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Level 3 Baseline Risk Assessment for Building 3515 at Oak Ridge National Laboratory Oak Ridge, Tennessee

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Lockheed Martin Energy Systems, Inc., Environmental Restoration Program
Oak Ridge National Laboratory Environmental Restoration Program

Level 3 Baseline Risk Assessment for Building 3515 at Oak Ridge National Laboratory Oak Ridge, Tennessee

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PREFACE

This baseline risk assessment for the Fission Product Pilot Plant (Building 3515) at the Oak Ridge National Laboratory (ORNL) provides the Decontamination and Decommissioning (D&D) Program at ORNL and Building 3515 project managers with information concerning the results of the Level 3 baseline risk assessment performed for this building. The document was prepared under Work Breakdown Structure 1.4.12.6.2.01 (Activity Data Sheet 3701, Facilities D&D) and includes information on the potential long-term impacts to human health and the environment if no action is taken to remediate Building 3515. Information provided in this document forms the basis for the development of remedial alternatives and the no-action risk portion of the Engineering Evaluation/Cost Analysis report.

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ACRONYMS

BRA	Baseline Risk Assessment
CDI	chronic daily intake
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLP	Contract Laboratory Program
CSL	Close Support Laboratory
COC	chemical of concern
COPC	chemical of potential concern
CSM	Conceptual Site Model
D&D	decontamination and decommissioning
DOE	United States Department of Energy
DQR	data quality requirement
EE/CA	Engineering Evaluation/Cost Assessment
Energy Systems	Martin Marietta Energy Systems, Inc. (now Lockheed Martin Energy Systems, Inc.)
EPA	United States Environmental Protection Agency
ER	Environmental Restoration
FS	Feasibility Study
GAAT	Gunite and Associated Tanks
GI	gastrointestinal
HEAST	(EPA) Health Effects Assessment Summary Tables
HI	hazard index
HQ	hazard quotient
ILCR	Incremental Lifetime Cancer Risk
IRIS	(EPA) Integrated Risk Information System
LLLW	liquid low-level waste
LMES	Lockheed Martin Energy Systems, Inc.
LOAEL	lowest-observed-adverse-effects level
MEPAS	Multimedia Environmental Pollutant Assessment System
NGVD	National Geodetic Vertical Datum of 1929
NOAEL	no-observed-adverse-effects level
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OU	operable unit
pCi	picocurie
PEF	particulate emission factor
QC	quality control
RAS	Risk Analysis Section (of ORNL)
RCRA	Resource Conservation and Recovery Act
RfC	reference concentration
RfD	reference dose
S&M	surveillance and maintenance
SFMP	Surplus Facilities Management Program
SF	slope factor
TAL	Target Analyte List
TDEC	Tennessee Department of Environment and Conservation

TLD	thermoluminescent dosimeter
TVA	Tennessee Valley Authority
WAG	Waste Area Grouping

EXECUTIVE SUMMARY

This report presents the results of the Level 3 Baseline Risk Assessment (BRA) performed for Building 3515 located at the Oak Ridge National Laboratory (ORNL). This BRA is intended to provide an analysis of the potential for adverse health effects (current or future) posed by contaminants at the facility. A Level 3 (least rigorous) BRA was conducted for this facility to use the limited available characterization data. Future plans for the facility (demolition) preclude additional characterization and a more rigorous analysis for risk assessment purposes.

Building 3515, also known as the Fission Product Pilot Plant (FPPP), is a surplus facility in the main plant area to the east of the South Tank Farm and is slated for decontamination and decommissioning (D&D). The building consists of two concrete cells (north and south) on a concrete pad and was used to extract radioisotopes of ruthenium, strontium, cesium, cerium, rhenium, and other elements from aqueous fission product waste. Building 3515 housed an operational pilot system for fission product recovery development from 1948 to 1958. For most of that period, the facility consisted essentially of a two-room hot cell with a control room or lean-to structure along the east and south sides of the building. After operations were moved to the Fission Product Development Laboratory (Building 3517), Building 3515 was abandoned and subsequently entombed in the concrete shell that remains.

Site characterization activities were performed from December 1993 through February 1994 to collect information necessary to begin planning the D&D of the building. Core samples were taken from within and beneath the floor slab outside of the building. Due to the high contamination fields encountered during the characterization effort, samples from the interior of the building were obtained remotely. A paint chip was collected from the south cell. Smear samples and direct radiation measurements were collected from both cells. Samples were analyzed for radionuclides and organic and inorganic chemicals.

To adequately characterize the risks posed by the facility, receptors for both current and potential future land uses were evaluated. The current land use condition considers a maintenance worker involved in routine maintenance activities in close proximity to Building 3515. The worker is assumed to spend 2 hours near the building every other month for a period of 25 years. The worker does not enter the building; therefore, external exposure is the only applicable exposure route. The worker is exposed from each of the external walls of the building and from the contaminated soil located beneath the exterior floor pad.

This risk evaluation is intended to provide exposure and risk estimates for a "no-action" (i.e., no remedial action) future land use scenario. A hypothetical no-action scenario makes the assumption that Building 3515 is abandoned by the United States Department of Energy (DOE) at the start of the risk evaluation. In this scenario, the DOE makes no attempt to prevent contaminant release from the facility or restrict access to the facility. Because Building 3515 is on the Oak Ridge Reservation (ORR) and because DOE is not likely to release the ORR property for development, the area around the building is expected to remain industrial even if the building is abandoned. Therefore, it is assumed that residential development will not occur at this site. However, it is assumed that an adult intruder could enter the building on a limited basis due to degradation of the building over time.

An adult intruder is assumed to enter the building for five 1-hour periods over the course of one year. Because the intruder would be in direct contact with contamination in the facility, this receptor provides an upperbound estimate of the potential human health risks.

If the building is abandoned by DOE (i.e., all building maintenance is discontinued), it will eventually decay and collapse. The possibility also exists that the building could be destroyed by a catastrophic event (e.g., earthquake, tornado). The building structure currently acts as a containment vessel for the contaminants inside. As the building decays or if it is destroyed, these contaminants will be released to the environment. Such releases could potentially result in exposure of off-site (i.e., outside of DOE property) residential receptors. For this reason, off-site residential receptors located at the White Oak Creek and the White Oak Dam have been included for evaluation under the future land use scenario. Contamination could potentially reach these receptors via overland runoff to surface water, infiltration and migration of contaminants in groundwater, and atmospheric transport (catastrophic event only).

Human health risks are evaluated using human exposure results and toxicity information. Risks are estimated differently for carcinogens and noncarcinogens (systemic toxicants). For carcinogenic contaminants, risk is expressed in terms of the probability of contracting cancer over a lifetime, over and above the normal background risk. This is the Incremental Lifetime Cancer Risk (ILCR) and is estimated as the product of the estimated exposure to a carcinogen and contaminant-specific, route-specific slope factor:

$$ILCR = SF \times CDI,$$

where

ILCR = Incremental lifetime cancer risk (unitless probability),
SF = Slope factor $(mg/kg\text{-}day)^{-1}$,
CDI = Chronic Daily Intake (mg/kg-day).

Within this BRA, risks are evaluated in the context of EPA-approved guidelines that include three regions for carcinogenic risk [risk <1.0E-6, no concern; risk between 1.0E-6 and 1.0E-4, range of concern (or target risk range); and risk ≥ 1.0E-4, unacceptable]. In the United States, the normal incidence of cancer occurrence is 3.0E-1 or .30 (American Cancer Society 1990). The ILCR (also referred to as excess cancer risk) is defined as the estimated increased risk that occurs over an assumed average lifespan of 70 years as the result of exposure to a specific known carcinogen. Therefore, an ILCR of one in one million (1.0E-6) may be interpreted as an increase in the baseline population cancer incidence from 300,000 per million population to 300,001 per million population. Current radiation protection standards for workers include a limit of 5 rem for the annual effective dose equivalent. This dose equates to a 25-year lifetime risk corresponding to 5.0E-2. Similar protection standards for members of the public include a limit of 0.1 rem per year. This dose equates to a 70-year lifetime risk of 4.0E-3 (ORNL 1993).

Noncarcinogenic effects of contaminants are quantified as hazard quotients (HQ). An HQ is the ratio of the estimated daily intake to the allowable daily intake or reference dose (RfD):

$$HQ = CDI/RfD,$$

where

HQ = Hazard quotient (unitless),
CDI = Chronic daily intake (mg/kg-day),
RfD = Reference dose (mg/kg-day).

Because the HQ does not define exposure-response relationships, its numerical value should not be construed as a direct estimate of risk; i.e., it is not a probability. It is a numerical indication of whether or not acceptable exposure levels are exceeded. United States Environmental Protection Agency EPA guidelines provide two regions in terms of noncarcinogenic toxicity [hazard index (HI) < 1, no concern, and HI ≥ 1, concern].

The ILCRs and HQs calculated using the described methodology are presented in the following text.

Current Land Use. The total ILCR for the maintenance worker considered under current land use is 3.0E-4. This risk is above the EPA range of acceptable risk and results entirely from external radiation. There are no noncarcinogenic health effects associated with the scenario. The dose rates around the building exterior (of which only one measured value exceeded the background radiation in that area of the plant site) are due to cesium-137 inside the building and beneath the exterior pad. It should be noted that an ILCR of 3.0E-4 is still within the 1.5 rem per year worker exposure limit used by ORNL.

Future Land Use. The total ILCRs to the adult intruder and the residents at White Oak Creek and White Oak Dam are presented in Table 1. Risks to the off-site residents are given for acute releases resulting from a catastrophic event and for chronic releases from the building and the soil beneath the exterior pad resulting from degradation of the building and pad over time.

Table 1. ILCRs and HIs associated with future land use scenarios

Receptor	ILCR	HI
Intruder	6.2E-2	4.9E-5
WOCResident (catastrophic event)	6.2E-1	-
WOC Resident (chronic release from bldg.)	4.8E-2	-
WOC Resident (chronic release from soil beneath pad)	9.9E-6	-
WOD Resident (catastrophic event)	5.9E-1	-

Table 1. (continued)

Receptor	ILCR	HI
WOD Resident (chronic release from bldg.)	4.5E-2	-
WOD Resident (chronic release from soil beneath pad)	9.4E-6	

WOC = White Oak Creek
WOD = White Oak Dam

All of the ILCRs presented in Table 1 exceed the EPA's range of acceptable risk except for the chronic release from soil beneath the exterior pad scenario. Risks to the intruder are dominated by external exposures to radionuclides (specifically, cesium-137). External exposures for the intruder were estimated using thermoluminescent dosimeter (TLD) data (i.e., direct radiation measurements) taken from inside the north and south cells.

Risks to the residents are driven by the ingestion of vegetables grown and irrigated with surface water potentially contaminated by contaminant releases from Building 3515. The driving contaminants for residential exposures are cesium-137 and strontium-90. Risks resulting from the catastrophic event should be evaluated in context with the probability of such an event occurring. Studies have suggested that the annual frequency of a severe earthquake at the ORR would be approximately 4.0E-8 (Benedict 1993).

The most significant human health risks at Building 3515 result from exposures to cesium-137 and strontium-90. Site characterization efforts estimated total activities of 9.3E+2 Curies and 5.3E+2 Curies for cesium and strontium, respectively. Cesium-137 results in significant external exposures to receptors located in close proximity to Building 3515 (i.e., maintenance worker and intruder), while both cesium-137 and strontium-90 result in significant internal exposures via ingestion of contaminated vegetables to off-site residential receptors.

Noncarcinogenic chemicals do not pose a significant human health risk at Building 3515. The total HI to the adult intruder is 4.9E-5, which is well below the EPA's level of concern.

It should be noted that all of the risk estimates presented in this BRA are associated with varying levels of uncertainty. Of particular importance is the limited amount of sampling data used to estimate exposure concentrations. Due to the high levels of contamination present in the building, characterization efforts for the interior of the facility had to be performed remotely, which prevented extensive sampling. In addition, off-site exposure concentrations were estimated using fate and transport computer models to simulate the migration of contaminants in the environment. Uncertainties arise in modeling from having to simulate an infinitely complex system using a finite number of variables.

Risk Perspective

To place the results presented in this risk assessment into perspective, one might consider the probability of an individual's developing cancer from unavoidable exposure to naturally occurring

background radiation. The lifetime risk of cancer incidence from background radiation in the general population is approximately 1.0E-2 (Energy Systems 1993). This value is 100 times greater than the upperbound (1.0E-4) of EPA's target risk range. In addition, Table 2 lists activities that increase the chance of cancer fatality by 1.0E-6. The reader should note that these values are for **fatal** cancers not the **incidence** of cancer.

Table 2. Risks that increase the chance of death by one part in one million (1.0E-6)[a]

Activity	Cause of death
Smoking 1.4 cigarettes	Cancer, heart disease
Flying 6000 miles by jet	Cancer caused by cosmic radiation
Living 2 months in average stone or brick building	Cancer from natural radioactivity
Eating 40 tablespoons of peanut butter	Liver cancer caused by aflatoxin B

[a] Taken from Wilson, 1979

The results of the Level 3 BRA for Building 3515 indicate that short-term on-site exposures resulting from contaminated media inside the building pose a potential human health risk. Estimated risks to a potential maintenance worker outside the facility exceed the EPA's target risk range; however, they are below the ORNL worker radiation limit. While it is unlikely that adult intruder exposures will ever occur at this facility, these exposures were evaluated to provide an upperbound estimate of the potential human health risks. The high levels of contamination indicate that D&D activities will need to be performed remotely to ensure the safety of D&D workers. Health risks to off-site residential receptors from exposures to contaminants released under both acute (catastrophic) and chronic scenarios are also above the levels of concern as set by EPA. Based on the results of this risk assessment, the chemicals of concern (COCs) at Building 3515 are cesium-137 and strontium-90.

A risk evaluation is an integrated evaluation of historical, contaminant, analytical, environmental, demographic, and toxicological data that are as site-specific as possible. To minimize the effects of uncertainties in the evaluation, each step is biased toward health-protective estimations. Because each step builds on the previous one, this biased approach should more than compensate for risk evaluation uncertainties. These calculations attempt to represent currently existing or expected future exposure or health risks. However, they are estimates of potential risks only if all of the conservative assumptions are realized.

1. INTRODUCTION

As part of its ongoing Environmental Restoration (ER) Program, the United States Department of Energy (DOE) has reduced operations at various federal facilities, including the Oak Ridge Reservation (ORR) in Oak Ridge, Tennessee, as missions have been determined obsolete or have been relocated. Many of the buildings at these facilities may pose a threat to human health and the environment as a result of radioactive and/or chemical contaminants remaining at the site. Therefore, these buildings have been placed in DOE's Decontamination and Decommissioning (D&D) Program for further evaluation and remediation. Elimination of potential environmental or public health risk, the significant reduction of the risk of adverse publicity, and the decrease in the risk of potential personnel contamination caused by these buildings are significant goals to be achieved by the D&D Program (Energy Systems 1992).

Building 3515 (Fission Product Pilot Plant) at Oak Ridge National Laboratory (ORNL) is managed by Lockheed Martin Energy Systems, Inc. (LMES) and has been placed in the ORNL D&D Program within the LMES ER Program. Remedial actions may be necessary at Building 3515 to avoid the potential spread of contamination and human and environmental exposures as the building and equipment deteriorate. The Risk Analysis Section (RAS) of the Health Sciences Research Division at ORNL has been tasked with preparing a baseline risk assessment (BRA) for Building 3515 to assess the potential risks to human health and the environment posed by current and potential future conditions at this facility.

The BRA is a four-stage process that provides an analysis of the potential for adverse health effects (current or future) caused by hazardous substances at and/or being released from a site in the absence of any actions to control or mitigate exposures and releases (EPA 1989a). Figure 1.1 provides an overview of the risk assessment process. Data collection/evaluation is the first stage of the process. During this stage, analytical and other site-specific data are used to characterize the nature and extent of contamination at the site. The second stage, exposure assessment, involves estimating exposures based on contaminant concentrations derived from the analytical data, fate and transport models, and information collected on the demography and behavior of receptor populations. The third stage, toxicity assessment, involves collecting information concerning the potential toxic characteristics of each contaminant at the site. The results of the toxicity assessment are combined with the exposure estimates to quantitatively or qualitatively evaluate potential risks to human health posed by each chemical of potential concern (COPC) at the facility in the fourth stage, which is the risk characterization stage.

This BRA was prepared following the methodology being developed for the D&D Program by RAS. This methodology follows United States Environmental Protection Agency (EPA) guidance for conducting BRAs at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites as presented in *Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual, Part A* (1989a). The D&D methodology provides information necessary to apply EPA guidance to D&D facilities and presents D&D management with risk information to be used in determining future remediation needs. In addition, it includes a tiered or graded approach to conducting the BRA; the purpose of the tiered approach is to save time and effort at facilities that do not warrant a rigorous BRA. The level of detail of the assessment is measured by the amount and resolution of the data used and the sophistication of the analysis employed. The selection of the level

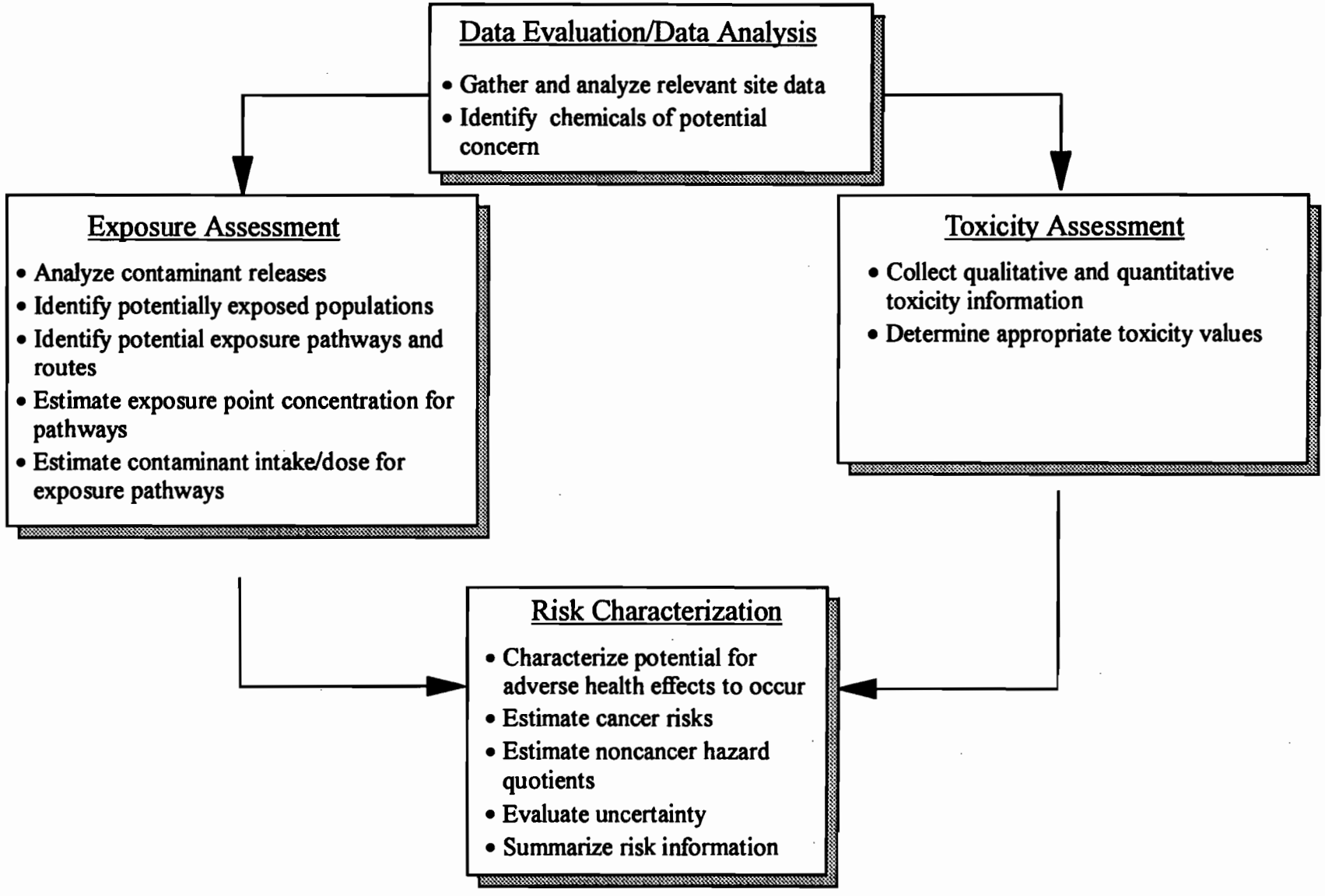


Fig. 1.1. Overview of the BRA process.

applied at a facility is dependent on the complexity of the problem and the types of decisions being made. The methodology includes guidance for conducting BRAs at three levels of effort:

- Level 1 requires a full characterization of the facility and provides a complete quantitative CERCLA BRA with statistical analysis. Two exposure scenarios are evaluated: abandonment and continued surveillance & maintenance (S&M). A preliminary endpoint analysis is also provided.

- Level 2 includes an extensive characterization of the facility but may be less rigorous than Level 1. The abandonment scenario is evaluated, and the continued S&M scenario is optional. The preliminary endpoint analysis is optional for this assessment. The primary differences between the Level 2 and Level 1 assessments are the amount of characterization data available and the level of fate and transport modeling applied.

- Level 3 uses minimal characterization data and relies heavily on historic knowledge of the facility. The quantitative assessment has a greater uncertainty than Levels 1 and 2 and therefore uses more "worst-case" assumptions. Only one exposure scenario (abandonment) is evaluated.

All three levels are designed to conform to EPA (1988, 1989a, 1989b, 1990, 1991) guidance for conducting BRAs under CERCLA.

1.1 PURPOSE AND SCOPE OF THE BRA

The purpose of this report is to present the BRA for Building 3515. The decision was made to conduct a Level 3 BRA for the building based on the fact that data from inside the facility are limited. Tentative future plans for the facility (demolition) also preclude a rigorous analysis. Therefore, additional data collection and a more rigorous BRA were not considered necessary for the purpose of this risk assessment. This BRA uses limited characterization combined with many "worst-case" assumptions for estimating potential exposures. The purpose of this risk assessment is to provide documentation to interested stakeholders (managers, regulators, and the general public) of any potential human health and environmental risks posed by contaminants at Building 3515. This BRA will also provide the "no action" alternative for comparison of remedial options at the facility.

1.2 BACKGROUND

ORNL is a large, multifunctional, research and development facility for the federal government, and it will continue to support applied research and engineering development programs in fission, fusion, conservation, fossil, and other energy technologies, as well as perform research in the physical and life sciences. Past research and development and waste management activities have resulted in a significant number of sites or areas that have been contaminated with low-level radioactive and/or hazardous chemical wastes that will potentially require remediation. Remediation of contamination will be conducted concurrently with other ongoing operational and maintenance activities, and as a result, remediation will be technically and logistically complicated.

Building 3515 is located at ORNL within the Gunite and Associated Tanks (GAAT) Operable Unit (OU) of Waste Area Grouping 1 (WAG 1). Therefore, Building 3515 D&D activities and remediation of the tanks and soils within the GAAT OU must be coordinated. The following

background information provides the reader with information concerning the GAAT OU for orientation purposes only. This information was taken from the *Remedial Investigation Report Feasibility Study For The Gunite and Associated Tanks Operable Unit At Waste Area Grouping* 1 (Radian 1993).

As noted previously, the GAAT OU and Building 3515 are within ORNL WAG 1, which includes most of the original ORNL research and development facilities and associated waste management units. WAG 1 covers approximately 150 acres (60.7 ha) (Fig. 1.2). Approximately 167 identified contaminated sites or areas have been incorporated within WAG 1. About 27 sites or areas are classified as requiring no further action. Other sites or areas are listed for remediation under the DOE surplus facilities program and are the responsibility of ORNL's D&D Program. The remaining 126 sites or areas include inactive underground waste storage tanks, waste burial grounds, surface impoundments, liquid low-level waste (LLLW) lines and leak sites, active underground waste storage tanks, and mercury spill areas.

The GAAT OU includes all 12 of the Gunite tanks in WAG 1 and 4 stainless steel tanks in the north tank farm which are being remediated at the same time because of their presence within the tank farm and location within the vicinity of the Gunite tanks. Building 3515 is located within the GAAT OU east of the south tank farm on Fourth Street south of Central Avenue (Fig. 1.3).

The building was built in 1948 and was modified throughout its operational life. The original facility consisted of a concrete pad with tanks and a tent surrounding the shield blocks. In 1950–51, construction of a hot cell was begun with 18-in. thick, solid masonry block walls and a 2-ft-thick, reinforced concrete roof. Lean-to buildings (i.e., supported roof sections extending from the main building) contained the operating area. A small valve pit that contains valves and controls is located on the north side of this building. Building 3515 was used to extract radioisotopes of ruthenium, strontium, cesium, cerium, and other elements from liquid waste that came from ORNL operations and Chalk River clean-up operations in Canada. Past operations in this facility resulted in severe contamination of the interior surfaces. This was primarily due to the practice of overflowing the piping and vessels with purge liquids for decontamination to allow entry for work. The building contains two rooms with solid masonry block walls shielding the process equipment. In addition, lean-tos were constructed to house the operating area for the processes and were later removed. Currently, concrete shielding surrounds the entire structure, and all doorways are sealed. The drain from this building contained highly radioactive material, resulting in the evacuation of the operating area due to high radiation fields from the drain. It is known that this line leaked and that the soil was extensively contaminated. The drain has since been covered with a new concrete floor (poured over the original floor) thereby preventing any additional movement of contaminants.

In 1976, Building 3515 was transferred to the Surplus Facilities Management Program (SFMP) for eventual D&D. Since that time, routine S&M has been performed, including extensive roof repairs. Building 3515 is now in the D&D Program.

The building interior is currently inaccessible since it is completely enclosed by an added concrete shield wall. A stainless steel roof was installed to prevent leakage of rainwater into the building. Limited information is available on the equipment or systems still located inside the building. A substantial amount of fission products still exists within the building; however, because of decay, the major radionuclides remaining are cesium-137 and strontium-90. As expected, only cesium-137 has been detected from the external radiation measurements. In addition, there is extensive contamination of the soil under and around this building due to the leaky drain line.

1.3 ORGANIZATION OF THE REPORT

This Level 3 BRA is presented in five chapters. An overview of the BRA methodology and background information on Building 3515 has been presented in Chapter 1. Chapter 2 describes the collection and evaluation of facility characterization data. The exposure assessment is presented in Chapter 3, while Chapter 4 presents the toxicity information for the toxicity assessment. Finally, Chapter 5 presents results of the risk characterization.

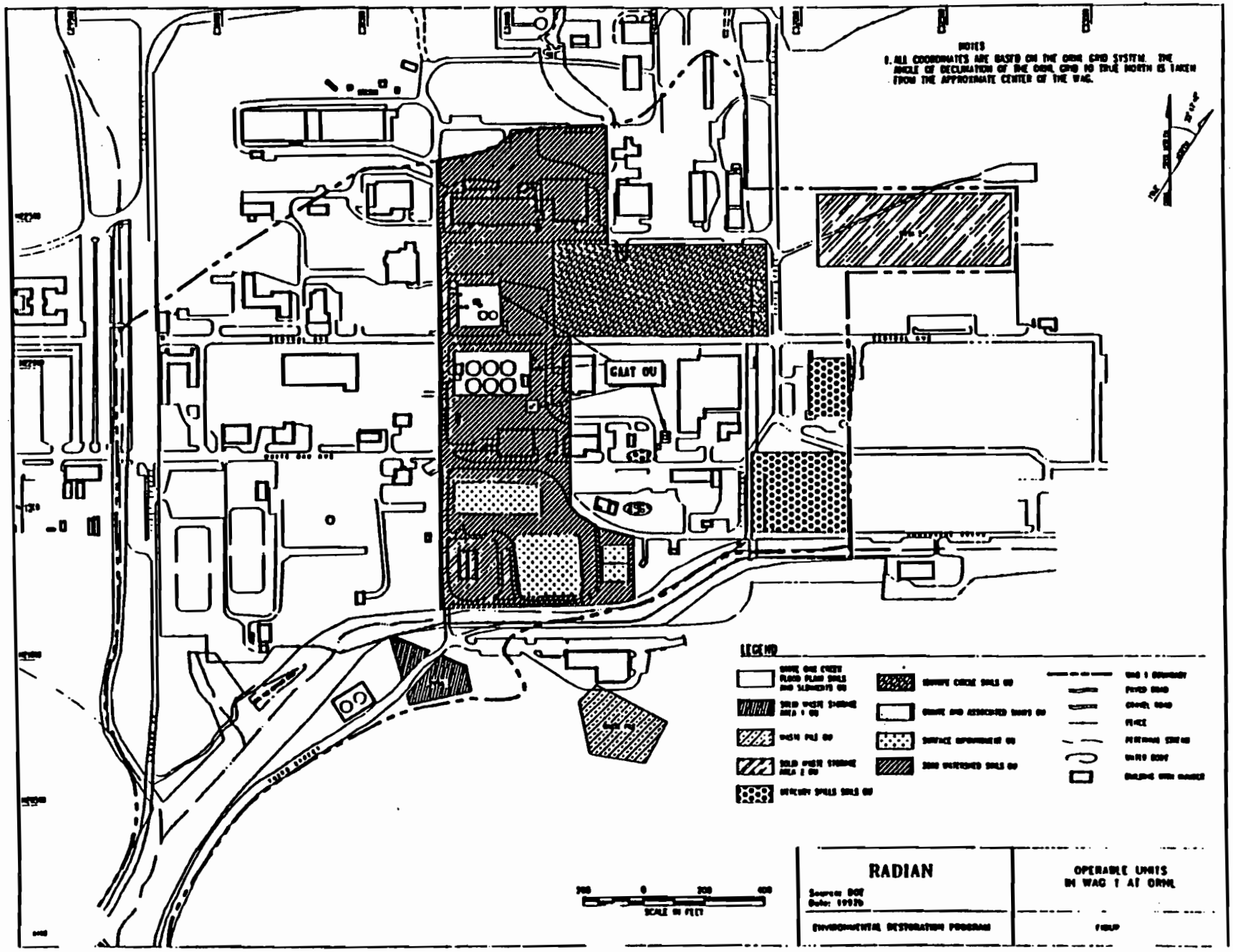


Fig. 1.2 Operable units in WAG 1 at ORNL.

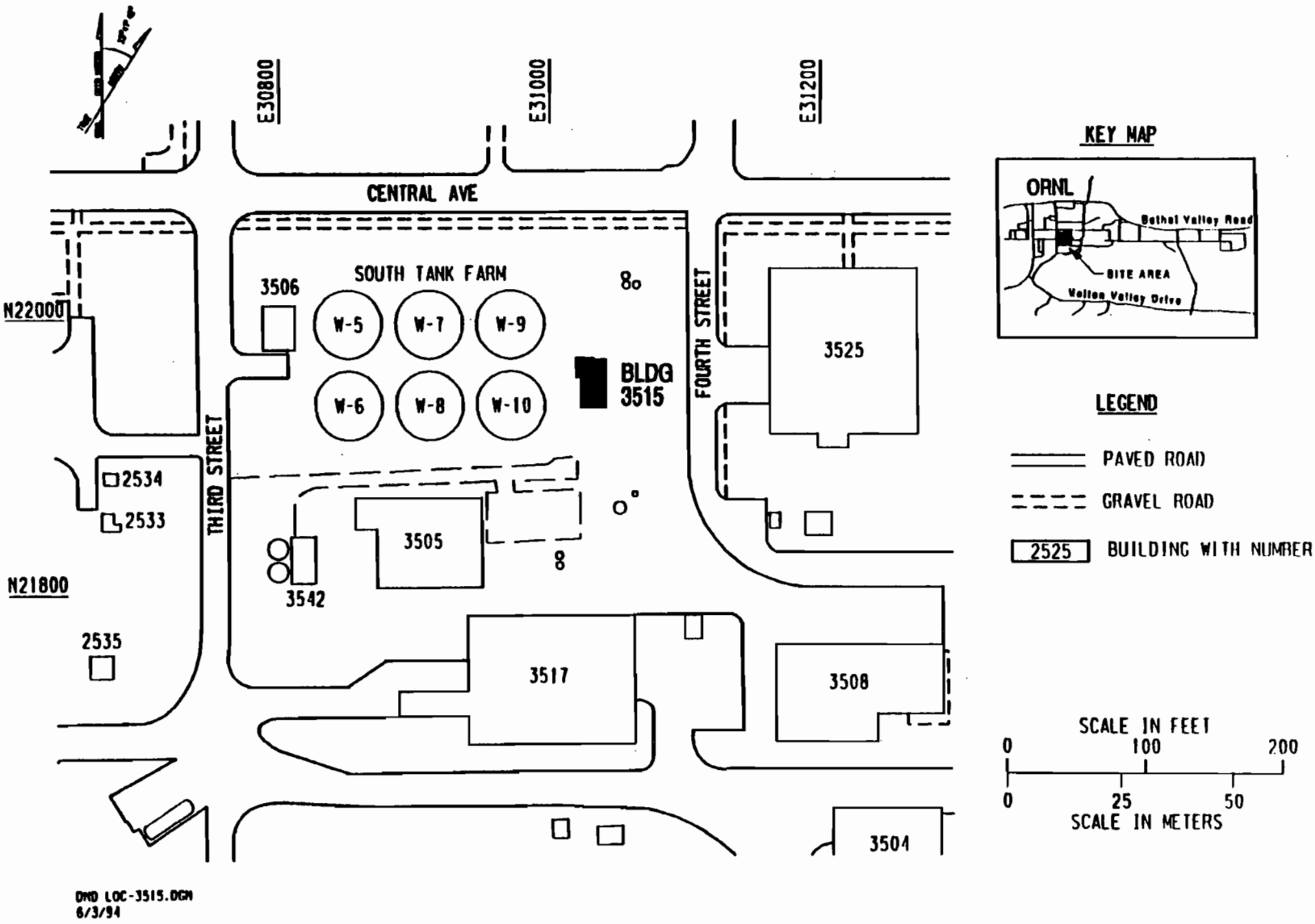


Fig. 1.3. Location of Building 3515.

2. DATA COLLECTION AND EVALUATION

The purpose of data collection and evaluation is to acquire chemical, radionuclide, facility structure, and receptor population data; assess the available data for data quality; and estimate the ability of the sampling and analytical methods used to meet the needs of a quantitative risk assessment. Chemicals of potential concern are determined after the data collection and evaluation activities have been completed.

The results of the data analysis are presented in this Level 3 BRA and provide quantitative and qualitative estimates of the identities, concentrations, volumes, and forms of chemical and/or radiological contaminants of concern at the facility.

This data evaluation chapter is organized into the following four sections: Data Collection (Sect. 2.1), Data Evaluation (Sect. 2.2), Selection of Contaminants of Potential Concern (Sect. 2.3), and Uncertainty (Sect. 2.4.)

2.1 DATA COLLECTION

The primary objective of data collection activities at D&D facilities such as Building 3515 is to provide the information necessary for estimating potential contaminant sources and inventories and the magnitude of potential future releases from the facility to the surrounding environment. To ensure that the data collected at a facility meet these objectives, the risk assessor must have some knowledge of past practices at the facility, potential contaminants present, and the potential current and future pathways for exposure at the facility. This will enable the risk assessor to target data collection activities to those contaminants and areas at the facility that represent a potential risk and determine when adequate data have been collected to fulfill the needs of the risk evaluation.

2.1.1 Characterization Data at Building 3515

A preliminary decommissioning study report of Building 3515 was prepared in 1984 (Horton 1984). Most of the information presented in this report was historical and qualitative in nature; however, a radiation survey around the exterior of the building was performed. The primary characterization data set for Building 3515 was collected during 1994. The 1994 efforts were conducted to plan D&D activities for this building. The characterization activities were conducted following the *Site Characterization Plan for Decontamination and Decommissioning of Buildings 3506 and 3515 at Oak Ridge National Laboratory, Oak Ridge, Tennessee* report (Bechtel 1993). Please refer to this site characterization plan for further information on sampling and analysis. The collected data fall into two categories: (1) engineering drawings/sketches/photographs from the 1950s and (2) sampling and survey data.

The engineering plans and sketches include various drawings and historical photographs taken over the lifetime of the building. The radiological surveys include data from the following: teletectors (a telescopic radiation measurement instrument, Geiger-Mueller tube), directional (shielded HP-290) detectors, thermoluminescent dosimeter (TLD) strings, and gross smear samples. Other data include limited core and soil samples from the outside of the building. A list of preliminary COPCs is presented in Table 2.1. A summary of the data is presented in Tables 2.2–2.8 and Figs 2.1–2.3. Finally, a summary of chemicals of potential concern (i.e., essential nutrients removed from Table 2.1) is presented in Table 2.9.

Table 2.1. Preliminary chemicals of potential concern

Radionuclides		Metals and Cyanide		
Americium-241	Uranium-238	Arsenic	Aluminum	Manganese
Plutonium-238	Actinium-228	Barium	Antimony	Nickel
Plutonium-239	Cesium-137	Cadmium	Beryllium	Potassium
Plutonium-240	Potassium-40	Chromium	Calcium	Sodium
Thorium-228	Radium-226	Lead	Cobalt	Thallium
Thorium-230	Strontium-90	Mercury	Copper	Vanadium
Thorium-232	Cobalt-60	Selenium	Iron	Zinc
Uranium-234	Carbon-14	Silver	Magnesium	Cyanide
Uranium-235	Tritium			

Table 2.2. Analytical results for metals and cyanide[a]

Location ID	73.SB001	73.SB002			South Cell
Sample ID	04131	04130	04279	03932	04243
Sample Type	Concrete Core	Concrete Core	Concrete Core	Soil	Paint Chips
Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
RCRA Metals					
Arsenic	<3.	4.5 J	4. J	5.5	2.4
Barium	57.5 J	55.9	23.6	54.5	4,300
Cadmium	<0.21	<0.36	0.94	2.3	<0.26
Chromium	10.1	9.4	20.4	21.9	<5.3
Lead	79.8	8.2 J	15.9 J	213	158
Mercury	<0.05	<0.05	<0.05	12.4 J	NA
Selenium	<2	<0.82 R[b]	<4.2 R[b]	<0.17	<1.4
Silver	<0.84	<0.44	<0.44	1.5	<0.6
Zinc	29.4 J	29.8	151	56.4 J	103
Other TAL Metals					
Aluminum	5,710	6,220	5,740	12,200	14,300
Antimony	<2.8	<2.6	<2.6	12. J	<6.1
Beryllium	0.42	0.34	0.34	1.2	<0.15
Calcium	255,000	284,000	284,000	41,300. J	15,000
Cobalt	3.6 J	4.1	2.3	15.1	18.9
Copper	16.3	128. J	8.3 R	15.7	8.7 J
Iron	5,980	6,780	6,270	34,600	2,680
Magnesium	20,600	20,300	9,280	3,410	472
Manganese	273	284	216	731	34.6
Nickel	5.8	6.5	6	19.1	4.8
Potassium	1,280. J	1,250	731	<2,500	414
Sodium	<322	224. J	202. J	189	106
Thallium	<0.26	0.22 J	0.62 J	<0.32	<0.18

Table 2.2. (continued)

Location ID	73.SB001	73.SB002			South Cell
Sample ID	04131	04130	04279	03932	04243
Sample Type	Concrete Core	Concrete Core	Concrete Core	Soil	Paint Chips
Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Vanadium	9.4	8.8	7.1	33.1	<2.8
TAL Cyanide					
Cyanide	<0.49	<0.53	<0.53	<0.03	NA

[a] Taken from: Bechtel, 1993
[b] Selenium nondetects were rejected because of zero percent recovery on the matrix spike analysis.
J = estimated value.
R = rejected value.

Note 1: Sample 04180 (trip blank) did not undergo metals and cyanide analyses.
Sample 04243 (paint chip) did not undergo mercury or cyanide analyses.
Note 2: Shaded values indicate that the total metal content is greater than RCRA toxicity characteristic equivalent limits.

Table 2.3. Radiological analysis results for Building 3515[a]

Sample ID	04131 (Concrete)			04130 (Concrete, 0.8 ft)			04279 (Concrete, 0.8–1.5 ft)			03932 (Soil)			04243 (Paint Chip[b])		
Location ID	73.SB001			73.SB002			73.SB002			73.SB002					
	Concen-tration (pCi/g)	Uncertainty (±)	Review qualifier /MDL	Concen-tration (pCi/g)	Uncertainty (±)	Review qualifier /MDL	Concen-tration (pCi/g)	Uncertainty (±)	Review qualifier /MDL	Concen-tration (pCi/g)	Uncertainty (±)	Review qualifier /MDL	Concen-tration (pCi/g)	Uncertainty (±)	Review qualifier /MDL
Gross Alpha	-1.40	9.50	U/9.72	7.60	4.50	--	10.70	4.20	--	7260.00	1460.00	--	78.00	17.00	
^{241}Am										382.00	101.00	--			
$^{239/240}$Pu	0.05	0.07	U/0.12	0.02	0.06	U/0.14	0.16	0.15	R	95.40	20.40	--			
^{238}Pu	0.06	0.09	U/0.15	0.03	0.09	U/0.22	0.05	0.10	U/0.20	5.70	1.60	--			
^{228}Th	0.44	0.23	--	0.34	0.23	J	0.68	0.37	--	5.51	1.97	--			
^{230}Th	0.89	0.34	--	0.85	0.39	--	0.85	0.42	--	5.57	1.88	J			
^{232}Th	0.36	0.19	--	0.55	0.30	--	0.28	0.22	--	1.09	0.76	J			
^{234}U	0.76	0.32	--	1.30	0.53	J	0.82	0.41	--	1.81	0.95	--			
^{235}U	0.00	0.00	U/0.06	0.03	0.06	UJ/0.08	0.03	0.07	U/0.09	0.04	0.22	U/0.59			
^{238}U	0.68	0.30	--	1.40	0.56	--	1.37	0.59	--	2.40	1.01	--			
^{228}Ac				0.29	0.19	--									
Gross Beta	39.90	7.10	--	18.80	6.30	--	10386.70	69.80	--	1390000.00	149000.00	--	110000.00	1200.00	
^{137}Cs	27.74	0.28	--	9.20	0.31	--	2404.00	6.00	--	1300000.00	150000.00	--	431000.00	753.00	
^{40}K	8.95	0.73	--	9.43	1.31	--	3.87	1.82	--						
^{226}Ra	0.20	0.07	--												
^{90}Sr	0.77	0.86	UJ/0.44	0.23	0.63	UJ/0.47	1370.00	16.10	--	254000.00	28100.00	--			
^{60}Co				0.00	0.00	U/0.08	0.00	0.00	U/0.27						
^{14}C													0.20		<0.198 /MDL

Table 2.3. (continued)

Sample ID	04131 (Concrete)			04130 (Concrete, 0.8 ft)			04279 (Concrete, 0.8–1.5 ft)			03932 (Soil)			04243 (Paint Chip[b])		
Location ID	73.SB001			73.SB002			73.SB002			73.SB002					
	Concen-tration (pCi/g)	Uncertainty (±)	Review qualifier /MDL	Concen-tration (pCi/g)	Uncertainty (±)	Review qualifier /MDL	Concen-tration (pCi/g)	Uncertainty (±)	Review qualifier /MDL	Concen-tration (pCi/g)	Uncertainty (±)	Review qualifier /MDL	Concen-tration (pCi/g)	Uncertainty (±)	Review qualifier /MDL
Tritium	-2.37	1.38	U/0.68	0.10	1.15	UJ/0.62	0.62	0.59	J	-0.05	0.25	U/0.45	0.18		<0.177 /MDL

[a] Taken from: Bechtel 1993.
[b] This sample was analyzed by the CSL only (rad screen).

Notes:

(1) Blanks indicate that no data were reported by the laboratory.
(2) Concentrations are as reported from the laboratory and are background-subtracted. Review qualifiers of U indicate that the reported MDL value should be used for most purposes.

Table 2.4. TLD string results for north cell, shallow dose (H_s)[a]

Penetration into cell (ft)	Shallow dose rate, H_s (mrem/h)			
	up	down	south	north
10.0	18886.2	21401.2	18305.4	21371.3
9.0	17143.7	23634.7	18706.6	21197.6
8.0	9958.1	12401.2	8796.4	10167.7
7.0	3425.1	5335.3	4437.1	3736.5
6.0	2604.8	2604.8	2658.7	2802.4
5.0	724.6	712.6	652.7	497.0
4.0	47.9	65.9	29.9	29.9
3.0	29.9	29.9	0.0	6.0
2.0	0.0	18.0	12.0	53.9
1.0	0.0	18.0	0.0	0.0

[a] Taken from: Bechtel 1993

Table 2.5. TLD string results for north cell, deep dose (H_d)[a]

Penetration into cell (ft)	Deep dose rate, H_d (mrem/h)			
	up	down	south	north
10.0	19167.7	21419.2	19820.4	20964.1
9.0	18263.5	23485.0	18113.8	20670.7
8.0	8994.0	8047.9	6407.2	11491.0
7.0	3329.3	3610.8	3652.7	3706.6
6.0	2610.8	2586.8	2485.0	2730.5
5.0	652.7	419.2	431.1	491.0
4.0	24.0	35.9	24.0	24.0
3.0	6.0	18.0	12.0	6.0
2.0	6.0	12.0	12.0	6.0
1.0	12.0	12.0	12.0	6.0

[a] Taken from: Bechtel 1993

Table 2.6. TLD string results for south cell, shallow dose (H_s)[a]

Penetration into cell (ft)	Shallow dose rate, H_s (mrem/h)			
	Up	Down	South	North
9.5	568.0	988.0	800.0	828.0
9.0	764.0	1300.0	1024.0	904.0
8.0	792.0	2136.0	896.0	1220.0
7.0	1404.0	4376.0	3164.0	1404.0
6.0	1208.0	2988.0	6952.0	1408.0
5.0	988.0	2580.0	2660.0	788.0
4.0	488.0	2616.0	1004.0	792.0
3.0	148.0	504.0	124.0	300.0
2.0	44.0	108.0	204.0	36.0
1.0	4.0	4.0	4.0	24.0

[a] Taken from: Bechtel 1993

Table 2.7. TLD string results for south cell, deep dose (H_d)[a]

Penetration into cell (ft)	Deep dose rate, H_d (mrem/h)			
	Up	Down	South	North
9.5	448.0	584.0	576.0	516.0
9.0	516.0	576.0	544.0	540.0
8.0	396.0	412.0	468.0	384.0
7.0	332.0	324.0	404.0	332.0
6.0	464.0	396.0	544.0	412.0
5.0	388.0	396.0	444.0	348.0
4.0	272.0	268.0	312.0	260.0
3.0	104.0	128.0	96.0	104.0
2.0	48.0	36.0	56.0	36.0
1.0	24.0	24.0	20.0	36.0

[a] Taken from: Bechtel 1993

Table 2.8. Smear analysis data[a]

Radionuclide	North Cell (μCi/smear)	South Cell (μCi/smear)
Gross Alpha	5.39E-5	3.00E-5
Gross Beta/Gamma	7.76E-3	2.04E-1
$^{137}Cs/^{137}Ba$	6.53E-3	2.59E-2
Gross ^{90}Sr		3.13E-2

[a] Taken from: Bechtel, 1993

Table 2.9. Chemicals of potential concern[a]

Radionuclides		Metals and Cyanide	
Americium-241	Uranium-238	Arsenic	Beryllium
Plutonium-238	Actinium-228	Barium	Cobalt
Plutonium-239	Cesium-137	Cadmium	Manganese
Plutonium-240	Potassium-40	Chromium	Nickel
Thorium-228	Radium-226	Selenium	Thallium
Thorium-230	Strontium-90	Silver	Vanadium
Thorium-232	Cobalt-60	Aluminum	Zinc
Uranium-234	Carbon-14	Antimony	Cyanide
Uranium-235	Tritium		

[a] Representative concentrations can be found in Tables 2.2 and 2.3.

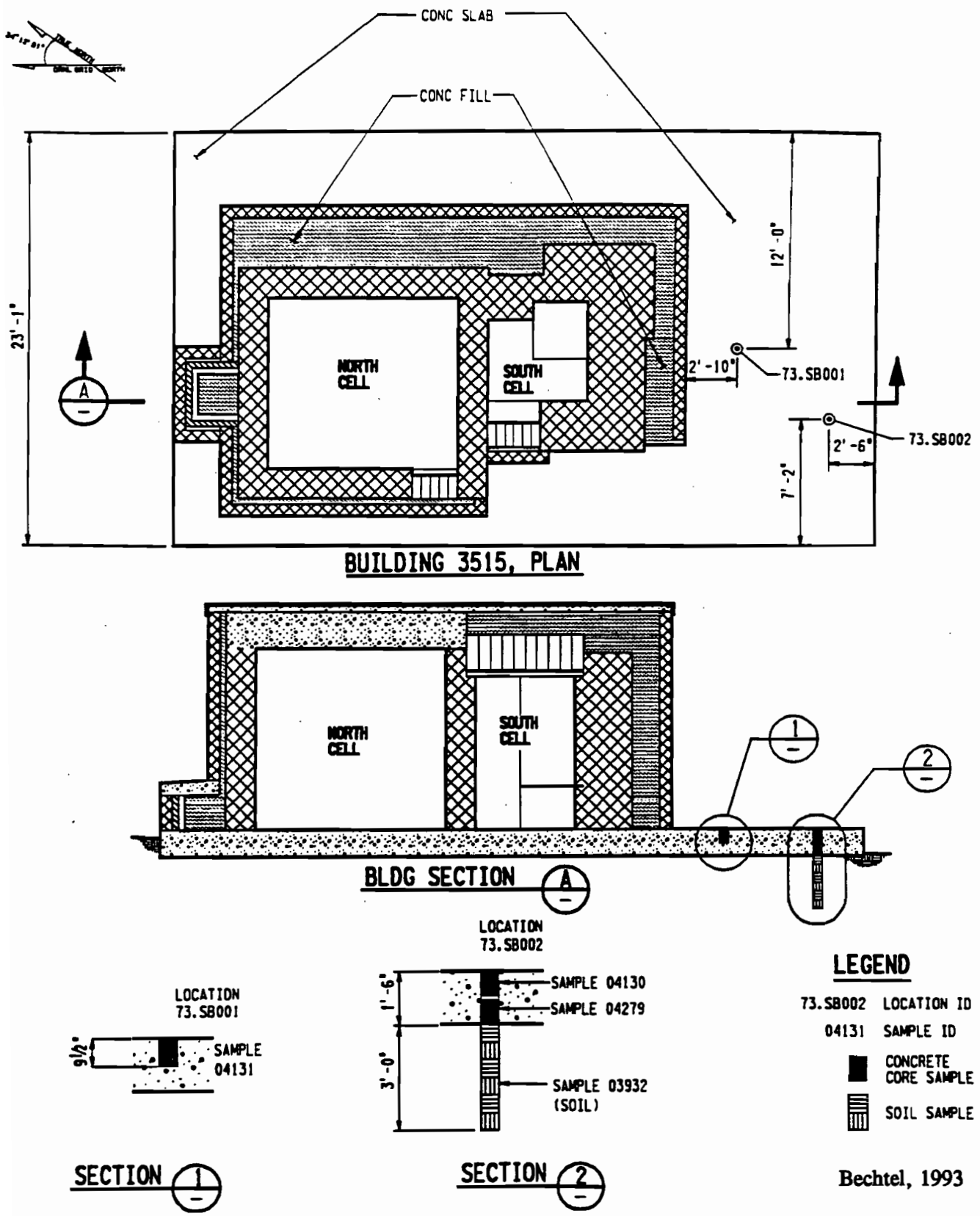
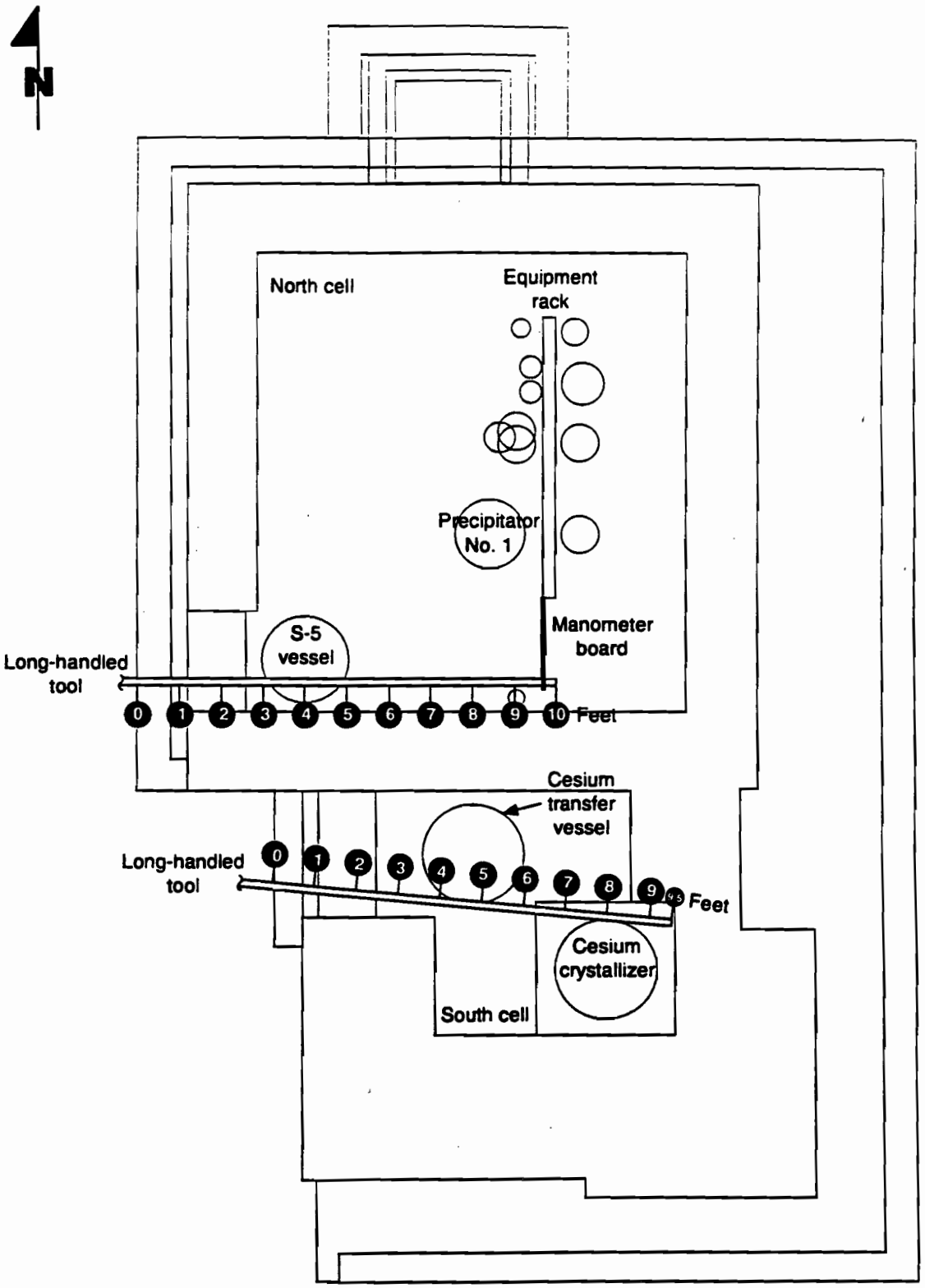


Fig. 2.1.Concrete core and sampling locations at Building 3515.



Bechtel, 1993

Fig. 2.2. Penetration distance of long-handled tools into cells from access holes.

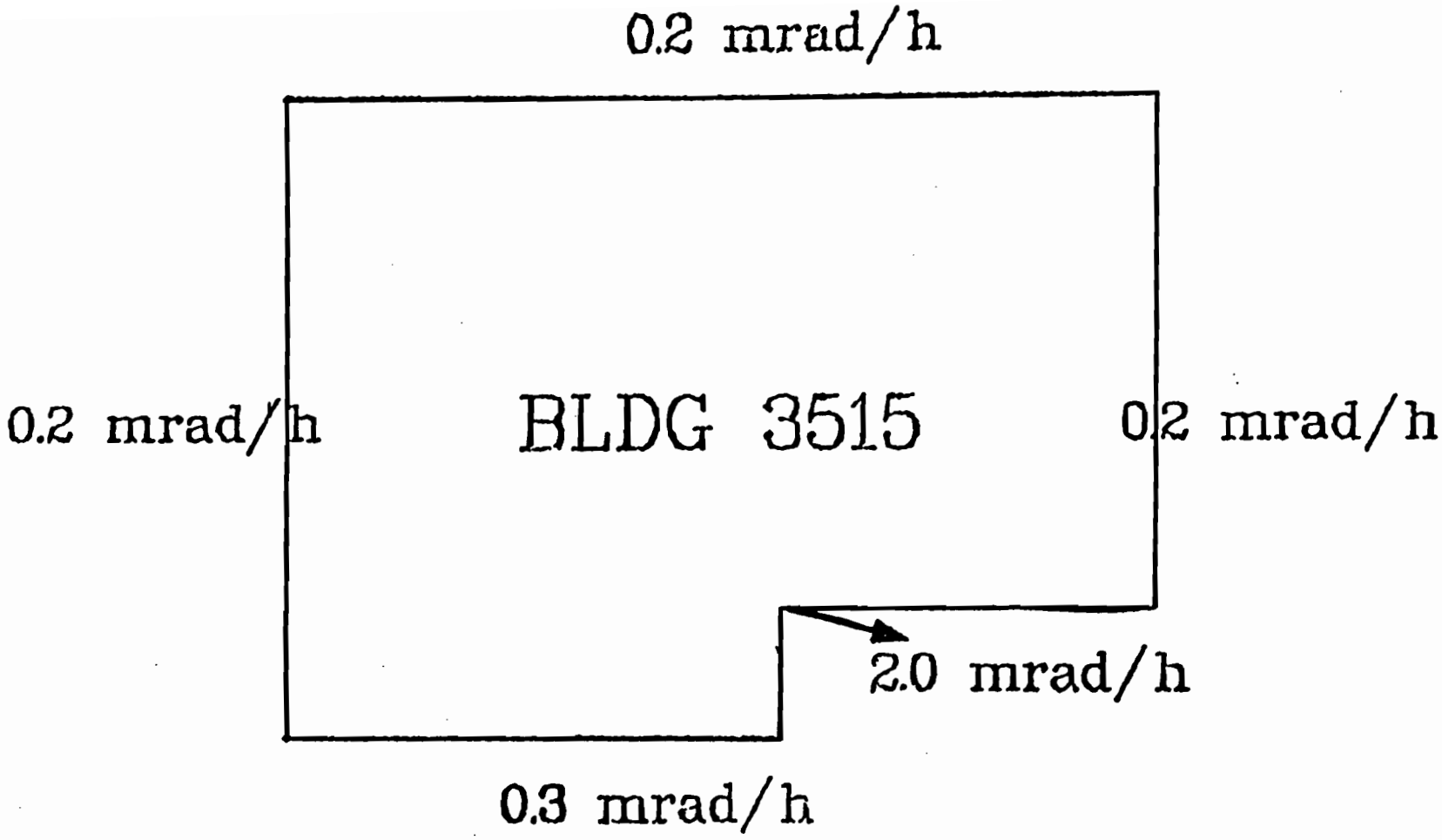


Fig. 2.3. Results of a radiation survey around the exterior of Building 3515.

2.1.2 Preliminary Chemicals of Potential Concern

As discussed briefly in Sect. 1.2, the equipment in the building was used to extract radioisotopes of ruthenium, strontium, cesium, cerium, rhenium, and other elements from aqueous fission waste. Therefore, the principal COPCs associated with the building are radionuclides, particularly cesium-137 and strontium-90. Several chemicals, such as arsenic, barium, and chromium, are present in the building as well. Site characterization activities, including sampling analysis, were undertaken in January and February 1994 to collect the information needed to plan the D&D of Building 3515. A list of the preliminary COPCs as derived from this study is given in Table 2.1.

2.2 DATA EVALUATION

The purpose of the data evaluation is to determine whether the data are of sufficient quality and quantity to meet the needs for the BRA; this is an iterative process. First, data quality requirements (DQRs) are established by determining the site-specific objectives of the BRA and the amount of uncertainty in the data which will allow these objectives to be met. The available data are then compared to these DQRs to determine which data are useable and whether there are sufficient data to conduct the Level 3 BRA. If adequate data are not available, a decision must be made to either (1) change the objectives of the BRA so that they can be met by the available data and/or (2) collect additional data. If additional data are collected, the comparison to DQRs is repeated with these new data. For Building 3515, adequate data were available to satisfy the DQRs for the Level 3 BRA.

2.2.1 Data Quality Requirements

Data quality requirements are qualitative and/or quantitative statements that specify the quality of the data required to support decisions during risk evaluation activities. The development and use of DQRs is an on-going process from initial project scoping through the BRA and Alternatives Risk Evaluation.

Information obtained from historical and operational investigations is used as the foundation for the scoping of the BRA (i.e., definition for the problem and objectives of the BRA) and development of initial DQRs. The DQRs for this Level 3 BRA are the satisfaction of three criteria: (1) determination of basic site characteristics, (2) initial identification of potential exposure pathways and exposure points, and (3) determination of future data needs. The existing characterization data have been compared to the DQRs established for this Level 3 BRA.

2.2.2 Potential Pathways and Exposure Points

The majority of contamination at Building 3515 is dispersed throughout the interior walls, floor, and equipment. In addition, a concrete pad, which serves as a cap for contaminated soil, is located adjacent to the building. The building has been encased with concrete since circa 1964 and therefore serves as a primary containment system for the contaminants. Currently, there is no information that suggests release of contaminants to the environment is occurring, although there is a measurable dose rate associated with the external walls of the building.

Current exposures are limited to maintenance workers who potentially receive external exposure during time spent in the external vicinity of the building. Access to the interior of the

building by the public and on-site workers is restricted by the concrete walls. No entrance routes into the building are available.

Future on-site and off-site exposures could result from deterioration of the building and/or concrete pad over time. Such deterioration would allow rain to infiltrate the building and pad causing contamination to be released to the environment. Future exposures could also result from natural disasters that demolish the building. It is also conceivable that an intruder could or might gain access to the building in the future thereby resulting in exposures from the surface- and fixed-contamination associated with the inside walls, floors, and equipment.

2.2.3 Evaluation of Existing Characterization Data

The quality and useability of the data are discussed in the following paragraphs. The documentation for both the chemical and radiological laboratory analyses met Remedial Investigation/ Feasibility Study (RI/FS) Quality Control (QC) Level III requirements. The QC level III mandates that QC data, including raw data, be reported in the Contract Laboratory Procedure (CLP) data package. The data were validated and met the RI/FS QC level II requirements. These requirements were sufficient for fulfilling the DQRs for this risk assessment.

2.2.3.1 Sampling data

Both chemical and radiological analyses were performed on a variety of samples. Samples consisted of three concrete cores taken from two coring locations in the building floor slab (pad) which is located outside of the south wall of the building, a subfoundation soil sample, and a paint chip sample from the south cell doorway. The concrete core and soil sampling locations are shown in Fig. 2.1. Table 2.2 lists the Target Analyte List (TAL) metal and cyanide concentrations detected in each concrete core, soil, and paint sample. The paint chip concentrations were used to calculate risks and hazard quotients (HQs) to an intruder resulting from ingestion, inhalation, and dermal exposure to surface contamination inside Building 3515.

Table 2.3 provides summary results of the radiological analyses for the concrete core, soil, and paint chip samples. The soil concentrations were used to calculate risks to off-site receptors resulting from soil contamination leaching into the groundwater due to deterioration of the concrete pad. Soil data collected from the WAG 1 soil boring were not used in this assessment because this soil was out of the scope of the project. Deterioration of the pad would allow rainfall to infiltrate the contaminated soil. Infiltration would allow the contamination to leach into the groundwater where it could be transported to off-site receptors. Smear analysis and thermoluminescent dosimeter (TLD) measurements were used in place of the limited radiological data obtained from the paint chips to calculate risks to an intruder. No sampling data were available for the valve pit area; therefore, this area was not evaluated in this BRA.

2.2.3.2 Radiological field measurements

Field radiological measurements were taken for both the north and south cell areas. Because of the high radiation fields encountered, measurements were obtained remotely using long-handled tools. Thermoluminescent dosimeter strings deployed on four sides of a 2-in. pole to face up, down, south, and north were used to obtain the horizontal absorbed dose profile for the interior of both cells. Thermoluminescent dosimeters in each string were approximately 1 ft apart and approximately 3 to 4 ft above the floor. This assembly was exposed to the cell radiation fields for 10 min.

Figure 2.2 shows the penetration points of the long-handled tools and the locations of the TLDs. Tables 2.4 through 2.7 present the results of these measurements. The TLD data were used to calculate external exposures and risks to an intruder inside Building 3515.

Smear analyses were also performed for both the north and south cells. Results of these analyses are given in Table 2.8. The smear for the north cell was taken from the floor and is assumed to have covered approximately 100 cm^2. The smear for the south cell is assumed to cover approximately 10–20 cm^2. The gross smears obtained from the south cell were too highly radioactive to be analyzed at the Close Support Laboratory (CSL) for gross alpha, gross beta/gamma, and gamma spectroscopy; therefore, a secondary smear was taken from the gross smear (by touching the two smears together) and analyzed at the CSL. Data obtained from the smear analyses were used to estimate risks to an intruder resulting from exposures to radiological surface contamination inside Building 3515.

A preliminary decommissioning study report for Building 3515 (Horton 1984) provided data concerning a radiation survey conducted around the exterior of the building. Results of this survey are shown in Fig. 2.3. The field measurements outlined in this report were used to calculate risks to maintenance workers resulting from external exposures while in close proximity to Building 3515. It should be noted that only the measurement taken on the west side was above background for this area of the ORR.

2.3 SELECTION OF CHEMICALS OF POTENTIAL CONCERN

Section 2.1.2 presents the preliminary identification of COPCs. The COPCs evaluated quantitatively in this BRA are presented in Table 2.9. Lead was detected in samples but will be evaluated qualitatively in this BRA because toxicity information is unavailable for this analyte.

2.4 UNCERTAINTY

The characterization data used in this BRA were not collected specifically for use in a risk assessment; therefore, data gaps existed and required several assumptions and approximations. For example, it is known that Building 3515 housed equipment to extract ruthenium, cerium, and other radionuclides. Both cerium and ruthenium are short-lived isotopes, but rhenium-187 has a half-life of 4.0E+10 years. Rhenium, however, does not appear in the sampling data.

Due to the high radiation fields encountered inside Building 3515, most of the data was obtained remotely using long-handled tools inserted through holes created in the building walls for this purpose. This limited the amount of data that could be obtained and introduced some uncertainty into the exact identification of sampling points. For both the shallow and deep doses obtained from TLD measurements, the up and north directions did not reach a maximum with increasing distance. Therefore, the reported values may not reflect the highest dose rates in the north cell. The presence of contaminated equipment (which was not sampled) in the cells introduces a great deal of complexity and uncertainty when extrapolating TLD measurements to estimate curie loadings. Additionally, the limited amount of smear data increases the uncertainty when extrapolating the data to the entire room.

3. EXPOSURE ASSESSMENT

The objective of this exposure assessment is to estimate the type and magnitude of potential exposures to the chemicals and radionuclides of potential concern (i.e., COPCs) that are present at or migrating from Building 3515. The exposure assessment is performed assuming both current and potential future uses of the facility and involves three main steps:

- Characterizing the exposure setting (Sect. 3.1).
- Identifying potential migration routes and exposure pathways (Sect. 3.2).
- Quantitatively and qualitatively estimating chemical- and radionuclide-specific exposure concentrations (Sect. 3.3).

The results of the exposure assessment are presented in Sect. 3.4, and the uncertainties associated with this assessment are discussed in Sect. 3.5.

3.1 CHARACTERIZATION OF THE EXPOSURE SETTING

The first step in the exposure assessment is characterizing the facility and the surrounding area where exposures may occur; this establishes the setting in which potential exposures could occur. The characterization of the exposure setting includes a description of the facility (Sect. 3.1.1.1) as well as the meteorology (Sect. 3.1.1.2); site hydrology (Sect. 3.1.1.3); demographics and land use (Sect. 3.1.2.1); and ecology (Sect. 3.1.2.2) of the area.

3.1.1 Physical Setting

3.1.1.1 Facility description

The interior of Building 3515 is currently inaccessible since it is completely enclosed by an added concrete shield wall. A stainless steel roof was installed to prevent leakage of rainwater into the building. There is limited information available on the equipment or systems still located inside the building. A substantial amount of fission products exists within the building; however, because of decay, the major radionuclides remaining are cesium-137 and strontium-90. As expected, only cesium-137 has been detected from the external radiation measurements. In addition, extensive contamination of the soil under and around this building is likely due to the leaky drain line. Furthermore, a small valve pit, which contains valves and controls, is located on the north side of the building.

3.1.1.2 Meteorology

The following information has been summarized from the *Remedial Investigation Report Feasibility Study for the Gunite and Associated Tanks Operable Unit at Waste Area Grouping 1* (Radian 1993).

The mean annual temperature for the Oak Ridge area is 58°F (14.4°C). The coldest month is usually January, with average temperatures of approximately 38°F (3.3°C) but occasionally dropping as low as 0°F (-17°C). July is typically the hottest month with average temperatures of

77°F (25°C) but with temperatures occasionally peaking at over 100°F (37.8°C). Average daily temperatures vary 53.6°F (12°C) over the course of the year. The Oak Ridge area receives an average 53.75 in. (136.5 cm) of precipitation annually. Periods of five days or more without precipitation occur on average only four to five times per year. Maximum monthly precipitation generally occurs from December through March and is associated with winter storms that are commonly of low intensity but long duration. Snowfall averages 10.4 in. (26.4 cm) per year as a contribution to the total precipitation. A second precipitation maximum occurs in July when short, heavy rainfall associated with thunderstorms is common. The higher intensity of the summer thunderstorms compared to the winter storms results in a higher percentage of runoff and less infiltration.

Winds in the Oak Ridge area are controlled to a large degree by the valley and ridge topography. Figure 3.1 shows a wind rose for the ORR at ORNL with the percentage of wind frequency by wind speed and compass orientation. Prevailing winds tend to be either up-valley (northeasterly) or down-valley (southwesterly). Daytime winds generally blow up-valley, while nighttime winds usually blow down-valley. Wind speeds are less than 7.4 mph (11.9 km/hour) 75% of the time. Tornadoes and high-velocity winds are rare, as are wind speeds exceeding 18.5 mph (30 km/hour).

3.1.1.3 Site-specific topography, geology, and soils

The original ORNL facilities are in Bethel Valley, between Chestnut Ridge to the northwest and Haw Ridge to the southeast. The valley floor occurs at an elevation of approximately 900 ft (275 m) above the National Geodetic Vertical Datum of 1929 (NGVD) (Fig. 3.2). The valley floor slopes gently southward across the ORNL site with an average slope of 4%. Chestnut Ridge rises above 1200 ft (365 m) NGVD, while Haw Ridge rises above 1040 ft (317 m) NGVD.

All of the GAAT OU (including Building 3515) is underlain by rocks of the Ordovician-aged Chickamauga Group in the upper part of the stratigraphic section (Fig. 3.3). These rocks strike northeast-southwest and dip toward the southeast. The Chickamauga Group consists of interbedded limestones and siltstones.

The most detailed, as well as the most recent, interpretation of the geology at ORNL is provided by the *WAG 1 Site Characterization Summary Report*. The bedrock geology at ORNL is shown in Fig. 3.4. Figure 3.5 shows a geologic cross section in the vicinity of the GAAT OU facilities (Building 3515). In addition, Building 3515 is underlain by Stockdale's Unit E.

The Benbolt Formation is a relatively heterogeneous formation that is 360 to 377 ft (110 to 115 m) thick and consists of thick interbeds of fossiliferous nodular limestone; unfossiliferous, amorphous micrite within a dark-gray siltstone matrix; dark-gray siltstone; and unfossiliferous calcarenite.

The Bowen Formation is a distinctive maroon-colored unit used as a reliable marker for both field and subsurface correlations. The Bowen Formation is 16 to 32 ft (5 to 10 m) thick and consists of maroon calcareous and shaley siltstone and thin beds of light-grey to olive-grey limestone and argillaceous limestone.

Fig. 3.1

ORNL-DWG 92M-7776

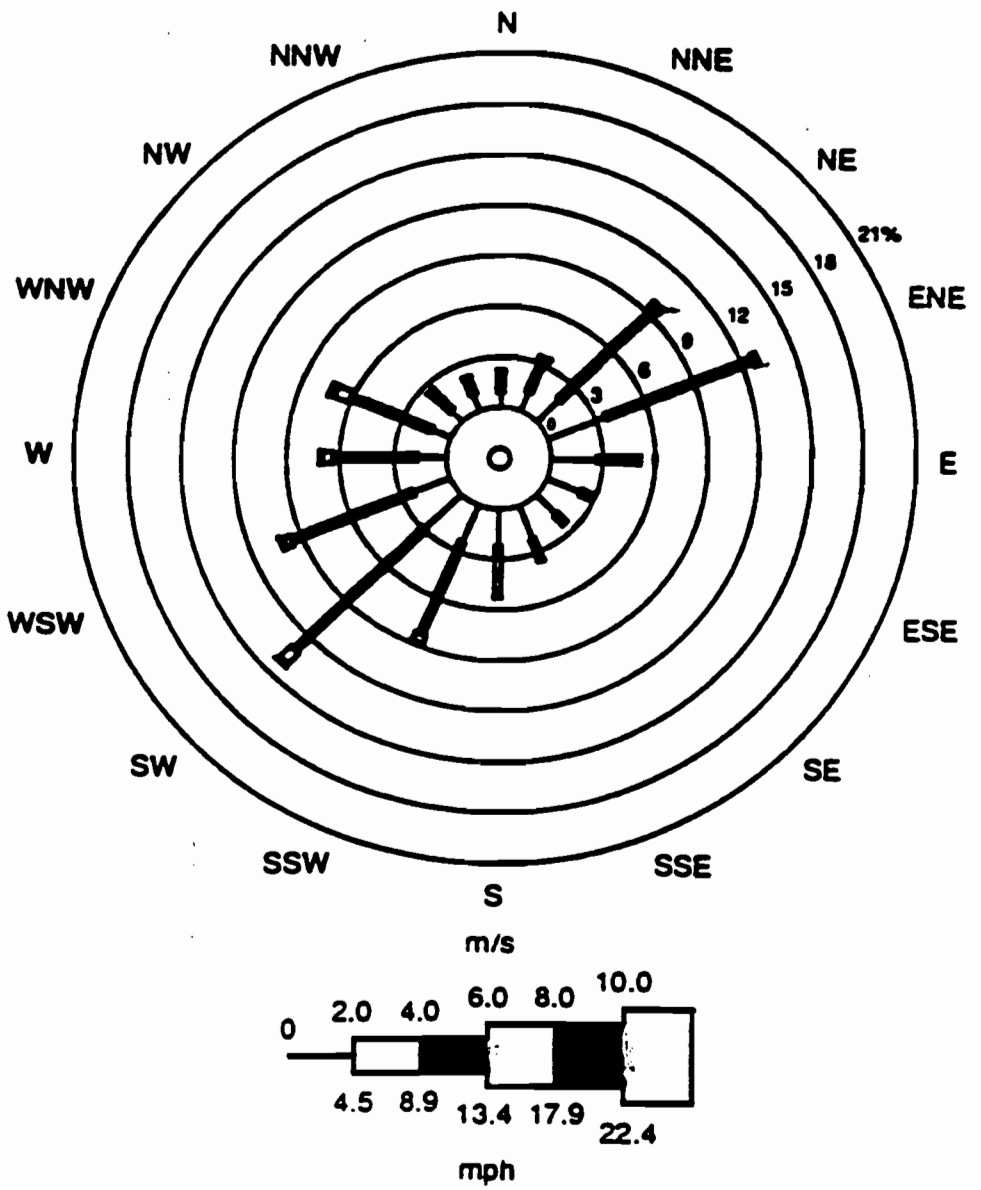


Fig. 3.1. 1991 wind rose for ORNL Tower MT2.

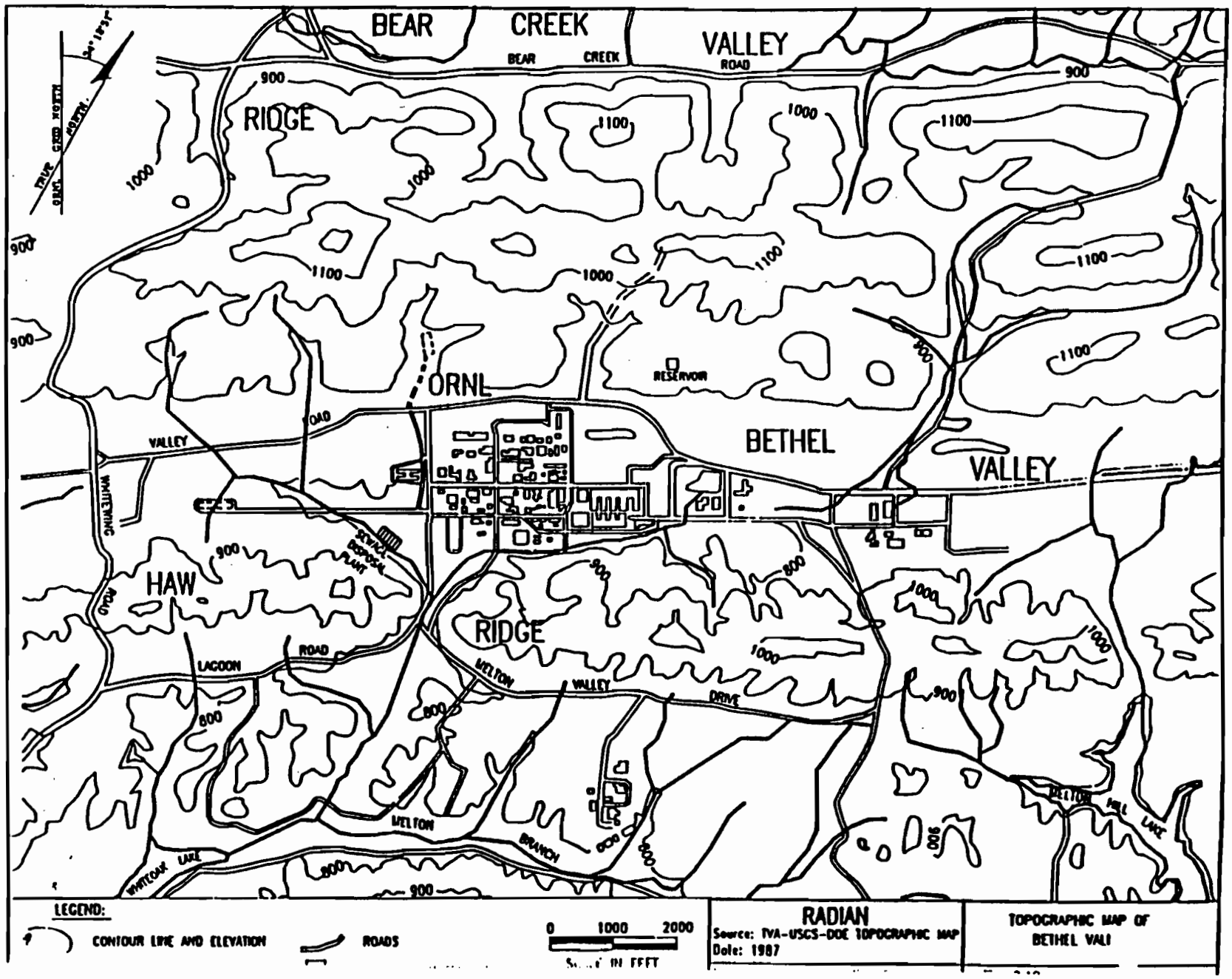


Fig. 3.2. Topographic map of Bethel Valley.

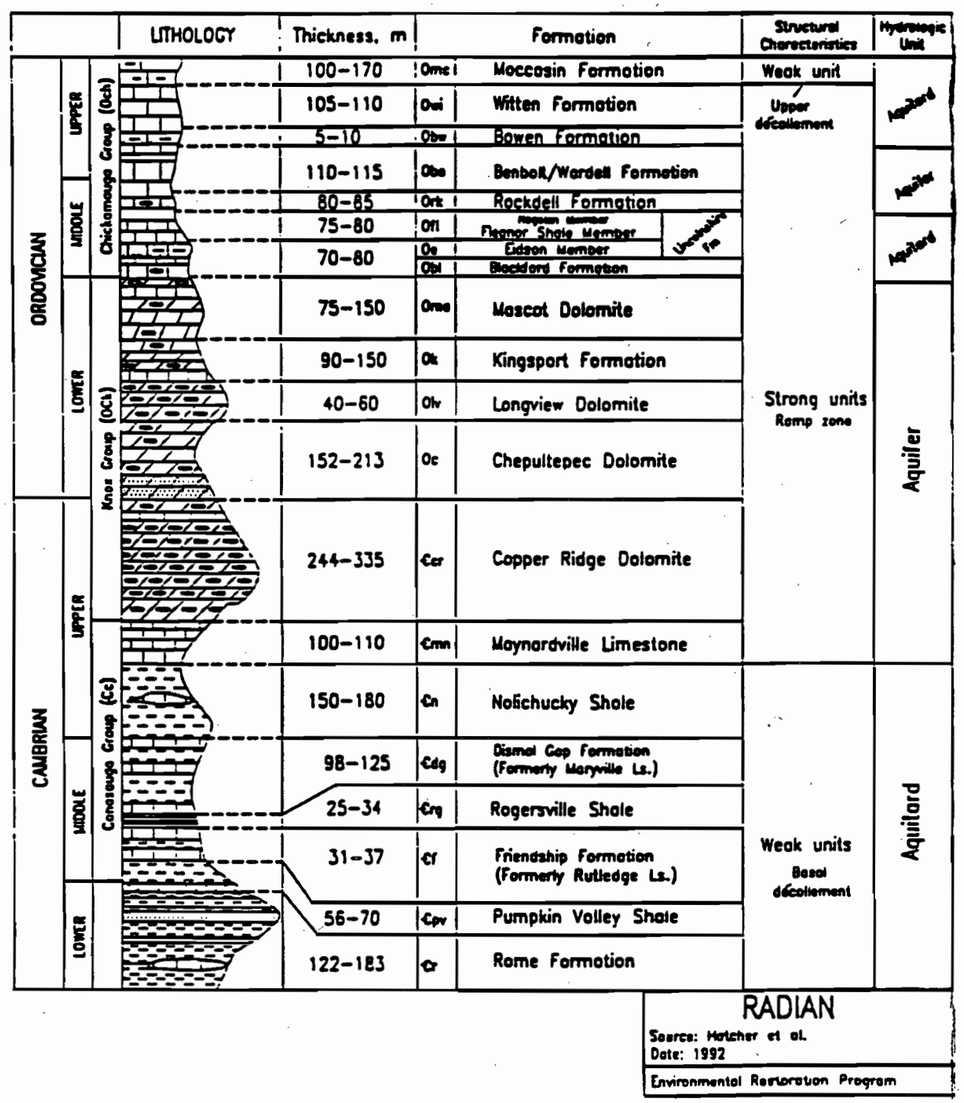


Fig. 3.3. Stratigraphic section in Bear Creek Valley, Chestnut Ridge, Bethel Valley, Haw Ridge, Melton Valley, and Copper Ridge.

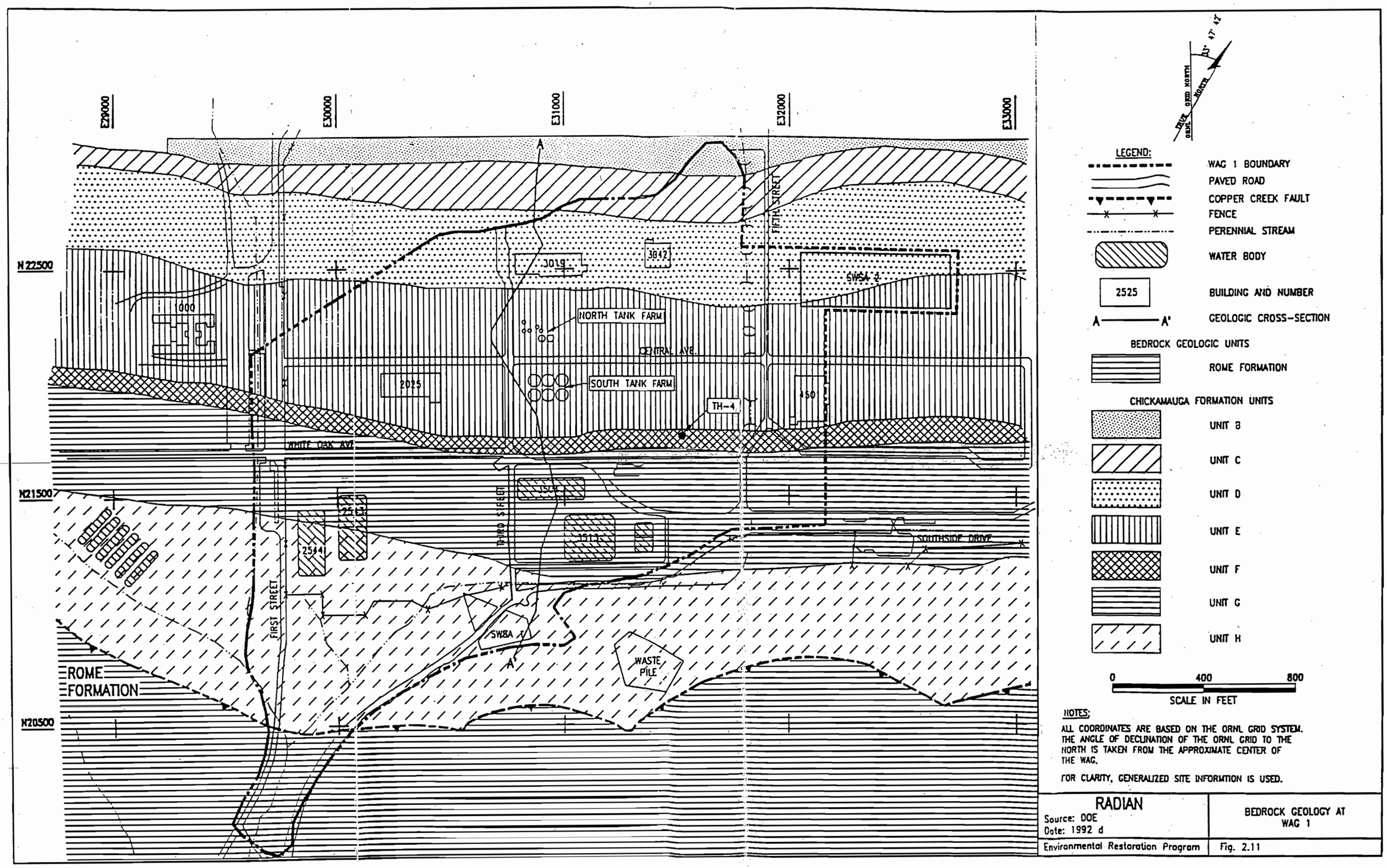


Fig. 3.4. Bedrock geology at WAG 1.

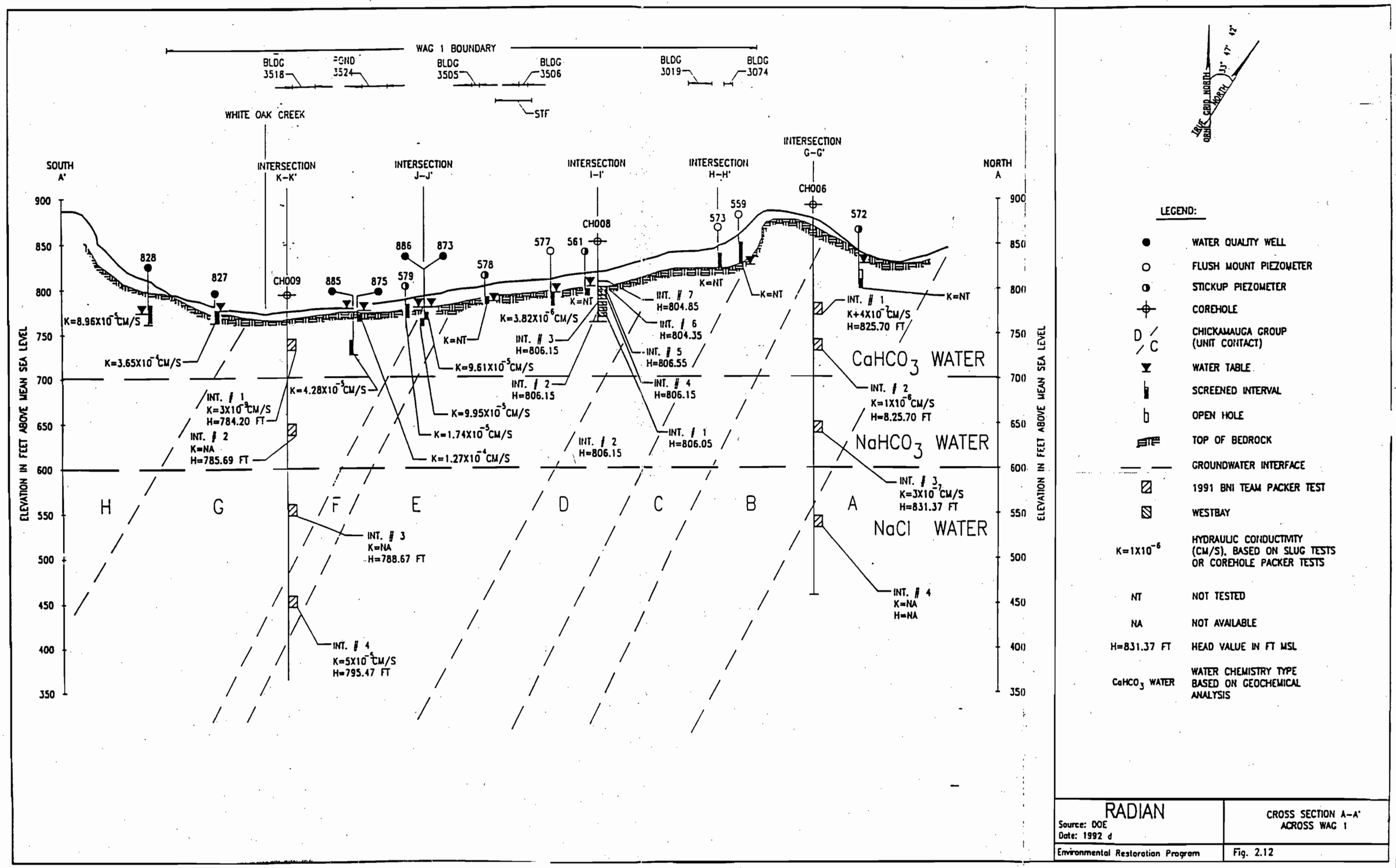


Fig. 3.5. Cross section A–A' across WAG 1.

3.1.1.4 Site hydrogeology

The Knox aquifer is the only true aquifer present on the ORR. Groundwater flow in the Knox aquifer is dominated by solution conduits developed from widening by dissolution of the original fracture network in the bedrock. The solution conduits store and transmit relatively large volumes of water.

All other rock types on ORR, including the Chickamauga Group in Bethel Valley, are classified as aquitards. (Figure 3.6 shows the conceptual model for aquitards.) Six different flow zones are defined in terms of increasing depth: (1) stormflow zone, (2) vadose zone, (3) water table interval, (4) intermediate interval, (5) deep interval, and (6) aquiclude. In general, the water table interval, intermediate interval, deep interval, and aquiclude are included within the groundwater zone and are encountered at various levels in the bedrock; stormflow and vadose zones are encountered in the overburden material.

Depending on lithology, the depths generally below 100 to 300 ft (30 to 100 m) exhibit no open fractures, and no significant quantity of water is transmitted. This zone is defined as the aquiclude. Above the aquiclude is a transition between the aquiclude and the water table interval that includes both the deep and intermediate intervals. In the deep interval, a few discrete fractures will transmit water. However, active fractures are few in number and shorter in length. Wells completed in the deep zone typically yield less than 0.03 gallons/min (0.1 L/min) with less than 1% of the total groundwater flow occurring in this zone. In the intermediate interval, additional open fractures exist, but the fractures are poorly connected. It has been estimated that less than 2% of the total groundwater flow occurs in this zone.

The water table interval coincides with a narrow zone of weathered bedrock. This zone is approximately 0.3 to 1.5 ft (1 to 5 m) thick and contains many open, closely-spaced, interconnected fractures. While the bedrock in the water table interval has been weathered, it has not been reduced to the clay and silt encountered in the overburden. The water table generally corresponds with the top of the weathered bedrock. It has been estimated that approximately 8% of the total groundwater flow occurs in the water table interval.

Almost all of WAG 1 is a local discharge area for groundwater flow, and most of the groundwater flow occurs at shallow depth toward the south with discharge primarily to White Oak Creek (Fig. 3.7). Consistent with the concept of a discharge area, vertical hydraulic gradients are generally upward with the water table present in the overburden over portions of WAG 1.

The issue of the effect of fill material on groundwater conditions in the vicinity of Building 3515 remains unresolved. Various types of fill material have been used in the utility and pipe trenches underlying much of WAG 1 and in the transfer lines for the tanks. In addition, several feet of bedrock and all of the overburden appear to have been excavated for the construction of the South Tank Farm; historical photographs show one large excavation for all six Gunite tanks at the South Tank Farm.

The use of fill material influences the occurrence and movement of groundwater as well as the movement of contamination on the ORR. Use of granular backfill material or inadequate compaction of the native clay material in pipeline and utility trenches, as well as around some of the tanks, have resulted in higher permeability zones. Groundwater or waste liquids can move along the preferential pathways created by the more permeable material. In the early 1960s, the dry well system at the

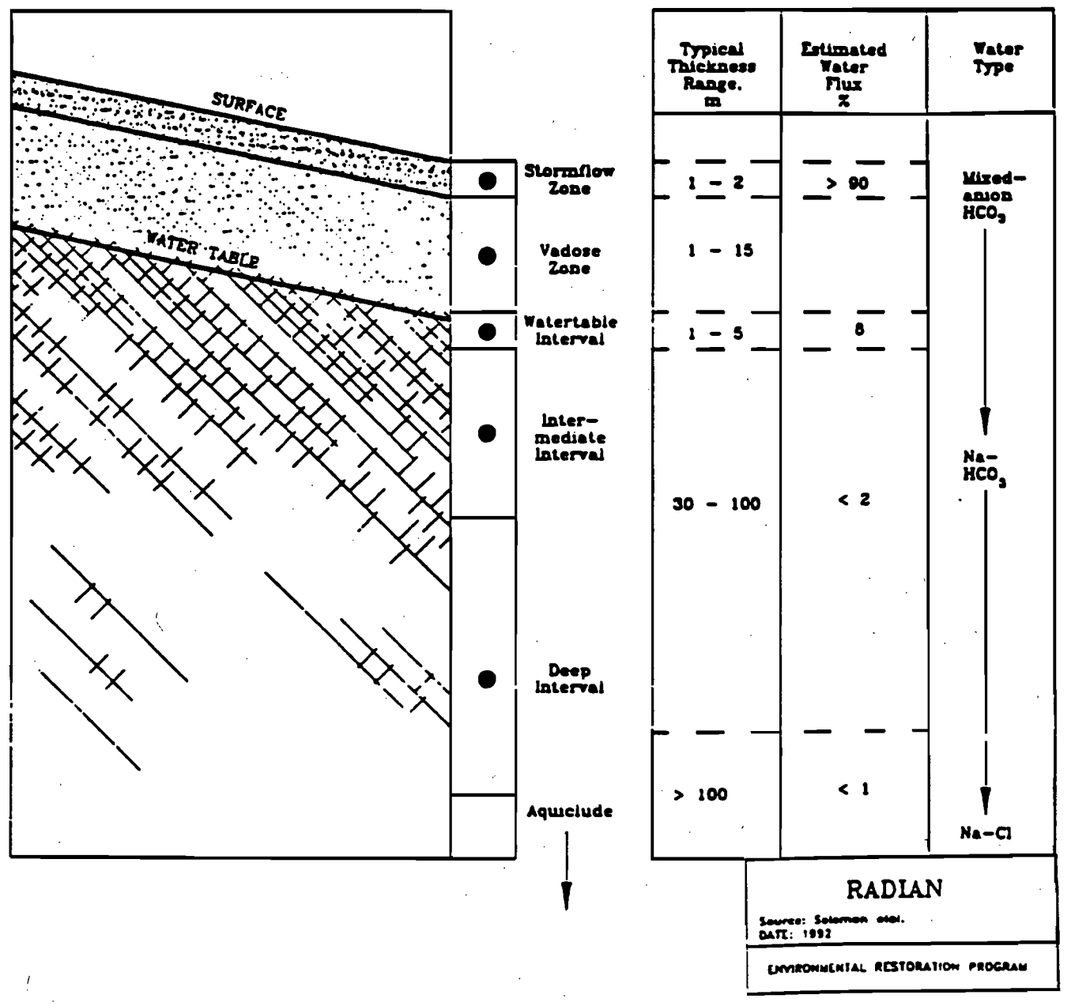


Fig. 3.6. Schematic vertical relationship of flow in aquitards of the ORR.

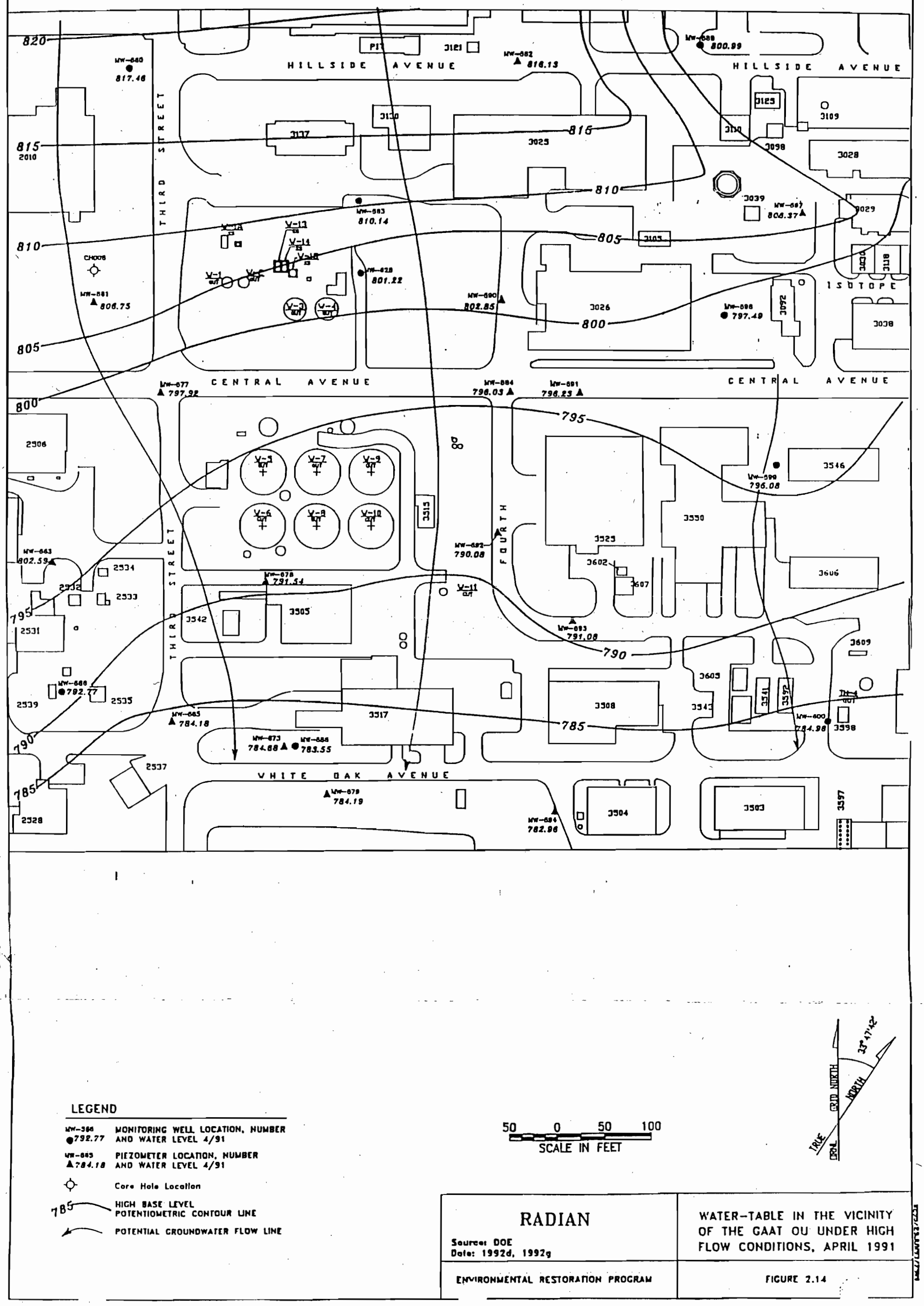


Fig. 3.7. Water table in the vicinity of the GAAT OU under high flow conditions, April 1991.

South Tank Farm was reportedly draining an average of 26,500 gallons (100,300 L) per day. The source of the volume of water is believed to have been groundwater that was drawn into the dry well systems located below the local water table.

3.1.2 Potentially Exposed Populations

Populations potentially exposed to contaminants in Building 3515 and/or released to the environment from Building 3515 include both human and ecological receptors. The potential human receptors can be divided into the following groups:

- Workers, including LMES employees and subcontractors at ORNL, DOE employees, Tennessee Department of Environment and Conservation (TDEC) employees, and EPA employees and other individuals who visit ORNL.

- Public receptors including residents of Oak Ridge and surrounding communities; individuals who use the recreational facilities on or near the ORR; and individuals who trespass onto the site seeking permanent or temporary shelter under future scenarios.

Potential ecological receptors are terrestrial and aquatic organisms who spend all or part of their lives on or near the ORR. Discussions of regional demographics, current and future land use, and ecology are presented in the following sections.

3.1.2.1 Demography and land use

The ORR covers approximately 35,300 acres (14,300 ha) of federally-owned land in eastern Tennessee (Fig. 3.8). ORNL is in the approximate center of the ORR (Fig. 3.9). The Tennessee Valley Authority's (TVA's) Melton Hill reservoir on the Clinch River and Watts Bar Reservoir on the Tennessee River form the eastern, southern, and western boundaries of the ORR. The residential area of the city of Oak Ridge forms the northern boundary.

Oak Ridge, with a population of 27,000, is the closest population center. [All population levels are based on 1990 U.S. census data (U.S. Department of Commerce 1991).] Although located predominantly to the west and south of the population center, the ORR is located inside the city limits of Oak Ridge. In addition to the city of Oak Ridge, the nearest population centers to the ORR include Oliver Springs (pop. 3400), 6.8 miles (11 km) to the northwest; Clinton (pop. 9,000), 10 miles (16 km) to the northeast; Lenoir City (pop. 6,100), 6.8 miles (11 km) to the southeast; Kingston (pop. 4600), 6.8 miles (11 km) to the southwest; and Harriman (pop. 7100), 8 miles (13 km) to the west. The population of Anderson County, which includes Oak Ridge, Oliver Springs, and Clinton, is 68,250. Knoxville, Tennessee, is the closest major metropolitan area. Knoxville is approximately 25 miles (40 km) east of the ORR and has a population of approximately 165,000. Knox County, which includes Knoxville, has a population of 335,749.

Figure 3.10 shows the population density within 10 miles (16 km) of the center of the ORR. Except for the city of Oak Ridge, land within 5 miles (8 km) of ORR is predominantly rural and is used primarily for residences and small farms. Fewer than 13,000 people live within 5 miles (8 km) of the center of the ORR, which includes a portion of the city of Oak Ridge. Figure 3.11 shows the population density within 50 miles (80 km) of the ORR.

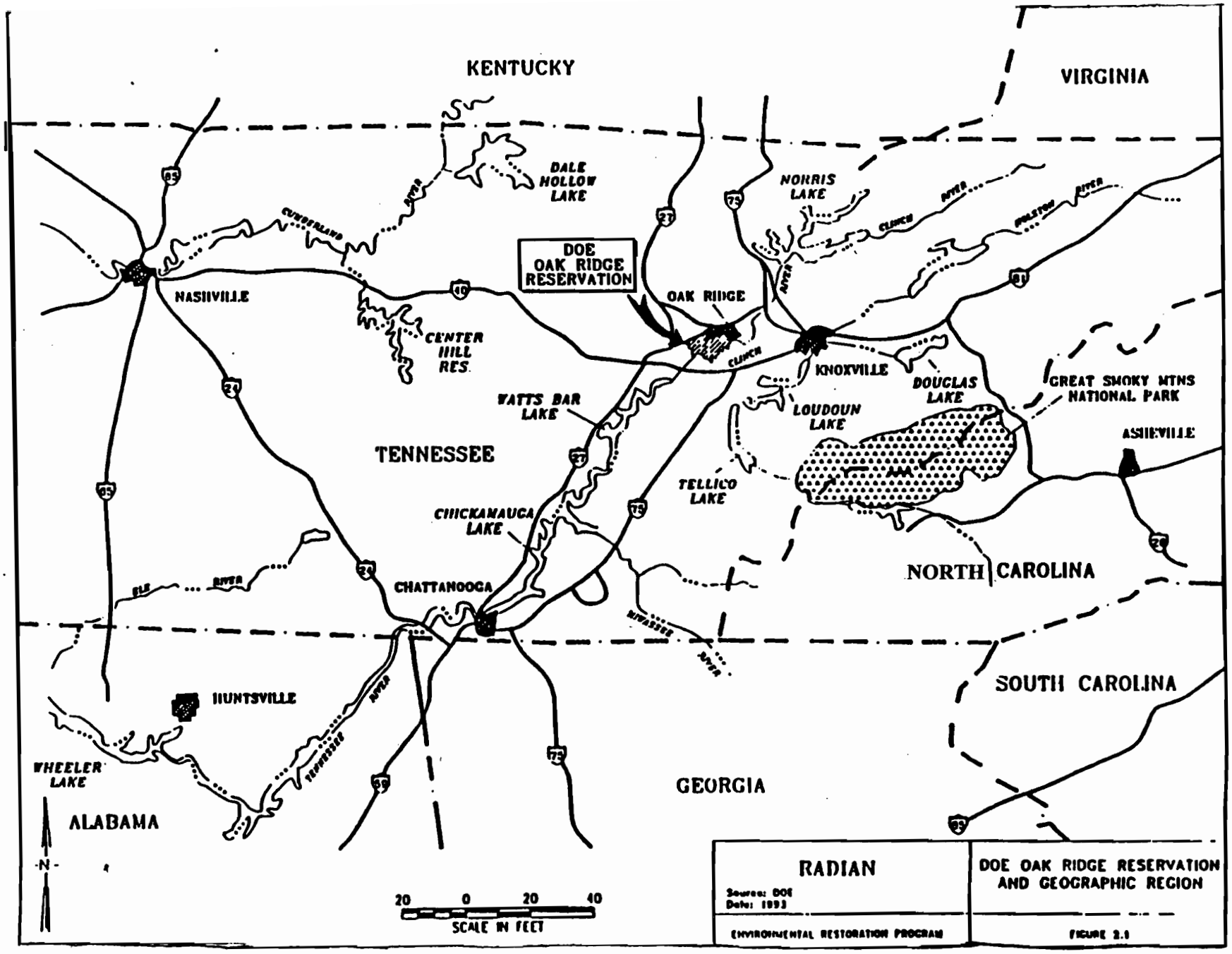


Fig. 3.8. DOE Oak Ridge Reservation and geographic region.

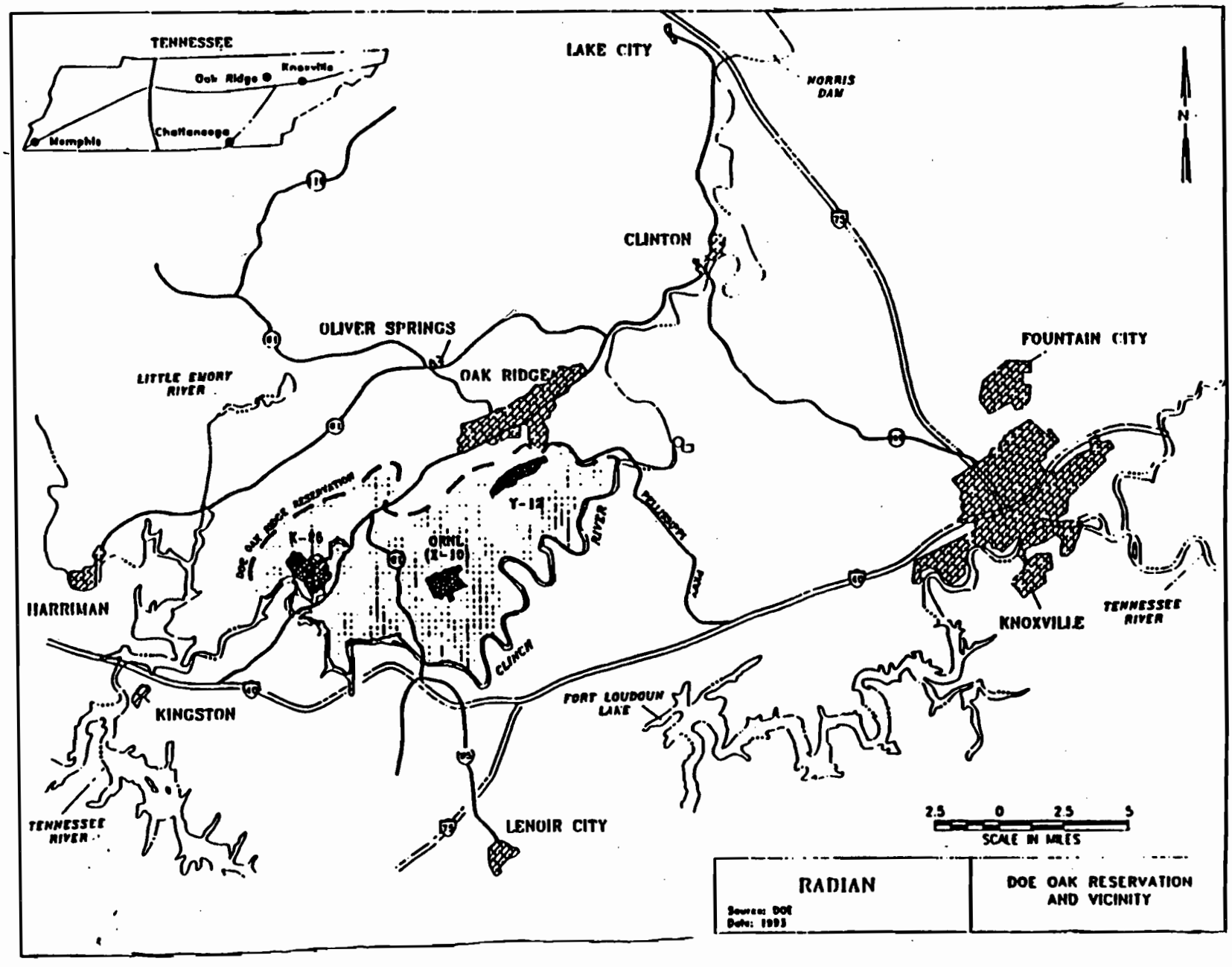


Fig. 3.9. DOE Oak Ridge Reservation and vicinity.

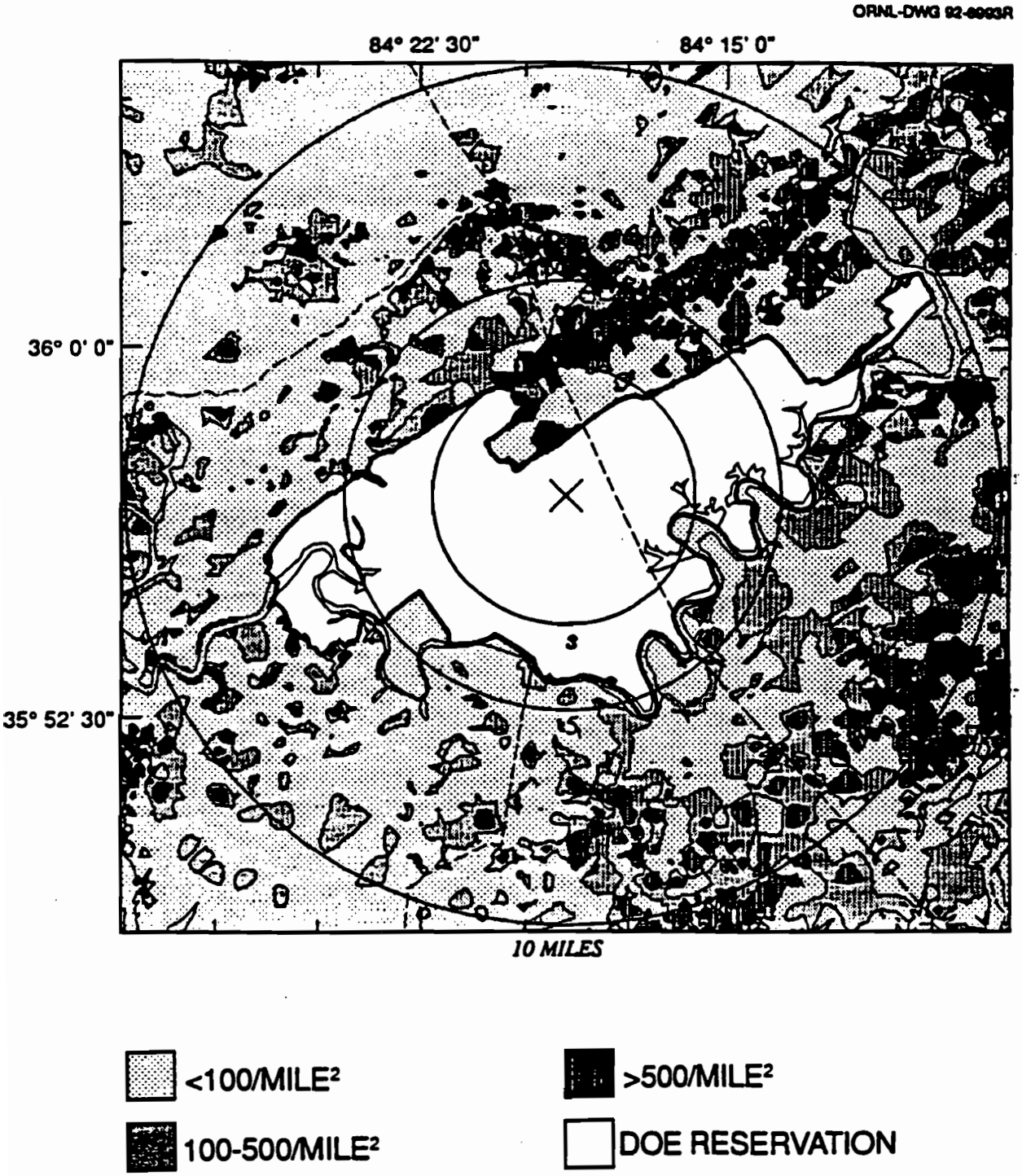


Fig. 3.10. Projected 1991 population densities within 10 miles (16 km) of the center of the Oak Ridge Reservation.

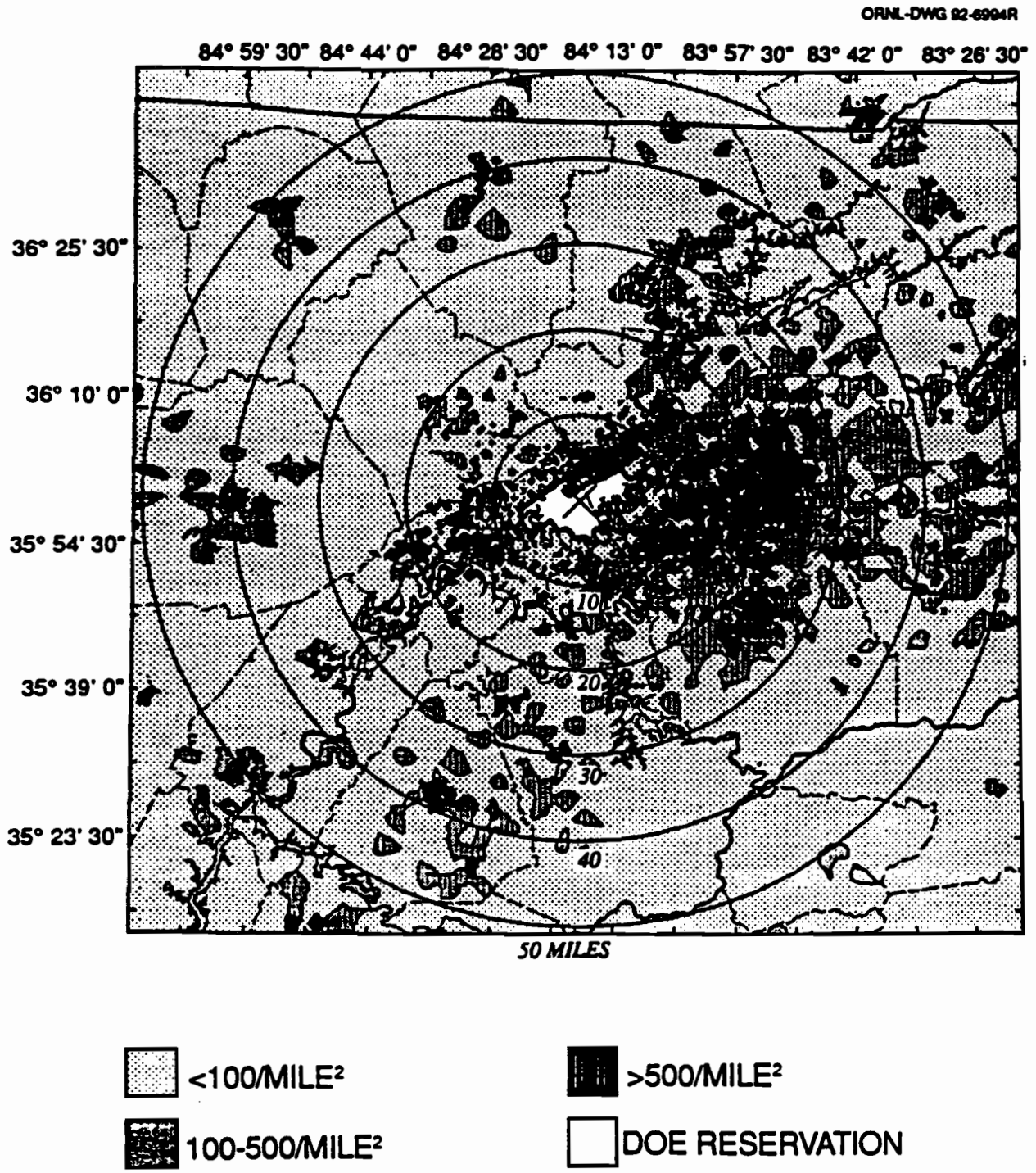


Fig. 3.11. Projected 1991 population densities within 50 miles (80 km) of the center of the Oak Ridge Reservation.

As of February 1993, the ORR employs approximately 16,000 regular employees, with 5782 employees working at ORNL. Most employees at ORNL work at facilities that are located in the general vicinity of Building 3515.

Current land use. Worker activities in the vicinity of Building 3515 are those common to industrial complexes. These include pedestrian and motor vehicle traffic, utility repair, and grounds maintenance. Currently, there is no worker activity within Building 3515. Activities for this facility include routine surveys (approximately once a year) and vegetation maintenance around the outside of the building. All activities are performed under applicable health and safety regulations and monitored by the Industrial Hygiene and Health Physics departments as necessary.

For this Level 3 BRA, a current exposure scenario has been developed to provide a conservative (i.e., health protective) estimate of potential exposure. The hypothetical current receptor is a maintenance worker who spends, on average, 2 hours per month, every other month (6 months per year), for 25 years working around the building. This receptor provides a worst-case or upperbound estimate of potential exposure for a current industrial receptor at the facility. Current exposure scenarios and receptors evaluated in this BRA are summarized in Table 3.1.

Table 3.1. Exposure scenarios and potential receptors for Building 3515

Scenario	Action	Receptors
Current Land Use		
Maintenance Worker Exposure	Routine - Maintenance and other work requiring access by workers to exterior of facility	Worker = routine, bi-monthly access to exterior of facility
Future Land Use - Abandonment		
Resident Living at White Oak Creek	Routine residential activities	Residential
Resident Living at White Oak Dam	Routine residential activities	Residential
Intruder	Adult intruder has complete access to both cells within facility	Adult Public

Future land use. Building 3515 is located in the main plant area of ORNL. This area is highly developed, and land use is expected to remain industrial for the future. The population of Oak Ridge is currently stable. Growth is hindered due to a lack of developable land. If DOE releases portions of the ORR to the public, expansion of Oak Ridge would be expected to follow.

This Level 3 BRA is intended to provide exposure and risk estimates for a "no-action" (i.e., no remedial action) future land use scenario. A hypothetical no-action scenario makes the assumption that Building 3515 is abandoned by DOE at the start of the BRA. In this scenario, DOE makes no attempt to prevent contaminant releases from the facility or restrict access to the facility. Because

Building 3515 is on the ORR and because DOE is not likely to release the ORR property for development, the area around the building is expected to remain industrial even if the building was abandoned. Therefore, it is assumed that residential development will not occur at this site. However, it is assumed that an adult intruder can enter the building once degradation has created an opening. This is a conservative exposure scenario designed to fulfill the intent of future no-action.

If the building is abandoned by DOE (i.e., all building maintenance is discontinued), it will eventually decay and collapse. The building structure currently acts as a containment vessel for the contaminants inside. As the building decays, these contaminants may be released to the surrounding environment via wind erosion and dust transport, washout with rain, and tracking of contaminants by humans and small animals potentially visiting the site. Contaminant release may also occur as a result of a catastrophic event such as a tornado touching down at or near Building 3515. Such contaminant releases could potentially result in exposure of off-site (i.e., outside of DOE property) residential receptors. As the building decays, access to the interior may become possible. One future land use scenario assumes an adult intruder spends five 1-hour periods in the facility snooping/investigating the building and its contents.

Two hypothetical off-site residential receptors are considered. One is assumed to be located at the ORR boundary directly downstream at the White Oak Dam, while the other receptor is located at White Oak Creek. The potential exposure scenarios and receptors associated with the future land-use scenario evaluated in this BRA are also summarized in Table 3.1.

3.1.2.2 Potential ecological receptors

Potentially affected habitats. Building 3515 is located inside the main industrial area of ORNL and has little natural habitat. The vegetation surrounding Building 3515 consists primarily of grass lawns and landscaping plants. The following information taken from the *Preliminary Risk Assessment Report for Waste Area Grouping 1 at Oak Ridge National Laboratory, Oak Ridge, Tennessee* (Bechtel 1992) also pertains to Building 3515, which as mentioned previously, is located within WAG 1.

The aquatic habitat at WAG 1 consists of White Oak Creek, First Creek, Fifth Creek, and part of the Northwest Tributary. These small streams are within the White Oak Creek watershed and receive discharges directly from ORNL facilities. Nonpoint sources such as solid waste storage areas or process ponds may also contribute contaminants to these streams. Surface impoundments constricted for use as waste settling basins provide additional aquatic habitat within WAG 1 (Bechtel 1992).

Potentially exposed populations. Thirty-seven species of mammals, 151 species of birds, and 61 species of reptiles and amphibians have been found on the ORR. The area, however, provides little natural terrestrial habitat, and the most common species are those generally associated with more urban and developed areas. In the lawn areas, mammalian species are likely to be those typical of old field areas such as house mice (*Mus musculus*), cotton rats (*Sigmodon hispidus*), white-footed mice (*Peromyscus leucopus*), short-tail shrews (*Blarina brevicauda*), eastern harvest mice (*Reithrodontomys humilis*), and groundhogs (*Marmota monax*). Shrubs and low-growing herbaceous plants provide food and nesting areas for birds such as sparrows, rufous-sided towhees (*Pipilo erythrophthalmus*), blue grosbeaks (*Guiraca caerulae*), brown thrashers (*Toxostoma rutum*),

cardinals (*Cardinalis cardinalis*), mockingbirds (*Mimus polyglottos*), and robins (*Turdus migratorius*). Waterfowl, such as Canada geese (*Branta canadensis*), frequent the area, as do frogs, toads, and reptiles (Bechtel 1992).

The most common fish species in the White Oak Creek watershed are two native minnows: blacknose dace (*Rhinichtys atratulus*) and creek chubs (*Semotilus atromaculatus*). Fathead minnows (*Pimephales promelas*), an introduced species, are also common, as are sunfish species [e.g., redbreast (*Lepomis auritus*) and bluegill (*L. macrochirus*)]. Benthic macroinvertebrate communities include primarily taxa that are pollution-tolerant, mainly chironomids.

The Ecological Evaluation in the Preliminary Assessment Report for WAG 1 (Bechtel 1992), which relied on data from the Biological Monitoring and Abatement Program and data collected during the Remedial Investigation, concluded that there is a present or potential risk of detrimental effects to the environment in the absence of remediation at WAG 1. As mentioned previously, there are currently no known releases of contaminants from Building 3515. Contamination released as a result of catastrophic events or through building decay may reach ecological receptors, but the effects, if any, are expected to be insignificant (Sample 1995). As such, a quantitative ecological risk evaluation would probably not be useful for decision making.

3.2 IDENTIFICATION OF POTENTIAL EXPOSURE PATHWAYS

The purpose of this section is to identify the potential pathways for human exposure to contaminants found in Building 3515 at ORNL. An exposure pathway is defined as the course a chemical or physical agent takes from its source to a potentially exposed receptor. For exposures to occur, complete exposure pathways must exist. A complete exposure pathway consists of the following four elements:

- A source and mechanism for release of a contaminant
- A retention or transport medium
- A point of potential human contact with the contaminated medium
- An exposure route at the exposure point

If any <u>one</u> of these elements is missing, the pathway is not complete and there is no exposure.

A Conceptual Site Model (CSM) is a graphic representation of the potential routes of contaminant migration from a source to a receptor (i.e., exposure pathway). The conceptual site model for Building 3515 is depicted in Fig. 3.12 and is discussed in the following sections.

3.2.1 Potential Sources and Receiving Media

The primary sources of contaminants at Building 3515 are the floors and walls of the building and possibly the process equipment in each cell. These sources are also exposure media for receptors within Building 3515. Exposure media are those contaminated media where actual or potential contact by receptors may occur. Potential release mechanisms can release contaminants from the

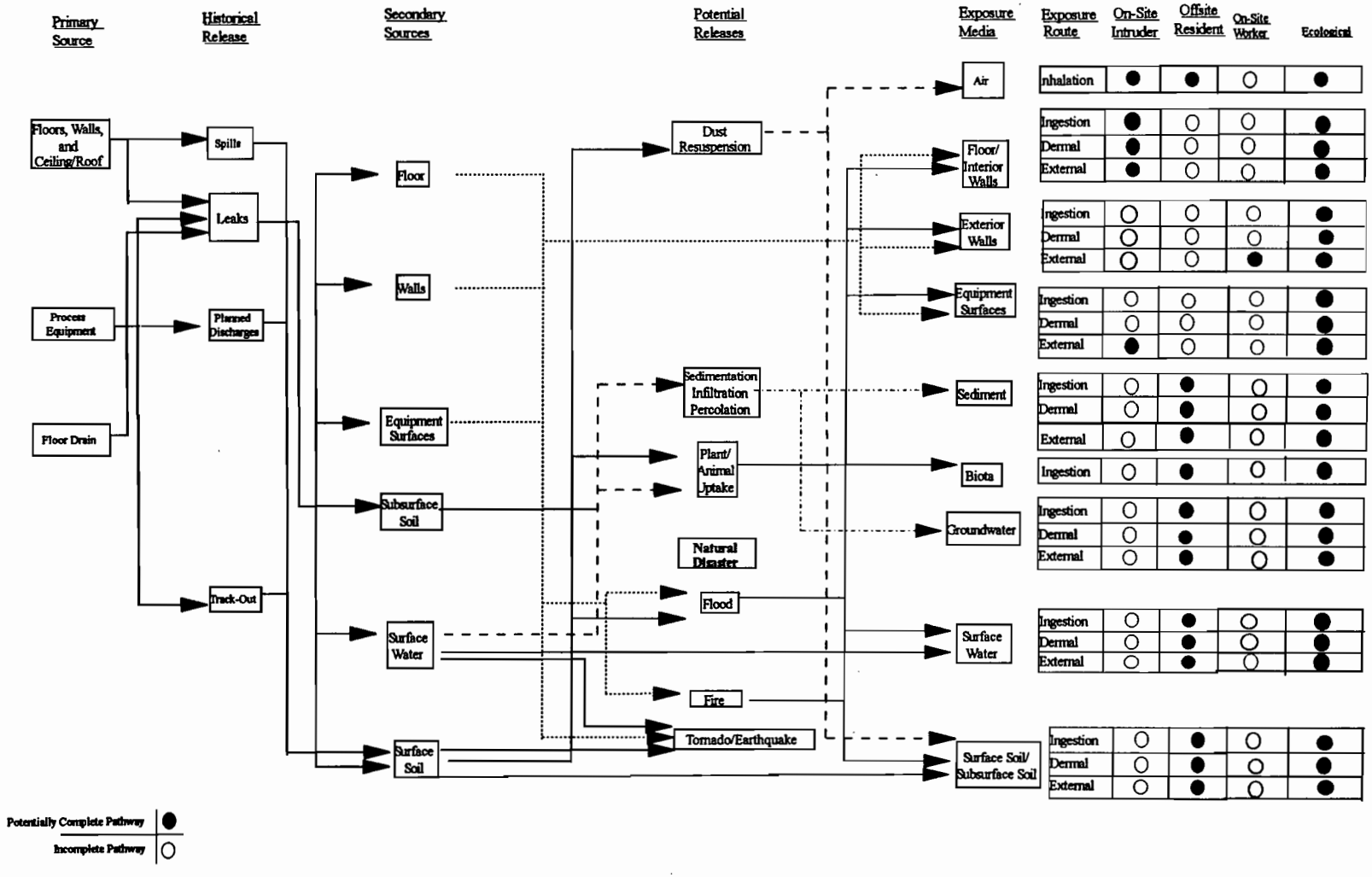


Fig. 3.12. Conceptual site model for Building 3515.

building to secondary sources and exposure media. Secondary sources include soil, water (ground and surface), and air.

Another primary source of contaminants is from the soil beneath the pad. The receptor (i.e., current maintenance worker) potentially may become exposed to radionuclides by external exposure.

Potential release mechanisms within the building include dust/particulate resuspension/deposition of contaminated concrete and paint from the floors and walls. Potential release mechanisms for contaminants to leave the building and enter the surrounding environment include particulate resuspension/deposition associated with building degradation or catastrophic event and rain washout. The magnitude of the release is controlled by the initiating event, integrity of the containment unit, and form of the contaminant. Once contaminants are in the environment, they become available for continued transport through the environment and uptake into the food chain. Releases of large volumes of the contaminants associated with the walls and floors are highly unlikely because of their association with these structural media. However, contaminants found in the concrete could potentially be released via rain washout (if roof integrity is lost).

Specific sources and receiving media evaluated for the current and future exposure scenarios in this BRA are presented in Sects. 3.2.1.1 and 3.2.1.2.

3.2.1.1 Current sources and receiving media

Contaminants are currently contained within the building. It is suspected that past releases via the floor drain have been stopped by the construction of a second concrete floor on top of the original floor. Some radiation is currently being released through the walls.

3.2.1.2 Future sources and receiving media

As contaminants are released from the building and pad, future receiving media are the soil, groundwater, surface water, and air.

3.2.2 Potential Exposure Points and Exposure Routes

An exposure point is the location and medium at which a receptor contacts a contaminant (e.g., concrete dust from the floor). Exposure routes are the potential uptake mechanisms by which exposure occurs once a receptor comes in contact with the contaminated media (i.e., ingestion, inhalation, etc.).

The walls and floors of Building 3515 (both the north and south cells) serve as locations at which a receptor may come in contact with contaminants. Contaminants in and on the walls and floors of Building 3515 reside in the concrete and concrete dust (particulates). Exposure routes for these media include incidental ingestion of dust, inhalation of airborne contaminants (including dust), dermal contact with chemicals, and external exposure from radionuclides. The concrete pad and the building itself also serve as sources of contact.

3.2.3 Summary of Potential Exposure Pathways

Exposure pathways combine the contaminant source, receiving medium, exposure point, and exposure route. Exposure pathways selected for evaluation in this Level 3 BRA for the potential

current and future exposure scenarios are described in the following text. Once all potential pathways have been identified, the potentially significant ones are selected for more detailed evaluation in the BRA. Potential exposure pathways may be eliminated from further consideration in the BRA if they are not complete, if their contribution to total exposure is negligible compared to other pathways, or due to the definition and scope of the BRA.

3.2.3.1 Potential current exposures

Building 3515 is currently sealed with concrete and there is no access to the inside of the structure. As such, current exposures are limited to external exposures to radiation by maintenance workers in close proximity to the building exterior. Potential exposures are described in the following paragraphs for each medium of concern. The current exposure pathways evaluated in this BRA are listed in Table 3.2.

Building structure (floors and walls, concrete pad, and process equipment). External exposure (radionuclides) to contaminants from the building structure (including the concrete pad adjacent to the building) are potential exposure pathways of concern for the hypothetical current receptor at Building 3515.

3.2.3.2 Potential future exposures

Future exposures to contaminants within Building 3515 may include direct contact with contaminated media (ingestion or dermal absorption), inhalation of particulate phase contaminants, and external exposure to radionuclides. Future exposures could also result from releases of contaminants to the environment. Potential exposures are discussed in the following paragraphs for each medium of concern. The future exposure pathways evaluated in this Level 3 BRA are listed in Table 3.3.

Air. Inhalation of contaminated dust is a pathway of concern at this site for future exposures. Intruders at Building 3515 would be potentially exposed via this route. Inhalation is also a potential pathway for off-site residents which are exposed to a pulse of contaminated air in the event of a catastrophic event.

Surface water. Ingestion and inhalation of contaminants from surface water are potential exposure pathways of concern for future off-site residents. Ingestion of vegetables irrigated with contaminated surface water is also a potential exposure pathway for off-site residents.

Building structure (floors and walls)

Dermal absorption (chemicals), incidental ingestion, inhalation, and external exposure (radionuclides) to contaminants present on the inside surfaces of the building structure are potential exposure pathways of concern for an intruder at Building 3515. Contaminants present in and under the facility or the concrete pad can also be sources of exposure (ingestion, inhalation, etc.) for off-site residents given a structural failure of the building (over time or by a catastrophic event).

Table 3.2. Selection of potentially complete current exposure pathways

D&D Facility Use Scenario	Exposure Medium	Receptor	Exposure Route			
			Inhalation	Ingestion	Dermal Absorption	External Radiation
Current	Air	Maintenance Workers [a]	O	NA	NA	O
	Building Structure	Maintenance Workers	NA	O	O	●
	Surface Water	Maintenance Workers	O	O	O	O
	Groundwater	Maintenance Workers	O	O	O	O
	Soil Under Pad	Maintenance Workers	O	O	O	●

●Potentially complete pathway
ONo complete pathway
NA Not Applicable
[a] Maintenance workers are ORNL plant employees who routinely access the exterior of Building 3515 for the purpose of S&M activities.

Table 3.3. Selection of potentially complete future exposure pathways

D&D Facility Use Scenario	Exposure Medium	Receptor	Exposure Route			
			Inhalation	Ingestion	Dermal Absorption	External Radiation
Future Off-Site Resident	Air	Adult Resident	●	NA	NA	●
	Building Structure (Floors and Walls)	Adult Resident	NA	NA	NA	NA
	Surface Water	Adult Resident	●	●	O	NA
	Groundwater	Adult Resident	O	O	O	NA
	Soil	Adult Resident	NA	NA	NA	NA
	Vegetables	Adult Resident	NA	●	NA	NA
Future Intruder	Air	Intruder[a]	●	NA	NA	O
	Building Structure (Floors and Walls)	Intruder	NA	●	●	●
	Surface Water	Intruder	O	O	O	NA
	Groundwater	Intruder	O	O	O	NA

●Potentially complete pathway
ONo complete pathway
NA Not Applicable
[a]The intruder is an adult individual who investigates/explores the facility after the loss of institutional controls.

3.3 QUANTIFICATION OF EXPOSURE

This section describes the quantitative estimation of exposures for each of the exposure pathways described previously. The process involves:

- identifying applicable human exposure models and input parameters,
- determining the concentration of each COPC in the exposure media at the point of human exposure, and
- estimating human intakes.

The potential exposure pathways at Building 3515 are identified in Tables 3.2 and 3.3.

3.3.1 Exposure Models

Exposures were estimated for ingestion, inhalation, dermal absorption, and external radiation exposure. All exposures were calculated for an adult only. Exposures were calculated using the following equations (EPA 1989a):

Ingestion

$$CDI = \frac{C \times IR \times CF \times FI \times EF \times ED}{BW \times AT} \qquad \text{(Chemicals)}$$

$$CDI = C \times IR \times ED \times EF \times FI \qquad \text{(Radionuclides)}$$

where

CDI	=	Chronic Daily Intake,
C	=	Exposure Concentration,
IR	=	Intake Rate of Dust/Soil/Water,
CF	=	Conversion Factor,
FI	=	Fraction Ingested,
EF	=	Exposure Factor,
ED	=	Exposure Duration,
BW	=	Body Weight,
AT	=	Averaging Time.

Inhalation

$$CDI = \frac{C \times IR \times EF \times ED \times \frac{1}{PEF}}{BW \times AT} \qquad \text{(Chemicals)}$$

$$CDI = C \times IR \times EF \times ED \times \frac{1}{PEF}$$ (Radionuclides)

where

CDI	=	Chronic Daily Intake,
C	=	Exposure Concentration,
IR	=	Intake Rate,
EF	=	Exposure Factor,
ED	=	Exposure Duration,
PEF	=	Particulate Emission Factor,
BW	=	Body Weight,
AT	=	Averaging Time.

External exposure to radionuclides

$$CDI = C \times ED \times (1 - S_e) \times T_e$$ [Radionuclides (pCi/g)]

$$CDI = C \times DR \times EF \times ED$$ [Radionuclides (mrem/hr)]

where

CDI	=	Chronic Daily Intake,
C	=	Exposure Concentration,
$(1-S_e)$	=	Gamma shielding factor,
T_e	=	Gamma exposure time factor,
DR	=	Dose Equivalent Rate,
EF	=	Exposure Frequency,
ED	=	Exposure Duration.

Estimation of external exposures from dose rate data

$$Dose = CxET$$

where

Dose	=	Lifetime Dose (mrem),
C	=	Exposure Concentration (mrem/hr),
ET	=	Exposure Time (hours).

Dermal contact with particulates

$$CDI = \frac{C \times CF \times SA \times AF \times ABS \times EF \times ED}{BW \times AT} \qquad \text{(Chemicals)}$$

where:

CDI	=	Chronic Daily Intake,
C	=	Exposure Concentration,
CF	=	Conversion Factor,
SA	=	Skin Surface Area Available for Contact,
AF	=	Soil to Skin Adherence Factor,
ABS	=	Absorption Factor,
EF	=	Exposure Factor,
ED	=	Exposure Duration,
PEF	=	Particulate Emission Factor,
BW	=	Body Weight,
AT	=	Averaging Time.

Residential agricultural pathways—radionuclide contaminant

Ingestion of vegetables:

$$CDI_v = C_v \times IR_v \times FI_v \times EF \times ED \times CF$$

where

CF	=	Units Conversion Factor,
C_v	=	Radionuclide Concentration in Vegetable,
ED	=	Exposure Duration,
EF	=	Exposure Frequency,
Fi_v	=	Fraction Ingested—Vegetable,
Ir_v	=	Ingestion Rate—Vegetable.

3.3.2 Exposure Parameters

One current and two future exposure scenarios were evaluated. The current exposure scenario is a maintenance worker. The future exposure scenarios are an adult intruder at the building and an adult resident at White Oak Creek and at White Oak Dam. The exposure parameters used to quantify exposure for each exposure pathway evaluated for these scenarios are described and summarized in Table 3.4. These exposure parameters are based on EPA guidance (EPA 1989a, 1989b). All receptors were assumed to be represented by an average adult weighing 70 kg with a 70-year lifespan.

Table 3.4. Exposure variables for Building 3515 exposure assessment

	Maintenance Worker	Adult Intruder	Adult Residents
C	Contaminant Specific	Contaminant Specific	Contaminant Specific
IR (inhalation)	$20m^3$/day	$20m^3$/day	$20m^3$/day
IR (soil ingestion)	-	50 mg/day	-
IR (water ingestion)	-	-	2 L/day
IR (vegetable ingestion)	-	-	0.2 kg/day
CF	1×10^{-6} kg/mg	1×10^{-6} kg/mg	1×10^{-6} kg/mg
FI	1 Unitless	1 Unitless	1 Unitless
FI_v	-	-	0.4 Unitless
ED	25 years	1 year	30 years
BW	70 kg	70 kg	70kg
AT (Noncarcinogens)	ED × 365 day/yr	ED × 365 day/yr	ED × 365 day/yr
AT (Carcinogens)	70 yrs × 365 day/yr	70 yrs × 365 day/yr	70yrs × 365 day/yr
PEF	4.28×10^9 m^3/kg	4.28×10^9 m^3/kg	4.28×10^9 m^3/kg
ABS (Metals)	0.001 (unitless)	0.001 (unitless)	0.001 (unitless)
ABS (Organics)	0.01 (unitless)	0.01 (unitless)	0.01 (unitless)
EF	12 hours/yr	5 hours/yr	350 day/yr
SA	3120 cm^2/day	3120 cm^2/day	5300 cm^2/day
AF	1.0 mg/cm^2	1.0 mg/cm^2	1.0 mg/cm^2
T_e	0.33	0.33	1.0
S_e	0.2 0.9996 (Concrete Pad)	0.2	0.2

3.3.2.1 Current maintenance worker

Current maintenance workers are to spend 2 hours a month every other month engaged in grounds maintenance and routine activities (12 hours/year) at the facility for 25 years.

3.3.2.2 Future intruder

The receptor for this scenario is an adult who has intruded and explored the abandoned building (that has decayed and an entry point has been made) at some time in the future for five 1-hour periods over a one-year period. This receptor is assumed to ingest 100 mg of dust per day at the facility (Table 3.4). The intruder is assumed to spend an equal amount of time in both the north and south cells of the building and is exposed by the ingestion, dermal exposure to chemicals, inhalation, and external exposure to radionuclides pathways. For inhalation exposure, the intruder is assumed to have an inhalation rate of 20 m^3/day. A particulate emission factor (PEF) of 4.28×10^9 m^3/kg was assumed for dust disturbed by intruder activities. For dermal contact an exposed surface area of 3120 cm^2 representing the average adult's head, hands, forearms, and lower legs was used. This was combined with a soil-to-skin adherence factor of 1.0 mg/cm^2 and absorption factors of 0.001 for metals and 0.01 for organic chemicals.

3.3.2.3 Off-site residents

Off-site residential receptors located at White Oak Creek and White Oak Dam were considered for the future land use scenario. The residential receptors are located on surface water bodies potentially contaminated by contaminant releases at Building 3515. Contamination at Building 3515 is transported to the surface water by overland runoff and by infiltration into the groundwater. The receptors are exposed by a variety of residential activities. Exposure pathways include direct ingestion of surface water, ingestion of produce irrigated with surface water, and inhalation of surface water droplets while bathing.

Contaminants are assumed to be released from Building 3515 under two scenarios. The first release scenario involves an acute release of contaminants resulting from a catastrophic event (e.g., earthquake, tornado) which destroys the building structure. The second scenario involves a chronic release of contaminants resulting from the slow degradation and deterioration of the building and exterior floor pad over an extended period of time. Under the catastrophic scenario, residents are also assumed to be exposed via the inhalation of and external exposure to contaminated air (in the form of a cloud) which is likely to result from such an event.

3.3.3 Exposure Concentrations

The exposure concentrations for this BRA are derived for the ingestion, inhalation, dermal contact, and external exposure pathways using many different types of data (e.g., pCi/g concentrations for the smear samples versus mrem doses for direct measurements). Off-site exposure concentrations were calculated for residents at White Oak Creek and White Oak Dam using fate and transport models. All exposure concentrations are representative of the first 70 years following the release of contamination.

Because of the uncertainty associated with estimating the true average exposure concentration, the upper confidence limit (i.e., the 95% upper confidence limit) on the arithmetic mean of each contaminant's concentrations was used as the exposure concentration where sufficient data were

available (EPA 1989a). The following paragraphs discuss how exposure concentrations were calculated for each type of data.

3.3.3.1 Core samples

Three core samples were taken from the exterior concrete pad along with a sample of the underlying soil. Concentrations in the underlying soil were used to calculate the inventory of radionuclides to which a maintenence worker would be exposed while spending time (30 minutes every other month for 25 years) on top of the pad. This inventory is presented in Table 3.5 and was derived using a soil volume of 3.1E7 cm^3 and a soil density of 1.3 g/cm^3. A radiation shielding factor of 0.9996 was assumed to be attributable to the overlying concrete pad. The derivation of this factor is given in Appendix A. The inventory of radionulides in the soil was decayed for 30 years and then used as source term for the chronic release scenario following failure of the concrete pad.

3.3.3.2 Smear samples

Measurements of transferable radioactive contamination (smear samples) for both the north and south cells were converted from $\mu Ci/100cm^2$ to pCi/g using the conversion equations in Appendix B. The smear data were reported as alpha or beta radiation (i.e., dpm/smear) and as concentrations of specific radionuclides (i.e., µCi/smear). The smear data were extrapolated to represent the entire surface area of the interior walls, ceiling, and floors.

3.3.3.3 Direct radiation measurements

The direct measurement and TLD string exposure concentrations were derived based on a lifetime exposure in mrems. Direct measurements for both beta/gamma and alpha were reported for each cell. The exposure rates used for calculating risk from external exposure in each cell correspond to the upper 95% confidence limit of the TLD data presented in Sect. 2.2.2. Exposure rates (mrem/hr) for the external walls of Building 3515 were taken directly from a preliminary decommissioning study report (Horton 1984).

3.3.3.4 Off-site modeling

Exposure concentrations for off-site residents at White Oak Creek and White Oak Dam were calculated using fate and transport models. For the catastrophic release scenario, it was assumed that the entire radiological inventory of Building 3515 would be made available for release into the environment. The total inventory by contaminant for Building 3515 is given in Table 3.6. Given the nature of a catastrophic event capable of destroying Building 3515 (e.g., an earthquake, tornado, hurricane, etc.), 20% of the inventory was assumed to become airborne and travel to off-site receptors through the air. Therefore, 80 % of the total inventory would be available for off-site transport via other transport pathways. It was assumed that approximately 90% of the remaining inventory (72% of the total inventory) would enter the storm flow zone and travel overland to White

Table 3.5. Initial and decayed inventory of radionuclides in subfoundation soil

Radionuclide	Initial Inventory (Ci)	Inventory After 30 yrs (Ci)
Am-241	1.55E-02	1.48E-02
Cs-137	5.29E+01	2.66E+01
Pu-238	2.32E-04	1.83E-04
Pu-239	3.88E-03	3.88E-03
Sr-90	1.03E+01	4.98E+00
Th-228	2.24E-04	4.26E-05
Th-230	2.27E-04	2.27E-04
Th-232	4.44E-05	4.44E-05
U-234	7.36E-05	7.36E-05
U-235	1.63E-06	1.63E-06
U-238	9.77E-05	9.77E-05

Table 3.6. Curie estimate for concrete in Building 3515[a]

Radionuclide	Total Activity per Concrete Group (Ci)			Total Activity in Building 3515
	Lower Part of Pad[b]	Added Shield[c]	Original Building Walls/Floors[d]	
$^{239/240}Pu$	2.40E-06	2.75E-05	2.02E-05	5.02E-05
^{238}Pu	3.00E-06	3.92E-05	2.53E-05	6.75E-05
^{228}Th	1.02E-05	8.25E-05	8.60E-05	1.79E-04
^{230}Th	1.28E-05	1.84E-04	1.08E-04	3.04E-04
^{232}Th	4.20E-06	9.63E-05	3.54E-05	1.36E-04
^{234}U	1.23E-05	2.18E-04	1.04E-04	3.34E-04
^{235}U	1.35E-06	1.48E-05	1.14E-05	2.76E-05
^{238}U	2.06E-05	2.20E-04	1.73E-04	4.14E-04
^{137}Cs	3.61E-02	3.91E-03	9.31E+02	9.31E+02
^{40}K	5.81E-05	1.94E-03	4.90E-04	2.49E-03
^{90}Sr	2.06E-02	9.63E-05	5.30E+02	5.30E+02
Tritium	9.31E-06	1.38E-04	7.85E-05	2.25E-04

[a] Estimate is taken from the *Site Characterization Report for Building 3515 at Oak Ridge National Laboratory, Oak Ridge, Tennessee*, ORNL/ER/Sub/87-99053/73 (August 1994).

[b] Estimate is based on concentration of bottom 9 in. of 73.SB002 and bottom 3 in. of the pad.

[c] Estimate is based on concentrations of 73.SB001 and the upper 9 in. of 73.SB002, the added concrete shield, the building roof, and the upper 1.25 ft of pad.

[d] Estimate is based on the Microshield model prediction and volume of the original walls and floors. On the basis of smear data and core results, it is expected that the order of magnitude of activity of the alpha emitters is the same as that of other areas.

Oak Creek and then downstream to White Oak Dam. The remaining 10% (8% of the total inventory) was assumed to leach into the groundwater and travel to White Oak Creek and then downstream to White Oak Dam.

For the chronic release scenario resulting from degradation of the building and exterior pad, no atmospheric transport was assumed. Releases from the building were assumed to begin in 15 years and increase with time as the building deteriorates. The amount of inventory assumed to be released from the building over 70 years is given in Table 3.7. Contamination from the building was assumed to leach onto the surface soil. Ninety percent is assumed to migrate via the overland pathway, and 10% migrates via the groundwater.

The exterior concrete pad was assumed to prevent rainfall infiltration for 30 years. After 30 years the pad was assumed to fail and leaching of the underlying contaminated soil would begin. The pad is assumed to prevent overland runoff of the contaminated soil even during its slow degradation. As such, the overland pathway was not considered as a transport route for the contaminated soil. Only groundwater transport is considered, using the inventory following 30 years of radioactive decay. The 30-year decayed inventory of radionuclides in the contaminated soil is given in Table 3.5.

Atmospheric transport of released contaminants was modeled using the GENII code. The overland and groundwater transport pathways were modeled using the Multimedia Environmental Pollutant Assessment System (MEPAS). A description of these models and the assumptions and input parameters used with the models is given in Appendix C.

The White Oak Creek resident is located at the point of overland and groundwater discharge into the creek. Specifically, the resident is located along the centerline of the discharging plume. This is not the most conservative location because the receptor is not exposed to that half of the contamination discharging downstream of the centerline. The White Oak Dam resident is assumed to be 9500 ft downstream of the overland and groundwater discharge into White Oak Creek.

3.4 RESULTS OF THE EXPOSURE ASSESSMENT

The exposure assessment for Building 3515 was conducted to evaluate potential exposures to the COPCs identified for the building. The assessment resulted in the identification of potential receptor populations, the pathways of exposure to contaminants within Building 3515, and the concentrations at which receptor populations may be exposed. The results of the quantitative exposure assessment are shown in Appendix D. Using the equations presented in Sect. 3.3.1, Chronic Daily Intakes (CDIs) were calculated for each receptor (current maintenance worker, future resident, future intruder) and contaminant present. These CDI values will be used along with toxicity values (Chapter 4) to derive excess cancer risk estimates for the carcinogenic contaminants and HQs for noncarcinogenic contaminants in Chapter 5 of this BRA.

3.5 UNCERTAINTY

Three major types of uncertainties should be considered when reviewing the results of the exposure assessment: uncertainties associated with predicting future land use, uncertainties

Table 3.7. Contaminant releases from Building 3515 under the chronic degradation scenario

Contaminant	Inventory After 15 yrs (Ci)	Inventory Released During Building Degradation (Ci)						
		0-10 yrs	11-20 yrs	21-30 yrs	31-40 yrs	41-50 yrs	51-60 yrs	61-70 yrs
Cs-137	6.60E+02	1.32E+01	3.23E+01	3.08E+01	4.67E+01	5.37E+01	4.83E+01	4.35E+01
H-3	9.64E-05	1.93E-06	4.72E-06	4.49E-06	6.82E-06	7.85E-06	7.06E-06	6.35E-06
K-40	2.49E-03	4.98E-05	1.22E-04	1.16E-04	1.76E-04	2.03E-04	1.82E-04	1.64E-04
Pu-238	6.00E-05	1.20E-06	2.94E-06	2.80E-06	4.25E-06	4.88E-06	4.39E-06	3.95E-06
Pu-239	5.02E-05	1.00E-06	2.46E-06	2.34E-06	3.55E-06	4.09E-06	3.67E-06	3.31E-06
Sr-90	3.68E+02	7.36E+00	1.80E+01	1.71E+01	2.60E+01	3.00E+01	2.69E+01	2.43E+01
Th-228	1.04E-04	2.08E-06	5.10E-06	4.85E-06	7.36E-06	8.47E-06	7.61E-06	6.85E-06
Th-230	3.04E-04	6.08E-06	1.49E-05	1.42E-05	2.15E-05	2.47E-05	2.23E-05	2.00E-05
Th-232	1.36E-04	2.72E-06	6.66E-06	6.34E-06	9.62E-06	1.11E-05	9.96E-06	8.96E-06
U-234	3.34E-04	6.68E-06	1.64E-05	1.56E-05	2.36E-05	2.72E-05	2.44E-05	2.20E-05
U-235	2.76E-05	5.52E-07	1.35E-06	1.29E-06	1.95E-06	2.25E-06	2.02E-06	1.82E-06
U-238	4.14E-04	8.28E-06	2.03E-05	1.93E-05	2.93E-05	3.37E-05	3.03E-05	2.73E-05

associated with estimating contaminant concentrations at receptor locations, and uncertainties associated with assumptions used in the exposure models. Uncertainties in the exposure assessment are discussed in the following paragraphs.

It is rarely possible to know what will occur at a site in the future. Assumptions must, therefore, be made regarding future land use. The conservative assumption that a receptor could trespass into the building is designed to provide an upperbound estimate of exposure and risk. Uncertainty in the estimated exposure concentrations result from normal analytical error and the fact that a few samples must be used to represent the concentration in a larger area.

Additional uncertainty in exposure concentrations results from the use of fate and transport models. Uncertainties arise from having to simulate an infinitely complex system using a finite number of variables. The accuracy of any simulation is a function of two overall factors. The first is how accurately the models reflect reality assuming the values of all independent variables are known exactly (i.e., model uncertainty). The second factor is how close the measurements of the independent variables used in the model are to "actual" values (i.e., parameter uncertainty).

Smear samples were collected from the floor. The data from the walls were used to represent the entire cell. This assumption could underestimate the concentration of transferrable radionuclide contamination in the cell.

Exposure parameters (e.g., inhalation rate, exposure frequency, exposure duration) used to model hypothetical receptors are a combination of reasonable and upperbound (generally upper 95% confidence limit) values. The use of upperbound values will tend to overestimate exposure. This provides a conservative health protective approach for the risk assessment.

4. TOXICITY ASSESSMENT

This chapter summarizes the potential toxicological effects of the COPCs included in the evaluation of Building 3515.

4.1 TOXICITY INFORMATION FOR NONCARCINOGENIC EFFECTS

Noncarcinogenic effects are evaluated by comparing an exposure experienced over a specified time period (e.g., 30 years) with an RfD (reference dose) [or reference concentration (RfC)] derived for a similar exposure period. The RfDs available for the COPCs present in Building 3515 are given in Table 4.1. To evaluate the noncarcinogenic effects from exposure to COPCs in Building 3515, the hazard index (HI) [the ratio of the exposure dose (i.e., CDI and/or dose found in Appendix D) to the RfD] is calculated for each COPC. This noncarcinogenic HI assumes that, below a given level of exposure (i.e., the RfD), even sensitive populations are unlikely to experience adverse health effects. If the exposure level (CDI) exceeds this threshold [i.e., if CDI/RfD exceeds one (1.0)], there may be concern for potential systemic health effects. The level of concern does not necessarily increase linearly as the HI approaches or exceeds unity; the HI is not a percentage or probability.

Subchronic RfDs are used to evaluate short-term exposure (2 weeks to 7 years) (EPA 1989a). For the purpose of this Level 3 BRA, subchronic RfDs have been used for assessing the intruder.

4.2 TOXICITY INFORMATION FOR CARCINOGENIC EFFECTS

For carcinogens, risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the carcinogen (i.e., the term "incremental" refers to excess individual lifetime cancer risk). Cancer risk from exposure to contamination is expressed as excess cancer risk or, stated differently, cancer incurred in addition to normally expected rates of cancer development. An excess cancer risk of 1.0E-06 indicates one person in one million is predicted to incur cancer from exposure to this contamination level over a 70-year lifetime.

To evaluate the carcinogenic risk from exposure to Building 3515 COPCs, the risk is calculated for each COPC [the multiplication of the exposure dose (i.e., CDI and/or dose) by the slope factor (SF), which is a chemical-specific value based on carcinogenic dose-response data]. Excess cancer risks falling between 1.0E-06 and 1.0E-04 are within EPA's range of concern, and cancer risks above 1.0E-04 are considered unacceptable by the EPA (1989a). Because the SFs are the 95th percentile upper confidence limit on the probability of a carcinogenic response, the carcinogenic risk estimate represents an upper confidence bound estimate. Therefore, a 5% probability exists that the actual risk will be higher than the estimate presented, and the actual risk may well be less than the estimate. Slope factors used in the evaluation of risk from exposure to Building 3515 COPCs are listed in Table 4.2. A risk factor of 7.3E-7 risk/mrem was used to calculate external exposure risk using the survey data from the exterior of the building and the TLD strings (ICRP 1991).

Table 4.1. Toxicity values for potential noncarcinogenic contaminants evaluated quantitatively

ANALYTE	CASRN	SUBCHRONIC ORAL RfD (mg/kg/day)	SUBCHRONIC DERMAL RfD (mg/kg/day)	SUBCHRONIC INHALATION RfD (mg/kg/day)	CONFIDENCE LEVEL	MF	UF	RfD SOURCE	RfD BASIS (VEHICLE)	CRITICAL EFFECT
Antimony	7440-36-0	4.00E-04	8.00E-06	-	Low	1	1000	IRIS	Water (Oral)	Decreased longevity; Alteration of blood chemistry in rats
Arsenic	7440-38-2	3.00E-04	1.20E-04	2.70E-04	Low	1	100	IRIS	Occupational	Keratosis, Hyperpigment ation
Barium	7440-39-3	7.00E-02	4.90E-03	1.40E-04	Medium	1	3	IRIS	Water (Oral)	Increased blood pressure; baritosis
Beryllium	7440-41-7	5.00E-03	2.50E-04	-	Low	1	100	IRIS	Oral	Slightly decreased body weight (rat)
Cadmium	7440-43-9	1.00E-03	6.00E-05	-	High	1	10	IRIS	Oral (Diet)	Renal toxicity; osteomalacia, osteoporosis, and significant proteinuria
Chromium (VI)	18540-29-9	2.00E-02	2.10E-03	-	Low	1	500	IRIS	Water (Oral)	Hepato- & Nephrotoxicity
Manganese (Water)	7439-96-5	5.00E-03	2.50E-04	1.40E-05	Medium	1	1	IRIS	Water (Oral)	Neural Tissue Damage
Nickel	7440-02-0	2.00E-02	2.00E-02	-	Medium	1	300	IRIS	Oral	Reduced organ weight; Decreases in whole body weight

Table 4.1. (continued)

ANALYTE	CASRN	SUBCHRONIC ORAL RfD (mg/kg/day)	SUBCHRONIC DERMAL RfD (mg/kg/day)	SUBCHRONIC INHALATION RfD (mg/kg/day)	CONFIDENCE LEVEL	MF	UF	RfD SOURCE	RfD BASIS (VEHICLE)	CRITICAL EFFECT
Selenium	7782-49-2	5.00E-03	3.00E-03	-	High	1	3	IRIS	Oral	Clinical selenosis
Silver	7440-22-4	5.00E-03	9.00E-04	-	-	-	-	IRIS	Oral	General argyria, ulcerative gingivitis
Vanadium	7440-62-2	7.00E-03	1.80E-04	-	Low	1	100	IRIS	Water (Oral)	Minor changes in serum chemistry
Zinc	7440-66-6	3.00E-01	1.50E-01	-	Medium	1	3	IRIS/ HEAST	Gavage	Hyperactivity; low body weight

Table 4.2. Toxicity values for potential carcinogenic contaminants evaluated quantitatively

Analyte	CASRN	ORAL SF (Risk/pCi) $(mg/kg/day)^{-1}$	INHALATION SF (Risk/pCi) $(mg/kg/day)^{-1}$	EXTERNAL EXPOSURE SF (Risk/year per pCi/g)	EPA CLASS	SF SOURCE
Arsenic	7440-38-2	-	5.00E+01	-	A	HEAST
Beryllium	7440-41-7	4.3E+00	8.40E+00	-	B2	HEAST
Cadmium (Water)	7440-43-9	-	6.10E+00	-	B1	HEAST
Chromium (VI)	18540-29-9	-	4.10E+01	-	A	HEAST
Radionuclides						
Americium-241	14596-10-2	3.3E-10	3.9E-08	4.6E-09	A	HEAST
Cesium-137	10045-97-3	3.2E-11	1.9E-11	2.1E-06	A	HEAST
Hydrogen-3	10028-17-8	7.2E-14	9.6E-14	-	A	HEAST
Plutonium-238	13981-16-3	3.0E-10	2.7E-08	1.9E-11	A	HEAST
Plutonium-239	15117-48-3	3.2E-10	2.8E-08	1.3E-11	A	HEAST
Potassium-40	13966-00-2	1.3E-11	7.5E-12	6.1E-07	A	HEAST
Strontium-90	10098-97-2	5.6E-11	6.9E-11	0.0E+00	A	HEAST
Thorium-228	14274-82-9	2.3E-10	9.7E-08	9.9E-07	A	HEAST
Thorium-230	14269-63-7	3.8E-11	1.7E-08	4.4E-11	A	HEAST

Table 4.2. (continued)

Analyte	CASRN	ORAL SF (Risk/pCi) $(mg/kg/day)^{-1}$	INHALATION SF (Risk/pCi) $(mg/kg/day)^{-1}$	EXTERNAL EXPOSURE SF (Risk/year per pCi/g)	EPA CLASS	SF SOURCE
Thorium-232	7440-29-1	3.3E-11	1.9E-08	2.0E-11	A	HEAST
Uranium-234	13966-29-5	4.4E-11	1.4E-08	2.1E-11	A	HEAST
Uranium-235	15117-96-1	4.7E-11	1.3E-08	2.7E-07	A	HEAST
Uranium-238	7440-61-1	6.2E-11	1.2E-08	5.3E-08	A	HEAST

4.3 ESTIMATION OF TOXICITY VALUES FOR DERMAL EXPOSURE

Oral RfDs and SFs are often adjusted for evaluation of the dermal exposure pathway (EPA 1989a); it is conservative in terms of risk to and/or HIs for human health to adjust the toxicity values in the manner described in the following discussion. Most RfDs/SFs are expressed as the amount of substance administered per time and body weight; however, dermal exposure to chemicals in soil and water are expressed as absorbed doses.

For the dermal assessments in this Level 3 BRA, the oral RfD/SF for each chemical (Building 3515 COPCs) was adjusted by the percent gastrointestinal absorption efficiency (%GI) for that chemical. The %GI is known for only a limited number of chemicals; for those chemicals where a %GI is currently not available in the literature, 100% was assumed. For many chemicals, estimates of %GI were based on qualitative information on the rate and extent of GI absorption; rapid or extensive absorption was assumed to be essentially complete, i.e., %GI = 100%. Wide ranges of %GI values can be found for some chemicals and in the absence of chemical-specific absorption data, estimates can be made based on data for related chemical structures. Most organic compounds are readily absorbed (i.e., %GI =100%) from the GI tract; for this risk assessment, no adjustments were made to chemicals with %GI $\geq$ 80%.

Minor adjustments to the oral RfDs/SFs (used in the dermal assessments only) were made for this BRA. The oral RfD was multiplied by the %GI/100%, and the SF was divided by the %GI/100% to give the absorbed dose RfD and absorbed dose SF, respectively. If unacceptable risks are identified for this exposure route, the associated chemicals should be examined in detail to ascertain the credibility of the dermal toxicity value prior to making decisions based on the dermal results. These toxicity values (listed in Tables 4.1 and 4.2) were then used in the evaluation of risk to human health from exposure to Building 3515 contaminants via dermal contact.

4.4 CHEMICALS FOR WHICH NO EPA TOXICITY VALUES ARE AVAILABLE

Slope factors and RfDs are not currently available for all known chemicals because their carcinogenic and/or noncarcinogenic effects have not yet been determined. These chemicals may contribute to carcinogenic and noncarcinogenic effects from exposure to Building 3515, but their effects cannot be quantified at the present time. Furthermore, several chemicals are not indicated by epidemiological studies to be carcinogenic; consequently, these chemicals do not have SFs. In addition, several COPCs have toxicity values that have been withdrawn from the EPA toxicity database.

4.5 UNCERTAINTIES RELATED TO TOXICITY INFORMATION

The methodology used in developing a noncarcinogenic toxicity value (RfD or RfC) involves identifying a threshold level below which adverse health effects will not occur. The RfD/RfC values are generally based on studies of the most sensitive animal species tested and the most sensitive endpoint measured (unless adequate human health data are available). From these studies, the experimental exposure representing the highest dose level tested at which no adverse effects were demonstrated [the no-observed-adverse-effect level (NOAEL)] was derived; in some cases, only a lowest-observed-adverse-effect level (LOAEL) is available. The RfD/RfC is derived from the NOAEL (or LOAEL) for the critical toxic effect by dividing the NOAEL (or LOAEL) by uncertainty

factors. These factors usually are in multiples of 10, with each factor representing a specific area of uncertainty in the extrapolation of the data. An uncertainty factor of 100 is typically used when extrapolating animal studies to humans; additional uncertainty factors are sometimes necessary when other experimental data limitations are found. Because of the large uncertainties (10–10,000) on some RfD/RfC toxicity values, exact/sharp safe levels of exposure for humans are not possible.

A two-part evaluation exists for assessing the carcinogenic potential of a chemical: (1) evaluating the likelihood that a chemical is a carcinogen (i.e., a weight-of-evidence assessment) and (2) determining the quantitative dose-response relationship (i.e., potency factor or SF); uncertainties occur with each evaluation. Based on weight-of-evidence studies using human and laboratory animal research, chemicals fall into one of five groups (EPA 1989a, 1993b): (1) Group A, human carcinogen; (2) Group B, probable human carcinogen; (3) Group C, possible human carcinogen; (4) Group D, not classified as to human carcinogenicity; and (5) Group E, evidence of no carcinogenic effects to humans. The SF for a chemical is a plausible upperbound estimate of the probability of a response per unit intake of a chemical over a lifetime; it is derived by applying a mathematical model to extrapolate from a relatively high administered dose (to animals) to the lower exposure levels expected for humans. The SF represents the 95th percentile upper confidence limit on the linear component of the slope of the tumorigenic dose-response curve in the low-dose region. A number of low-dose extrapolation models have been developed, and EPA generally uses the linearized multistage model in the absence of adequate information to support other models.

4.6 SUMMARY OF TOXICITY INFORMATION

The purpose of any toxicity assessment is to present the potential adverse health effects associated with COPCs. This usually consists of an evaluation of the relationship between the extent of exposure to a particular contaminant and the increased likelihood or severity of adverse health effects as a result of that exposure relative to a baseline. The toxicity assessment generally involves two steps. The first step comprises determining whether exposure to an agent can cause an increase in the incidence of a particular health effect and whether that health effect will occur in humans. The second step involves characterizing the relationship between the received dose of the contaminant and the incidence of adverse health effects in exposed populations. Tables 4.1–4.2 summarize the toxicity information for the Building 3515 COPCs.

4.7 TOXICITY PROFILES

As noted previously, the chemical-specific information in Appendix E provides general qualitative information as well as a chemical-specific discussion about health effects related to those contaminants that were found to be of concern (i.e., exhibited a risk within or above EPA's target risk range), also known as chemicals of concern (COCs). Carcinogenic and noncarcinogenic health effects are considered. Data used in this section are from human and laboratory animal research and from occupational studies to characterize likely health effects resulting from exposure to the COCs. Refer to the *Toxicity Profiles for Use in Hazardous Waste Risk Assessment and Remediation* report (BEIAS 1994) for further information regarding specific chemicals. Information on chemicals evaluated qualitatively has also been included; for this BRA, lead was the only analyte evaluated qualitatively.

5. RISK CHARACTERIZATION

The purpose of the risk characterization is to integrate and summarize the information presented in the exposure and toxicity assessments; it is the final step in the human health risk assessment process. Potential carcinogenic effects are characterized by estimating the probability that an individual will develop cancer over a lifetime from projected intakes (and exposure) and chemical-specific dose-response data (i.e., SFs). Potential noncarcinogenic effects are characterized by comparing projected intakes of contaminants to toxicity values (i.e., RfDs). The numerical risk/HQ estimates that are presented in this section must be interpreted in the context of the uncertainties and assumptions associated with the risk assessment process and with the data upon which the risk estimates are based.

For carcinogenic contaminants, risk is expressed in terms of the probability of contracting cancer over a lifetime, over and above the normal background risk. This is the Incremental Lifetime Cancer Risk (ILCR) and is estimated as the product of the estimated exposure to a carcinogen and the contaminant-specific, route-specific slope factor:

$$ILCR = SF \times CDI,$$

where

ILCR	=	Incremental lifetime cancer risk (unitless probability),
SF	=	Slope factor $(mg/kg\text{-}day)^{-1}$,
CDI	=	Chronic daily intake (mg/kg-day).

For dose rate data, the ILCR is calculated using the following equation:

$$ILCR = SF \times Dose,$$

where

ILCR	=	Incremental lifetime cancer risks (unitless probability),
SF	=	Slope factor $(mg/kg\text{-}day)^{-1}$,
Dose	=	External radiation dose (pCi-yr/g) or (mrem).

The previous equations are linear and are usually applicable for estimating low level risks (i.e., below estimated risks of 0.01). For situations where risks are above 0.01, an alternative calculation was used:

$$ILCR = 1\text{-}exp(\text{-}CDI \times SF),$$

where

ILCR	=	Incremental lifetime cancer risks (unitless probability),
exp	=	the exponential,
CDI	=	Chronic daily intake (mg/kg-day),
SF	=	Slope factor $(mg/kg\text{-}day)^{-1}$.

In the United States, the normal incidence of cancer occurrence is 3.0E-1 or .30 (American Cancer Society 1990). The ILCR (also referred to as excess cancer risk) is defined as the estimated increased risk that occurs over an assumed average lifespan of 70 years as the result of exposure to a specific known carcinogen. Therefore, an incremental lifetime cancer risk of one in one million (1.0E-6) may be interpreted as an increase in the baseline population cancer incidence from 300,000 per million population to 300,001 per million population. Current radiation protection standards for workers include a limit of 5 rem for the annual effective dose equivalent. This dose equates to a 25-year lifetime risk corresponding to 5.0E-2. Similar protection standards for members of the public include a limit of 0.1 rem per year. This dose equates to a 70-year lifetime risk of 4.0E-3 (ORNL 1993).

Noncarcinogenic effects of contaminants are quantified as HQs. An HQ is the ratio of the estimated daily intake to the allowable daily intake or RfD:

$$HQ = CDI/RfD,$$

where

HQ	=	Hazard quotient (unitless),
CDI	=	Chronic daily intake (mg/kg-day),
RfD	=	Reference dose (mg/kg-day).

Because the HQ does not define exposure-response relationships, its numerical value should not be construed as a direct estimate of risk; i.e., it is not a probability. It is a numerical indication of whether or not acceptable exposure levels are exceeded.

In the case of simultaneous exposure to several contaminants, an HI may be calculated to evaluate the potential risk associated with exposure to a mixture by summing the HQ for each contaminant and exposure pathway:

$$HI = HQ_1 + HQ_2 + HQ_3 + ...,$$

where

HI = Hazard index (unitless).

Mechanistically, it may not be appropriate to sum HQs unless the contaminants that make up the mixture have similar modes of action on the identical organ. Very little synergistic or greater-than-additive interactions among environmental toxicants have been identified in the scientific literature. A number of antagonistic or less than additive interactions are known, and these could be overestimated in an additive model. In general, an HI less than 1 indicates estimated intakes are below the intake that would cause toxic effects.

This section presents risks to human health posed by contaminants in Building 3515. Excess cancer risk estimates and HQs were calculated for a plausible maintenance worker (current), hypothetical residents located off-site (future), and a hypothetical adult intruder (future) for the ingestion, dermal exposure to chemicals, inhalation, and external exposure to radionuclides pathways as appropriate. These risks are evaluated within the context of EPA-approved guidelines that include three regions for carcinogenic risk [risk <1E-6, no concern; risk between 1E-6 and 1E-4,

range of concern (or target risk range); and risk ≥ 1E-4, unacceptable] and two regions in terms of noncarcinogenic toxicity (HI < 1, no concern, and HI ≥ 1, concern).

In relationship to the regulatory decisions to be made, if the BRA (and comparisons of exposure concentrations to other chemical-specific criteria/standards) indicates there are no unacceptable risks to human health or the environment, an alternatives evaluation, Feasibility Study (FS), Engineering Evaluation Cost Assessment (EECA), and remedial/removal action are generally not warranted based on risk (EPA 1991). When the BRA indicates that risks to a hypothetical resident (or a reasonable maximum exposure scenario) are unacceptable (i.e., risk ≥ 1E-4), action (i.e., alternatives evaluation, FS, EECA, and remedial/removal action) is generally warranted and risk management decisions are made. The EPA considers risks between 1.0E-6 and 1.0E-4 in the target risk range, and an FS and EECA may be performed to determine if remedial action would both reduce risk and be cost effective (EPA 1991). The uncertainties in the risk assessment process and the data and assumptions used must also be considered when determining the need for future work at a facility.

The results of the risk characterization are presented in the following text and tables.

5.1 CURRENT LAND USE

The following sections present the results of the risk characterization for current land use conditions as represented by the maintenance worker scenario.

5.1.1 Excess Cancer Risk (ILCR)

The excess cancer risks associated with the maintenance scenario are summarized in Table 5.1. A complete table of results can be found in Appendix F. The current land use scenario considers a maintenance worker involved in routine maintenance activities in close proximity to Building 3515. The worker is assumed to spend 2 hours near the building every other month for a period of 25 years. The worker does not enter the building; therefore, external exposure is the only applicable exposure route. The worker is exposed from each of the external walls of the building and from the subsurface contamination located beneath the exterior floor slab (pad).

The total ILCR for the maintenance worker is 3.0E-4 (Table 5.1); this value is above the EPA's range of acceptable risk but below the radiation protection limit of 5 rem per year, which corresponds to a lifetime risk of 5.0E-2 for 25 years of exposure. The risk to the maintenance worker is also below the ORNL worker radiation limit of 1.5 rem per year, corresponding to a lifetime risk of 6.0E-3.

External exposures from the building walls, which have been averaged to account for the amount of time spent by the worker near each wall (i.e., 30 minutes near each wall), are similar in magnitude. It should be noted that all but one field measurement taken from outside the building were below background radiation levels for that particular area of the plant. Exposures from the contaminated soil under the pad were assumed to be reduced by the shielding effects of the overlying concrete pad which is approximately 61 cm thick. This provides almost complete shielding (99 %). The level of contamination in the soil, however, is high enough to produce measurable ILCRs (1.5E-5).

It is likely that most of the ILCR for the worker is attributable to high concentration of

cesium-137 in the walls and soil. This assumption is consistent with the description of previous uses of Building 3515 and with contaminant-specific analyses of collected samples.

Table 5.1. ILCRs to the maintenance worker associated with the current land use scenario

Exposure Route	ILCRs
Exterior Bldg (E)	6.2E-5
Exterior Bldg (N)	6.2E-5
Exterior Bldg (S)	6.2E-5
Exterior Bldg (W)	9.4E-5
Soil Beneath Exterior Pad	1.5E-5
TOTAL	3.0E-4

E = East Wall
N = North Wall
S = South Wall
W = West Wall

5.1.2 Noncarcinogenic Effects

No potential exposures to chemical noncarcinogens are known for the maintenance worker scenario. Noncarcinogens were detected in the paint chip samples taken from inside the south cell, but the worker is assumed not to enter the building. Noncarcinogens in the soil beneath the exterior pad are, similarly, unaccessible to the worker.

5.2 FUTURE LAND USE

The following sections present the results of the risk characterization for the future land use conditions. Receptors considered for the future land use condition include off-site residents located at White Oak Creek and White Oak Dam and an adult intruder who enters both the north and south cells of Building 3515. The residential scenarios involve two types of potential releases. The first release scenario involves a catastrophic event (e.g., earthquake, tornado) which destroys the building structure all at once. The second scenario involves a chronic release resulting from the slow degradation and deterioration of the building and exterior floor pad over an extended period of time.

5.2.1 Excess Cancer Risks (ILCRs)

5.2.1.1 Intruder

The excess cancer risks associated with the hypothetical intruder scenario are summarized in Table 5.2. A table of all the results for this scenario can be found in Appendix F. The total ILCR for the intruder is 6.2E-2, which is well above the EPA level of concern. This ILCR also exceeds the public radiation protection limit of 1 rem per year which corresponds to a lifetime risk of 4.0E-3.

The intruder represents a conservative scenario in which an adult enters Building 3515 for five

1-hour periods over the course of a year. The intruder is assumed to spend an equal amount of time in both the north and south cells of the building and is potentially exposed by the incidental ingestion, dermal exposure to chemicals, inhalation of dust, and external exposure to radionuclides pathways.

As shown in Table 5.2, the driving exposure pathway is external exposure to radionuclides, primarily in the north cell. External exposures were estimated using TLD measurements taken from inside the cells. The TLDs were placed approximately 1 ft apart on a long pole which was inserted into the cells from the outside of the building. The external exposures are suspected to be attributable to high concentrations of cesium-137 located inside Building 3515. Contamination is present on the floors, walls, ceilings, and equipment surfaces. It is suspected, but not known, that cesium-137 is also contained inside the process equipment. Samples were not taken from inside the equipment. However, all sources of cesium-137 are assumed to be accounted for in the TLD measurements.

Radionuclide exposures for the ingestion and inhalation pathways were estimated using exposure concentrations extrapolated from smear data. The smear samples were assumed to be representative of the entire surface area of the walls, ceilings, and floors of the cells. Because the smear data came from the floor, which is suspected to have the highest amount of contamination, the extrapolated exposure concentrations are likely to be conservative (i.e., most protective of human health).

Risks due to carcinogenic chemicals (2.8E-11) are well below the EPA's range of concern. Beryllium presents an ILCR of 2.4E-11 from dermal exposure (refer to Appendix F). Exposure concentrations for carcinogenic chemicals were derived from chemical concentrations in a paint chip sample taken from the south cell doorway. No paint chip samples (or other appropriate samples) were taken from the north cell. Therefore, the concentrations in the south cell sample were assumed to be representative of the entire building interior.

5.2.1.2 Off-site residents—catastrophic release

The estimated risks for the off-site residents under the catastrophic release scenario are presented in Table 5.3. A table of all results for this scenario can be found in Appendix F. Total ILCRs are 6.2E-1 and 5.9E-1 for the White Oak Creek and White Oak Dam residents, respectively.

The catastrophic event results in three mechanisms of contaminant transport in the environment: air, overland, and groundwater. Risks due to air inhalation are negligible for both the White Oak Creek and White Oak Dam residents (risk < 2.0E-14). The air transport pathway also results in external exposure from the contaminated cloud. The duration of exposure to the cloud is assumed to be limited to 48 hours due to the acute nature of the contamination release, and the resulting risks from external exposures are below the EPA range of concern.

The most significant exposure pathway for both receptors is the ingestion of vegetables grown and irrigated with the contaminated surface water, which poses a risk of 6.2E-1 and 5.9E-1 to White Oak Creek and White Oak Dam residents, respectively. The driving contaminants are cesium-137 and strontium-90 which pose ILCRs of 3.7E-1 and 3.9E-1, respectively, to the White Oak Creek resident, and ILCRs of 3.6E-1 and 3.7E-1, respectively, to the White Oak Dam resident. Contaminant-specific risks for both the White Oak Creek and White Oak Dam residents are presented in Appendix F.

Table 5.2. ILCRs and HIs to the intruder associated with the future land use scenario

Exposure Route	ILCRs and HIs		
	Radionuclides (ILCR)	Carcinogenic Chemicals (ILCR)	Noncarcin-ogenic Chemicals (HI)
Ingestion of Particulates (N)	2.1E-6	-	-
Ingestion of Particulates (S)	9.3E-5	3.8E-12	3.6E-5
Dermal Contact (S)	-	2.4E-11	4.6E-5
Inhalation of Particulates (N)	1.2E-10	-	-
Inhalation of Particulates (S)	1.1E-8	1.8E-13	1.2E-6
External (N)	5.5E-2	-	-
External (S)	7.1E-3	-	-
TOTAL (N)	5.5E-2	-	-
TOTAL (S)	7.2E-3	2.8E-11	8.3E-5
TOTAL	6.2E-2	2.8E-11	4.9E-5

N = North Cell
S = South Cell

Table 5.3. ILCRs to residents associated with the future catastrophic release scenario[a]

Exposure Route	ILCRs to Resident at:	
	White Oak Creek	White Oak Dam
Ingestion of Water	1.7E-4	1.6E-4
Ingestion of Veg.	6.2E-1	5.9E-1
Inhalation of Water	3.7E-14	3.5E-14
Inhalation of Air	1.2E-14	4.2E-16
External	2.0E-7	7.0E-9
TOTAL	6.2E-1	5.9E-1

[a] assumes 100% release of contaminant inventory.

Ingestion of contaminated vegetables represents a relatively conservative exposure pathway when the resident is assumed to be self-sufficient (i.e, a subsistence farmer), as was the case in this risk assessment. The resident is assumed to get his entire dietary intake of fruits and vegetables from plants grown and irrigated with contaminated surface water.

A more reasonable scenario for evaluating risk is the consumption of surface water used for drinking water. This exposure pathway poses risks of 1.7E-4 and 1.6E-4 to White Oak Creek and White Oak Dam residents, respectively, and are just above the EPA's range of concern. The ingestion and inhalation of water exposure pathways are attributable to the contaminated surface

water that results from the discharge of contaminated groundwater and overland runoff coming from the point of the release. Most of the surface water contamination results from the discharge of overland runoff because a greater proportion of surface soil contamination is assumed to migrate through the stormflow zone (i.e., overland) than through the saturated zone (i.e., groundwater). It is expected that the White Oak Creek resident risks would be slightly higher than the White Oak Dam resident risks due to the closer proximity of the White Oak Creek resident to Building 3515.

It should be noted that the risks presented in Table 5.3 represent consequences if the catastrophic event occurred but do not include the probability of the catastrophic event actually occurring. The likelihood of an event capable of destroying Building 3515 and releasing all of its contamination is very low given the nature of the building structure. Previous investigations have suggested that the annual frequency of a severe earthquake at the ORR would be 4.0E-8. The suggested annual frequency of a severe tornado would be 4.0E-10 (Benedict 1993). The risk associated with an event is equal to the product of the risk (e.g., ILCR) if the event occurs and the probability of the event [Risk = ILCR × Probability]. Incorporating the probability of occurrence into the consequences presented in Table 5.3 would bring the ILCRs for both receptors well below the EPA's range of concern.

5.2.1.3 Off-site resident—chronic

The chronic release scenario for the off-site resident involves migration of contamination from Building 3515 and subfoundation soil resulting from the slow degradation of the building structure and of the exterior concrete pad over time. The degradation of the building and pad allows rainfall to infiltrate through structural cracks, which then allows contamination to leach into the environment (e.g., pulse releases over an extended period of time). The estimated risks for the off-site residents under the chronic release from the building scenario are presented in Table 5.4. Estimated risks for the chronic release from soil beneath the pad scenario are presented in Table 5.5. A complete table of results for these scenarios can be found in Appendix F.

Table 5.4. ILCRs to residents associated with the future chronic building release scenario[a]

Exposure Route	ILCRs to Resident at:	
	White Oak Creek	White Oak Dam
Ingestion of Water	8.6E-6	8.1E-6
Ingestion of Veg.	4.8E-2	4.5E-2
Inhalation of Water	1.2E-15	1.1E-15
TOTAL	4.8E-2	4.5E-2

[a] assumes 15 yrs of inventory decay followed by pulse releases.

Table 5.5. ILCRs to residents associated with the future chronic pad release scenario[a]

Exposure Route	ILCRs for Resident at:	
	White Oak Creek	White Oak Dam
Ingestion of Water	1.8E-9	1.7E-9
Ingestion of Veg.	9.9E-6	9.4E-6
TOTAL	9.9E-6	9.4E-6

[a] assumes release of soil contaminant inventory following 30 yrs of decay.

The total ILCRs to the White Oak Creek resident from the building and pad releases are 4.8E-2 and 9.9E-6, respectively. The total ILCRs to the White Oak Dam resident from the building and pad releases are 4.5E-2 and 9.4E-6, respectively. Risks associated with both chronic release scenarios are above the EPA's level of concern. Similar to the residential risks associated with the catastrophic release scenario discussed previously, ingestion of vegetables is the driving exposure pathway for both the building and pad release scenarios; the driving contaminants are cesium-137 and strontium-90 (see Appendix F). As noted previously, the vegetable ingestion pathway is the most conservative (i.e., uses the most worst-case assumptions) pathway evaluated. The ILCRs for contaminated drinking water for the chronic building release are 8.6E-6 and 8.1E-6 for White Oak Creek and White Oak Dam residents, respectively.

5.2.2 Noncarcinogenic Effects

5.2.2.1 Intruder

Noncarcinogenic effects for the hypothetical intruder scenario are summarized in Table 5.2. A complete table of results for this scenario can be found in Appendix F. The HI associated with the intruder is 8.3E-5. This value is well below the EPA's level of concern for noncarcinogenic effects (i.e., the HI is < 1.0). It should be noted that lead was detected in the paint chip sample used to estimate intruder risks. However, no toxicity values are available for lead. The intruder was assumed to be exposed via ingestion, inhalation, and dermal contact. The driving contaminants are arsenic, antimony, and barium (see Appendix F). The controlling pathway is dermal exposure; however, noncarcinogens do not appear to represent a hazard to the intruder.

5.2.2.2 Off-site resident—catastrophic release

Noncarcinogenic effects were not considered for the off-site resident scenarios. A limited amount of data were available for estimating the total inventories of noncarcinogens in Building 3515 required for off-site modeling purposes. As discussed previously, noncarcinogenic effects were considered for the intruder scenario, and no significant His were identified. The intruder represents a reasonable worst case scenario due to the receptor's direct contact with contamination in the building; it is suspected that noncarcinogenic effects to an off-site resident would be negligible.

5.2.2.3 Off-site resident—chronic release

Noncarcinogenic effects for residents were not considered for the same reasons outlined in the previous discussion for the catastrophic release scenario.

5.3 SUMMARY OF THE RISK CHARACTERIZATION

Several of the evaluated scenarios resulted in ILCRs that exceed the range of acceptable risk set by EPA (between 1.0E-6 and 1.0E-4). Under current land use conditions, estimated excess cancer risks due to external exposures to radionuclides (specifically cesium-137) are above the EPA's range of acceptable risk for the maintenance worker. It should be noted, however, that current radiation protection standards for workers include a limit of 5 rem for the annual effective dose equivalent. Moreover, ORNL has imposed an annual limit of 1.5 rem. A 5 rem annual dose equates to a 25-year lifetime risk corresponding to 2.0E-2. The worker was only assumed to be in close proximity to the building and pad for 2 hours every other month over a period of 25 years for which measured exposure rates were available. The magnitude of the risk associated with the scenario attests to the high contamination levels present at Building 3515 but also to the conservatism used in deriving exposure concentrations from limited data sampling.

Excess cancer risks due to external exposures to radionuclides (specifically cesium-137) also exceeded the EPA's acceptable risk range for the hypothetical adult intruder under the future land use scenario. The intruder, considered a reasonable worst-case scenario in that exposures result from direct contact with contamination in Building 3515, was only assumed to be in the building for five 1-hour periods over the course of one year. For external exposures, direct field measurements (TLD string data) were available for both the north and south cells. The magnitude of the risks associated with the scenario attests to high levels of contamination in the building. Building 3515 is well sealed from intrusion by the thick concrete walls and roof. Therefore, it is unlikely that an intruder would gain access to the building. However, future degradation of the building, if the facility is abandoned, could make this scenario possible.

Excess cancer risks to the off-site residents are above the EPA's range of acceptable risk for both the catastrophic and chronic building release scenarios. For all residential scenarios, the major contributing pathway to risk is the ingestion of contaminated vegetables (due to cesium-137 and strontium-90). Risks associated with the catastrophic event should be taken in context with the probability of such an event occurring (approximately 4.0E-8 annual frequency). The future residential receptors are located far enough from Building 3515 that contamination concentrations are significantly reduced due to dispersion in the air, overland runoff, and groundwater. In addition, the time required for contamination at the building to reach off-site receptors, particularly via groundwater, is of sufficient length to allow for some radioactive decay. The fact that off-site residential risks are still above levels of concern for the chronic release scenario suggests that further action may be necessary at Building 3515.

Hazards due to noncarcinogenic chemicals do not appear to be a significant human health problem at Building 3515. Noncarcinogenic hazards were addressed only for the conservative intruder scenario and were found not to be of concern (total HI = 4.9E-5 and is less than the EPA unacceptable HI of 1.0). It can be assumed that noncarcinogens would, therefore, not pose a risk to off-site receptors.

5.4 EVALUATION OF UNCERTAINTY

Risk evaluation as a scientific activity is subject to uncertainty with regard to both risk evaluations in general and site-specific risk evaluations. A risk evaluation is an integrated evaluation of historical, contaminant, analytical, environmental, demographic, and toxicological data that are as site-specific as possible. All of the uncertainties associated with each step of the risk evaluation process impact the risk characterization. Of particular importance for this BRA was the limited amount of sampling data, which required some samples to be assumed representative for the entire building. A complete discussion of uncertainties associated with the data is given in Sect. 2.4.

The toxicological parameters used to quantify potential risk to a receptor include SFs for carcinogens and RfDs for noncarcinogenic chemicals. These values are generally derived from laboratory animal studies. The overriding uncertainties associated with the use of laboratory animal studies are:

- the extrapolation of toxic effects observed at the high doses necessary to conduct animal studies and the high doses used to estimate radiation effects (e.g., from nuclear bombs) to predict effects that might occur at the much lower, relevant doses and

- the extrapolation from toxic effects in animals to toxic effects in man (i.e., responses of animals may be different from responses of man).

The risk of increased incidence of cancer from exposure to low-level radiation is estimated by applying a risk factor to either the radiation dose or the radionuclide intake. Regardless of the type of risk factor used, the same basic uncertainties remain. The uncertainties are related to the model used for determining the health effects of radiation exposure.

The model most frequently used for determining risk of radiation exposure is the linear nonthreshold model. This model assumes that there is some increased risk for any increment of radiation exposure, there being no threshold below which effects are not seen. This is the most conservative model for evaluating radiation risk. It uses data from high dose radiation exposures (such as from the survivors of the atomic bomb) and extrapolates risk from these high exposures to the low-level environment or occupational dose range. A complete discussion of the uncertainties associated with the toxicity data is provided in Chapter 4.

5.4.1 Assumptions

The major assumptions used in this assessment and which contribute to the uncertainty in the risk characterization are:

- contaminant concentrations remain constant over the exposure period;

- the building will be allowed to decay in place without decontamination activities being performed;

- most of the contamination at the facility is able to travel overland as runoff during storm events to surface water;

- selected intake rates and population characteristics (weight, lifespan, vegetable and drinking water sources and intakes, and other activities) are representative of the potentially exposed populations;

- all intake of contaminants is from site-related exposure media, and no other sources contribute to the receptor's health risk; and

- chemical concentrations identified in a small number of samples (often 1 sample) were assumed to be representative of the entire surface area of the walls, ceiling, and floor.

5.5 CONCLUSIONS

The results of the Level 3 BRA for Building 3515 indicate that short-term on-site exposures resulting from contaminated media inside the building pose a potential human health risk. Estimated risks to a potential maintenance worker outside the facility exceed the EPA's target risk range; however, they are below the ORNL worker radiation limit. While it is unlikely that adult intruder exposures will ever occur at this facility, these exposures were evaluated to provide an upperbound estimate of the potential human health risks. The high levels of contamination indicate that D&D activities will need to be performed remotely to ensure the safety of D&D workers. Health risks to off-site residential receptors from exposures to contaminants released under both acute (catastrophic) and chronic scenarios are also above the levels of concern as set by EPA. Based on the results of this risk assessment, the COCs at Building 3515 are cesium-137 and strontium-90.

To minimize the effects of uncertainties in the evaluation, each step is biased toward health-protective estimations. Because each step builds on the previous one, this biased approach should more than compensate for risk evaluation uncertainties. These calculations do not represent currently existing or expected future exposure or health risks. Rather, they are estimates of potential risks only if all of the conservative assumptions are realized.

To place the results presented in this risk assessment into perspective, one might consider the probability of an individual's developing cancer from unavoidable exposure to naturally occurring background radiation. The lifetime risk of cancer incidence from background radiation in the general population is approximately 1.0E-2 (Energy Systems 1993). This value is 100 times greater than the upperbound (1.0E-4) of EPA's target risk range. In addition, Table 5.6 lists activities that increase the chance of cancer fatality by 1.0E-6. The reader should note that these values are for **fatal** cancers, not the **incidence** of cancer.

Table 5.6. Risks that increase the chance of death by one part in one million (1.0E-6)[a]

Activity	Cause of death
Smoking 1.4 cigarettes	Cancer, heart disease
Flying 6000 miles by jet	Cancer caused by cosmic radiation
Living 2 months in average stone or brick building	Cancer from natural radioactivity
Eating 40 tablespoons of peanut butter	Liver cancer caused by aflatoxin B

[a] Taken from Wilson, 1979

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Appendix A

DERIVATION OF CONCRETE PAD SHIELDING FACTOR

A. DERIVATION OF CONCRETE PAD SHIELDING FACTOR

1. Shielding Factor Equation

$$\text{Shielding Factor} = 1 - (\Gamma/\Gamma_0) = 1 - (B * e^{-\mu x})$$

Where:

Γ = exposure rate at a given distance with shielding considered
Γ_0 = exposure rate at a given distance with no shielding considered
B = 31.56 (buildup factor, which is a characteristic of the shielding material) (Turner 1984)
μ = 1.833E-1 cm^{-1} (attenuation factor) (Turner 1984)
x = 61 cm (thickness of the shielding layer)

Thus,

$$\text{Shielding Factor for the Pad} = 1 - (\Gamma/\Gamma_0) = 1 - (31.56 * e^{-(0.1833 * 61)}) = 1 - 0.00044 = 0.99956$$

Appendix B

SMEAR DATA CONVERSIONS

B. SMEAR DATA CONVERSIONS

South Cell

Cell Volume = 5.05E6 cm^3
Cell Surface Area = 1.85E5 cm^2
Density of Concrete = 2.4 g/cm^3
Depth of Transferable Contamination = 0.1 cm
Cs-137 smear = 2.59E4 pCi/20 cm^2
Sr-90 smear = 3.13E4 pCi/20 cm^2

Transferable Cs-137 = Smear (pCi/20 cm^2) x Surface Area (cm^2) = 2.4E8 pCi
Transferable Sr-90 = Smear (pCi/20 cm^2) x Surface Area (cm^2) = 2.9E8 pCi

Dust Volume = Surface Area (cm^2) x Depth (cm) = 1.8E4 cm^3

Amount of Concrete Dust = Dust Volume (cm^3) x Concrete Density (g/cm^3) = 4.4E4 g

[Cs-137] = Transferable Cs-137 (pCi) / Amount of Dust (g) = 5.4E3 pCi/g

[Sr-90] = Transferable Sr-90 (pCi) / Amount of Dust (g) = 6.5E3 pCi/g

North Cell

Cell Volume = 2.83E7 cm^3
Cell Surface Area = 5.57E5 cm^2
Density of Concrete = 2.4 g/cm^3
Depth of Transferable Contamination = 0.1 cm
Cs-137 smear = 6.53E3 pCi/100 cm^2

Transferable Cs-137 = Smear (pCi/100 cm^2) x Surface Area (cm^2) = 3.64E7 pCi

Dust Volume = Surface Area (cm^2) x Depth (cm) = 5.57E4 cm^3

Amount of Concrete Dust = Dust Volume (cm^3) x Concrete Density (g/cm^3) = 1.34E5 g

[Cs-137] = Transferable Cs-137 (3.64E7 pCi) / Amount of Dust (g) = 2.7E2 pCi/g

Appendix C

MODELS

C. MODELS

MEPAS MODEL

The Multimedia Pollutant Assessment System (MEPAS) is a screening level fate and transport model commonly used in modeling the migration of environmental pollutants. It simulates one dimensional plug flow with longitudinal dispersion for transport through the vadose zone(s) and three dimensional groundwater dispersion in the aquifer.

An average annual infiltration rate is calculated from climatological inputs (see Table C.1) using a modified Blaney-Criddle method. One- and three-dimensional solutions to the advective-dispersive equation are used to calculate flux rates through the discrete vadose and saturated zones. Advection represents the transport of solute caused by the mass motion of water, and dispersion represents solute transport by unaccounted variations in the fluid velocity and molecular motion. Dispersion is considered in the longitudinal, lateral, and vertical directions. Aquifer properties are assumed to be homogenous, and the flow is assumed to be in the longitudinal direction. Radionuclide daughter products are assumed to be transported at the same rate as the parent.

Input parameters used to model the fate and transport of contaminants released from Building 3515 are given in Table C.2. MEPAS outputs, which constituted surface water concentrations for this BRA, are geared towards risk assessments, giving average concentrations for one hundred 70-year lifetimes.

Table C.1. Climatological data for Building 3515

Month	Avg. Temperature (F)	Avg. Rainfall (inches)	Avg. Windspeed (mph)	Cloudiness (tenths)	Thunderstorms (#/month)
January	36	5.25	3.8	6.7	12.4
February	42	4.60	4.0	6.5	11.4
March	50	6.21	4.3	6.5	12.6
April	58	4.41	4.3	5.9	10.8
May	65	4.23	3.8	5.9	10.7
June	73	4.26	3.3	5.5	10.3
July	77	5.21	3.1	5.8	11.9
August	75	3.75	2.9	5.5	10.4
September	69	3.80	2.9	5.6	8.3
October	57	2.89	3.0	5.0	7.9
November	48	4.50	3.4	6.1	10.1
December	39	5.65	3.5	6.5	10.9

Table C.2. Fate and transport model input parameters

Parameter	Units	Top-Soil	Vadose Zone I	Vadose Zone II	Aquifer
Infiltration Rate	ft/day	1.5	-	-	-
Moisture Content	%	42.0	-	-	-
Bulk Density	g/cm^3	1.3	1.3	1.7	2.6
Textural Classification	none	-	Silty Loam	Sandy Loam	Clay Loam
Sand	%	-	30	60	30
Silt	%	-	50	25	40
Clay	%	-	20	15	30
Organic Matter	%	-	1.5	.30	.10
Iron and Aluminum	%	-	1.0	2.0	1.0
Soil pH	none	-	5.5	5.0	7.0
Thickness	ft	-	1.6	11.4	5.0
Total Porosity	%	-	50.0	37.0	20.0
Field Capacity	%	-	42.0	33.0	-
Long. Dispersivity	ft	-	1.0	1.0	120.0
Hydraulic Conductivity	ft/day	-	38.0	13.0	-
Effective Porosity	%	-	-	-	20.0
Darcy Velocity	ft/day	-	-	-	1.0
Travel Distance	ft	-	-	-	1200
Trans. Dispersivity	ft	-	-	-	24.0
Vertical Dispersivity	ft	-	-	-	.139

GENII MODEL

The dose to a receptor associated with an atmospheric release of radionuclides depends on the spatial and temporal distribution of the radionuclides in the environment. This distribution is a function of the way in which the material is released and of the environment between the release point and the receptor. Atmospheric releases from Building 3515 resulting from a natural disaster were simulated using the GENII environmental fate and transport model.

The GENII code uses a selection of straight-line Gaussian-plume models to estimate air concentrations at specified receptor locations. The code requires data describing the frequency, speed, and stability of winds as well as information concerning the direction and distance of receptors relative to the point of release. The residential receptor at the White Oak Dam was assumed to be 9000 ft in the southwest direction from Building 3515. The resident at White Oak Creek was assumed to be 1200 ft in the south-southwest direction.

The release scenario modeled consisted of an acute release of several radionuclides from Building 3515 following a natural disaster that destroys the facility. It was assumed that 20% of the total inventory of radiological contaminants would become airborne and migrate to offsite receptor locations. The movement of airborne contaminants and subsequent atmospheric concentrations can be influenced by the roughness of terrain and by the presence of buildings in the area surrounding the point of release. The GENII model conservatively assumes that the terrain is relatively flat with uniform surface conditions in all directions. Buildings tend to "downwash" airborne contaminants resulting in lower atmospheric concentrations. The Building 3515 scenario, building downwash was conservatively assumed not to occur.

It should be noted that a natural disaster capable of destroying Building 3515 would very likely be associated with powerful and unstable winds. This would result in much greater dispersion of airborne contaminants than is estimated by the model. Thus, the modeled atmospheric concentrations used in this BRA are very conservative. The source term used to model the atmospheric release and the resulting exposure concentrations are given in Table C.3.

Table C.3. Atmospheric residential exposure concentrations modeled by GENII

Radionuclide	Release (Ci)	Concentrations (pCi/g)	
		White Oak Creek	White Oak Dam
Cs-137	1.86E+2	2.16E+1	7.66E-1
H-3	4.50E-5	5.23E-6	1.85E-7
K-40	4.98E-4	5.79E-5	2.05E-6
Pu-238	1.35E-5	1.57E-6	5.56E-8
Pu-239	1.00E-5	1.16E-6	4.12E-8
Sr-90	1.06E+2	1.23E+1	4.37E-1
Th-228	3.58E-5	4.16E-6	1.47E-7
Th-230	6.08E-5	7.07E-6	2.50E-7
Th-232	2.72E-5	3.16E-6	1.12E-7
U-234	6.68E-5	7.77E-6	2.75E-7
U-235	5.52E-6	6.42E-7	2.27E-8
U-238	8.28E-5	9.63E-6	3.41E-7

Appendix D

EXPOSURE CONCENTRATIONS AND CHRONIC DAILY INTAKE TABLES

Table D.1. Exposure concentrations and chronic daily intakes for receptor exposures

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Bldg. Accident	Air	WOC[d]	Inhalation	Radionuclides	Cs-137	2.2E+01	2.0E-04	
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	H-3	5.2E-06	4.9E-11	
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	K-40	5.8E-05	5.4E-10	
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	Pu-238	1.6E-06	1.5E-11	
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	Pu-239	1.2E-06	1.1E-11	
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	Sr-90	1.2E+01	1.1E-04	
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	Th-228	4.2E-06	3.9E-11	
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	Th-230	7.1E-06	6.6E-11	
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	Th-232	3.2E-06	3.0E-11	
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	U-234	7.8E-06	7.3E-11	
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	U-235	6.4E-07	6.0E-12	
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	U-238	9.6E-06	9.0E-11	
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Cs-137	2.2E+01	9.5E-02	
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	H-3	5.2E-06	2.3E-08	
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	K-40	5.8E-05	2.5E-07	
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Pu-238	1.6E-06	6.9E-09	
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Pu-239	1.2E-06	5.1E-09	
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Sr-90	1.2E+01	5.4E-02	
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Th-228	4.2E-06	1.8E-08	
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Th-230	7.1E-06	3.1E-08	

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Th-232	3.2E-06	1.4E-08	
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	U-234	7.8E-06	3.4E-08	
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	U-235	6.4E-07	2.8E-09	
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	U-238	9.6E-06	4.2E-08	
Resident	Bldg. Accident	Air	WOD[e]	Inhalation	Radionuclides	Cs-137	7.7E-01	7.2E-06	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	H-3	1.9E-07	1.7E-12	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	K-40	2.1E-06	1.9E-11	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Pu-238	5.6E-08	5.2E-13	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Pu-239	4.1E-08	3.8E-13	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Sr-90	4.4E-01	4.1E-06	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Th-228	1.5E-07	1.4E-12	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Th-230	2.5E-07	2.3E-12	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Th-232	1.1E-07	1.0E-12	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	U-234	2.8E-07	2.6E-12	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	U-235	2.3E-08	2.1E-13	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	U-238	3.4E-07	3.2E-12	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Cs-137	7.7E-01	3.4E-03	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	H-3	1.9E-07	8.1E-10	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	K-40	2.1E-06	9.0E-09	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Pu-238	5.6E-08	2.4E-10	

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Th-232	3.2E-06	1.4E-08	
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	U-234	7.8E-06	3.4E-08	
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	U-235	6.4E-07	2.8E-09	
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	U-238	9.6E-06	4.2E-08	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Cs-137	7.7E-01	7.2E-06	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	H-3	1.9E-07	1.7E-12	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	K-40	2.1E-06	1.9E-11	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Pu-238	5.6E-08	5.2E-13	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Pu-239	4.1E-08	3.8E-13	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Sr-90	4.4E-01	4.1E-06	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Th-228	1.5E-07	1.4E-12	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Th-230	2.5E-07	2.3E-12	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Th-232	1.1E-07	1.0E-12	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	U-234	2.8E-07	2.6E-12	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	U-235	2.3E-08	2.1E-13	
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	U-238	3.4E-07	3.2E-12	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Cs-137	7.7E-01	3.4E-03	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	H-3	1.9E-07	8.1E-10	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	K-40	2.1E-06	9.0E-09	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Pu-238	5.6E-08	2.4E-10	

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Pu-239	4.1E-08	1.8E-10	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Sr-90	4.4E-01	1.9E-03	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Th-228	1.5E-07	6.4E-10	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Th-230	2.5E-07	1.1E-09	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Th-232	1.1E-07	4.9E-10	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	U-234	2.8E-07	1.2E-09	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	U-235	2.3E-08	1.0E-10	
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	U-238	3.4E-07	1.5E-09	
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	Cs-137	1.3E+02	2.7E+06	
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	H-3	2.1E-04	4.4E+00	
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	K-40	2.1E-03	4.3E+01	
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	Pu-238	1.1E-05	2.4E-01	
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	Pu-239	1.0E-05	2.2E-01	
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	Sr-90	7.2E+01	1.5E+06	
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	Th-228	2.2E-05	4.7E-01	
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	Th-230	6.3E-05	1.3E+00	
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	Th-232	2.8E-05	6.0E-01	
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	U-234	7.0E-05	1.5E+00	
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	U-235	5.8E-06	1.2E-01	
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	U-238	4.8E-04	1.0E+01	

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	Cs-137	1.3E+02	1.5E+10	
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	H-3	2.1E-04	2.4E+04	
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	K-40	2.1E-03	2.5E+05	
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	Pu-238	1.1E-05	1.3E+03	
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	Pu-239	1.0E-05	1.2E+03	
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	Sr-90	7.2E+01	8.7E+09	
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	Th-228	2.2E-05	2.6E+03	
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	Th-230	6.3E-05	7.4E+03	
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	Th-232	2.8E-05	3.3E+03	
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	U-234	7.0E-05	8.1E+03	
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	U-235	5.8E-06	6.7E+02	
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	U-238	4.8E-04	5.6E+04	
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	Cs-137	1.3E+02		
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	H-3	2.1E-04	3.9E-01	
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	K-40	2.1E-03		
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	Pu-238	1.1E-05		
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	Pu-239	1.0E-05		
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	Sr-90	7.2E+01		
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	Th-228	2.2E-05		
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	Th-230	6.3E-05		

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	Th-232	2.8E-05		
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	U-234	7.0E-05		
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	U-235	5.8E-06		
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	U-238	4.8E-04		
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	Cs-137	6.5E+00	1.4E+05	
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	H-3	6.5E-06	1.4E-01	
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	K-40	1.5E-04	3.2E+00	
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	Pu-238	7.3E-07	1.5E-02	
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	Pu-239	7.6E-07	1.6E-02	
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	Sr-90	3.6E+00	7.6E+04	
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	Th-228	9.5E-07	2.0E-02	
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	Th-230	4.6E-06	9.7E-02	
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	Th-232	2.1E-06	4.3E-02	
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	U-234	5.1E-06	1.1E-01	
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	U-235	4.2E-07	8.8E-03	
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	U-238	5.0E-05	1.1E+00	
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	Cs-137	6.5E+00	7.6E+08	
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	H-3	6.5E-06	7.6E+02	
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	K-40	1.5E-04	1.8E+04	
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	Pu-238	7.3E-07	8.5E+01	

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	Pu-239	7.6E-07	8.8E+01	
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	Sr-90	3.6E+00	4.4E+08	
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	Th-228	9.5E-07	1.1E+02	
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	Th-230	4.6E-06	5.4E+02	
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	Th-232	2.1E-06	2.4E+02	
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	U-234	5.1E-06	5.9E+02	
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	U-235	4.2E-07	4.9E+01	
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	U-238	5.0E-05	5.9E+03	
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	Cs-137	6.5E+00		
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	H-3	6.5E-06	1.2E-02	
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	K-40	1.5E-04		
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	Pu-238	7.3E-07		
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	Pu-239	7.6E-07		
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	Sr-90	3.6E+00		
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	Th-228	9.5E-07		
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	Th-230	4.6E-06		
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	Th-232	2.1E-06		
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	U-234	5.1E-06		
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	U-235	4.2E-07		
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	U-238	5.0E-05		

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Am-241	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Cs-137	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	H-3	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Pu-238	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Pu-239	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Sr-90	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Th-228	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Th-230	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Th-232	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	U-234	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	U-235	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	U-238	1.4E-03	2.9E+01	
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Am-241	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Cs-137	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	H-3	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Pu-238	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Pu-239	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Sr-90	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Th-228	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Th-230	0.00	0.00	

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Th-232	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	U-234	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	U-235	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	U-238	1.4E-03	1.6E+05	
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Am-241	0.00		
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Cs-137	0.00		
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	H-3	0.00	0.00	
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Pu-238	0.00		
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Pu-239	0.00		
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Sr-90	0.00		
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Th-228	0.00		
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Th-230	0.00		
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Th-232	0.00		
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	U-234	0.00		
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	U-235	0.00		
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	U-238	1.4E-03		
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	Cs-137	1.2E+02	2.5E+06	
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	H-3	2.0E-04	4.2E+00	
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	K-40	2.0E-03	4.1E+01	
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	Pu-238	1.1E-05	2.2E-01	

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	Pu-239	9.8E-06	2.1E-01	
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	Sr-90	6.8E+01	1.4E+06	
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	Th-228	2.1E-05	4.4E-01	
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	Th-230	6.0E-05	1.3E+00	
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	Th-232	2.7E-05	5.6E-01	
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	U-234	6.6E-05	1.4E+00	
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	U-235	5.4E-06	1.1E-01	
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	U-238	4.6E-04	9.6E+00	
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	Cs-137	1.2E+02	1.4E+10	
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	H-3	2.0E-04	2.3E+04	
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	K-40	2.0E-03	2.4E+05	
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	Pu-238	1.1E-05	1.2E+03	
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	Pu-239	9.8E-06	1.1E+03	
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	Sr-90	6.8E+01	8.2E+09	
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	Th-228	2.1E-05	2.4E+03	
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	Th-230	6.0E-05	7.0E+03	
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	Th-232	2.7E-05	3.1E+03	
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	U-234	6.6E-05	7.6E+03	
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	U-235	5.4E-06	6.3E+02	
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	U-238	4.6E-04	5.3E+04	

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	Cs-137	1.2E+02		
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	H-3	2.0E-04	3.7E-01	
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	K-40	2.0E-03		
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	Pu-238	1.1E-05		
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	Pu-239	9.8E-06		
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	Sr-90	6.8E+01		
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	Th-228	2.1E-05		
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	Th-230	6.0E-05		
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	Th-232	2.7E-05		
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	U-234	6.6E-05		
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	U-235	5.4E-06		
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	U-238	4.6E-04		
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	Cs-137	6.2E+00	1.3E+05	
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	H-3	6.2E-06	1.3E-01	
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	K-40	1.4E-04	3.0E+00	
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	Pu-238	6.9E-07	1.4E-02	
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	Pu-239	7.1E-07	1.5E-02	
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	Sr-90	3.4E+00	7.2E+04	
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	Th-228	8.1E-07	1.9E-02	
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	Th-230	4.3E-06	9.1E-02	

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	Th-232	1.9E-06	4.1E-02	
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	U-234	4.8E-06	1.0E-01	
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	U-235	3.9E-07	8.3E-03	
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	U-238	4.8E-05	1.0E+00	
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	Cs-137	6.2E+00	7.2E+08	
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	H-3	6.2E-06	7.2E+02	
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	K-40	1.4E-04	1.8E+04	
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	Pu-238	6.9E-07	8.0E+01	
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	Pu-239	7.1E-07	8.3E+01	
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	Sr-90	3.4E+00	4.1E+08	
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	Th-228	8.9E-07	1.0E+02	
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	Th-230	4.3E-06	5.0E+02	
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	Th-232	1.9E-06	2.3E+02	
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	U-234	4.8E-06	5.6E+02	
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	U-235	3.9E-07	4.6E+01	
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	U-238	4.8E-05	5.6E+03	
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	Cs-137	6.2E+00		
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	H-3	6.2E-06	1.1E-02	
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	K-40	1.4E-04		
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	Pu-238	6.9E-07		

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	Pu-239	7.1E-07		
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	Sr-90	3.4E+00		
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	Th-228	8.9E-07		
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	Th-230	4.3E-06		
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	Th-232	1.9E-06		
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	U-234	4.8E-06		
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	U-235	3.9E-07		
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	U-238	4.8E-05		
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Am-241	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Cs-137	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	H-3	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Pu-238	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Pu-239	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Sr-90	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Th-228	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Th-230	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Th-232	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	U-234	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	U-235	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	U-238	1.3E-03	2.7E+01	

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Am-241	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Cs-137	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	H-3	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Pu-238	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Pu-239	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Sr-90	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Th-228	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Th-230	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Th-232	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	U-234	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	U-235	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	U-238	1.3E-03	1.5E+05	
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Am-241	0.00		
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Cs-137	0.00		
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	H-3	0.00	0.00	
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Pu-238	0.00		
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Pu-239	0.00		
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Sr-90	0.00		
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Th-228	0.00		
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Th-230	0.00		

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Th-232	0.00		
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	U-234	0.00		
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	U-235	0.00		
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	U-238	1.3E-03		
Intruder	Bldg. Chronic	Debris	North	Ingestion	Radionuclides	Cs-137	2.7E+02	6.8E+04	
Intruder	Bldg. Chronic	Debris	North	Inhalation	Radionuclides	Cs-137	2.7E+02	6.3E+00	
Intruder	Bldg. Chronic	Debris	North	External (deep)	Radionuclides	TLD string	7.7E+03	3.9E+04	
Intruder	Bldg. Chronic	Debris	North	External (shallow)	Radionuclides	TLD string	7.9E+03	4.0E+04	
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Aluminum	1.4E+04	8.3E-08	5.8E-06
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Antimony	6.1E+00	3.6E-11	2.5E-09
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Arsenic	2.4E+00	1.4E-11	9.8E-10
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Barium	4.3E+03	2.5E-08	1.8E-06
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Beryllium	1.5E-01	8.7E-13	6.1E-11
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Cadmium	2.6E-01	1.5E-12	1.1E-10
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Chromium (III)	5.3E+00	3.1E-11	2.2E-09
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Chromium (IV)	5.3E+00	3.1E-11	2.2E-09
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Cobalt	1.9E+01	1.1E-10	7.7E-09
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Lead	1.6E+02	9.2E-10	6.4E-08
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Manganese	3.5E+01	2.0E-10	1.4E-08

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Nickel	4.8E+00	2.8E-11	2.0E-09
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Selenium	1.4E+00	8.2E-12	5.7E-10
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Silver	6.0E-01	3.5E-12	2.4E-10
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Thallium	1.8E-01	1.0E-12	7.3E-11
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Vanadium	2.8E+00	1.6E-11	1.1E-09
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Zinc	1.0E+02	6.0E-10	4.2E-08
Intruder	Bldg. Chronic	Debris	South	Ingestion	Radionuclides	Cs-137	2.7E+02	6.8E+04	
Intruder	Bldg. Chronic	Debris	South	Ingestion	Radionuclides	Sr-90	6.5E+03	1.6E+06	
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Aluminum	1.4E+04	5.3E-09	3.7E-07
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Antimony	6.1E+00	2.2E-12	1.6E-10
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Arsenic	2.4E+00	8.8E-13	6.2E-11
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Barium	4.3E+03	1.6E-09	1.1E-07
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Beryllium	1.5E-01	5.5E-14	3.9E-12
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Cadmium	2.6E-01	9.6E-14	6.7E-12
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Chromium (III)	5.3E+00	2.0E-12	1.4E-10
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Chromium (IV)	5.3E+00	2.0E-12	1.4E-10
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Cobalt	1.9E+01	7.0E-12	4.9E-10
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Lead	1.6E+02	5.8E-11	4.1E-09
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Manganese	3.5E+01	1.3E-11	8.9E-10
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Nickel	4.8E+00	1.8E-12	1.2E-10

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Selenium	1.4E+00	5.2E-13	3.6E-11
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Silver	6.0E-01	2.2E-13	1.5E-11
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Thallium	1.8E-01	6.6E-14	4.6E-12
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Vanadium	2.8E+00	1.0E-12	7.2E-11
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Zinc	1.0E+02	3.8E-11	2.7E-09
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Aluminum	1.4E+04		
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Antimony	6.1E+00	3.3E-15	2.3E-13
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Arsenic	2.4E+00	1.3E-15	9.1E-14
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Barium	4.3E+03	2.3E-12	1.6E-10
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Beryllium	1.5E-01	8.2E-17	5.7E-15
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Cadmium	2.6E-01	1.4E-16	9.9E-15
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Chromium (III)	5.3E+00	2.9E-15	2.0E-13
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Chromium (IV)	5.3E+00	2.9E-15	2.0E-13
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Cobalt	1.9E+01		
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Lead	1.6E+02	8.6E-14	6.0E-12
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Manganese	3.5E+01	1.9E-14	1.3E-12
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Nickel	4.8E+00	2.6E-15	1.8E-13
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Selenium	1.4E+00	7.6E-16	5.3E-14
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Silver	6.0E-01	3.3E-16	2.3E-14
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Thallium	1.8E-01		

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Vanadium	2.8E+00	1.5E-15	1.1E-13
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Zinc	1.0E+02	5.6E-14	3.9E-12
Intruder	Bldg. Chronic	Debris	South	Inhalation	Radionuclides	Cs-137	2.7E+02	6.3E+00	
Intruder	Bldg. Chronic	Debris	South	Inhalation	Radionuclides	Sr-90	6.5E+03	1.5E+02	
Intruder	Bldg. Chronic	Debris	South	External (deep)	Radionuclides	TLD string	3.6E+02	1.8E+03	
Intruder	Bldg. Chronic	Debris	South	External (shallow)	Radionuclides	TLD string	1.6E+03	7.9E+03	
Worker	Bldg. Chronic	Walls	East	External	Radionuclides	Meter	2.9E-01	8.6E+01	
Worker	Bldg. Chronic	Walls	North	External	Radionuclides	Meter	2.9E-01	8.6E+01	
Worker	Bldg. Chronic	Walls	South	External	Radionuclides	Meter	2.9E-01	8.6E+01	
Worker	Bldg. Chronic	Walls	West	External	Radionuclides	Meter	4.3E-01	1.3E+02	
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Am-241	3.8E+02	1.4E-03	
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Cs-137	1.3E+06	4.9E+00	
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	H-3	0.00	0.00	
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Pu-238	5.7E+00	2.1E-05	
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Pu-239	9.5E+01	3.6E-04	
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Sr-90	2.5E+05	9.6E-01	
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Th-228	5.5E+00	2.1E-05	
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Th-230	5.6E+00	2.1E-05	
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Th-232	1.1E+00	4.1E-06	

Table D.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	Exposure Concentration[a]	Chronic Daily Intake	
								Carcinogenic Effects[b]	Noncarcinogenic Effects[c]
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	U-234	1.8E+00	6.8E-06	
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	U-235	4.0E-02	1.5E-07	
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	U-238	2.4E+00	9.0E-06	

[a] Concentration units are pCi/g or mg/kg for air, soil, and debris; pCi/L for water; and mrem/hr for TLD and meter data.
[b] Units are kg•day/mg for chemicals and pCi or mrem for radionuclides.
[c] Units are kg•day/mg.
[d] White Oak Creek.
[e] White Oak Dam.

Appendix E

TOXICITY PROFILES

E. TOXICITY PROFILES

E.1 RADIONUCLIDES

Radionuclides (or radioisotopes) are unstable isotopes of a chemical element that decay or disintegrate spontaneously, emitting radiation, to achieve a more stable state. The charged particles are termed "alpha and beta radiation" and the neutral particles are termed "gamma radiation or photons." Interaction of charged particles and photons with matter will produce ionization events, which may cause living cell tissue damage. Because the deposition of energy by ionizing radiation is a random process, sufficient energy may be deposited (in a critical volume) within a cell and result in cell modification or death (ICRP 1991). In addition, ionizing radiation has sufficient energy that interactions with matter will produce an ejected electron and a positively charged ion (known as free radicals) that are highly reactive and may combine with other elements, or compounds within a cell, to produce toxins or otherwise disrupt the overall chemical balance of the cell. These free radicals can also react with deoxyribonucleic acid (DNA), causing genetic damage, cancer induction, or even cell death.

A radionuclide is characterized by its half-life, which is the time required for half of the number of atoms in a sample to decay, and by the type and energies of the radiations emitted. Radiation emissions fall into two major categories: particulate (electrons, alpha particles, beta particles or positrons) or electromagnetic radiation (gamma and x-rays) (ATSDR 1989). Some radionuclides also emit protons or neutrons, but are not of concern with the radionuclides in this evaluation. All radionuclides are classified by EPA as Group A carcinogens based on their property of emitting ionizing radiation and on the extensive weight of evidence provided by epidemiological studies of humans with cancers induced by high doses of radiation.

Alpha particles are nuclei of ^{4}He atoms and consist of two protons and two neutrons. Alpha particles are emitted mostly in the decay of radioisotopes of elements with high atomic number (e.g., uranium). The alpha particles emitted by a particular radionuclide occur at discrete energies characteristic of that radioisotope. Alpha particles have the ability to react (and/or ionize) with other molecules, but they have very little penetrating power and lack the ability to pass through a piece of paper or human skin. Therefore, external exposure is not a concern with respect to alpha particles. However, alpha-emitting radionuclides are of concern when there is a potential for inhalation or ingestion of the radionuclide. Alpha particles are directly ionizing and deposit their energy in dense concentrations [termed high linear energy transfer (high LET)], resulting in short paths of highly localized ionization reactions. The probability of cell damage increases as a result of the increase in ionization events occurring in smaller areas; this may also be the reason for increased cancer incidence caused by inhalation of radon gas. In addition, the cancer incidence in smokers may be directly attributed to the naturally occurring alpha emitter, polonium-210, common in tobacco products.

Beta emissions usually refer to the continuous spectrum of negative electrons emitted in beta decay, but some radionuclides also decay by positron emission resulting in a continuous spectrum of positively charges electrons. Beta or positron radiation, like alpha radiation, is directly ionizing but, unlike alpha activity, deposit their energy along a longer track length (low-LET), resulting in more space between ionization events. Beta-emitting radionuclides can cause injury to the skin and superficial body tissue but are most destructive when inhaled or ingested. Many beta emitters are similar chemically to naturally occurring essential nutrients and will therefore tend to accumulate in specific tissues. For example, strontium-90 is chemically similar to calcium and, as a result,

accumulates in the bones, where it causes continuous exposure. The health effects of alpha and beta particle emissions depend upon the target organ. Those seeking the bones would cause a prolonged exposure to the bone marrow and affect blood cell formation, possibly resulting in leukemia, other blood disorders, or bone cancers. Those seeking the liver would result in liver diseases or cancer, while those seeking the thyroid would cause thyroid and metabolic disorders. In addition, beta radiation may lead to damage of genetic material (DNA), causing hereditary defects (BEIAS Toxicity Profiles).

Transformation of the atomic nucleus can result in gamma emissions or x-rays. The resulting energy released have differing origins; gamma emissions are released from the atomic nucleus, whereas x-rays result from changes in the orbiting electron structure. Both external exposure (exposure to gamma radiation emitted by radionuclides outside the body) and internal exposure (exposure to gamma radiation emitted by radionuclides taken into the body) are of concern for gamma-emitting radionuclides. Gamma rays have high penetrating ability in living tissue and are capable of reaching all internal body organs. Without such sufficient shielding such as, lead, concrete, or steel, gamma radiation can penetrate the body from the outside and does not require ingestion or inhalation to penetrate sensitive organs. Gamma rays are characterized as low-LET radiation, as is beta radiation; however, the behavior of beta radiation differs from that of gamma radiation in that beta particles deposit most of their energy in the medium through which they pass, while gamma rays often escape the medium because of higher energies, thereby creating difficulties in determining actual internal exposure. For this reason, direct whole-body measurements are necessary to detect gamma radiation, while urine/fecal analyses are usually effective in detecting beta radiation (BEIAS Toxicity Profiles).

People continuously receive background radiation from naturally occurring radioactive decay processes that occur on the earth's surface including: radiation naturally occurring inside their bodies, from the atmosphere as fallout from nuclear testing or explosions, and from space or cosmic sources. Cesium-137 (from nuclear fallout) decays to barium-137m, the highest contributor to fallout-induced gamma radiation (NCRP 1977). Beta radiation from the soil is a less penetrating form of radiation but has many contributing sources, most commonly: potassium-40, cesium-137, lead-214, and bismuth-214 (NCRP 1977). Alpha radiation is also emitted by radionuclides in the soil, but is not measurable more than a few centimeters from the ground surface. The majority of alpha emissions are attributable to radon-222 and radon-220 and their decay products (NCRP 1977).

The general health effects of radiation can be divided into stochastic and nonstochastic effects. Stochastic effects are those which the probability of occurrence, but not the severity, is assumed to be a function of dose (without threshold). There is no clear causal relationship between exposure and observed effect. Nonstochastic effects are those which the severity varies with dose, but a threshold for occupance of the effects is assumed. The risks from exposure to radionuclides calculated in this evaluation are those associated with stochastic effects.

Radiation can damage cells in different ways. It can cause damage to DNA within the cell, and the cell either may not be able to recover from this type of damage or may survive but function abnormally. If an abnormally functioning cell divides and reproduces, a tumor or mutation in the tissue may develop. The rapidly dividing cells that line the intestines and stomach and the blood cells in bone marrow are extremely sensitive to this damage. Organ damage results from the damage caused to the individual cells. This type of damage has been reported with doses of 10 to 500 rads (0.1 to 5.0 gray, in SI units). Acute radiation sickness is seen only after doses of >50 rads (0.5 gray) which is a dose rate usually achieved only in a nuclear accident (ATSDR 1989).

When the radiation-damaged cells are reproductive cells, genetic damage can occur in the offspring of the person exposed. The developing fetus is especially sensitive to radiation. The type of malformation that may occur is related to the stage of fetal development and the cells that are differentiating at the time of exposure. Radiation damage to children exposed in the womb is related to the dose the pregnant mother receives. Mental retardation is a possible effect of fetal radiation exposure (ATSDR 1989).

The most widely studied population that has had known exposure to radiation is the atomic bomb survivors of Hiroshima and Nagasaki, Japan. Data indicate an increase in the rate of leukemia and cancers in this population. However, the rate at which cancer incidence is significantly affected by low radiation exposures, such as results of exposure to natural background and industrially contaminated sites, is still undergoing study and is uncertain (BEIAS Toxicity Profiles).

E.1.1 Cesium-137

Cesium-137, a product of nuclear fission reactions, has a radioactive half-life of 30.2 years. In ~95% of the radioactive decay, cesium-137 emits a beta particle with a maximum energy of 0.514 MeV and is transformed to the metastable state of barium-137m. Barium-137m then in turn decays 90% of the time by emitting a 0.662 MeV gamma-ray. Cesium-137 enters the human body via ingestion and behaves similarly to potassium. It is rapidly and almost completely absorbed from the GI tract and is distributed uniformly throughout the body (ICRP 1991). Because of its relatively short metabolic half-life (110 days), an acute dose of cesium-137 is almost completely excreted in the urine within a year of its initial exposure. However, when considering a potentially long-term (chronic exposure), cesium-137 would always be present in the body.

E.1.2 Strontium-90

Strontium is a soft, silvery metal and is found in the minerals celestite and strontianite. It is malleable and ductile and is an excellent conductor of electricity. Strontium exists as a number of isotopes. One such isotope is strontium-90 which is a dangerous radioisotope found in the fallout of some nuclear explosions.

Radiostrontium is a fallout hazard because, being chemically similar to calcium, it becomes incorporated into bone where it may damage the bone marrow and induce cancer. It has a radioactive half-life of 29.1 years, and emits a beta particle of 0.546 MeV.

E.2 CONTAMINANTS EVALUATED QUALITATIVELY

E.2.1 Lead

Lead (Pb) is a naturally occurring bluish-gray metal that is found in small quantities in the earth's crust. Lead and its compounds can be found in plants and animals that are used for human consumption, as well as in air, drinking water, rivers, lakes, oceans, dust, and soil. Industry is supplied with lead from mined ores or from recycled scrap metal. The primary use of lead is in the manufacture of storage batteries. Lead is also used in the production of ammunition, miscellaneous metal products, and various chemicals, including gasoline additives (ATSDR, 1990).

The general population's exposure to lead (and its compounds) is from breathing air, drinking water, and consuming foods that contain lead. Another source of exposure is from breathing or ingesting dust or dirt laden with lead. Children, especially those of preschool age, are at a particular risk to lead exposure. Children commonly place their hands, toys and other items in their mouths. Lead-contaminated dirt and dust frequently comes into contact with these items, resulting in a consumption of large amounts of lead. Another source of lead exposure to children is via the ingestion of paint chips (ATSDR, 1990).

Lead exposure is particularly dangerous for the developing fetus, because of its sensitivity to lead. Young children are also sensitive to the effects of lead and tend to absorb more of the lead they ingest. A pregnant woman exposed to lead results in a transfer of lead to the fetus, which may cause preterm birth, reduced birth weight, and a decreased intelligence quotient (IQ) in the infant. A decrease in IQ scores and reduced growth in young children may also occur when they are exposed to lead. When middle-aged men are exposed to lead, an increase in blood pressure may also occur. Lead can severely damage the brain and kidneys in adults as well as children when they are exposed to high levels of lead. Additionally, lead exposure at high levels will cause abortion as well as damage to the male reproductive system (ATSDR, 1990).

E.3 REFERENCES

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Appendix F

INCREMENTAL LIFETIME CANCER RISK VALUES AND HAZARD INDEXES FOR RECEPTOR EXPOSURES

Table F.1. Incremental lifetime cancer risks (ILCRs) for receptor exposures

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Resident	Bldg. Accident	Air	WOC[d]	Inhalation	Radionuclides	Cs-137	2.0E-04	1.9E-11	3.9E-15
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	H-3	4.9E-11	9.6E-14	4.7E-24
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	K-40	5.4E-10	7.5E-12	4.0E-21
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	Pu-238	1.5E-11	2.7E-08	4.0E-19
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	Pu-239	1.1E-11	2.8E-08	3.0E-19
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	Sr-90	1.1E-04	6.9E-11	8.0E-15
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	Th-228	3.9E-11	9.7E-08	3.8E-18
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	Th-230	6.6E-11	1.7E-08	1.1E-18
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	Th-232	3.0E-11	1.9E-08	5.7E-19
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	U-234	7.3E-11	1.4E-08	1.0E-18
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	U-235	6.0E-12	1.3E-08	7.8E-20
Resident	Bldg. Accident	Air	WOC	Inhalation	Radionuclides	U-238	9.0E-11	1.2E-08	1.1E-18
Resident	Bldg. Accident	Air	WOD[e]	Inhalation	Radionuclides	Cs-137	7.2E-06	1.9E-11	1.4E-16
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	H-3	1.7E-12	9.6E-14	1.7E-25
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	K-40	1.9E-11	7.5E-12	1.4E-22
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Pu-238	5.2E-13	2.7E-08	1.4E-20
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Pu-239	3.8E-13	2.8E-08	1.1E-20
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Sr-90	4.1E-06	6.9E-11	2.8E-16
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Th-228	1.4E-12	9.7E-08	1.3E-19
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Th-230	2.3E-12	1.7E-08	4.0E-20
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	Th-232	1.0E-12	1.9E-08	2.0E-20

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	U-234	2.6E-12	1.4E-08	3.6E-20
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	U-235	2.1E-13	1.3E-08	2.8E-21
Resident	Bldg. Accident	Air	WOD	Inhalation	Radionuclides	U-238	3.2E-12	1.2E-08	3.9E-20
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Cs-137	9.5E-02	2.1E-06	2.0E-07
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	H-3	2.3E-08	0.00	0.00
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	K-40	2.5E-07	6.1E-07	1.6E-13
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Pu-238	6.9E-09	1.9E-11	1.3E-19
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Pu-239	5.1E-09	1.3E-11	6.4E-20
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Sr-90	5.4E-02	0.00	0.00
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Th-228	1.8E-08	9.9E-07	1.8E-14
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Th-230	3.1E-08	4.4E-11	1.4E-18
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	Th-232	1.4E-08	2.0E-11	2.7E-19
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	U-234	3.4E-08	2.1E-11	7.3E-19
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	U-235	2.8E-09	2.7E-07	7.5E-16
Resident	Bldg. Accident	Air	WOC	External	Radionuclides	U-238	4.2E-08	5.3E-08	2.2E-15
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Cs-137	3.4E-03	2.1E-06	7.0E-09
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	H-3	8.1E-10	0.00	0.00
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	K-40	9.0E-09	6.1E-07	5.5E-15
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Pu-238	2.4E-10	1.9E-11	4.7E-21
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Pu-239	1.8E-10	1.3E-11	2.3E-21
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Sr-90	1.9E-03	0.00	0.00

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Th-228	6.4E-10	9.9E-07	6.4E-16
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Th-230	1.1E-09	4.4E-11	4.8E-20
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	Th-232	4.9E-10	2.0E-11	9.7E-21
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	U-234	1.2E-09	2.1E-11	2.6E-20
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	U-235	1.0E-10	2.7E-07	2.6E-17
Resident	Bldg. Accident	Air	WOD	External	Radionuclides	U-238	1.5E-09	5.3E-08	7.8E-17
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	Cs-137	2.7E+06	3.2E-11	8.4E-05
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	H-3	4.4E+00	7.2E-14	3.2E-13
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	K-40	4.3E+01	1.3E-11	5.4E-10
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	Pu-238	2.4E-01	3.0E-10	7.0E-11
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	Pu-239	2.2E-01	3.2E-10	6.9E-11
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	Sr-90	1.5E+06	5.6E-11	8.4E-05
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	Th-228	4.7E-01	2.3E-10	1.1E-10
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	Th-230	1.3E+00	3.8E-11	5.0E-11
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	Th-232	6.0E-01	3.3E-11	2.0E-11
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	U-234	1.5E+00	4.4E-11	6.5E-11
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	U-235	1.2E-01	4.7E-11	5.7E-12
Resident	Bldg. Accident	Water	WOC	Ingestion	Radionuclides	U-238	1.0E+01	6.2E-11	6.2E-10
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	Cs-137	1.4E+05	3.2E-11	4.3E-06
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	H-3	1.4E-01	7.2E-14	9.8E-15
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	K-40	3.2E+00	1.3E-11	3.9E-11

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	Pu-238	1.5E-02	3.0E-10	4.5E-12
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	Pu-239	1.6E-02	3.2E-10	5.0E-12
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	Sr-90	7.6E+04	5.6E-11	4.2E-06
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	Th-228	2.0E-02	2.3E-10	4.6E-12
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	Th-230	9.7E-02	3.8E-11	3.6E-12
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	Th-232	4.3E-02	3.3E-11	1.4E-12
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	U-234	1.1E-01	4.4E-11	4.7E-12
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	U-235	8.8E-03	4.7E-11	4.1E-13
Resident	Bldg. Chronic	Water	WOC	Ingestion	Radionuclides	U-238	1.1E+00	6.2E-11	6.5E-11
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Am-241	0.00	3.3E-10	0.00
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Cs-137	0.00	3.2E-11	0.00
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	H-3	0.00	7.2E-14	0.00
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Pu-238	0.00	3.0E-10	0.00
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Pu-239	0.00	3.2E-10	0.00
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Sr-90	0.00	5.6E-11	0.00
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Th-228	0.00	2.3E-10	0.00
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Th-230	0.00	3.8E-11	0.00
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	Th-232	0.00	3.3E-11	0.00
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	U-234	0.00	4.4E-11	0.00
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	U-235	0.00	4.7E-11	0.00
Resident	Pad Chronic	Water	WOC	Ingestion	Radionuclides	U-238	2.9E+01	6.2E-11	1.8E-09

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	Cs-137	2.5E+06	3.2E-11	7.9E-05
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	H-3	4.2E+00	7.2E-14	3.0E-13
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	K-40	4.1E+01	1.3E-11	5.2E-10
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	Pu-238	2.2E-01	3.0E-10	6.6E-11
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	Pu-239	2.1E-01	3.2E-10	6.5E-11
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	Sr-90	1.4E+06	5.6E-11	7.9E-05
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	Th-228	4.4E-01	2.3E-10	1.0E-10
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	Th-230	1.3E+00	3.8E-11	4.7E-11
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	Th-232	5.6E-01	3.3E-11	1.8E-11
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	U-234	1.4E+00	4.4E-11	6.1E-11
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	U-235	1.1E-01	4.7E-11	5.4E-12
Resident	Bldg. Accident	Water	WOD	Ingestion	Radionuclides	U-238	9.6E+00	6.2E-11	6.0E-10
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	Cs-137	1.3E+05	3.2E-11	4.1E-06
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	H-3	1.3E-01	7.2E-14	9.3E-15
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	K-40	3.0E+00	1.3E-11	3.8E-11
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	Pu-238	1.4E-02	3.0E-10	4.2E-12
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	Pu-239	1.5E-02	3.2E-10	4.7E-12
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	Sr-90	7.2E+04	5.6E-11	4.0E-06
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	Th-228	1.9E-02	2.3E-10	4.3E-12
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	Th-230	9.1E-02	3.8E-11	3.4E-12
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	Th-232	4.1E-02	3.3E-11	1.3E-12

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	U-234	1.0E-01	4.4E-11	4.4E-12
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	U-235	8.3E-03	4.7E-11	3.9E-13
Resident	Bldg. Chronic	Water	WOD	Ingestion	Radionuclides	U-238	1.0E+00	6.2E-11	6.2E-11
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Am-241	0.00	3.3E-10	0.00
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Cs-137	0.00	3.2E-11	0.00
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	H-3	0.00	7.2E-14	0.00
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Pu-238	0.00	3.0E-10	0.00
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Pu-239	0.00	3.2E-10	0.00
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Sr-90	0.00	5.6E-11	0.00
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Th-228	0.00	2.3E-10	0.00
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Th-230	0.00	3.8E-11	0.00
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	Th-232	0.00	3.3E-11	0.00
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	U-234	0.00	4.4E-11	0.00
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	U-235	0.00	4.7E-11	0.00
Resident	Pad Chronic	Water	WOD	Ingestion	Radionuclides	U-238	2.7E+01	6.2E-11	1.7E-09
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	Cs-137	1.5E+10	3.2E-11	3.7E-01
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	H-3	2.4E+04	7.2E-14	1.7E-09
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	K-40	2.5E+05	1.3E-11	3.2E-06
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	Pu-238	1.3E+03	3.0E-10	3.9E-07
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	Pu-239	1.2E+03	3.2E-10	3.8E-07
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	Sr-90	8.7E+09	5.6E-11	3.9E-01

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	Th-228	2.6E+03	2.3E-10	5.9E-07
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	Th-230	7.4E+03	3.8E-11	2.8E-07
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	Th-232	3.3E+03	3.3E-11	1.1E-07
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	U-234	8.1E+03	4.4E-11	3.6E-07
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	U-235	6.7E+02	4.7E-11	3.2E-08
Resident	Bldg. Accident	Water	WOC	Ingestion of veg	Radionuclides	U-238	5.6E+04	6.2E-11	3.5E-06
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	Cs-137	7.6E+08	3.2E-11	2.4E-02
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	H-3	7.6E+02	7.2E-14	5.4E-11
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	K-40	1.8E+04	1.3E-11	2.3E-07
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	Pu-238	8.5E+01	3.0E-10	2.5E-08
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	Pu-239	8.8E+01	3.2E-10	2.8E-08
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	Sr-90	4.4E+08	5.6E-11	2.4E-02
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	Th-228	1.1E+02	2.3E-10	2.5E-08
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	Th-230	5.4E+02	3.8E-11	2.0E-08
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	Th-232	2.4E+02	3.3E-11	7.9E-09
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	U-234	5.9E+02	4.4E-11	2.6E-08
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	U-235	4.9E+01	4.7E-11	2.3E-09
Resident	Bldg. Chronic	Water	WOC	Ingestion of veg	Radionuclides	U-238	5.9E+03	6.2E-11	3.6E-07
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Am-241	0.00	3.3E-10	0.00
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Cs-137	0.00	3.2E-11	0.00
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	H-3	0.00	7.2E-14	0.00

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Pu-238	0.00	3.0E-10	0.00
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Pu-239	0.00	3.2E-10	0.00
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Sr-90	0.00	5.6E-11	0.00
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Th-228	0.00	2.3E-10	0.00
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Th-230	0.00	3.8E-11	0.00
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	Th-232	0.00	3.3E-11	0.00
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	U-234	0.00	4.4E-11	0.00
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	U-235	0.00	4.7E-11	0.00
Resident	Pad Chronic	Water	WOC	Ingestion of veg	Radionuclides	U-238	1.6E+05	6.2E-11	9.9E-06
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	Cs-137	1.4E+10	3.2E-11	3.6E-01
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	H-3	2.3E+04	7.2E-14	1.7E-09
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	K-40	2.4E+05	1.3E-11	3.0E-06
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	Pu-238	1.2E+03	3.0E-10	3.6E-07
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	Pu-239	1.1E+03	3.2E-10	3.6E-07
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	Sr-90	8.2E+09	5.6E-11	3.7E-01
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	Th-228	2.4E+03	2.3E-10	5.6E-07
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	Th-230	7.0E+03	3.8E-11	2.6E-07
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	Th-232	3.1E+03	3.3E-11	1.0E-07
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	U-234	7.6E+03	4.4E-11	3.4E-07
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	U-235	6.3E+02	4.7E-11	3.0E-08
Resident	Bldg. Accident	Water	WOD	Ingestion of veg	Radionuclides	U-238	5.3E+04	6.2E-11	3.3E-06

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	Cs-137	7.2E+08	3.2E-11	2.2E-02
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	H-3	7.2E+02	7.2E-14	5.1E-11
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	K-40	1.8E+04	1.3E-11	2.2E-07
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	Pu-238	8.0E+01	3.0E-10	2.4E-08
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	Pu-239	8.3E+01	3.2E-10	2.6E-08
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	Sr-90	4.1E+08	5.6E-11	2.3E-02
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	Th-228	1.0E+02	2.3E-10	2.4E-08
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	Th-230	5.0E+02	3.8E-11	1.9E-08
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	Th-232	2.3E+02	3.3E-11	7.4E-09
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	U-234	5.6E+02	4.4E-11	2.5E-08
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	U-235	4.6E+01	4.7E-11	2.2E-09
Resident	Bldg. Chronic	Water	WOD	Ingestion of veg	Radionuclides	U-238	5.6E+03	6.2E-11	3.5E-07
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Am-241	0.00	3.3E-10	0.00
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Cs-137	0.00	3.2E-11	0.00
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	H-3	0.00	7.2E-14	0.00
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Pu-238	0.00	3.0E-10	0.00
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Pu-239	0.00	3.2E-10	0.00
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Sr-90	0.00	5.6E-11	0.00
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Th-228	0.00	2.3E-10	0.00
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Th-230	0.00	3.8E-11	0.00
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	Th-232	0.00	3.3E-11	0.00

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	U-234	0.00	4.4E-11	0.00
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	U-235	0.00	4.7E-11	0.00
Resident	Pad Chronic	Water	WOD	Ingestion of veg	Radionuclides	U-238	1.5E+05	6.2E-11	9.4E-06
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	Cs-137		1.9E-11	
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	H-3	3.9E-01	9.6E-14	3.7E-14
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	K-40		7.5E-12	
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	Pu-238		2.7E-08	
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	Pu-239		2.8E-08	
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	Sr-90		6.9E-11	
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	Th-228		9.7E-08	
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	Th-230		1.7E-08	
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	Th-232		1.9E-08	
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	U-234		1.4E-08	
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	U-235		1.3E-08	
Resident	Bldg. Accident	Water	WOC	Inhalation	Radionuclides	U-238		1.2E-08	
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	Cs-137		1.9E-11	
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	H-3	1.2E-02	9.6E-14	1.2E-15
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	K-40		7.5E-12	
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	Pu-238		2.7E-08	
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	Pu-239		2.8E-08	
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	Sr-90		6.9E-11	

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	Th-228		9.7E-08	
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	Th-230		1.7E-08	
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	Th-232		1.9E-08	
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	U-234		1.4E-08	
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	U-235		1.3E-08	
Resident	Bldg. Chronic	Water	WOC	Inhalation	Radionuclides	U-238		1.2E-08	
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Am-241		3.9E-08	
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Cs-137		1.9E-11	
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	H-3	0.00	9.6E-14	0.00
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Pu-238		2.7E-08	
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Pu-239		2.8E-08	
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Sr-90		6.9E-11	
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Th-228		9.7E-08	
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Th-230		1.7E-08	
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	Th-232		1.9E-08	
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	U-234		1.4E-08	
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	U-235		1.3E-08	
Resident	Pad Chronic	Water	WOC	Inhalation	Radionuclides	U-238		1.2E-08	
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	Cs-137		1.9E-11	
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	H-3	3.7E-01	9.6E-14	3.5E-14
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	K-40		7.5E-12	

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	Pu-238		2.7E-08	
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	Pu-239		2.8E-08	
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	Sr-90		6.9E-11	
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	Th-228		9.7E-08	
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	Th-230		1.7E-08	
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	Th-232		1.9E-08	
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	U-234		1.4E-08	
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	U-235		1.3E-08	
Resident	Bldg. Accident	Water	WOD	Inhalation	Radionuclides	U-238		1.2E-08	
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	Cs-137		1.9E-11	
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	H-3	1.1E-02	9.6E-14	1.1E-15
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	K-40		7.5E-12	
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	Pu-238		2.7E-08	
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	Pu-239		2.8E-08	
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	Sr-90		6.9E-11	
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	Th-228		9.7E-08	
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	Th-230		1.7E-08	
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	Th-232		1.9E-08	
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	U-234		1.4E-08	
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	U-235		1.3E-08	
Resident	Bldg. Chronic	Water	WOD	Inhalation	Radionuclides	U-238		1.2E-08	

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Am-241		3.9E-08	
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Cs-137		1.9E-11	
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	H-3	0.00	9.6E-14	0.00
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Pu-238		2.7E-08	
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Pu-239		2.8E-08	
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Sr-90		6.9E-11	
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Th-228		9.7E-08	
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Th-230		1.7E-08	
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	Th-232		1.9E-08	
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	U-234		1.4E-08	
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	U-235		1.3E-08	
Resident	Pad Chronic	Water	WOD	Inhalation	Radionuclides	U-238		1.2E-08	
Intruder	Bldg. Chronic	Debris	North	Ingestion	Radionuclides	Cs-137	6.8E+04	3.2E-11	2.1E-06
Intruder	Bldg. Chronic	Debris	South	Ingestion	Inorganics	Beryllium	8.7E-13	4.3E+00	3.8E-12
Intruder	Bldg. Chronic	Debris	South	Ingestion	Radionuclides	Cs-137	6.8E+04	3.2E-11	2.1E-06
Intruder	Bldg. Chronic	Debris	South	Ingestion	Radionuclides	Sr-90	1.6E+06	5.6E-11	9.1E-05
Intruder	Bldg. Chronic	Debris	South	Dermal	Inorganics	Beryllium	5.5E-14	4.3E+02	2.4E-11
Intruder	Bldg. Chronic	Debris	North	Inhalation	Radionuclides	Cs-137	6.3E+00	1.9E-11	1.2E-10
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Arsenic	1.3E-15	5.0E+01	6.5E-14
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Beryllium	8.2E-17	8.4E+00	6.9E-16
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Cadmium	1.4E-16	6.1E+00	8.6E-16

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Intruder	Bldg. Chronic	Debris	South	Inhalation	Inorganics	Chromium (IV)	2.9E-15	4.1E+01	1.2E-13
Intruder	Bldg. Chronic	Debris	South	Inhalation	Radionuclides	Cs-137	6.3E+00	1.9E-11	1.2E-10
Intruder	Bldg. Chronic	Debris	South	Inhalation	Radionuclides	Sr-90	1.5E+02	6.9E-11	1.1E-08
Intruder	Bldg. Chronic	Debris	North	External	Radionuclides	TLD string	3.9E+04	7.3E-07	2.8E-02
Intruder	Bldg. Chronic	Debris	North	External	Radionuclides	TLD string	4.0E+04	7.3E-07	2.8E-02
Intruder	Bldg. Chronic	Debris	South	External	Radionuclides	TLD string	1.8E+03	7.3E-07	1.3E-03
Intruder	Bldg. Chronic	Debris	South	External	Radionuclides	TLD string	7.9E+03	7.3E-07	5.8E-03
Worker	Bldg. Chronic	Walls	East	External	Radionuclides	Meter	8.6E+01	7.3E-07	6.2E-05
Worker	Bldg. Chronic	Walls	North	External	Radionuclides	Meter	8.6E+01	7.3E-07	6.2E-05
Worker	Bldg. Chronic	Walls	South	External	Radionuclides	Meter	8.6E+01	7.3E-07	6.2E-05
Worker	Bldg. Chronic	Walls	West	External	Radionuclides	Meter	1.3E+02	7.3E-07	9.4E-05
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Am-241	1.4E-03	4.6E-09	6.6E-12
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Cs-137	4.9E+00	2.1E-06	1.0E-05
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	H-3	0.00	0.00	0.00
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Pu-238	2.1E-05	1.9E-11	4.2E-16
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Pu-239	3.6E-04	1.3E-11	4.5E-15
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Sr-90	9.6E-01	0.00	0.00
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Th-228	2.1E-05	9.9E-07	2.1E-11
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Th-230	2.1E-05	4.4E-11	9.2E-16
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	Th-232	4.1E-06	2.0E-11	8.1E-17
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	U-234	6.8E-06	2.1E-11	1.5E-16

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	U-235	1.5E-07	2.7E-07	4.0E-14
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	U-238	9.0E-06	5.3E-08	4.7E-13

[a] Units are pCi with the exception of external exposures for the intruder and worker which are mrem.
[b] Units are risk/pCi.
[c] Dimensionless.

Table F.2. Noncarcinogenic effects (hazard indices) for receptor exposures

Receptor	Release	Exposure Media	Exposure Route	Exposure Location	Contaminant Class	Contaminant	CDI[a]	RFD[b]	HQ[c]
Intruder	Bldg. Chronic	Debris	Ingestion	South Cell	Inorganics	Antimony	2.5E-09	4.0E-04	6.2E-06
Intruder	Bldg. Chronic	Debris	Ingestion	South Cell	Inorganics	Arsenic	9.8E-10	3.0E-04	3.3E-06
Intruder	Bldg. Chronic	Debris	Ingestion	South Cell	Inorganics	Barium	1.8E-06	7.0E-02	2.5E-05
Intruder	Bldg. Chronic	Debris	Ingestion	South Cell	Inorganics	Beryllium	6.1E-11	5.0E-03	1.2E-08
Intruder	Bldg. Chronic	Debris	Ingestion	South Cell	Inorganics	Cadmium	1.1E-10	1.0E-03	1.1E-07
Intruder	Bldg. Chronic	Debris	Ingestion	South Cell	Inorganics	Chromium (III)	2.2E-09	1.0E+00	2.2E-09
Intruder	Bldg. Chronic	Debris	Ingestion	South Cell	Inorganics	Chromium (IV)	2.2E-09	5.0E-03	4.3E-07
Intruder	Bldg. Chronic	Debris	Ingestion	South Cell	Inorganics	Manganese	1.4E-08	1.4E-01	1.0E-07
Intruder	Bldg. Chronic	Debris	Ingestion	South Cell	Inorganics	Nickel	2.0E-09	2.0E-02	9.8E-08
Intruder	Bldg. Chronic	Debris	Ingestion	South Cell	Inorganics	Selenium	5.7E-10	5.0E-03	1.1E-07
Intruder	Bldg. Chronic	Debris	Ingestion	South Cell	Inorganics	Silver	2.4E-10	5.0E-03	4.9E-08
Intruder	Bldg. Chronic	Debris	Ingestion	South Cell	Inorganics	Vanadium	1.1E-09	7.0E-03	1.6E-07
Intruder	Bldg. Chronic	Debris	Ingestion	South Cell	Inorganics	Zinc	4.2E-08	3.0E-01	1.4E-07
Intruder	Bldg. Chronic	Debris	Dermal	South Cell	Inorganics	Antimony	1.6E-10	8.0E-06	2.0E-05
Intruder	Bldg. Chronic	Debris	Dermal	South Cell	Inorganics	Arsenic	6.2E-11	1.2E-04	5.0E-07
Intruder	Bldg. Chronic	Debris	Dermal	South Cell	Inorganics	Barium	1.1E-07	4.9E-03	2.3E-05
Intruder	Bldg. Chronic	Debris	Dermal	South Cell	Inorganics	Beryllium	3.9E-12	5.0E-05	7.7E-08
Intruder	Bldg. Chronic	Debris	Dermal	South Cell	Inorganics	Cadmium	6.7E-12	1.0E-05	6.7E-07
Intruder	Bldg. Chronic	Debris	Dermal	South Cell	Inorganics	Chromium (III)	1.4E-10	5.0E-03	2.7E-08
Intruder	Bldg. Chronic	Debris	Dermal	South Cell	Inorganics	Chromium (IV)	1.4E-10	1.0E-04	1.4E-06
Intruder	Bldg. Chronic	Debris	Dermal	South Cell	Inorganics	Manganese	8.9E-10	5.6E-03	1.6E-07
Intruder	Bldg. Chronic	Debris	Dermal	South Cell	Inorganics	Nickel	1.2E-10	5.4E-03	2.3E-08
Intruder	Bldg. Chronic	Debris	Dermal	South Cell	Inorganics	Selenium	3.6E-11	2.2E-03	1.6E-08

Table F.1. (continued)

Receptor	Release	Exposure Media	Exposure Location	Exposure Route	Contaminant Class	Contaminant	CDI[a]	SF[b]	ILCR[c]
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	U-235	1.5E-07	2.7E-07	4.0E-14
Worker	Pad Chronic	Soil	Pad	External	Radionuclides	U-238	9.0E-06	5.3E-08	4.7E-13

[a] Units are pCi with the exception of external exposures for the intruder and worker which are mrem.
[b] Units are risk/pCi.
[c] Dimensionless.
[d] White Oak Creek.
[e] White Oak Dam

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