10^{+3}$	$2.99 \times 10^{+3}$	$1.64 \times 10^{+3}$	$1.03 \times 10^{+3}$	$2.99 \times 10^{+2}$	$3.88 \times 10^{+1}$
SD-2-E	$1.16 \times 10^{+4}$	$1.09 \times 10^{+4}$	$8.74 \times 10^{+3}$	$8.74 \times 10^{+3}$	$2.18 \times 10^{+3}$	$1.46 \times 10^{+3}$	$8.01 \times 10^{+2}$	$5.02 \times 10^{+2}$	$1.46 \times 10^{+2}$	$1.89 \times 10^{+1}$
SD-3-A	$2.34 \times 10^{+4}$	$2.19 \times 10^{+4}$	$1.75 \times 10^{+4}$	$1.75 \times 10^{+4}$	$4.38 \times 10^{+3}$	$2.92 \times 10^{+3}$	$1.61 \times 10^{+3}$	$1.01 \times 10^{+3}$	$2.92 \times 10^{+2}$	$3.79 \times 10^{+1}$
SD-3-B	$2.17 \times 10^{+4}$	$2.04 \times 10^{+4}$	$1.63 \times 10^{+4}$	$1.63 \times 10^{+4}$	$4.07 \times 10^{+3}$	$2.72 \times 10^{+3}$	$1.49 \times 10^{+3}$	$9.37 \times 10^{+2}$	$2.72 \times 10^{+2}$	$3.53 \times 10^{+1}$
SD-3-C	$9.30 \times 10^{+3}$	$8.72 \times 10^{+3}$	$6.98 \times 10^{+3}$	$6.98 \times 10^{+3}$	$1.74 \times 10^{+3}$	$1.16 \times 10^{+3}$	$6.40 \times 10^{+2}$	$4.01 \times 10^{+2}$	$1.16 \times 10^{+2}$	$1.51 \times 10^{+1}$
1956 Total	$1.93 \times 10^{+4}$	$1.51 \times 10^{+4}$	$1.00 \times 10^{+4}$	$1.19 \times 10^{+4}$	$4.67 \times 10^{+3}$	$2.09 \times 10^{+3}$	$9.06 \times 10^{+2}$	$5.68 \times 10^{+2}$	$3.18 \times 10^{+2}$	$4.42 \times 10^{+1}$
1957 Total	$2.12 \times 10^{+5}$	$1.99 \times 10^{+5}$	$1.59 \times 10^{+5}$	$1.59 \times 10^{+5}$	$3.98 \times 10^{+4}$	$2.65 \times 10^{+4}$	$1.46 \times 10^{+4}$	$9.16 \times 10^{+3}$	$2.65 \times 10^{+3}$	$3.45 \times 10^{+2}$
TOTAL	$2.32 \times 10^{+5}$	$2.14 \times 10^{+5}$	$1.69 \times 10^{+5}$	$1.71 \times 10^{+5}$	$4.45 \times 10^{+4}$	$2.86 \times 10^{+4}$	$1.55 \times 10^{+4}$	$9.73 \times 10^{+3}$	$2.97 \times 10^{+3}$	$3.89 \times 10^{+2}$
Release Fraction	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	80%	100%	0.1%	100%
1957 Emissions (Ci):	$2.12 \times 10^{+2}$	$1.99 \times 10^{+2}$	$1.59 \times 10^{+2}$	$1.59 \times 10^{+2}$	$3.98 \times 10^{+1}$	$2.65 \times 10^{+1}$	$1.17 \times 10^{+4}$	$9.16 \times 10^{+3}$	$2.65 \times 10^{+0}$	$3.45 \times 10^{+2}$

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 5.0×10^{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 2.15×10^{22} U-235 atoms. Based on a U-235 fission cross-section of 577 barns (577×10^{-24} cm^2), the average graphite reactor neutron flux resulted in 6.2×10^{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^{-1})	Fission Yield	Ci/Ton at End of Cooling	Total Ci Processed	Release Fraction	Release Total (Ci)
I-131	$6.96 \times 10^{+5}$	9.96×10^{-7}	0.029	$2.70 \times 10^{+2}$	$2.95 \times 10^{+4}$	80%	$2.36 \times 10^{+4}$
I-132	$8.14 \times 10^{+3}$	8.38×10^{-5}	0.044	2.73×10^{-91}	2.99×10^{-89}	80%	2.39×10^{-89}
I-133	$7.31 \times 10^{+4}$	9.48×10^{-6}	0.065	1.75×10^{-7}	1.91×10^{-5}	80%	1.53×10^{-5}
I-129	$5.36 \times 10^{+14}$	1.27×10^{-15}	0.010	5.58×10^{-6}	6.11×10^{-4}	80%	4.89×10^{-4}
Ce-144	$2.45 \times 10^{+7}$	2.78×10^{-8}	0.061	$6.60 \times 10^{+2}$	$7.23 \times 10^{+4}$	0.1%	$7.23 \times 10^{+1}$
Cs-137	$9.46 \times 10^{+8}$	7.20×10^{-10}	0.059	$1.86 \times 10^{+1}$	$2.04 \times 10^{+3}$	0.1%	$2.04 \times 10^{+0}$
Kr-85	$3.39 \times 10^{+8}$	2.01×10^{-9}	0.003	$2.62 \times 10^{+0}$	$2.87 \times 10^{+2}$	100%	$2.87 \times 10^{+2}$
Xe-133	$4.55 \times 10^{+5}$	1.50×10^{-6}	0.065	$1.70 \times 10^{+2}$	$1.86 \times 10^{+4}$	100%	$1.86 \times 10^{+4}$
Zr-95	$5.67 \times 10^{+6}$	1.20×10^{-7}	0.064	$2.02 \times 10^{+3}$	$2.22 \times 10^{+5}$	0.1%	$2.22 \times 10^{+2}$
Nb-95	$3.02 \times 10^{+6}$	2.25×10^{-7}	0.064	$2.45 \times 10^{+3}$	$2.69 \times 10^{+5}$	0.1%	$2.69 \times 10^{+2}$
Ru-103	$3.41 \times 10^{+6}$	2.03×10^{-7}	0.029	$1.10 \times 10^{+3}$	$1.20 \times 10^{+5}$	0.1%	$1.20 \times 10^{+2}$
Ru-106	$3.18 \times 10^{+7}$	2.14×10^{-8}	0.004	$3.26 \times 10^{+1}$	$3.57 \times 10^{+3}$	0.1%	$3.57 \times 10^{+0}$
Sr-89	$4.55 \times 10^{+6}$	1.50×10^{-7}	0.048	$1.67 \times 10^{+3}$	$1.83 \times 10^{+5}$	0.1%	$1.83 \times 10^{+2}$
Sr-90	$8.74 \times 10^{+8}$	7.80×10^{-10}	0.058	$1.98 \times 10^{+1}$	$2.17 \times 10^{+3}$	0.1%	$2.17 \times 10^{+0}$
Ba-140	$1.11 \times 10^{+6}$	6.16×10^{-7}	0.063	$1.43 \times 10^{+3}$	$1.56 \times 10^{+5}$	0.1%	$1.56 \times 10^{+2}$
La-140	$1.45 \times 10^{+5}$	4.71×10^{-6}	0.063	4.02×10^{-2}	$4.40 \times 10^{+0}$	0.1%	4.40×10^{-3}
Pu	$7.69 \times 10^{+11}$*	9.01×10^{-13}*	NA	NA	$3.08 \times 10^{+1}$	0.1%	3.08×10^{-2}
U-235	$2.24 \times 10^{+16}$	3.10×10^{-17}	NA	NA	$1.51 \times 10^{+0}$	0.1%	1.51×10^{-3}
U-238	$1.42 \times 10^{+17}$	4.87×10^{-18}	NA	NA	$2.11 \times 10^{+2}$	0.1%	2.11×10^{-1}

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	1.51×10^{-7}	8.80	0.49	6.69×10^{-2}	10.89	10.72	10.72
Feb-47	$2.6 \times 10^{+7}$	1	4.86	10.89	5.79×10^{-8}	5.42	0.19	2.67×10^{-2}	10.89	10.32	10.70
Apr-47	$9.4 \times 10^{+5}$	1	3.01	10.89	2.09×10^{-9}	0.28	0.01	9.92×10^{-4}	8.39	1.19	2.13
Aug-47	$5.6 \times 10^{+6}$	1	4.84	10.89	1.26×10^{-8}	1.54	0.04	5.92×10^{-3}	10.89	5.44	7.89
Oct-47	$9.0 \times 10^{+7}$	1	4.86	10.89	1.99×10^{-7}	9.46	0.64	8.62×10^{-2}	10.89	10.72	10.72
Oct-47	$1.2 \times 10^{+7}$	1	4.86	10.89	2.57×10^{-8}	2.91	0.09	1.20×10^{-2}	10.89	8.20	10.02
Nov-47	$9.5 \times 10^{+7}$	1	4.86	10.89	2.11×10^{-7}	9.57	0.68	9.06×10^{-2}	10.89	10.72	10.72
Nov-47	$9.3 \times 10^{+7}$	1	4.86	10.89	2.08×10^{-7}	9.54	0.67	8.94×10^{-2}	10.89	10.72	10.72
Nov-47	$9.4 \times 10^{+7}$	13	63.17	141.59	2.71×10^{-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	2.05×10^{-7}	9.52	0.66	8.86×10^{-2}	10.89	10.72	10.72
Dec-47	$9.2 \times 10^{+7}$	1	4.86	10.89	2.04×10^{-7}	9.51	0.66	8.82×10^{-2}	10.89	10.72	10.72
Dec-47	$9.2 \times 10^{+7}$	1	4.86	10.89	2.04×10^{-7}	9.51	0.66	8.82×10^{-2}	10.89	10.72	10.72
Dec-47	$9.6 \times 10^{+7}$	1	4.86	10.89	2.13×10^{-7}	9.59	0.69	9.17×10^{-2}	10.89	10.72	10.72
Total Liberated in 1947 (Ci):			119.62	272.30	4.40×10^{-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):			$9.6 \times 10^{+1}$	$2.2 \times 10^{+2}$	3.5×10^{-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	$6.8 \times 10^{+7}$	1	4.86	0.49	8.04	0.53	10.56	10.56	1.79×10^{-5}	3.88×10^{-4}	4.82×10^{-3}
Feb-47	$2.6 \times 10^{+7}$	1	4.84	0.28	7.91	0.20	10.56	10.56	1.79×10^{-5}	3.88×10^{-4}	4.82×10^{-3}
Apr-47	$9.4 \times 10^{+5}$	1	0.87	0.01	1.10	0.01	4.80	10.45	1.79×10^{-5}	3.88×10^{-4}	4.82×10^{-3}
Aug-47	$5.6 \times 10^{+6}$	1	3.35	0.07	4.72	0.04	10.28	10.56	1.79×10^{-5}	3.88×10^{-4}	4.82×10^{-3}
Oct-47	$9.0 \times 10^{+7}$	1	4.86	0.55	8.04	0.68	10.56	10.56	1.79×10^{-5}	3.88×10^{-4}	4.82×10^{-3}
Oct-47	$1.2 \times 10^{+7}$	1	4.46	0.14	6.72	0.09	10.56	10.56	1.79×10^{-5}	3.88×10^{-4}	4.82×10^{-3}
Nov-47	$9.5 \times 10^{+7}$	1	4.86	0.56	8.04	0.72	10.56	10.56	1.79×10^{-5}	3.88×10^{-4}	4.82×10^{-3}
Nov-47	$9.3 \times 10^{+7}$	1	4.86	0.56	8.04	0.71	10.56	10.56	1.79×10^{-5}	3.88×10^{-4}	4.82×10^{-3}
Nov-47	$9.4 \times 10^{+7}$	13	63.2	7.23	104.56	9.30	137.24	137.24	2.32×10^{-4}	5.05×10^{-3}	6.27×10^{-2}
Dec-47	$9.2 \times 10^{+7}$	1	4.86	0.55	8.04	0.71	10.56	10.56	1.79×10^{-5}	3.88×10^{-4}	4.82×10^{-3}
Dec-47	$9.2 \times 10^{+7}$	1	4.86	0.55	8.04	0.70	10.56	10.56	1.79×10^{-5}	3.88×10^{-4}	4.82×10^{-3}
Dec-47	$9.2 \times 10^{+7}$	1	4.86	0.55	8.04	0.70	10.56	10.56	1.79×10^{-5}	3.88×10^{-4}	4.82×10^{-3}
Dec-47	$9.6 \times 10^{+7}$	1	4.86	0.56	8.04	0.73	10.56	10.56	1.79×10^{-5}	3.88×10^{-4}	4.82×10^{-3}
Total Liberated in 1947 (Ci):			115.58	12.11	189.35	15.13	257.88	263.82	4.46×10^{-4}	9.71×10^{-3}	1.21×10^{-1}
Release Fraction:			10%	10%	10%	10%	10%	10%	10%	10%	10%
1947 Release Total (Ci):			11.56	$1.2 \times 10^{+0}$	$1.9 \times 10^{+1}$	$1.5 \times 10^{+0}$	$2.6 \times 10^{+1}$	$2.6 \times 10^{+1}$	4.5×10^{-5}	9.7×10^{-4}	1.2×10^{-2}

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.

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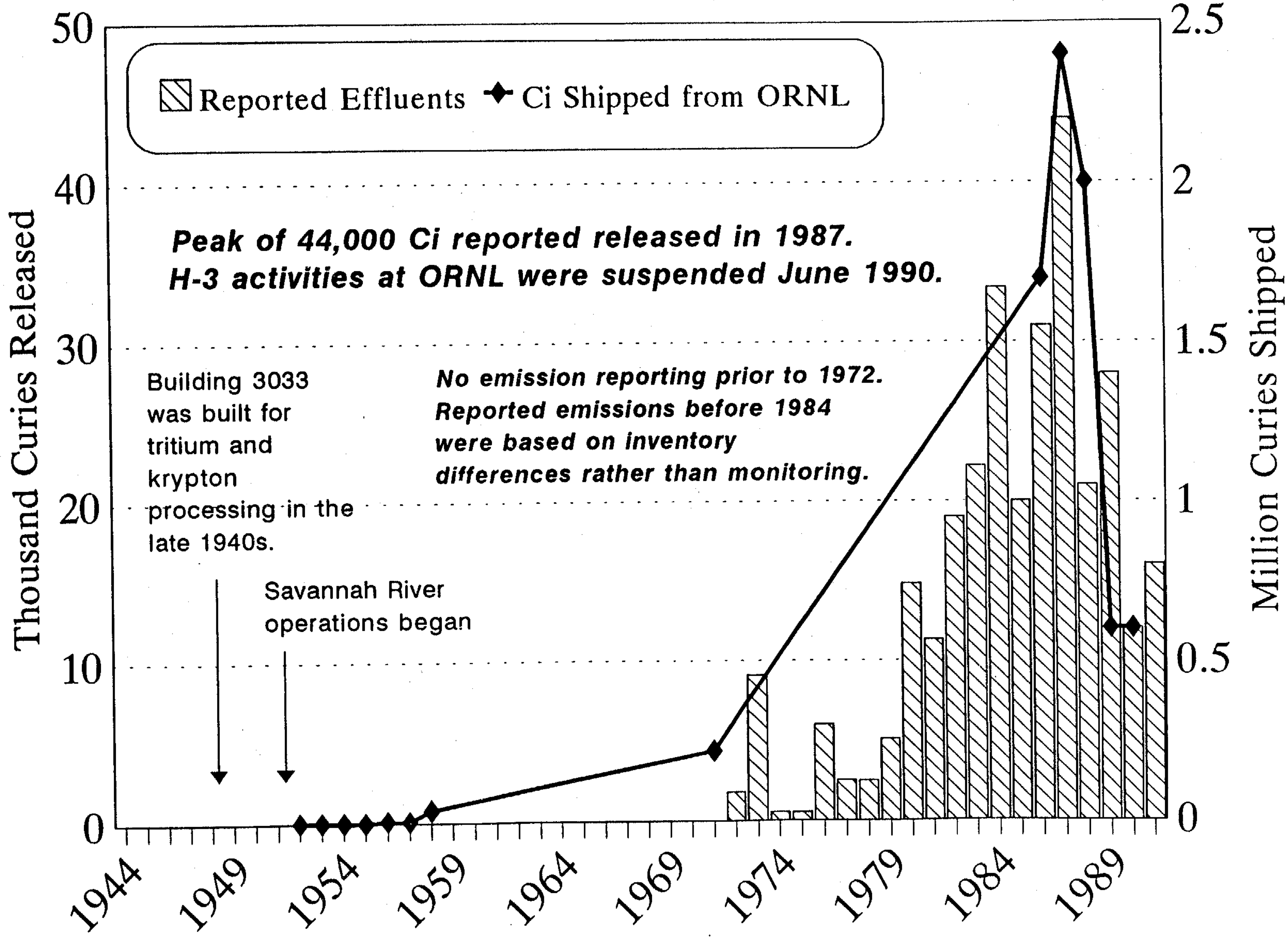
FIGURE E-1
X-10 TRITIUM AIR EMISSIONS AND SHIPMENTS



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.

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

(Equation 1)

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

(Equation 2)

Step 1 <u>Rearrange Equation 1</u>

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

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

or

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

Step 2 Sum Equation 1a and Equation 2

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

Step 3 Solve for "x"

$$\text{If } y = 2698\ kg, \text{ then } x =$$

$$2711\ kg = x\ kg + 2698\ kg$$

$$13\ kg = x$$

Step 4 Calculate source terms

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

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

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 ± 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.

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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 $^{234}U/^{235}U$ (kg)	Estimated $^{234}U/^{235}U$ (kg)	Total Activity—Measured & Estimated $^{234}U/^{235}U$ (Ci)[a]	Measured Depleted ^{238}U (kg)	Estimated Depleted ^{238}U (kg)	Total Activity—Measured & Estimated Depleted ^{238}U (Ci)[b]	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 $^{234}U/^{235}U$ (kg)	Estimated $^{234}U/^{235}U$ (kg)	Total Activity—Measured & Estimated $^{234}U/^{235}U$ (Ci)[a]	Measured Depleted ^{238}U (kg)	Estimated Depleted ^{238}U (kg)	Total Activity—Measured & Estimated Depleted ^{238}U (Ci)[b]	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 $^{234}U/^{235}U$ (kg)	Estimated $^{234}U/^{235}U$ (kg)	Total Activity—Measured & Estimated $^{234}U/^{235}U$ (Ci)[a]	Measured Depleted ^{238}U (kg)	Estimated Depleted ^{238}U (kg)	Total Activity—Measured & Estimated Depleted ^{238}U (Ci)[b]	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

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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.

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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
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	0.38	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	MMES, 1985	200	12	mg/kg (wet)	Carp	
Fish	PCBs	1985	CRM 12.0	MMES, 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	MMES, 1984	5	0.15	pCi/kg (wet)	Bluegill	Five composites of 10 fish each
Fish	Pu-238	1984	CRM 12.0	MMES, 1985	5	0.23	pCi/kg (wet)	Shad	Five composites of 10 fish each
Fish	Pu-238	1985	CRM 12.0	MMES, 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	MMES, 1984	5	0.83	pCi/kg (wet)	Bluegill	Five composites of 10 fish each
Fish	Pu-239	1984	CRM 12.0	MMES, 1985	5	1.5	pCi/kg (wet)	Shad	Five composites of 10 fish each
Fish	Pu-239	1985	CRM 12.0	MMES, 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	
Fish	U-234	1983	CRM 12.0	MMES, 1984	1	3.1	pCi/kg (wet)	Shad	One composite of 10 fish
Fish	U-234	1984	CRM 12.0	MMES, 1985	1	53	pCi/kg (wet)	Shad	One composite of 10 fish
Fish	U-234	1985	CRM 12.0	MMES, 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)	Crappie	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	MMES, 1984	1	0.14	pCi/kg (wet)	Bluegill	One composite of 10 fish
Fish	U-235	1984	CRM 12.0	MMES, 1985	1	2.5	pCi/kg (wet)	Shad	One composite of 10 fish
Fish	U-235	1985	CRM 12.0	MMES, 1986	1	0.49	pCi/kg (wet)	Bluegill	One composite of 10 fish
Fish	U-238	1983	CRM 12.0	MMES, 1984	1	2.2	pCi/kg (wet)	Shad	One composite of 10 fish
Fish	U-238	1984	CRM 12.0	MMES, 1985	1	30	pCi/kg (wet)	Shad	One composite of 10 fish
Fish	U-238	1985	CRM 12.0	MMES, 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	26	mg/kg (dry)	N/A	
Sediment	Chromium	1984	CRM 10.0	MMES, 1985	1	9	mg/kg (dry)	N/A	
Sediment	Chromium	1984	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)		
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-235	1989-90	CRM 0 to 12	Cook et al., 1992	18	0.69	pCi/g (dry)	N/A	
Sediment	U-238	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	Lead	1973	CRM 11.0	UCC, 1974	12	<0.02	mg/L	N/A	
Water	Lead	1974	CRM 11.0	UCC, 1975	12	0.03	mg/L	N/A	
Water	Lead	1975	CRM 11.0	UCC, 1976	12	0.25	mg/L	N/A	
Water	Lead	1976	CRM 11.0	UCC, 1977	12	0.02	mg/L	N/A	
Water	Lead	1977	CRM 11.0	UCC, 1978	12	0.02	mg/L	N/A	
Water	Lead	1978	CRM 11.0	UCC, 1979	12	<0.01	mg/L	N/A	
Water	Lead	1979	CRM 11.0	UCC, 1980	12	<0.01	mg/L	N/A	
Water	Lead	1980	CRM 11.0	UCC, 1981	12	<0.01	mg/L	N/A	
Water	Lead	1981	CRM 11.0	UCC, 1982	12	<0.01	mg/L	N/A	
Water	Lead	1982	CRM 11.0	UCC, 1983a	12	0.02	mg/L	N/A	
Water	Lead	1983	CRM 11.0	MMES, 1984	12	<0.01	mg/L	N/A	
Water	Lead	1984	CRM 6.8	TVA, 1985a	1	<0.001	mg/L	N/A	
Water	Lead	1984	CRM 11.0	MMES, 1985	12	0.006	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, 1976	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	0.03	mg/L	N/A	
Water	Nickel	1979	CRM 11.0	UCC, 1980	12	0.01	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	?	<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)	bass	Avg of quarterly composites of 10
Fish	Co-60	1982	CRM 20.8	UCC, 1983a	4	41	pCi/kg (wet)	blue gill	Avg of quarterly composites of 10
Fish	Co-60	1983	CRM 20.8	MMES, 1984	4	110	pCi/kg (wet)	shad	Avg of quarterly composites of 10
Fish	Co-60	1984	CRM 20.8	MMES, 1985	4	24	pCi/g (dry)	catfish	Avg of quarterly composites of 10
Fish	Co-60	1985	CRM 20.8	MMES, 1986	NA	14	pCi/kg (wet)	bluegill	
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 20.6	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	One composite of 10 fish
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)	bass	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)	bass	Avg of quarterly composites of 10
Fish	Cs-137	1985	CRM 20.8	MMES, 1986	NA	1200	pCi/kg (wet)	bass	
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)	Bluegill	Composites of 10 samples each
Fish	Pu-239	1976	CRM 20	UCC, 1977	3	0.27	pCi/kg (wet)	Shad	Composites of 10 samples each
Fish	Pu-239	1977	CRM 20	UCC, 1978	5	0.086	pCi/kg (wet)	Bluegill	Composites of 10 samples each
Fish	Pu-239	1978	CRM 20.8	UCC, 1979	4	0.02	pCi/kg (wet)	Bluegill	Composites of 10 samples each
Fish	Pu-239	1979	CRM 20.8	UCC, 1980	5	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	6467	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	NA	120	pCi/kg (wet)	bluegill	
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 (ash 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	NA	2.7	pCi/kg (wet)	bluegill	
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	NA	0.35	pCi/kg (wet)	bluegill	
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	56	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		pCi/g (dry)	N/A	
Sediment	Co-60	1955	CRM 16.3	Cottrell, 1960	1	18	pCi/g (dry)	N/A	
Sediment	Co-60	1955	CRM 15.2	Cottrell, 1960	1		pCi/g (dry)	N/A	
Sediment	Co-60	1955	CRM 14.0	Cottrell, 1960	1	23	pCi/g (dry)	N/A	
Sediment	Co-60	1956	CRM 19.1	Cottrell, 1960	1	26	pCi/g (dry)	N/A	
Sediment	Co-60	1956	CRM 16.3	Cottrell, 1960	1	39	pCi/g (dry)	N/A	
Sediment	Co-60	1956	CRM 15.2	Cottrell, 1960	1	59	pCi/g (dry)	N/A	
Sediment	Co-60	1956	CRM 14.0	Cottrell, 1960	1	29	pCi/g (dry)	N/A	
Sediment	Co-60	1957	CRM 19.1	Cottrell, 1960	1	30	pCi/g (dry)	N/A	
Sediment	Co-60	1957	CRM 16.3	Cottrell, 1960	1	15	pCi/g (dry)	N/A	
Sediment	Co-60	1957	CRM 15.2	Cottrell, 1960	1	14	pCi/g (dry)	N/A	
Sediment	Co-60	1957	CRM 14.0	Cottrell, 1960	1	17	pCi/g (dry)	N/A	
Sediment	Co-60	1958	CRM 19.1	Cottrell, 1960	1	4	pCi/g (dry)	N/A	
Sediment	Co-60	1958	CRM 16.3	Cottrell, 1960	1	21	pCi/g (dry)	N/A	
Sediment	Co-60	1958	CRM 15.2	Cottrell, 1960	1	9	pCi/g (dry)	N/A	
Sediment	Co-60	1958	CRM 14.0	Cottrell, 1960	1	16	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	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	10	pCi/g (dry)	N/A	
Sediment	Co-60	1966	CRM 16.3	UCC, 1967	NA	8.1	pCi/g (dry)	N/A	
Sediment	Co-60	1967	CRM 20.7	UCC, 1968	NA	68	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	
Sediment	Cs-137	1990	CRM 13	TVA, 1991	1	23.74	pCi/g	N/A	USAEC Intake
Sediment	Cs-137	1990	CRM 17	TVA, 1991	1	0.19	pCi/g	N/A	Beach- 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-Ba137	1954	CRM 19.1	Cottrell, 1960	1	12	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1954	CRM 16.3	Cottrell, 1960	1	27	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1954	CRM 15.2	Cottrell, 1960	1	22	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1954	CRM 14.0	Cottrell, 1960	1	24	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1955	CRM 19.1	Cottrell, 1960	1	7	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1955	CRM 16.3	Cottrell, 1960	1	22	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1955	CRM 15.2	Cottrell, 1960	1	34	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1955	CRM 14.0	Cottrell, 1960	1	29	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1956	CRM 19.1	Cottrell, 1960	1	116	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1956	CRM 16.3	Cottrell, 1960	1	208	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1956	CRM 15.2	Cottrell, 1960	1	268	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1956	CRM 14.0	Cottrell, 1960	1	115	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1957	CRM 19.1	Cottrell, 1960	1	528	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1957	CRM 16.3	Cottrell, 1960	1	177	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1957	CRM 15.2	Cottrell, 1960	1	119	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1957	CRM 14.0	Cottrell, 1960	1	184	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1958	CRM 19.1	Cottrell, 1960	1	44	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1958	CRM 16.3	Cottrell, 1960	1	223	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	1958	CRM 15.2	Cottrell, 1960	1	146	pCi/g (dry)	N/A	
Sediment	Cs-Ba137	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 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	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	5	pCi/g (dry)	N/A	
Sediment	Ru-106	1956	CRM 16.3	Cottrell, 1960	1	8	pCi/g (dry)	N/A	
Sediment	Ru-106	1956	CRM 15.2	Cottrell, 1960	1	11	pCi/g (dry)	N/A	
Sediment	Ru-106	1956	CRM 14.0	Cottrell, 1960	1	6	pCi/g (dry)	N/A	
Sediment	Ru-106	1957	CRM 19.1	Cottrell, 1960	1	14	pCi/g (dry)	N/A	
Sediment	Ru-106	1957	CRM 16.3	Cottrell, 1960	1	6	pCi/g (dry)	N/A	
Sediment	Ru-106	1957	CRM 15.2	Cottrell, 1960	1	3	pCi/g (dry)	N/A	
Sediment	Ru-106	1957	CRM 14.0	Cottrell, 1960	1	4	pCi/g (dry)	N/A	
Sediment	Ru-106	1958	CRM 19.1	Cottrell, 1960	1	3	pCi/g (dry)	N/A	
Sediment	Ru-106	1958	CRM 16.3	Cottrell, 1960	1	7	pCi/g (dry)	N/A	
Sediment	Ru-106	1958	CRM 15.2	Cottrell, 1960	1	6	pCi/g (dry)	N/A	
Sediment	Ru-106	1958	CRM 14.0	Cottrell, 1960	1	16	pCi/g (dry)	N/A	
Sediment	Ru-Rh-106	1960	CRM 19.1	UCC, 1961	NA	27	pCi/g (dry)	N/A	
Sediment	Ru-Rh-106	1961	CRM 19.1	UCC, 1962	NA	95	pCi/g (dry)	N/A	
Sediment	Sr-89	7/24/84	CRM 18.3	TVA, 1985b	2	1	pCi/g (dry)	N/A	
Sediment	Sr-89	1990	CRM 13	TVA, 1991	1	<0.54	pCi/g	N/A	USAEC Intake
Sediment	Sr-89	1990	CRM 17	TVA, 1991	1	<1.2	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	
Sediment	Sr-90	1990	CRM 13	TVA, 1991	1	<0.17	pCi/g	N/A	USAEC Intake
Sediment	Sr-90	1990	CRM 17	TVA, 1991	1	<.0.43	pCi/g	N/A	Beach- Soaring Eagle Campground
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	
Sediment	U-234	1990	CRM 13	TVA, 1991	1	<0.024	pCi/g	N/A	USAEC Intake
Sediment	U-234	1990	CRM 17	TVA, 1991	1	<0.053	pCi/g	N/A	Beach- Soaring Eagle Campground
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	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	Co-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	
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	
Water	Co-60	1978	CRM 14.5	UCC, 1979	4	0.27	pCi/L	N/A	
Water	Co-60	1979	CRM 14.5	UCC, 1980	4	0.11	pCi/L	N/A	
Water	Co-60	1980	CRM 14.5	UCC, 1981	4	0.41	pCi/L	N/A	
Water	Co-60	1981	CRM 14.5	UCC, 1982	4	0.14	pCi/L	N/A	
Water	Co-60	1982	CRM 14.5	UCC, 1983a	4	1.6	pCi/L	N/A	
Water	Co-60	1983	CRM 14.5	MMES, 1984	4	0.24	pCi/L	N/A	
Water	Co-60	1984	CRM 14.5	MMES, 1985	4	<0.54	pCi/L	N/A	
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	
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	
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	1969	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	
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	
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	
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	
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	
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	
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	
Water	Cs-137	1978	CRM 14.5	UCC, 1979	4	3.18	pCi/L	N/A	
Water	Cs-137	1979	CRM 14.5	UCC, 1980	4	0.05	pCi/L	N/A	
Water	Cs-137	1980	CRM 14.5	UCC, 1981	4	0.18	pCi/L	N/A	
Water	Cs-137	1981	CRM 14.5	UCC, 1982	4	0.22	pCi/L	N/A	
Water	Cs-137	1982	CRM 14.5	UCC, 1983a	4	1.9	pCi/L	N/A	
Water	Cs-137	1983	CRM 14.5	MMES, 1984	4	0.51	pCi/L	N/A	
Water	Cs-137	1984	CRM 14.5	MMES, 1985	4	<0.54	pCi/L	N/A	
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 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	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	
Water	Ru-106	1962	CRM 14.6	Cowser and Snyder, 1966	93	769	pCi/L	N/A	
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	
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	
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	
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	
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	
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	
Water	Ru-106	1978	CRM 14.5	UCC, 1979	4	1.82	pCi/L	N/A	
Water	Ru-106	1979	CRM 14.5	UCC, 1980	4	0.14	pCi/L	N/A	
Water	Ru-106	1980	CRM 14.5	UCC, 1981	4	0.27	pCi/L	N/A	
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	
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	
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	
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	
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	
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	

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	
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	
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	
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	
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	
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	
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	
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	
Water	Tritium	1978	CRM 14.5	UCC, 1979	4	3600	pCi/L	N/A	
Water	Tritium	1979	CRM 14.5	UCC, 1980	4	2200	pCi/L	N/A	
Water	Tritium	1980	CRM 14.5	UCC, 1981	4	3233	pCi/L	N/A	
Water	Tritium	1981	CRM 14.5	UCC, 1982	4	3620	pCi/L	N/A	
Water	Tritium	1982	CRM 14.5	UCC, 1983a	4	7600	pCi/L	N/A	
Water	Tritium	1983	CRM 14.5	MMES, 1984	4	8400	pCi/L	N/A	
Water	Tritium	1984	CRM 14.5	MMES, 1985	4	17000	pCi/L	N/A	
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	
Water	Tritium	1990	CRM 13	TVA 1991	1	481.00	pCi/L	N/A	
Water	Tritium	1990	CRM 17	TVA 1991	1	827.00	pCi/L	N/A	
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	CRM 14.5	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-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	Uranium	1983	CRM 14.5	MMES, 1984	12	4	pCi/L	N/A	
Water	Uranium	1984	CRM 14.5	MMES, 1985	12	<6.2	pCi/L	N/A	
Water	Zr-95-Nb-95	1962	CRM 20.8	UCC, 1963	NA	0.9	pCi/L	N/A	Calculated value
Water	Zr-95-Nb-95	1963	CRM 20.8	UCC, 1964	NA	0.2	pCi/L	N/A	Calculated value
Water	Zr-95-Nb-95	1964	CRM 20.8	UCC, 1965	NA	0.07	pCi/L	N/A	Calculated value
Water	Zr-95-Nb-95	1965	CRM 20.8	UCC, 1966	NA	<0.1	pCi/L	N/A	Calculated value
Water	Zr-95-Nb-95	1966	CRM 20.8	UCC, 1967	NA	<0.1	pCi/L	N/A	Calculated value
Water	Zr-95-Nb-95	1967	CRM 20.8	UCC, 1968	NA	<0.1	pCi/L	N/A	Calculated value
Water	Zr-95-Nb-95	1968	CRM 20.8	UCC, 1969	NA	<0.1	pCi/L	N/A	Calculated value
Water	Zr-95-Nb-95	1969	CRM 20.8	UCC, 1970	NA	<0.1	pCi/L	N/A	Calculated value
Water	Zr-95-Nb-95	1970	CRM 20.8	UCC, 1971	NA	<0.1	pCi/L	N/A	Calculated value
Water	Zr-95-Nb-95	1971	CRM 20.8	UCC, 1972	12	<0.10	pCi/L	N/A	Calculated value
Water	Zr-95-Nb-95	1971	CRM 14.5	UCC, 1972	4	0.5	pCi/L	N/A	
NA = Information not available									
N/A = Not applicable									

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	
ediment	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	EFPC 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	13	100	mg/kg	N/A	Carrighan Towers
Soil	Chromium	1984	EFPC floodplain	Hibbitts, 1984	28	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 Value	Units	Species (Fish)	Comments
Soil	PCBs	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	Th-232	1984	EFPC floodplain	Hibbitts, 1984	7	10	pCi/g	N/A	Parcel 564 (apx. EFPCM 12.5-13)
Soil	Thorium	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	Carrighan Towers
Soil	Thorium	1984	EFPC floodplain	Hibbitts, 1984	28	100	mg/kg	N/A	Parcel 564 (apx. EFPCM 12.5-13)
Soil	U-235	1984	EFPC floodplain	Hibbitts, 1984	7	5.9	pCi/g	N/A	Parcel 564 (apx. EFPCM 12.5-13)
Soil	U-238	1984	EFPC floodplain	Hibbitts, 1984	7	70	pCi/g	N/A	Parcel 564 (apx. EFPCM 12.5-13)
Soil	Uranium	1983	EFPC floodplain	Hibbitts, 1984	3	<90	mg/kg	N/A	Jefferson Jr High
Soil	Uranium	1984	EFPC floodplain	Hibbitts, 1984	68	48	mg/kg	N/A	Civic Center
Soil	Uranium	1984	EFPC floodplain	Hibbitts, 1984	17	57	mg/kg	N/A	Southfield Apartments
Soil	Uranium	1984	EFPC floodplain	Hibbitts, 1984	13	56	mg/kg	N/A	Carrighan Towers
Soil	Uranium	1984	EFPC floodplain	Hibbitts, 1984	28	220	mg/kg	N/A	Parcel 564 (apx. 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	0.02	mg/L	N/A	
Water	Chromium	1985	NHP Outfall	MMES, 1986	12	<0.01	mg/L	N/A	
Water	Lead	1971	NHP Outfall	UCC, 1972	12	0.03	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	0.02	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	<0.01	mg/L	N/A	
Water	Lead	1984	EFPCM 14.36	TVA, 1985a	1	0.002	mg/L	N/A	
Water	Lead	1984	NHP Outfall	MMES, 1985	12	0.03	mg/L	N/A	
Water	Lead	1985	NHP Outfall	MMES, 1986	12	<0.01	mg/L	N/A	
Water	Mercury	1971	NHP Outfall	UCC, 1972	9	0.007	mg/L	N/A	
Water	Mercury	1972	NHP Outfall	UCC, 1973	12	0.0009	mg/L	N/A	
Water	Mercury	1973	NHP Outfall	UCC, 1974	12	0.001	mg/L	N/A	
Water	Mercury	1974	NHP Outfall	UCC, 1975	12	<0.0005	mg/L	N/A	
Water	Mercury	1975	NHP Outfall	UCC, 1976	12	0.0009	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	Baseflow- 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		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	1	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.)

NA = 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.

Material	Pathway	Dose (Sv/yr)	Conversion (Risk/Sv)	Risk (1 year)	% Importance
Radionuclides					
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%**
	Soil to Vegetables to Humans (Ingestion)	2.57E-05	7.3%	1.88E-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
Radionuclides (continued)					
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	
			Total Risk (Air) =	**1.81E-06**	**100%**
	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	
			Total Risk (Surface Water) =	**1.61E-06**	**89%**
	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	
			Total Risk (Soil) =	**3.03E-08**	**2%**
			Total Risk =	**3.45E-06**	
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	
			Total Risk (Air) =	**1.97E-06**	**100%**
	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	
			Total Risk (Surface Water) =	**1.39E-06**	**70%**
	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	
			Total Risk (Soil) =	**1.75E-07**	**9%**
			Total Risk =	**3.54E-06**	
Material	**Pathway**	**Lifetime Risk**	**Conversion (yr/lifetime)**	**Risk (1 year)**	**% Importance**
Carcinogenic Chemicals					
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	
			Total Risk (Soil) =	**1.53E-07**	**100%**
			Total Risk =	**1.53E-07**	

TABLE I-1: BETWEEN-MEDIA COMPARISONS-- K-25 SITE SUMMARY

Material	Pathway	Lifetime Risk	Conversion (yr/lifetime)	Risk (1 year)	% Importance
Carcinogenic Chemicals (continued)					
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**	
Material	**Pathway**			**Hazard Index**	**% Importance**
Noncarcinogenic Chemicals					
Chromium (III)	Surface Water to Humans (Ingestion)			9.00E-04	
	Surface Water to Livestock/Game (Beef) to Humans (Ingestion)			1.53E-05	
	Surface Water to Fish to Humans (Ingestion)			2.96E-04	
			Total Hazard (Surface Water) =	**1.21E-03**	**100%**
	Soil to Humans (Ingestion)			8.71E-05	
	Soil to Livestock /Game (Beef) to Humans (Ingestion)			4.80E-04	
	Soil to Dairy Cattle (Milk) to Humans (Ingestion)			1.55E-04	
	Soil to Vegetables to Humans (Ingestion)			1.39E-04	
	Soil to Pasture to Livestock/Game (Beef to Humans (Ingestion)			8.73E-05	
	Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)			2.58E-05	
	Soil to Humans (Dermal Contact)			5.05E-05	
			Total Hazard (Soil) =	**1.02E-03**	**85%**
			Total Hazard =	**2.24E-03**	

TABLE I-1: BETWEEN-MEDIA COMPARISONS-- K-25 SITE SUMMARY

8/27/93

Material	Pathway			Hazard Index	% Importance
Noncarcinogenic Chemicals (continued)					
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	
			Total Hazard (Air) =	**2.00E-03**	1%
	Surface Water to Humans (Ingestion)			1.50E-01	
	Surface Water to Fish to Humans (Ingestion)			1.93E-02	
			Total Hazard (Surface Water) =	**1.69E-01**	100%
	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	
			Total Hazard (Soil) =	**2.10E-02**	12%
			Total Hazard =	**1.92E-01**	
1,1,1-Trichloroethane	Air to Humans (Inhalation)			2.93E-03	
			Total Hazard (Air) =	**2.93E-03**	100%
			Total Hazard =	**2.93E-03**	

TABLE I-2: BETWEEN-MEDIA COMPARISONS-- X-10 SITE SUMMARY

8/27/93

Material	Pathway	Dose (Sv/yr)	Conversion (Risk/Sv)	Risk (1 year)	% Importance
Radionuclides					
Argon-41	Air to Humans (Immersion)	1.36E-06	7.3%	9.93E-08	
			Total Risk (Air) =	**9.93E-08**	**100%**
			Total Risk =	**9.93E-08**	
Barium-140	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**	
Cerium-144	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	
			Total Risk (Air) =	**1.88E-07**	**100%**
	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
Radionuclides (continued)					
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**	

Material	Pathway	Dose (Sv/yr)	Conversion (Risk/Sv)	Risk (1 year)	% Importance
Radionuclides (continued)					
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) =	**5.93E-04**	**100%**
			Total Risk =	**5.93E-04**	
Krypton-85	Air to Humans (Immersion)	6.18E-11	7.3%	4.51E-12	
			Total Risk (Air) =	**4.51E-12**	**100%**
			Total Risk =	**4.51E-12**	
Lanthanum-140	Air to Humans (Inhalation)	2.80E-08	7.3%	2.04E-09	
	Air to Humnas (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) =	**5.80E-08**	**100%**
			Total Risk	**5.80E-08**	
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	
	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) =	**1.24E-08**	**<1%**
			Total Risk =	**4.29E-06**	
Plutonium-238	Water to Fish to Humans (Ingestion)	2.35E-07	7.3%	1.72E-08	
			Total Risk (Surface Water) =	**1.72E-08**	**100%**
			Total Risk =	**1.72E-08**	

TABLE I-2: BETWEEN-MEDIA COMPARISONS-- X-10 SITE SUMMARY

Material	Pathway	Dose (Sv/yr)	Conversion (Risk/Sv)	Risk (1 year)	% Importance
Radionuclides (continued)					
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	
			Total Risk (Surface Water) =	**1.89E-08**	**35%**
			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) =	**2.75E-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%**
	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**	
Ruthenium-106	Air to Humans (Inhalation)	8.03E-08	7.3%	5.86E-09	
	Air to Vegetables to Humans (Ingestion)	6.78E-08	7.3%	4.95E-09	
	Air to Pasture to Livestock/Game (Beef) to Humans (Ingestion)	1.92E-08	7.3%	1.40E-09	
			Total Risk (Air) =	**1.22E-08**	**<1%**
	Water to Humans (Ingestion)	8.19E-05	7.3%	5.98E-06	
	Water to Fish to Humans (Ingestion)	1.48E-05	7.3%	1.08E-06	
			Total Risk (Surface Water) =	**7.06E-06**	**100%**
	Soil to Air to Humans (Inhalation)	8.13E-08	7.3%	5.93E-09	
	Soil to Humans (Ingestion)	2.41E-07	7.3%	1.76E-08	
	Soil to Livestock/Game (Beef) to Humans (Ingestion)	2.88E-07	7.3%	2.10E-08	
	Soil to Vegetation to Humans (Ingestion)	6.25E-06	7.3%	4.56E-07	
	Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion)	6.29E-07	7.3%	4.59E-08	
	Soil to Humans (Ground Exposure)	7.82E-08	7.3%	5.71E-09	
			Total Risk (Soil) =	**5.52E-07**	**8%**
			Total Risk =	**7.62E-06**	

Material	Pathway	Dose (Sv/yr)	Conversion (Risk/Sv)	Risk (1 year)	% Importance
Radionuclides (continued)					
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	
	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**	
Tritium		1.39E-04	7.3%	1.01E-05	100%
			Total Risk =	**1.01E-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**	

Material	Pathway	Dose (Sv/yr)	Conversion (Risk/Sv)	Risk (1 year)	% Importance
Radionuclides (continued)					
Uranium-238	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**	
Xenon-133	Air to Humans (Immersion)	2.11E-07	7.3%	1.54E-08	
			Total Risk (Air) =	**1.54E-08**	**100%**
			Total Risk =	**1.54E-08**	
Zirconium-95	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

8/27/93

Material	Pathway	Dose (Sv/yr)	Conversion (Risk/Sv)	Risk (1 year)	% Importance
Radionuclides					
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) =	**1.22E-09**	**100%**
			Total Risk =	**1.22E-09**	
Technetium-99	Surface Water to Fish to Humans (Ingestion)	1.49E-07	7.3%	1.09E-08	
		Total Risk	**(Surface Water) =**	**1.09E-08**	**100%**
			Total Risk =	**1.09E-08**	
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) =	**2.57E-06**	**100%**
			Total Risk =	**2.57E-06**	
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	
			Total Risk (Air) =	**6.39E-06**	**55%**
	Surface Water to Fish to Humans (Ingestion)	1.60E-04	7.3%	1.17E-05	
		Total Risk	**(Surface Water) =**	**1.17E-05**	**100%**
	Soil to Air to Humans (Inhalation)	1.36E-06	7.3%	9.93E-08	
	Soil to Humans (Ingestion)	1.39E-07	7.3%	1.01E-08	
	Soil to Dairy Cattle (Milk) to Humans (Ingestion)	8.32E-08	7.3%	6.07E-09	
	Soil to Vegetables to Humans (Ingestion)	2.37E-06	7.3%	1.73E-07	
			Total Risk (Soil) =	**2.89E-07**	**2%**
			Total Risk =	**1.84E-05**	
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	
			Total Risk (Air) =	**3.16E-06**	**31%**
	Surface Water to Fish to Humans (Ingestion)	1.41E-04	7.3%	1.03E-05	
		Total Risk	**(Surface Water) =**	**1.03E-05**	**100%**
	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) =	**3.06E-06**	**30%**
			Total Risk =	**1.65E-05**	

TABLE I-3: BETWEEN-MEDIA COMPARISONS-- Y-12 SITE SUMMARY

Material	Pathway	Lifetime Risk	Conversion (yr/lifetime)	Risk (1 year)	% Importance
Carcinogenic Chemicals					
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	70	1.53E-08	
			Total Risk (Soil) =	1.15E-07	100%
			Total Risk =	1.15E-07	
Carbon Tetrachloride	Air to Humans (Inhalation)	4.32E-05	70	6.17E-07	
			Total Risk (Air) =	6.17E-07	100%
			Total Risk =	6.17E-07	
Methylene Chloride	Air to Humans (Inhalation)	2.55E-06	70	3.64E-08	
			Total Risk (Air) =	3.64E-08	100%
			Total Risk =	3.64E-08	
PCBs	Surface Water to Fish to Humans (Ingestion)	4.21E-03	70	6.01E-05	
		Total Risk	**(Surface Water) =**	6.01E-05	100%
	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	
			Total Risk (Soil) =	1.50E-05	25%
			Total Risk =	7.52E-05	
Tetrachloroethylene	Air to Humans (Inhalation)	1.56E-06	70	2.23E-08	
			Total Risk (Air) =	2.23E-08	100%
			Total Risk =	2.23E-08	
Trichloroethylene	Air to Humans (Inhalation)	2.51E-10	70	3.59E-12	
			Total Risk (Air) =	3.59E-12	100%
			Total Risk =	3.59E-12	

TABLE I-3: BETWEEN-MEDIA COMPARISONS-- Y-12 SITE SUMMARY

Material	Pathway			Hazard Index	% Importance
Noncarcinogenic Chemicals					
Chromium (III)	Surface Water to Livestock/Game (Beef) to Humans (Ingestion)			1.40E-04	
	Surface Water to Fish to Humans (Ingestion)			4.50E-05	
		Total Hazard (Surface Water) =		**1.85E-04**	**20%**
	Soil to Humans (Ingestion)			7.86E-05	
	Soil to Livestock/Game (Beef) to Humans (Ingestion)			4.33E-04	
	Soil to Dairy Cattle (Milk) to Humans (Ingestion)			1.39E-04	
	Soil to Vegetables to Humans (Ingestion)			1.26E-04	
	Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion)			7.87E-05	
	Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)			2.32E-05	
	Soil to Humans (Dermal Contact)			4.56E-05	
		Total Hazard (Soil) =		**9.24E-04**	**100%**
			Total Hazard =	**1.11E-03**	
Lead	Surface Water to Fish to Humans (Ingestion)			5.28E-02	
		Total Hazard (Surface Water) =		**5.28E-02**	**6%**
	Soil to Humans (Ingestion)			6.63E-02	
	Soil to Livestock/Game (Beef) to Humans (Ingestion)			1.59E-02	
	Soil to Dairy Cattle (Milk) to Humans (Ingestion)			2.78E-02	
	Soil to Vegetables to Humans (Ingestion)			6.63E-01	
	Soil to Pasture to Livestock/Game (Beef) to Humans (Ingestion)			1.73E-02	
	Soil to Pasture to Dairy Cattle (Milk) to Humans (Ingestion)			2.78E-02	
	Soil to Humans (Dermal Contact)			3.85E-02	
		Total Hazard (Soil) =		**8.57E-01**	**100%**
			Total Hazard =	**9.09E-01**	
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	
		Total Hazard (Air) =		**5.87E-01**	**<1%**
	Surface Water to Fish to Humans (Ingestion)			2.89E+00	
		Total Hazard (Surface Water) =		**2.89E+00**	**<1%**
	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	
		Total Hazard (Soil) =		**1.37E+03**	**100%**
			Total Hazard =	**1.38E+03**	
1,1,1-Trichloroethane	Air to Humans (Inhalation)			3.18E-04	
		Total Hazard (Air) =		**3.18E-04**	**100%**
			Total Hazard =	**3.18E-04**	

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