MARTIN MARIETTA

**ENVIRONMENTAL
RESTORATION
PROGRAM**

**Level III Baseline Risk Evaluation for
Building 3505 at Oak Ridge National
Laboratory, Oak Ridge, Tennessee**

W. B. Mostella, Jr.

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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National Laboratory, Oak Ridge, Tennessee**

W. B. Mostella, Jr.

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Prepared by
Health Sciences Research Division
Oak Ridge National Laboratory
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ACRONYMS AND ABBREVIATIONS

AEC	United States Atomic Energy Commission
Am	americium
BRE	baseline risk evaluation
CASRN	Chemical Abstracts Services Registry Number
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CEW	Clinton Engineer Works
COPC	contaminant of potential concern
Cs	cesium
D&D	decontamination and decommissioning
DOE	United States Department of Energy
DQR	data quality requirement
Energy Systems	Martin Marietta Energy Systems, Inc.
EPA	United States Environmental Protection Agency
ER	Environmental Restoration
FFA	Federal Facility Agreement
GAAT	Gunite and Associated Tanks
He	helium
HEAST	(EPA) Health Effects Assessment Summary Tables
HEW	Hanford Engineer Works
HI	hazard index
HQ	hazard quotient
IRIS	(EPA) Integrated Risk Information System
LD ₅₀	dose lethal to 50% of test subjects
LET	linear energy transfer
LOAEL	lowest observed adverse effects level
MeV	million electron volts
MRF	Metal Recovery Facility
NOAEL	no observed adverse effects level
Np	neptunium
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OU	operable unit
pCi	picocurie
Pu	plutonium
RAS	Risk Analysis Section (of ORNL)
RCRA	Resource Conservation and Recovery Act
RfC	reference concentration
RfD	reference dose
RI	(CERCLA) remedial investigation
S&M	surveillance and maintenance
SF	slope factor
Sr	strontium
SRE	screening risk evaluation

ACRONYMS AND ABBREVIATIONS (continued)

SWMU	solid waste management unit
Tc	technetium
U	uranium
WAG	waste area grouping

EXECUTIVE SUMMARY

The Level III Baseline Risk Evaluation (BRE) for Building 3505, the ORNL Metal Recovery Facility, provides an analysis of the potential for adverse health effects, current or future, associated with the presence of hazardous substances in the building.

The Metal Recovery Facility was used from 1952 through 1960 to process large quantities of radioactive material using the PUREX process for the recovery of uranium-238, plutonium-239, neptunium-237, and americium-241. The facility consists of seven process cells (A through G), a canal, a dissolver room, a dissolver pit, an office, locker room, storage area, control room, electrical gallery, shop, and makeup area. The cells were used to house the nuclear fuel reprocessing equipment, and the canal was constructed to be used as a water-shielded transfer canal. Currently, there are no known releases of radioactive contaminants from Building 3505.

To perform the BRE, historical radiological survey data were used to estimate the concentration of alpha- and beta/gamma emitting radionuclides in the various cells, rooms, and other areas in Building 3505. Data from smear surveys were used to estimate the amount of transferrable contamination (to which receptors can be exposed via inhalation and ingestion), and data from probe surveys were used to estimate the amount of both fixed and transferrable contamination (from which receptors can receive external exposure).

Two land use scenarios, current and future, and their subsequent exposure scenarios were explored in the BRE. Under the current land use scenario, two exposure scenarios were evaluated. The first was a worst-case industrial exposure scenario in which the receptor is a maintenance worker who works 8 hours/day, 350 days/year in the building for 25 years. In the second, more realistic exposure scenario, the receptor is a surveillance and maintenance (S&M) worker who spends two 8-hour days/year in the building for 25 years.

The future land use scenario was a no-action (i.e., no-remedial-action) scenario involving an adult trespasser who resides 24 hours/day, 350 days/year for 30 years on the site at some future point when DOE has abandoned the building and has made no attempt to either restrict access to the facility or prevent contaminant releases from it. While it is unlikely that a trespasser would ever take up residence in this building [the United States Department of Energy (DOE) does not intend to release the ORR property for development and the area around the facility is expected to remain industrial even if the building is abandoned], this receptor was evaluated to provide an upperbound estimate of the potential human health risks.

Any contamination released as a result of catastrophic events or building decay might reach ecological receptors, but the effect of the contamination, if any, would be small compared to existing levels of environmental contamination from other sources. Therefore, the risk to the ecological sectors was not evaluated as part of this BRE. The release of contamination due to catastrophic events might also potentially result in exposure of people living outside the boundary of DOE property. However, such off-site exposures have not been included in the BRE because the quantity of radioactive and chemical contaminants at this site is insufficient to cause significant exposures to off-site receptors.

During 1993, one of the cells in the Metal Recovery Facility, Cell G, was decontaminated to determine the effectiveness of a dry decontamination technique and provide data about the use of this technique in the eventual decommissioning of the facility. Details of the procedure and analytical results are presented in the decontamination report (ORNL/ER-219). The primary radioisotope of concern in Cell G was plutonium-239 as stated in the decontamination report. Based on the information on the decontamination of cell G, it was assumed that the alpha contamination detected was attributable mainly to plutonium-239. However, americium-241, uranium-238, cesium-137, strontium-90, and technetium-99 were also associated with the separation process which took place at the facility. The process was performed in Cells A through G, the dissolver pit, the dissolver room, and the canal. Because no data were provided that analyze for the distribution of the specific radionuclides in these areas, it is reasonable to assume that other alpha emitters, such as americium-241 and uranium-238, might be present in addition to the presence of plutonium. The human health risks at Building 3505 might be underestimated if the potential risks from these other radionuclides were not considered.

Since any combination of the alpha and beta/gamma emitters might be present in a cell or other building area, it was decided that the risk from each of the nine possible permutations of alpha and beta/gamma emitters should be evaluated. These permutations were called "alpha/beta pairs" in this study and comprised the following:

- americium-241 and strontium-90 (Am+Sr), americium-241 and technetium-99 (Am+Tc), and americium-241 and cesium-137 (Am+Cs)
- neptunium-241 and strontium-90 (Np+Sr), neptunium-241 and technetium-99 (Np+Tc), and neptunium-241 and cesium-137 (Np+Cs)
- plutonium-239 and strontium-90 (Pu+Sr), plutonium-239 and technetium-99 (Pu+Tc), and plutonium-239 and cesium-137 (Pu+Cs)
- uranium-238 and strontium-90 (U+Sr), uranium-238 and technetium-99 (U+Tc), and uranium-238 and cesium-137 (U+Cs)

It was decided that the most conservative approach to evaluating the risk at this facility would be to consider each alpha/beta pair and its contribution to risk as if only that pair of radionuclides were present. In other words, risks were calculated as if:

- the alpha activity detected 1) by probe or 2) by smears were attributable to only americium-241, plutonium-239, or uranium-238 and
- the beta/gamma activity detected 1) by probe or 2) by smears were attributable to only strontium-90, technetium-99, or cesium-137.

Human health risks are evaluated by combining human exposure estimates and toxicity information. 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:

$$\text{ILCR} = \text{SF} \times \text{CDI}$$

where :

ILCR = Incremental lifetime cancer risk (unitless probability)
SF = Slope factor (mg/kg • day)⁻¹
CDI = Chronic daily intake (mg/kg • day)

In weighing exposures to potentially carcinogenic compounds, a reasonable level of risk must be identified. The United States Environmental Protection Agency (EPA) specifies a risk range of 10^{-6} to 10^{-4} associated with the consideration and selection of remedial alternatives for Superfund sites (EPA, 1990). The lower end of this range is generally applied to residential risks while occupational risks may be considered acceptable at the higher end of this range. In the United States, the incidence of cancer occurrence is 3×10^{-1} , or 0.30 (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 (1×10^{-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 (1.5 rem at ORNL) for the annual effective dose equivalent. This dose equates to a 25-year lifetime risk of 2×10^{-2} (6×10^{-3} at ORNL). Analogous protection standards for members of the public mandate a limit of 0.1 rem per year. This dose equates to a 70-year lifetime risk of 4×10^{-3} .

Table 1 provides a summary of the estimated ILCR ranges calculated for each of the cells, the canal, locker room, shop, office, dissolver room and pit, and the building as a whole. These estimates are presented for each of the three receptors (maintenance worker, S&M worker, and future trespasser) according to the data type (smear or probe) used for the risk evaluation.

The total incremental lifetime cancer risk determined for Cell A, the canal, and the entire building was 1.0 for both the smear and probe data, which indicates a probability of 1 chance in 1 of an individual developing cancer, regardless of which radionuclide(s) is present. This value applies to each of the alpha/beta pairs. The external exposure pathway is the dominant driver of the risk at the three locations. However, the only deviation from this trend was found to occur at Cell A for the S&M worker receptor where the total risk ranged from 3×10^{-6} to 1. Each alpha emitter paired with cesium-137 resulted in the higher risk along the external exposure pathway for the smear data.

The external exposure pathway proved to be the dominant pathway for the adult resident receptor at Cell B based on both the smear and probe data concentration data.

For the S&M worker receptor, risks from Cells C, D, E, and F; the dissolver room; the electrical gallery; and the control room were determined to be within the acceptable range, as established by EPA, of 10^{-6} to 10^{-4} . This trend applies to the maintenance worker receptor

except for Cell D, E, and F and the dissolver room, where there is a slightly higher risk from the smear concentration at Cell D and E and an even higher risk for the same data type at Cell F and the dissolver room.

The risk associated with the locker room, office area, and shop area are below the lifetime risk of the current radiation standards of 2×10^{-2} for the maintenance worker and S&M worker; however, the EPA standard is exceeded for the residential receptor. As shown in Table 1, the lifetime risk for these areas was determined to be of 2×10^{-2} . The external exposure pathway is the primary contributor to the risk.

Table 1. Total risk ranges for combinations of radionuclides at Building 3505

Location	Data Type	Receptors		
		Maintenance Worker	S&M Worker	Adult Resident
Cell A	Smear	1E+00	3E-06 to 1E+00	1E+00
	Probe	1E+00	1E+00	1E+00
Cell B	Smear	4.5E-03 to 8E-01	1E-6 to 8E-01	1E+00
	Probe	8E-01	8E-01	1E+00
Cell C	Smear	7E-05 to 2E-04	6E-07 to 2E-06	2E-04 to 1E-03
	Probe	8E-05 to 1E-04	9E-07 to 2E-06	4E-04 to 1E-03
Cell D	Smear	7E-05 to 1E-03	6E-07 to 9E-06	2E-04 to 1E-03
	Probe	7E-05 to 1E-04	8E-07 to 2E-06	2E-04 to 1E-03
Cell E	Smear	1E-04 to 6E-03	1E-06 to 5E-05	8E-04 to 3E-02
	Probe	9E-05 to 2E-04	7E-07 to 1E-06	2E-04 to 9E-04
Cell F	Smear	1E-02 to 4E-02	3E-04 to 4E-3	7E-2 to 9E-1
	Probe	9E-05 to 2E-04	7E-07 to 1E-06	2E-04 to 9E-04
Canal	Smear	1E+00	1E+00	1E+00
	Probe	1E+00	1E+00	1E+00
Dissolver Pit	Smear	4E-02	5E-08 to 7E-05	3E-05 to 8E-05
	Probe	-	-	-
Dissolver Room	Smear	1E-06 to 2E-01	6E-09 to 1E-05	2E-06 to 6E-01
	Probe	-	-	-
Electrical Gallery	Smear	2E-08 to 7E-07	2E-10 to 6E-9	8E-08 to 4E-06
	Probe	-	-	-
Locker Room	Smear	-	-	-
	Probe	3E-03	3E-3	2E-02
Office Area	Smear	-	-	-
	Probe	3E-03	3E-03	2E-02

Table 1. (continued)

Location	Data Type	Receptors		
		Maintenance Worker	S&M Worker	Adult Resident
Shop	Smear	-	-	-
	Probe	4E-03	4E-03	2E-02
Control room	Air monitoring	1E-04 to 2E-04	1E-04 to 2E-04	2E-04 to 3E-04
Entire Building	Smear	1E+00	1E+00	1E+00
	Probe	1E+00	1E+00	1E+00

To place the results presented in this risk assessment in perspective, one should 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 $1E-02$ (MMES, 1993). This value is 100 times greater than the upperbound (10^{-4}) of EPA's target risk range. In addition, the activities that increase the chance of cancer fatality by $1E-06$ are presented in Table 2. It should be noted 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 ($1E-06$)^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

Adequate data were unavailable to quantify the risks associated with mercury and asbestos present at the facility; therefore, these contaminants can only be addressed quantitatively. The asbestos is present in the facility as pipe insulation. Two kinds of cancer are known to result from asbestos exposure: lung cancer and mesothelioma (a cancer of the membrane surrounding the lung and other organs). Evidence also suggests increased risk of cancer of the stomach, intestines, esophagus, and pancreas. In addition, asbestos is known to be highly toxic by inhalation of dust particles. Exposure to asbestos would need to be controlled according to OSHA standards.

Mercury-contaminated soil was discovered beneath the trough drain on the north side of Building 3505. Mercury is highly toxic by skin absorption, and inhalation of fumes or vapors could be of serious concern if the receptor comes into direct contact with the element. It is most likely that a receptor would inhale the fume or vapor if the area containing mercury is disturbed.

Absorption by the respiratory and intestinal tract is also of concern. In summary, all inorganic compounds of mercury are highly toxic by ingestion, inhalation, and skin absorption.

It is the purpose of the D&D program to mitigate potential risks to workers, the public, and the environment from contamination at D&D program facilities. For this facility, removal of portions of the concrete surface from the cells, approximately ¼ in. of concrete, where most of the contamination resides, followed by cleaning the surfaces of the cells and rooms with sodium hydroxide, oxalic acid, and detergent would result in a 95% reduction in activity levels; this can be expected to result in a corresponding reduction in exposure and risk.

Using the risk evaluation results, it is possible to conclude that the dominant pathway of concern in Building 3505 is external exposure. The EPA-specified risk range of 10^{-6} to 10^{-4} was exceeded, in most cases, by the external exposure route mainly due to beta/gamma emitters, specifically, strontium-90 and cesium-137. In some instances, the estimated risk associated with ingestion and inhalation pathways exceeded the EPA limits but did so by only a few orders of magnitude. Cells A and B and the canal appear to consistently exceed EPA standards as well as current radiation protection standards for workers. According to the estimated ILCR for the building, external exposure is the highest risk pathway for all alpha/beta pairs.

The risks associated with the locker room, office area, and shop area are below the lifetime risk factor of the current radiation standards of 2×10^{-2} for workers; however, the EPA standard is exceeded for the residential receptor by an order of magnitude. As discussed in this report, the lifetime risks for these areas were determined to be of 2×10^{-2} . The external exposure pathway is the only contributor to the elevated risk. In general, the areas that have risks exceeding the EPA standard and the current radiation standard are (in order of decreasing tendency for generating higher risk) the canal, Cell A, Cell B, and the dissolver room.

1. INTRODUCTION

As part of its ongoing Environmental Restoration Program, the U.S. 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 the 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, 1992a).

DOE's ORR is in eastern Tennessee, approximately 25 miles (40 km) west of Knoxville (Fig. 1.1). The ORR was originally referred to as the Clinton Engineer Works (CEW), a name derived from the nearby small town of Clinton, Tennessee. The site was selected on September 19, 1942, as the location of several facilities that were part of the Manhattan Engineer District (Coobs and Gissel, 1986). The name Oak Ridge came into general use in the summer of 1943, when it was chosen for the new community's permanent housing area (Groves, 1983).

The X-10 Site, which later became the Oak Ridge National Laboratory (ORNL), is one of three facilities constructed on the ORR in 1943. The other two facilities, the K-25 Site and the Y-12 Plant, primarily focused on the production of enriched uranium, while X-10 served as a temporary pilot model for plutonium production facilities being built at the Hanford Engineer Works (HEW) in eastern Washington State (Coobs and Gissel, 1986). The X-10 facility originally had a planned life of only one year, but given the need for nuclear research, ORNL has operated continuously since that time.

With its wartime mission completed, the CEW was transferred in 1947 from the Manhattan Engineer District to the Atomic Energy Commission (AEC) (now known as DOE), a civilian agency created to provide oversight of the nation's nuclear industry. The CEW was renamed the ORR in 1947 after the establishment of the AEC (Groves, 1983).

The scope and direction of ORNL programs have seen many changes over the years, including the continuation and expansion of nuclear reactor fuel reprocessing research, large scale production of radioisotopes, and operation of a variety of reactors. Many of the activities of the past 50 years generated radioactive and mixed (containing both radioactive and hazardous components) waste materials. Management of these radioactive wastes has been of primary importance since the beginning of operations and has evolved over time.

Building 3505, the Metal Recovery Facility (MRF), at ORNL, is managed by Martin Marietta Energy Systems, Inc. (Energy Systems) and has been placed in the ORNL D&D Program within the Energy Systems Environmental Restoration (ER) Program. The D&D of Building 3505 may be necessary to avoid the potential spread of contamination and human and environmental exposures as the building and equipment deteriorate.

RADIAN
DOE OAK RESERVATION
AND VICINITY

Source: DOT
Date: 1993

Fig. 1.1. DOE Oak Ridge Reservation and vicinity

The methodology includes a tiered or graded approach to conducting the BRE. The purpose of the tiered approach is to save time and effort at facilities that do not warrant a rigorous baseline risk evaluation. The level of detail of the evaluation is measured by the amount and resolution of the data used and the sophistication of the analysis employed. The methodology includes guidance for conducting BREs at three levels of effort:

- Level I requires a full characterization of the facility and provides a complete quantitative "CERCLA-like" BRE [i.e., one that adheres to the intent of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)]. Two exposure scenarios are evaluated: abandonment and continued surveillance and maintenance (S&M). A preliminary end-point analysis is also provided.
- Level II includes an extensive characterization of the facility but may be less rigorous than Level I. The abandonment scenario is evaluated, and the continued S&M scenario is optional. The preliminary end-point analysis is optional for this evaluation. The primary differences between the Level II and Level I evaluations are the amount of characterization data available and the level of fate and transport modeling applied.
- Level III uses minimal characterization data. This assessment relies heavily on historic knowledge of the facility. The quantitative evaluation has a greater uncertainty than Levels I and II and therefore uses more "worst-case" assumptions. Only one exposure scenario (abandonment) is evaluated.

1.1 PURPOSE AND SCOPE OF THE BRE

The purpose of this report is to present a Level III BRE for Building 3505. The decision to conduct a Level III BRE was based on the fact that only residual surface contamination exists in the building; therefore, a rigorous analysis is not warranted. In addition, future plans for the facility (demolition) also preclude a rigorous analysis. This BRE uses worst-case assumptions for potential exposures. Specifically, workers are assumed to ingest 50 mg and hypothetical future adult residents are assumed to ingest 100 mg of contaminated dust resulting from concrete degradation. The purpose of this risk evaluation is to provide interested parties (managers, regulators, and the general public) with a preliminary estimation of any potential human health and environmental threats posed by contaminants at Building 3505. An extensive data set exists for the building structure. However, as discussed in Sect. 2 of this report, despite the large volume of existing data, the facility has not been well characterized. A limited number of samples have been taken to fill some data gaps. This, in combination with some extrapolation from radiological field surveys, provides enough information for use in a Level III evaluation.

The BRE is a four-stage process that provides an analysis of the potential for adverse health effects (current or future) caused by hazardous substance releases from a site in the absence of any actions to control or mitigate these releases (EPA 1989). Figure 1.2 provides an overview of the risk evaluation process for D&D Program facilities.

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. The

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Fig. 1.2. Overview of risk evaluation process

Fig. 1.3. WAG 1

second stage, an exposure assessment, involves the estimation of exposures based on contaminant concentrations estimated 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 the collection of information concerning the potential toxic characteristics of each contaminant. The results of the toxicity assessment are combined with the exposure estimates to quantitatively or qualitatively evaluate potential risks to human health and the environment posed by each contaminant of potential concern at the facility in the fourth stage, risk characterization (Energy Systems, 1992b).

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, and 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 which 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.

The approach for remediating the large number of ORNL sites is to first organize sites into Waste Area Groupings (WAGs). A WAG is a group of solid waste management units (SWMUs) or other areas of contamination that are geographically contiguous or are located within defined hydrologic units (DOE, 1992a). [Reference to SWMUs is derived from the original DOE effort to meet the permit requirements of the Resource Conservation and Recovery Act (RCRA).] Twenty WAGs were identified originally.

Building 3505 is within ORNL WAG 1, which includes most of the original ORNL research and development facilities and associated waste management units (see Fig. 1.3). WAG 1 covers approximately 150 acres (60.7 ha). A total of 167 identified contaminated sites or areas have been classified as requiring no further action. Fourteen of the sites are listed for remediation under the DOE surplus facilities program and are the responsibility of ORNL's D&D Program. The remaining 126 sites 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.

To address complex remediation management issues resulting from the large number of sites within a WAG, the concept of the "operable unit" (OU) was developed in accordance with the Federal Facility Agreement (FFA) (DOE, 1992a). According to the FFA, an OU is a discrete remedial action site designation that contributes to the final remediation of a facility or site. Each OU should be a discrete, identifiable action with a controllable scope. Where possible, physical media and waste units in each OU should be geographically distinct from those in other OUs to minimize the potential for recontamination. However, because of the complexity of WAG 1, some overlap of OUs is inevitable and potentially desirable to ensure final remediation of WAG 1.

The WAG 1 Remedial Investigation (RI) Plan indicated that WAG 1 RI data would be collected in phases (ORNL, 1989). The results of the WAG 1 Phase I RI are documented in three reports: the *OU Strategy Document* (DOE, 1992b), the *Preliminary Risk Assessment Report* (DOE, 1992c), and the *Site Characterization Summary Report (SCSR)* (DOE, 1992d; 1992e; 1992f; 1992g; and 1992h). On the basis of information collected and documented in the SCSR, 10 OUs have been defined for WAG 1, as described in the *OU Strategy Document* and shown in Fig. 1.4.

2. DATA EVALUATION

Before a Level III BRE can be performed, it is necessary to collect and evaluate existing data. This section presents the results of the data collections and evaluation for the Building 3505 BRE. The objective of this section is the presentation and evaluation of the facility characterization data. More specifically, the collection and evaluation of data for use in determining the potential for exposures to contaminants of potential concern (COPCs) that are present at or migrating from the facilities scheduled for D&D. The data collection phase comprises the acquisition of any information concerning past industrial processes, accidents, remediations, and present conditions that have occurred or now exist at or near the building. The data evaluation phase consists of assessing the available data and identifying any additional data that may be required to adequately characterize the potential sources(s) of environmental contamination associated within the facility.

The purpose of the evaluation is to determine which of the available data are of acceptable quality for use in the quantitative risk evaluation, which are of acceptable quality for qualitative use in the risk evaluation, and which are inappropriate for the risk evaluation. Generally, the evaluation is accomplished in two stages. Evaluation of existing data is conducted in Stage 1 to accomplish the following [in accordance with (EPA, 1989)]:

- Determine basic site characteristics
- Initially identify potential exposure pathways and exposure points
- Help determine additional data needs

If data gaps are identified in Stage 1, additional sampling and analyses may be performed under Stage 2 to fill these gaps. A final data evaluation analysis is then conducted.

The results of the data collection and evaluation are presented in this document with the identities and the quantitative estimates of the concentrations, volumes, and forms of the radiological contaminants of concern at the facility.

2.1 DATA COLLECTION

Data collection provides the risk assessor with some knowledge of past practices at the facility, potential contaminants present, and the potential current and future pathways for exposure at the facility. This knowledge enables the risk assessor to target data collection activities to those contaminants in areas of the building that represent a potential risk and determine when adequate data have been collected to fulfill the needs of the risk evaluation.

2.1.1 Historical Data for Building 3505

Data for Building 3505 were obtained from documents and correspondence prepared during the 1980s and early 1990s. These historical data can be divided into the following categories:

- Reports of operational history of the facility
- Health and Safety air monitoring data
- Radiation surveys and sampling data (smear sampling and coring data)

Table 2.1 lists the sources from which these data were drawn.

Table 2.1. Data sources for Building 3505 Level III BRE

Source	Data Type	Date of Document
Alternatives Study For D&D of Building 3505, ORNL (Final Issue)	Current Radiological Condition of building (probe/smear sampling)	May 27, 1994
Summary of the Radiological Characterization of Building 3505	Residual Characterization of building (probe/smear sampling)	September 1982
Radionuclide Characterization of Subsurface Soil on the Site of Building 3505 at ORNL	Subsurface soil radiological contamination characterization (probe results)	December 29, 1982 (date issued)
Decontamination Project for Cell G of the Metal Recovery Facility at ORNL	Cell G average alpha contamination	February 1994 (date issued)
Completion of Equipment Removal from Cells A and B, Building 3505 (Intra-Laboratory Correspondence)	Beta/gamma probe results	August 12, 1985
Decontamination of the Metal Recovery Facility Canal (Intra-Laboratory Correspondence)	Beta/gamma probe results	July 19, 1984
Removal of Equipment from Cell E, Metal Recovery Facility (MRF) (Internal Correspondence)	Beta/gamma/Alpha probe and smear results	September 22, 1986
Metal Recovery Facility, Building 350-5, D&D-Report on Cells C and D (Internal Correspondence)	Beta/gamma/Alpha probe and smear results	August 25, 1987
Completion of Cell F D&D, Metal Recovery Facility (MRF) (Internal Correspondence)	Beta/gamma/Alpha probe and smear results	September 22, 1986
Report on Completion of Cell G D&D at Building 3505 (MRF) (Internal Correspondence)	Beta/gamma/Alpha probe and smear results	March 14, 1986
Completion of Equipment Removal from Electrical Gallery, Building 3505 (Intra-Laboratory Correspondence)	Beta/gamma/Alpha probe and smear results	September 5, 1985
ORNL Facility Air Monitoring Data (Air Monitoring Report)	Air Monitoring Data	1993 and 1994

2.1.1.1 Contents of correspondence and reports

The reports contain information on radiological contamination in the building, decontamination projects that have been performed, and an alternatives evaluation. The intra-laboratory and internal correspondence in Table 2.1 concerned the size, condition, and status of Cells A through F and the canal; removal of equipment such as piping, columns, pumps, motor, brackets, and electrical conduit and fixtures; the results of radiological surveys of the walls and floors of the cells after equipment removal; decontamination of the canal and Cell G;

and the amounts of solid and liquid waste removed from the building. The smear and probe results are listed in Appendix A.

According to these documents, 25 separate campaigns were performed during this facility's operational history to separate uranium, plutonium, neptunium, and americium. Plutonium contamination exists to varying degrees throughout most of the building, being primarily associated with the floors, walls, and building structures associated with the process system. Residual fission products such as cesium-137 and strontium-90 have also been reported at this building (*Alternatives Study for D&D of Building 3505, ORNL*).

2.1.1.2 Radiological sampling and survey data

The storage area, control room, shop, and the south part of the makeup area are regulated areas as defined in Code of Federal Regulations, Chapter 10, Part 835. Fixed contamination, but no transferrable contamination, is present in these areas. The known areas of fixed and transferrable contamination are the north part of the makeup area, the north gallery, and the mezzanine. The cells, the dissolver room and pit, and the canal are highly contaminated with radionuclides. See Fig. 2.1 for the layout of Building 3505.

Probe and smear readings were collected from the cells, rooms and other areas in Building 3505. The radiological surveys performed at these locations are depicted in Table 2.2. Smear and probe readings were given in dpm/100 cm² and mrem/hr (Appendix B).

Table 2.2. Radiological survey of locations within Building 3505

Location	Alpha		Beta/gamma	
	Probe	Smear	Probe	Smear
Cell A	x	x	x	x
Cell B	x	x	x	x
Cell C	x	x		
Cell D	x	x		
Cell E	x	x		x
Cell F	x	x		
Canal			x	x
Dissolver Pit		x		x
Dissolver Room		x		x
Electric Gallery		x		
Locker Room			x	
Office Area			x	
Shop			x	

Note: Cell G was decontaminated 1993

Fig. 2.1. Building 3505 Plan View

The concentration values used in the risk evaluation were determined from the available smear and probe data given in Appendix B and are presented in Table C1.1 of Appendix C.

2.1.2 Preliminary Contaminants of Potential Concern

Decontamination of cell G was performed in 1993. Based on the processes known to have occurred at Building 3505 and the information available concerning Cell G, the principal contaminant of potential concern associated with the process equipment and building structure is believed to be plutonium-239. Core bores taken from Cell G indicated that up to 95% of the activity resides in the first 0.64 cm (0.25 in.) of concrete. In addition, because uranium, plutonium, neptunium, and americium were isolated in this facility during its early years of operation as a nuclear fuel reprocessing plant, it is plausible to assume that some of these radionuclides are still present; therefore, americium-241, uranium-238, and neptunium-237 are included as preliminary contaminants of concern. Finally, because the presence of cesium-137, technetium-99, and strontium-90 has been reported in this building, both are included on the preliminary list.

2.1.2.1 Excluded contaminants of potential concern

Elemental mercury has been found in the soil beneath the trough drain on the east side of the building, but because it was not used in the processes conducted in this building, the quantity of soil contamination cannot be quantified (*Alternatives Study for D&D of Building 3505, ORNL*). Therefore, the mercury will be evaluated qualitatively.

Asbestos is also known to be present on the pipes. It is not certain as to the amount of asbestos present, so this contaminant will also be given a qualitatively.

2.1.3 Potential Pathways and Exposure Points

Both fixed and transferrable alpha and beta/gamma contamination are present in significant levels in the cell walls and floors and other areas. Current exposures are limited to incidental ingestion and dermal contact with contaminants, inhalation of radioisotope-contaminated dust, and external exposure to radiation by workers or site visitors. The primary sources of potential future releases include the cells, the canal, the dissolver pit, and the dissolver room.

In the future, releases resulting from deterioration of the building, natural disasters, or D&D operations are possible. In the event of these releases, exposures could occur to contaminated environmental media, including soil and surface water, as well as exposures to airborne particulate-phase contaminants. Future pathways of exposure include incidental ingestion of contaminated dust, dermal contact with contaminated dust, inhalation of contaminated dust, and external exposure.

2.2 SUMMARY OF DATA EVALUATION

2.2.1 Data Quality Requirements

Data quality requirements (DQR) are the qualitative and quantitative statements that specify the quality of the data required to support decisions during risk evaluation activities. The development and use of DQRs is a continuing process from initial project scoping through the BRE and alternative risk evaluation. The development and use of DQRs are described briefly in the following paragraphs.

Information obtained from historical and operational investigations is used as the basis for the scoping of the BRE (i.e., definition of the problem and objectives of the BRE) and development of initial DQRs. The DQRs for this Level III BRE 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 historical data have been compared to these DQRs. The results of this evaluation are discussed in Sect. 2.2.2.

2.2.2 Historical Data

The historical data for Building 3505 consists of internal correspondences, air monitoring reports, and related documents. The correspondences provide details and information of past site activities related to decontamination projects and radiological characterization. In addition, some of the historical data represent the conditions that existed at the building from its period of operation to abandonment. Levels of residual contamination and information on the physical condition are present in the historical information.

2.2.2.1 Radiation surveys

The data consist of radiological surveys and air monitoring information. The radiological surveys, given in the internal correspondence, are useful for determining areas that need further analysis for specific radioisotopes, estimating potential exposures to fixed and transferrable radioactive contamination, and determining which areas may require additional data collection. The instruments used in these surveys are not capable of distinguishing between radionuclides. Therefore, assumptions regarding the distribution and identities of radionuclides have been made for this BRE.

2.2.2.2 DQR 1: Determination of basic site characteristics

The historical data available for the Building 3505 are adequate for determining basic site characteristics. From the historical data, it can be surmised that Building 3505 is contaminated to varying degrees with constituents associated with nuclear fuel processing. Based on the decontamination project performed on Cell G, the primary radioisotope of concern is Pu-239. Other contaminants which were involved in the fuel processing included uranium, neptunium, americium, cesium, and strontium isotopes. Hypothetically, americium or uranium could be the primary radioisotope of concern at the facility. The radionuclide exists to varying degrees throughout the building, being primarily associated with flooring and walls in Cells A through F, the dissolver room, the pit, and the canal.

The principal contaminant of potential concern is plutonium-239. Other COPCs include uranium, neptunium, americium, cesium, and strontium isotopes. Plutonium-239 contamination exists to varying degrees throughout the building, being primarily associated with flooring and walls in cells A through F, the dissolver room, the pit, and the canal.

2.2.2.3 DQR 2: Initial identification of potential exposure pathways and exposure points

The historical data provide adequate information to identify the following potential exposures within the building: 1) inhalation of airborne contaminants (radionuclide dust), 2) incidental ingestion of contaminants on surfaces through hand to mouth transfer (eating, smoking, etc.), 3) external exposure to radiation, and 4) off-site exposures due to releases associated with the deterioration of the building, fire, and natural disasters.

2.2.2.4 DQR 3: Identification of additional data needs

The historical data were insufficient to determine the identity of radionuclides present in beta/gamma smears and verify the results of the historical surveys. However, the following assumptions were used to suitably estimate the amount of contaminated material in Building 3505 and complete the BRE.

- The primary radioisotope of concern in Cell G is plutonium-239. Therefore, it was assumed that the primary contaminant in Cells A through F could also be plutonium-239. However, due to other radionuclides being involved in the process, it is plausible to assume that either of the following radionuclides might also be present: americium-241, uranium-238, neptunium-237, cesium-137, and strontium-90.
- Core samples taken from Cell G indicate that most of the contamination (up to 95% of the activity) resides in the first 0.64 cm (0.25 in.) of concrete. Therefore, it was assumed that Cells A through F are similarly contaminated.
- Smear samples are assumed to be approximately 0.1 cm in depth.

2.3 SELECTION OF CONTAMINANTS OF POTENTIAL CONCERN

Based on the evaluation of available data and satisfaction of the DQRs set forth for the BRE, plutonium-239 is assumed to be the principal contaminant. Contamination from radionuclides exists to varying degrees throughout most of the building and is associated with the floor and walls and building structures associated with nuclear fuel processing. The other COPCs selected for analysis in this BRE include americium-241, uranium-234 and uranium-238, cesium-137, neptunium-237, and strontium-90. Data to support the quantitative risk characterization for asbestos and heavy metals (such as mercury) were excluded for the reasons given in Sect. 2.1.2.

2.4 UNCERTAINTY

Uncertainties in the radiological survey data are associated with the sampling methodology and the inability of the survey instruments to distinguish between radionuclides.

The values from the smear sampling and probe surveys are reported in the form of disintegrations per minute per 100 cm² (dpm/100cm²). The actual distribution of contaminant concentrations cannot be determined by this methodology. Therefore, assumptions had to be made concerning the identification and spatial distribution of radionuclides present. All transferrable and fixed radiological contamination was assumed to consist of plutonium-239, americium-241, strontium-90, cesium-137 or uranium-238. Although the plutonium isotope was of primary concern in cell G, the other radioisotopes could be present in the building due to the past activities at the facility.

3. EXPOSURE ASSESSMENT

The objective of the exposure assessment is to estimate the type and magnitude of potential exposures to the radionuclides of potential concern that are present at or migrating from Building 3505. The exposure assessment is performed assuming both current and potential future uses of the building. The steps in performing an exposure assessment include:

- Characterizing the exposure setting (Sect. 3.1).
- Identifying potential migration routes and exposure pathways (Sect. 3.2).
- Quantitatively and qualitatively estimating radionuclide-specific exposures (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 following sections characterize the environmental setting and provide a description of Building 3505 and the OU components. Characterization of the environmental setting includes discussions on demography, land use, meteorology, geology, soils, and hydrogeology.

3.1.1 Facility Description

The MRF was a pilot- and small-scale-production, nuclear fuel reprocessing plant that operated from 1952 to 1960 processing materials using the PUREX process. It was used to recover uranium, plutonium, neptunium, and americium. In 1960, operations were suspended as a result of a lack of adequate containment for processing large quantities of radioactive material. Since that time, the facility has not been used for processing any radioactive materials.

3.1.1.1 Location and use

Building 3505 is directly adjacent to the WAG 1 Guniting and Associated Tanks (GAAT) OU south of the guniting tank farm near the intersection of Third Street and Central Avenue. The main processing area in Building 3505 is a single-story, steel-siding structure enclosing seven above-grade, concrete-shielded process cells and a below-grade dissolver pit. Building 3505 also includes operating galleries for the process cells and an equipment shop, change rooms, and offices.

Building 3505 proper was constructed in several stages. Cells A through E, the dissolver pit, and portions of the office areas were the first areas constructed. Later additions included Cells F and G, the upper portions of Cells B and C, and additional areas near the offices including the shop area. The canal was constructed shortly after operations began and was used as a water-shielded transfer canal.

A majority of the surfaces of the building, including the structural steel framing, built-up roof, metal roof, and the exterior metal siding, exhibits extensive rust and peeling. Generally, the building is in need of large scale maintenance and repair.

3.1.2 Construction and Description

Building 3505 comprises an adjacent below-grade transfer canal and processing cells. The canal is a 15-ft-deep, unlined concrete structure. Originally open, it has now been provided with a metal cover. There are seven process cells constructed of high-density reinforced concrete or concrete block, galleries, and support areas. In addition, the building contains a dissolver pit and dissolver room. The physical dimensions of the rooms in Building 3505 are given in Table 3.1.

Table 3.1. Building 3505 room dimensions

Room	Length	Width	Height
Canal	53 ft	6 ft	15 ft
Dissolver pit	10 ft	10 ft	10 ft
Dissolver room	16 ft	35 ft	20 ft
Cell A	19 ft	21 ft	17 ft
Cell B and C	8 ft	9 ft	29 ft
Cell D thru F	8 ft	9 ft	17 ft
Electrical gallery	77 ft	8 ft	8 ft*

* The gallery is 8 ft high but slopes to 7 ft

3.1.3 Past Activities and Current Building Contamination Status

Beginning in 1984, various areas of the facility were decontaminated. All of the process equipment was removed from the canal, all cells, the makeup area, and the electrical gallery. The specific information for each cell or building area is derived from internal Energy Systems memoranda (Williams, 1984; McNabb, 1985a,b; McNabb, 1986a,b,c; McNabb, 1987).

The canal area was decontaminated first, including removing all equipment from the canal and all sludge found in the bottom of the canal. The walls of the canal were cleaned, and the canal was filled with rock. The ground areas surrounding the canal were cleaned and left in place. All waste was disposed of in an ORNL solid waste storage area (SWSA).

The equipment from Cells A and B and the dissolver pit was removed in 1985. The cells were then closed and the wastes disposed of in compliance with regulations applicable to the nature of the waste generated. In 1986, Cells E, F, and G, and the electrical gallery were stripped of their equipment and cleaned. Equipment from Cells C and D was removed, and the cell walls were cleaned in 1987. In all cases, the waste materials were sent to the SWSA for disposal.

As noted in Sect. 2.1.1.2, the storage area, control room, shop, and the south part of the makeup area in Building 3505 are regulated areas where fixed contamination, but no transferrable contamination, is present. The cells, dissolver room and pit, and canal are highly contaminated.

The decommissioning efforts for each cell are described in various Energy Systems memoranda (Williams, 1984), (McNabb, 1985a,b), (McNabb, 1986a,b,c), and (McNabb, 1987). These memoranda describe the post-decommissioning radiological conditions in the cells as well as the attempts to clean the surfaces with oxalic acid, sodium hydroxide, and detergent. Those attempts were typically unsuccessful, leaving significant levels of surface contamination on the cell walls and floor. The *Feasibility Study for Building 3505 Decommissioning* (ORNL, 1980) describes the decontamination project performed on Cell G. Although generally successful, significant areas at penetrations and along edges of steel plates (e.g., door, floor pan) remain severely contaminated.

Mercury contaminated soil was found beneath the trough drain on the north side of the building. However, because mercury was not used in the processes conducted in this building, there is no basis for attempting to determine the extent of soil contamination.

3.1.4 Meteorology

Since 1947, the National Oceanic and Atmospheric Administration weather station at Norris Dam [approximately 23 miles (39 km) north of ORR] has maintained long-term meteorological records for the area. These data are also available from the National Oceanic and Atmospheric Administration Atmospheric Turbulence and Diffusion Division laboratory in Oak Ridge from 1959 to the present. Site-specific data for shorter periods of time are available from various sources within ORR.

The climate in the ORR vicinity is strongly influenced by the presence of the Great Smoky Mountains to the southeast and the Cumberland Mountains to the northwest. These mountains frequently divert the hot, southeasterly winds that develop in the summer along the southern Atlantic coast. In the winter, the Cumberland Mountains retard and weaken the force of cold winter air that commonly reaches south to these latitudes. These moderating influences result in warm, humid summers and cool winters. Noticeable extremes in precipitation, temperature, and winds seldom occur.

The mean annual temperature for the Oak Ridge area is 58°F (14.4°C) (Webster and Bradley, 1988). 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 (Davis et al., 1984).

The Oak Ridge area receives an average 53.75 in. (136.5 cm) of precipitation annually (Energy Systems, 1992a). Periods of five days or more without precipitation occur on average only four to five times per year (Boegly, 1984). Maximum monthly precipitation generally occurs from December through March and is associated with winter storms that are commonly of low intensity but long duration. Approximately 40% of the annual precipitation falls during

this interval. 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 (Davis et al., 1984). The higher intensity of the summer thunderstorms compared to the winter storms results in a higher percentage of runoff and less infiltration. The higher runoff and increased potential for evapotranspiration in the summer months also render the summer storms less effective in providing recharge to groundwater. September and October are normally the driest months of the year.

Winds in the Oak Ridge area are controlled to a large degree by the valley and ridge topography. Fig. 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).

Evapotranspiration is estimated regionally to range from 32 to 35 in. (81 to 89 cm) or 60% to 65% of rainfall (Farnsworth, Thompson, and Peck, 1982). Evapotranspiration in the Oak Ridge area is estimated to be 29 to 30 in. (74 to 76 cm) or 55% to 56% of annual rainfall (TVA, 1972; Moore, 1988; Hatcher et al., 1992). Values for evapotranspiration depend on site-specific conditions, including the nature of vegetation. In addition, evaporation varies within any given year and is greatest in association with the growing season, which in the ORR vicinity averages 220 days from April through September. During the growing season, evapotranspiration often exceeds the rate of precipitation, resulting in soil moisture deficits (Energy Systems, 1992a).

3.1.5 General Site Geology

ORR is in the western portion of the Valley and Ridge Physiographic Province in eastern Tennessee, which is part of the southern Appalachian fold-and-thrust belt (Fig. 3.2). In Tennessee, the Valley and Ridge Province is bordered on the west by the Cumberland Plateau and on the east by the Blue Ridge. ORR is approximately 6 miles (10 km) east of the eastern Cumberland Escarpment that separates the Valley and Ridge from the Cumberland Plateau.

The stratigraphic bedrock units present in ORR comprise a diverse assemblage of lithologies from Cambrian to early Mississippian in ages, although consisting predominantly of Cambrian- and Ordovician-aged marine deposits. Total thickness of these units is about 9500 ft (3 km). These units were deformed during the late Paleozoic (Permian-Pennsylvanian) age Alleghanian orogeny when the Blue Ridge sheet to the east pushed the Valley and Ridge sedimentary rocks in front of it. A variety of deformation structures developed in the Valley and Ridge, although the characteristic feature is a succession of northeast-trending thrust faults that structurally stack and replicate the Paleozoic rocks. About 10 major thrust faults dominate the structure in the Valley and Ridge Province at the latitude of ORR.

Two major thrust faults, the Copper Creek and White Oak Mountain faults, are traceable through ORR (Figs. 3.3 and 3.4). The section between White Oak Mountain and Copper Creek faults is referred to as the White Oak Mountain thrust sheet. Figure 3.5 shows a stratigraphic

ORNL-DWG 92M-7776

Fig. 3.1.

<p style="text-align: center;">RADIAN</p> <p>Source: MMIS DATE: 1992</p>	<p>1991 WIND ROSE FOR ORNL TOWER MT2 (100m LEVEL), WITH 80.4% OF POSSIBLE DATA</p>
<p>Wind rose for the Oak Ridge Reservation at ORNL</p>

LOCATIONS OF THE OAK
RIDGE RESERVATION IN THE
SOUTHERN APPALACHIAN
VALLEY AND RIDGE PROVINCE

Fig. 3.2. Location of the Oak Ridge Reservation in the Southern Appalachian Valley and Ridge Province.

LEGEND:

pCb PRECAMBRIAN BASEMENT
 Cr ROME FORMATION
 Ec CONASAUGA GROUP
 OCK KNOX GROUP
 Och CHICKAMAUGA GROUP

1 0.5 0 0.5 1
 MILE

NOTE: MODIFIED FROM SECTION BY JANET L. HOPSON, UNIVERSITY OF TENNESSEE.

RADIAN

Source: Hatcher et al.
 Date: 1992

GEOLOGIC CROSS-SECTION
 BASED ON SEISMIC LINE ON
 TENNESSEE 95

Fig. 3.4.

Geologic cross section based on seismic line on Tennessee Highway 95

		LITHOLOGY	Thickness, m	Formation		Structural Characteristics	Hydrologic Unit	
ORDOVICIAN	UPPER		100-170	Omc	Moccasin Formation	Weak unit Upper décollement	Aquifer	
			105-110	Owi	Witten Formation			
			5-10	Obw	Bowen Formation			
	MIDDLE		110-115	Obe	Benbolt/Wardell Formation		Strong units Ramp zone	Aquifer
			80-85	Ork	Rockdell Formation			
			75-80	Ofl	Hogson Member Flegnor Shale Member	Limestone fm		
	70-80		Oe Obl	Eidson Member Blackford Formation				
	LOWER		75-150	Oma	Mascot Dolomite	Strong units Ramp zone		Aquifer
			90-150	Ok	Kingsport Formation			
			40-60	Olv	Longview Dolomite			
152-213		Oc	Chepultepec Dolomite					
244-335		Cr	Copper Ridge Dolomite					
CAMBRIAN	UPPER		100-110	Cmn	Maynardville Limestone	Weak units Basal décollement	Aquifer	
	MIDDLE		150-180	Cn	Nolichucky Shale			
			98-125	Cdg	Dismal Gap Formation (Formerly Maryville Ls.)			
			25-34	Crg	Rogersville Shale			
			31-37	Cf	Friendship Formation (Formerly Rutledge Ls.)			
			LOWER	56-70	Cpv			Pumpkin Valley Shale
	122-183			Cr	Rome Formation			

Fig. 3.5. Stratigraphic section in Bear Creek Valley, Chestnut Ridge, Bethel Valley, Haw Ridge, Melton Valley, and Copper Ridge

RADIAN

Source: Hatcher et al.
Date: 1992

Environmental Restoration Program

STRATIGRAPHIC SECTION IN BEAR CREEK VALLEY,
CHESTNUT RIDGE, BETHEL VALLEY, HAW RIDGE,
MELTON VALLEY, AND COPPER RIDGE

section of the White Oak Mountain thrust sheet in the vicinity of ORNL. The rocks present in this area range in age from lower Cambrian to upper Ordovician.

As a result of differential erosion subsequent to deformation, a series of valleys and ridges have formed paralleling the thrust faults. Generally, the more erosion-resistant siltstone, sandstone, and dolomite units form the region's ridges, and the less erosion-resistant shales and shale-rich carbonates underlie the valleys. Northwest-facing slopes on the ridges tend to be relatively short, steep, and smooth. Southwest-facing slopes tend to be longer, shallower, and hummocky to dissected. The general features distinguishing the Valley and Ridge Province include:

- parallel ridges and valleys commonly aligned from northeast to southwest;
- topography caused by erosion of interstratified weak and strong formations that are exposed at the surface;
- a few major transverse, superimposed streams with subsequent streams forming a trellis-like drainage pattern;
- many ridges with accordant summit levels; and
- many water and wind gaps through resistant ridges.

3.1.6 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. 3.6). 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.

Building 3505 is underlain by rocks of the Ordovician-aged Chickamauga Group in the upper part of the stratigraphic section (Fig. 3.5). These rocks strike northeast-southwest and dip toward the southeast. Dips range from 25° to 40°, with an average dip of approximately 35°. The Copper Creek fault outcrops on the lower to middle northwestern slope of Haw Ridge. This thrust fault separates the younger Chickamauga Group from the overlying siltstone and sandstone of the middle Cambrian-aged Rome Formation that forms the crest of the ridge and is part of the Copper Creek thrust sheet.

The Chickamauga Group consists of interbedded limestones and siltstones. Detailed mapping of the ORNL area was first conducted by Stockdale (1951). Stockdale divided the Chickamauga into eight mappable units designated "A" (oldest) through "H" (youngest), based on differences in lithology. Lee and Ketelle (1988) confirmed Stockdale's unit designations based on examination of core and geophysical logs from five boreholes drilled to provide stratigraphic overlap perpendicular to strike. Differences in the reported unit thickness and variations in the descriptions of informal subdivisions within individual units reported by Stockdale (1951) and by Lee and Ketelle (1988) suggest significant lateral lithologic variability in some units.

Hatcher et al. (1992) refined the previous stratigraphy to subdivide the group into standard stratigraphic units based on field criteria recognized elsewhere in the region. The subdivision of the Chickamauga Group in Bethel Valley was based on the appearance of distinctive red bed units that could be correlated with detailed stratigraphic analysis along the structure. The provisional stratigraphic nomenclature proposed by Hatcher et al. (1992) is shown in Fig. 3.5.

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 (DOE 1992d, 1992e, 1992f, 1992g, 1992h). The bedrock geology at ORNL shown in Fig. 3.7 is derived from the construction of six new boreholes, 286 soil borings, related data gathering activities, and the evaluation of previous information.

Figure 3.8 shows a geologic cross section in the vicinity of Building 3505. Except for Tank TH-4 which is underlain by Stockdale's Unit F, all facilities associated with Building 3505 are underlain by Stockdale's Unit E.

Hatcher et al. (1992) refer to Unit E as the Benbolt Formation, which was originally described by Cooper and Prouty (1943) based on exposures located in Virginia. Hatcher describes the Benbolt Formation as a relatively heterogeneous formation that is 360 to 377 ft (110 to 115 m) thick. "The Benbolt consists of thick interbeds of fossiliferous nodular limestone; unfossiliferous, amorphous micrite within a dark-gray siltstone matrix; dark-gray siltstone; and unfossiliferous calcarenite" (Hatcher et al., 1992). The Benbolt weathers to a characteristic pale buff color.

Hatcher et al. (1992) refer to Unit F as the Bowen Formation also based on exposures located in Virginia originally described by Cooper and Prouty (1943). The Bowen Formation is a very distinctive maroon-colored unit used as a reliable marker for both field and subsurface correlations. The Bowen Formation is 16 ft to 32 ft (5 m 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.

Fractures on the ORR are well developed in all stratigraphic units and are the most pervasive mesoscopic structure (Hatcher et al., 1992). Both systematic and nonsystematic fractures are present and were formed at various times during the tectonic history of the southern Appalachians. Structural deformations include early Paleozoic basin subsidence, late Paleozoic folding and thrusting, Mesozoic rifting, and Cenozoic erosional unloading. Although there is some scatter in the orientation of the fractures, most fracture networks tend to develop systematic orientations over a particular area, allowing patterns to be interpreted (Solomon et al., 1992). Fracture orientations observed in a previous study of the Chickamauga Group in Bethel Valley include bed-normal extension fractures parallel and perpendicular to bedding strike, bed-oblique shear fractures, and bed-parallel shear fractures (Hatcher et al., 1992).

Fracture density is highly variable; reported values on ORR range from 5 to 200 per 3.3 ft (1 m) (Solomon et al., 1992). Fracture lengths generally range from several inches (centimeters) up to 3.3 ft (1 m). Fracture spacing in limestones ranges from less than 2 in. (5 cm) in very thin beds to more than 9.8 ft (3 m) in very thick or massive beds. Haase, Walls,

Fig. 3.7. Bedrock geology of Building 3505

and Farmer (1985) reported that fracture density is greater in thinner beds, and many fractures are filled or coated with secondary minerals (often calcite).

A relatively thin overburden has developed over the bedrock in Bethel Valley. Investigation during the site characterization of WAG 1 indicated that this overburden is typically less than 30 ft (9 m) thick (DOE, 1992d). In the vicinity of the North Tank Farm and South Tank Farm, the thickness of the overburden is between 10 and 20 ft (3.1 and 6.1 m). The overburden materials may contain three components: soil materials (residual soil, alluvium, and colluvium), saprolite (weathered bedrock containing relic structures), and fill material (recompacted natural soil, imported material, and waste). As a result of the construction activities for Building 3505, fill is probably the primary material encountered, while natural soil structure or saprolite has probably been eliminated.

Natural soils that develop over the Chickamauga bedrock are generally fine-grained with the predominant soil classification being a low- to high-plasticity clay and silt containing greater than 50% fines. Soils forming over Unit E (Benbolt Formation) are classified as Hapludults or Hapludalfs, while soils forming over Unit F (Bowen Formation) are classified as Hapludalfs-Argiudalfs-Rendolls-Rock Ledges Complex (Hatcher et al., 1992). Hapludalfs and Hapludults are groups within the Alfisol and Ultisol orders, respectively. Alfisols have a clay-enriched subsoil horizon and more than 35% base saturation at a depth of 5.9 to 6.6 ft (1.8 to 2.0 m). Ultisols are similar to Alfisols but are mostly highly weathered and experience less than 35% base saturation at a depth of 5.9 to 6.6 ft (1.8 to 2.0 m). These soil types are mapped as Collegedale/Gladeville and Carbo/Gladeville series by Moneymaker (1981). Because of construction activities over much of ORNL, most of the natural soil structure has been disturbed.

Saprolite is weathered bedrock that maintains some of the structural features (i.e., bedding and folding) of the parent material. Saprolite represents a transition zone between soil and bedrock materials. Saprolite was encountered in less than 5% of the borings completed during the WAG 1 site characterization activities. The saprolite was most commonly encountered in the overburden above Unit H but was also encountered above Unit E. Because of the infrequent, irregular, and discontinuous pattern of saprolite development, insufficient data were available for the preparation of a saprolite distribution map.

3.1.7 Site Hydrogeology

Solomon et al. (1992) described a conceptual model for groundwater flow and contaminant transport in the ORR. The model represents an integration of data, information, and concepts from many previous hydrologic investigations to provide a generic description of the ORR hydrogeology. This new conceptual model provides the overview of the ORR hydrogeology necessary to support detailed site investigations.

Initial intergranular porosity that existed in the original deposition of the sediments [porosity values ranged from 25% or more for unconsolidated sediments (Freeze and Cherry, 1979)] comprising the bedrock underlying ORR has been reduced as a result of processes associated with induration and lithification. Processes include both mechanical compaction (grain rearrangement and grain breakage) and chemical compaction (pressure dissolution at grain-to-grain contacts), with subsequent deposition as a cement. Both processes occurred as a result of original

deposition and burial and subsequent deformation. Typically, these processes can account for a reduction in primary porosity of one or two orders of magnitude (Brahama et al., 1988). Reported values for porosity of unfractured Chickamauga rock collected from depths greater than 2000 ft (610 m) ranged between 0.39% and 1.5% (deLaguna et al., 1988). Moore (1989) estimated the effective porosity at ORR to be in the range of 0.001% to 0.1%. Presence and movement of groundwater at ORR depend on secondary porosity derived from the development of an extensive fracture network in the bedrock and on the properties of the overburden.

The conceptual model of the hydrogeology described by Solomon et al. (1992) assigns the Knox Group and the Maynardville limestone of the Conasauga Group to part of the Knox aquifer. 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 that underlies ORNL, are classified as aquitards. (Figure 3.9 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.

Since the bedrock matrix is relatively impermeable, groundwater flow in the bedrock is controlled primarily by the presence of joints and fractures. As previously described, joints and fractures pervade the rocks on ORR due to the complex tectonic history of the area. Although the nature and orientation of the fractures vary over the ORR, a fracture network generally develops a systematic orientation within a particular area. In the Chickamauga Group in Bethel Valley, three orthogonal fracture sets have developed (Hatcher et al., 1992). One fracture set was formed by bedding planes that have an average strike of approximately N55°E; the dip is variable but is commonly about 30° to 48°SE (Stockdale, 1951). A second fracture set is also parallel to strike but perpendicular to the bedding plane; the dip varies with the dip of the bedding plane, which is a function of depth, and dips more steeply near the surface. The third fracture set is perpendicular to strike.

The effectiveness of the fracture network in controlling groundwater flow depends on the fracture spacing, degree of interconnectivity between fractures, and the effective fracture aperture. All three parameters have been observed to vary laterally with changes in the lithology as well as the thickness of the unit or individual beds. More important to the conceptual model, the three parameters vary with depth and provide the distinction between the different flow zones in the bedrock. The description of several intervals within the groundwater zone reflects the change in the fracture network with depth.

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.

RADIAN

Source: Solomon et al.
DATE: 1992SCHEMATIC VERTICAL
RELATIONSHIP OF FLOW
IN AQUITARDS OF THE ORR

Fig. 3.9. Schematic vertical relationship of flow of aquitards of the Oak Ridge Reservation

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. Solomon et al. (1992) estimate 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. Solomon et al. (1992) estimate that approximately 8% of the total groundwater flow occurs in the water table interval.

Lee and Ketelle (1988) proposed the concept of stratabound flow for movement of groundwater in the fractured bedrock at ORR. The movement of groundwater in the bedrock is still influenced by the hydraulic gradient, but the control on the direction of movement will be the orientation and interconnectivity of the effective fracture network. Since the fracture network is related to the lithology of the stratigraphic units or individual beds, certain strata will have better developed fracture networks than others. These better developed networks will provide preferential flow paths parallel to the strike of the strata.

The overburden consists of regolith composed mostly of clay and silt material that is derived mainly from weathering of underlying bedrock material. The thickness of the overburden at ORNL in Bethel Valley is generally less than 30 ft (9 m). This fine-grained material has significant intergranular porosity resulting in a large water storage capacity and a low permeability.

The conceptual model defines two zones within the overburden: the stormflow zone and the vadose zone. The stormflow zone consists of the upper 3 ft to 6 ft (1 m to 2 m) of overburden and corresponds approximately with the root zone of vegetation (Solomon et al., 1992). Although the stormflow zone is composed of essentially the same overburden material as the vadose zone, the stormflow zone has a significantly higher permeability, which is created primarily by root channels, worm holes, clay aggregation, and fractures that can be collectively referred to as large pores (Solomon et al., 1992) or macropores. Field data indicate that the stormflow zone can be as much as 1000 times more permeable than the underlying vadose zone (Solomon et al., 1992).

Between rains, void spaces in both the stormflow and vadose zones are unsaturated while the stormflow zone will become partially or completely saturated during rainfall. Recharge through the vadose zone will be limited to discrete permeable features (i.e., relic fractures or macropores) while the surrounding material remains unsaturated and contains trapped air. Since downward infiltration of precipitation is limited by the lower permeability of the vadose zone, the stormflow zone will transmit significant volumes of water laterally to the surface water system. Detailed water balance calculations indicate that approximately 90% of groundwater flow occurs within the stormflow zone (Solomon et al., 1992).

The chemical characteristics of the ORR groundwater change with depth. These changes are probably related to the nature of flow in the fracture network and the residence time for the water in the formation, although this has not been quantified (Solomon et al., 1992). Groundwater in the upper part of the system (including the stormflow zone, the water table interval, and the intermediate interval) is a mixed bicarbonate type with calcium cation predominant [$\text{Ca}(\text{HCO}_3)_2$]. With increasing depth, the groundwater chemistry changes to a sodium bicarbonate type (NaHCO_3). In Bethel Valley, this transition occurs at depths in the range of 100 to 160 ft (30 to 50 m) below land surface and is used to mark the separation of the intermediate and deep intervals. With further increasing depth, the groundwater chemistry gradually changes to a sodium chloride type (NaCl) with elevated dissolved solid content that ranges from approximately 40,000 to 300,000 mg/L. This transition occurs at depths from 590 to 787 ft (180 to 240 m) in Bethel Valley and marks the transition between the deep interval and the aquiclude. The composition of this groundwater resembles NaCl brines associated with major sedimentary basins such as the Gulf Coast of the United States. The origin of the brine is unknown, although it is probably formation waters that have undergone extensive water/rock interactions.

The conceptual model for groundwater flow in the Chickamauga Group aquitard in Bethel Valley indicates that approximately 98% of the flow occurs within 50 ft (15 m) of the land surface. Approximately 90% of this flow would occur in the stormflow zone within 3 to 6 ft (1 to 2 m) of the surface. An additional 8% of the flow would occur within the top 3 to 15 ft (1 to 5 m) of the fractured bedrock. Groundwater flow paths are relatively short with lengths on the order of 10 to a few hundred ft before discharging into local surface drainage features.

The *Site Characterization Summary Report* reports site characterization activity results for WAG 1 that are generally consistent with the conceptual model. Flow in the bedrock is through fractures with the hydraulic conductivity generally decreasing with depth, although there is a range in the data that reflects significant site-specific variability. The overburden material generally consists of a low-plasticity clay which has a relatively low hydraulic conductivity. The *Site Characterization Summary Report* does not specifically address identification of a distinct stormflow zone in the overburden.

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. 3.10). 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 3505 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. To control potential leaks from the tanks, a system of dry wells was installed. The concrete pads on which the actual tanks were constructed have larger diameters than the

LEGEND

WV-396 MONITORING WELL LOCATION, NUMBER
 732.77 AND WATER LEVEL 4/91
 WV-885 PIZOMETER LOCATION, NUMBER
 A784.18 AND WATER LEVEL 4/91
 Core Hole Location
 HIGH BASE LEVEL
 POTENTIOMETRIC CONTOUR LINE
 POTENTIAL GROUNDWATER FLOW LINE

A horizontal scale bar labeled "SCALE IN FEET" with markings at 50, 0, 50, and 100.

RADIANT

WATER-TABLE IN THE VICINITY
OF THE GAAT OU UNDER HIGH
- THE CONDITIONS APRIL 1991

Fig. 3.10. Water Table in the Vicinity of Building 3505 Under High Flow Conditions, April 1991.

tanks (as if the tanks were cups sitting on the saucer-like pads). The pads include a curb and gutter system that drains by means of a 6-in. (15-cm)-diameter terra cotta drain tile system to six individual dry wells, all of which connect to a common drain for pumping to the equalization basin (see Sects. 2.2 and 2.3). Design drawings indicate that a 3-ft (0.9-m)-thick layer of 2-in. (5.1-cm) crushed limestone was placed around the exterior wall from the base to the top of the tank [about 12 ft (3.7 m)]. If a tank were to leak, the liquid would flow down through the crushed rock, collect in the curb and gutter system, and be captured in the dry wells where routine monitoring would detect the leak.

The use of fill material influences the occurrence and movement of groundwater as well as the movement of contamination at ORR (Stockdale, 1951; Ashwood et al., 1986; Huff, 1985; Stansfield and Francis, 1986; Geraghty & Miller, 1986). 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 South Tank Farm was reportedly draining an average of 26,500 gallons (100,300 L) per day (Mynatt and Webster, 1963). 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.

3.1.8 Potentially Exposed Population

Populations potentially exposed to contaminants in Building 3505 and/or released to the environment from Building 3505 include both human and ecological receptors. The potential human receptors can be divided into the following groups:

- Employees of Energy Systems and its subcontractors at ORNL, DOE, the Tennessee Department of Environment and Conservation (TDEC), and the U.S. Environmental Protection Agency (EPA) and other individuals who visit ORNL.
- Residents of Oak Ridge and surrounding communities.
- Individuals who use the recreational facilities on or near the ORR.
 - Individuals who trespass onto the site seeking permanent or temporary shelter under future scenarios.

Potential ecological receptors are terrestrial and aquatic organisms that 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.

3.1.8.1 Demography and Land Use

ORR covers approximately 35,300 acres (14,300 ha) of federally-owned land in eastern Tennessee (Fig. 3.11). ORNL is in the approximate center of ORR (refer back to Fig. 1.1). TVA's Melton Hill reservoir on the Clinch River and Watts Bar Reservoir on the Tennessee

Fig. 3.11. DOE Oak Ridge Reservation and Geographic Region.

River form the eastern, southern, and western boundaries of 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, ORR is located inside the city limits. In addition to the city of Oak Ridge, the nearest population centers to ORR include Oliver Springs (pop. 3400), 6.8 miles (11 km) to the northwest; Clinton (pop. 9000), 10 miles (16 km) to the northeast; Lenoir City (pop. 6100), 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 is the closest major metropolitan area. Knoxville is approximately 25 miles (40 km) east of ORR and has a population of approximately 165,000. Knox County, which includes Knoxville, has a population of 335,749.

Figure 3.12 shows the population density within 10 miles (16 km) of the center of 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 ORR, which includes a portion of the city of Oak Ridge. Figure 3.13 shows the population density within 50 miles (80 km) of the ORR.

As of February 1993, ORR employs approximately 16,000 regular employees, with 5782 employees working at ORNL. Most employees at ORNL work at facilities that are located either within or adjacent to Building 3505.

Current Land Use

Workers' activities in the vicinity of Building 3505 are those common to industrial complexes. These include pedestrian and motor vehicle traffic, utility repair, and grounds maintenance. Currently, there are no worker activities within Building 3505 except for routine surveillance and maintenance requiring protective clothing and daily checks on alpha and beta instruments and checks on pressure drops across filters. Protective clothing and respirator protection is required when entering the process cells. Activities are regulated and conducted under approved health and safety plans and monitored by the Industrial Hygiene and Health Physics Departments as necessary.

For this Level III BRE, two hypothetical current exposure scenarios have been developed to provide a conservative (i.e., health-protective) estimate of potential exposure. The first hypothetical current receptor is a maintenance worker who spends 8 h/d, 250 d/year for 25 years working in the building. This receptor provides a worst-case or upper-bound estimate of potential exposure at the facility. A second more realistic receptor is represented by an S&M worker who spends two 8-h days per year in the facility for 25 years. This second receptor provides a more realistic, but still health-protective, estimate of potential exposure at the facility. It is also assumed that protective measures are not taken by either worker. Current exposure scenarios and receptors evaluated in this BRE are summarized in the next section in Table 3.2.

<p>RADIAN</p> <p>Source: WWES</p> <p>DATE: 1992</p>	<p>PROJECTED 1991 POPULATION DENSITIES WITHIN 10 MILES (16km) OF THE CENTER OF THE OAK RIDGE RESERVATION</p>
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Fig. 3.12. Projected 1991 population densities within 10 miles (16 km) of the Center of the Oak Ridge Reservation

RADIAN

Source: WMCS
DATE: 1992

ENVIRONMENTAL RESTORATION PROGRAM

PROJECTED 1991 POPULATION
DENSITIES WITHIN 50 MILES
(80km) OF THE CENTER OF
THE OAK RIDGE RESERVATION

Fig. 3.13. Projected 1991 Population Densities within 50 miles (80 km) of the Center of the Oak Ridge Reservation.

Future Land-Use

Building 3505 is located in the main plant area of ORNL. This area is highly developed, and land use is expected to remain industrial for the foreseeable future. The population of Oak Ridge is currently stable. Growth is hindered by a lack of developable land. If DOE were to release portions of the ORR to the public, expansion of Oak Ridge would be expected to follow.

This BRE 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 is based on the assumption that, at the outset of the BRE, Building 3505 has already been abandoned by DOE. In this scenario, DOE makes no attempt to prevent contaminant releases from the facility or restrict access to the facility. Because Building 3505 is on the ORR and the DOE does not intend to release this 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 also assumed that an adult trespasser (e.g., a squatter) can enter the building and take up residence. This is a conservative exposure scenario designed to fulfill the intent of a future no-action. It is unlikely that a trespasser could enter the building even if access to the building were not restricted because the building is on DOE property under controlled access. Actual future exposures are likely to be limited to S&M workers (as described for current land use) or the occasional trespassing worker if S&M activities are discontinued.

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 will be released to the surrounding environment via wind erosion and dust transport, washout with rain, windborne vapors, and, potentially, tracking of contaminants by humans and small animals visiting the site. Such contaminant releases could potentially result in exposure of off-site (i.e., outside DOE property) residential receptors. Such off-site exposures have not been included in the quantitative risk evaluation because the quantity of radioactivity is insufficient to result in significant off-site exposures. The potential exposure scenarios and receptors associated with the future land-use scenario evaluated in this BRE are summarized in Table 3.2.

Table 3.2. Land use scenarios evaluated in the BRE

Scenario	Action	Final Property Dispersement	Receptors
Current Land Use			
"Worst-case" worker exposure	Maintenance and other work requiring daily access by workers.	NA	Worker—routine, daily access
Normal S&M exposure	Normal S&M activities require worker access twice per year.	NA	Worker—limited access to facility
Future Land Use			
Abandonment	Complete immediate abandonment of the building.	None; DOE releases property without converting the land to any predetermined use (i.e., "as is" conditions).	Trespasser—an adult trespasser may take up residence in the vacant building.
	Loss of institutional controls on the building.		

3.1.9 Potential Ecological Receptors

The following information is taken from the *Preliminary Risk Assessment Report for Waste Area Grouping 1 at Oak Ridge National Laboratory, Oak Ridge, Tennessee* (Bechtel, 1992).

3.1.9.1 Potentially affected habitats

Building 3505 is located inside the main industrial area of ORNL and has little natural habitat. The vegetation surrounding Building 3505 consists primarily of grass lawns and landscaping plants.

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).

3.1.9.2 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 caerulea*), 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 (*Rhinichthys atratulus*) and creek chubs (*Semotilus atromaculatus*). Fathead minnows (*Pimephales promelas*) and 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 (Bechtel, 1992), which relied on data from the Biological Monitoring and Abatement Program, and data collected during the RI 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 3505. Contamination released as a result of catastrophic events or through building decay may reach ecological receptors, but the effect, if any, caused by the contaminants released from Building 3505 would be hard to differentiate from the level of contamination (and its effects) that already exists within WAG 1.

3.2 IDENTIFICATION OF EXPOSURE PATHWAYS

The purpose of this section is to discuss the potential for human exposure to contaminants found in Building 3505. This section presents characterizations of the potentially exposed populations and identify actual or potential pathways of exposure. An exposure results where exposure pathways are complete. 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 or environmental contact with the contaminated medium
- An exposure route at the exposure point

If any one 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. The CSMs for Building 3505 are depicted in Fig. 3.14 and are discussed in the following paragraphs.

The primary source of contaminants at Building 3505 was the process equipment located in the canal, cells, makeup area, and electrical gallery. The primary mechanism for historical releases were leaks and spills from these process systems. Leaks and spills from the process equipment contaminated the walls and floors, which subsequently function as secondary sources of contamination. As depicted in Fig. 3.14, releases from the secondary sources can result in contamination of the exposure media. Exposure media are those contaminated media that receptors can potentially contact and may include secondary sources.

Potential operational releases include resuspension of contaminated dust from pedestrian and vehicular (tow motor) traffic and resuspension of dust from insulation and walls. Potential releases due to natural phenomena include wash-out of particulate-bound or dissolved-phase contaminants from storm water after partial or complete loss of the roof and wind dispersion of contaminants. Once contaminants are in the environment they become available for uptake into the food chain. Human and ecological exposures may result when contaminated aquatic or terrestrial biota are consumed (i.e., fish) or when crops are grown in contaminated soil or irrigated with contaminated surface or groundwater.

3.2.1 Potential Sources and Receiving Media

Plutonium-239 will be considered the primary radioisotope of concern in the canal, all cells, the makeup area, and in the electrical gallery. Even though this is the most obvious choice as a radioisotope of potential concern, other radioisotopes will be considered in this evaluation including uranium-238, americium-241, cesium-137, strontium-90, and technetium-99. Areas where high concentrations or large volumes of these contaminants exist are potential sources for

Fig. 3.14. Conceptual Site Model for Building 3505.

release. The magnitude of the release is controlled by the initiating event, the integrity of the containment unit, and the form of the contaminant.

Much of the plutonium (or other radioisotopes being considered) in this facility exists as surface contamination particles; the remainder is associated with the building structure. This association makes releases of large volumes of contaminants highly unlikely. Asbestos is found in the walls and ceilings of the building and may be contaminated with varying amounts of plutonium or other COPCs. The nature of this material presents a possible source for release of contamination under upset conditions (such as a tornado) or during activities that result in a loss of integrity of the insulation such as removal.

Potential receiving media include the air, process equipment, and building structure under current conditions, and environmental media (soil, water, and air) in the future as a result of releases following natural disaster or building decay.

3.2.1.1 Current sources and receiving media

Current contaminant release from the building structure can occur by generation of dust resulting from pedestrian and traffic across the concrete floor. Transport of significant dust borne contaminants outside of the building via this traffic is not expected to occur.

3.2.1.2 Future sources and receiving media

Future sources of contaminant release include all media inside Building 3505, such as building structure and insulation. The magnitude of the release and transport of contaminants depend on the initiating event. Catastrophic events such as tornados have a potential for releasing large quantities of contaminated material to the environment over a very short time period. Other events such as storm water runoff following partial or complete loss of the building roof could result in long-term releases of smaller quantities of contaminants. The media receiving these releases would be the soil adjacent to the building, groundwater via infiltration/percolation of rain water, and the atmosphere. Releases to the atmosphere may result in deposition of contaminants over varying distances depending on temperature, particle size, wind speed, and other factors.

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 once a receptor comes in contact with the contaminated media (i.e., ingestion, inhalation, etc.).

3.2.2.1 Potential current exposures

Current exposure routes at Building 3505 are limited to incidental ingestion and dermal contact with contaminants, inhalation of dust, and external exposure to radiation by workers and visitors. Health and safety measures at ORNL mitigate exposures to workers or visitors by requiring the use of protective clothing and respirators, prohibiting eating or smoking in former process areas, and limiting access to areas of high radiological contamination. Potential exposures are discussed in the following paragraphs for each medium of concern. The current

exposure pathways evaluated in this BRE are listed in Table 3.3. Current exposures to surface water, groundwater, and soil are beyond the scope of this document.

Table 3.3. 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	Building Workers ^a	●	N/A	N/A	○
	Building Structure	Building Workers	N/A	●	●	●
	Surface Water	Building Workers	○	○	○	○
	Groundwater	Building Workers	○	○	○	○
	Soil	Building Workers	○	○	○	○

● Complete pathway

○ No complete pathway

N/A Not applicable

^a Building workers are ORNL employees who routinely access Building 3505 for the purpose of maintenance.

Air. Inhalation of contaminated dusts is a pathway of concern at this site. Maintenance and S&M workers entering Building 3505 could be exposed via this route.

Building Structure (Floor, Walls, Etc.). Dermal absorption, incidental ingestion of contaminants, and external exposure to radionuclides present on the inside surfaces of the building structure are potential exposure pathways for current maintenance workers and visitors.

Soil. Contaminated soil adjacent to and beneath the building could potentially expose maintenance workers by dermal contact, incidental ingestion, and inhalation of fugitive dusts. Off-site exposures to contaminants in the soil could result from deposition of air- or waterborne contaminants. Current exposure to contaminants in soil is considered to be outside the scope of the D&D Program and is not evaluated in this BRE.

3.2.2.2 Potential future exposures

Table 3.4 presents the evaluation of potential future exposure pathways evaluated in the BRE. Future exposures to contaminants at Building 3505 include incidental ingestion and dermal contact with contaminated media, inhalation of radioactive contaminated particulate-phase contaminants and external exposure to radionuclides. Future exposures could also result from releases of contaminants to the environment.

Table 3.4. Selection of Potential Future Exposure Pathways

D&D Facility Use Scenario	Exposure Medium	Receptor	Exposure Route			
			Inhalation	Ingestion	Dermal Absorption	External Radiation
Abandonment	Air	Trespasser/Adult ^b	●	N/A	N/A	○
	Building Structure	Trespasser/Adult	N/A	●	●	●
	Surface Water	Trespasser/Adult	○	○	○	N/A
	Groundwater	Trespasser/Adult	○	○	○	N/A
	Soil	Trespasser/Adult	○	○	○	○

● Potentially complete pathway

○ No complete pathway

N/A Not applicable

^a The adult trespasser is an individual who takes up residence in the building after the loss of institutional controls.

Air. Workers and trespassers within the building, as well as ORNL workers in surrounding facilities and off-site residents could be potentially exposed via this route.

Building Structure (Floor, Walls, Process Equipment, Etc.). Future workers or trespassers could incur exposure by dermal absorption, incidental ingestion of contaminants, or external exposure to radionuclides present on the inside surfaces of the building structure and on any remaining equipment in the building.

3.2.2.3 Complete exposure pathways

As depicted in Tables 3.3 and 3.4, complete exposure pathways include inhalation of dust, incidental ingestion of contaminated dust from casual hand-to-mouth contact, and external exposure to radiation. However, activities at Building 3505 are conducted under an approved Health and Safety Plan. Workers are required to wear protective clothing including respirators when they are engaged in activities that could resuspend dusts. In addition, smoking and eating are prohibited in the former process areas of the building, reducing the potential for incidental contaminant ingestion.

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 contaminant of potential concern in the exposure media at the point of human exposure, and
- estimating human intakes.

3.3.1 Exposure Models

Exposures were estimated for ingestion, inhalation, dermal absorption, and external radiation exposure using the following equations derived from the *Risk Assessment Guidance for Superfund* (RAGS) (EPA, 1989a). Table 3.5 defines the variables, which have been derived from standard intake rates, skin surface areas, adherence factors, exposure frequency, and duration according to EPA (1989a) and EPA *OSWER Directive 9285.6-03*, used in each exposure equation.

Ingestion of dust

$$\frac{CS \times IR \times CF \times FI \times EF \times ED}{BW \times AT}$$

Inhalation of dust

$$\frac{CW \times IR \times EF \times ED \times \frac{1}{PEF}}{BW \times AT}$$

External exposure to radionuclides

$$CS \times CF \times ED \times (1 - S_e) \times T_e$$

Dermal contact with dust

$$\frac{CS \times CF \times SA \times AF \times ABS \times EF \times ED}{BW \times AT}$$

Table 3.5. Definition of Exposure Variables for Building 3505 Exposure Assessment

Equation	Receptor	Variable	Definition	Value and Units Used
Ingestion of dust	Building worker	<i>CS</i>	Exposure concentration	mg/kg (from values in Tables 3.6–3.13)
		<i>IR</i>	Intake rate	50 mg/day
		<i>CF</i>	Conversion factor	1×10^{-6} kg/mg
		<i>FI</i>	Fraction ingested	1 (unitless)
		<i>EF</i>	Exposure factor	250 d/year
		<i>ED</i>	Exposure duration	25 years
		<i>BW</i>	Body weight	70 kg
		<i>AT</i>	Averaging time	Noncarcinogen: $ED \times 365$ d/year Carcinogen: $70 \text{ yr} \times 365$ d/year
	Adult resident	<i>CS</i>	Exposure concentration	mg/kg (from values in Tables 3.6–3.13)
		<i>IR</i>	Intake rate	100 mg/day
		<i>CF</i>	Conversion factor	1×10^{-6} kg/mg
		<i>FI</i>	Fraction ingested	1 (unitless)
		<i>EF</i>	Exposure factor	350 d/year
		<i>ED</i>	Exposure duration	24 years
		<i>BW</i>	Body weight	70 kg
		<i>AT</i>	Averaging time	Noncarcinogen: $ED \times 365$ d/year Carcinogen: $70 \text{ yr} \times 365$ d/year
Inhalation of dust	Building worker	<i>CS</i>	Exposure concentration	mg/m ³ (from values in Tables 3.6–3.13)
		<i>IR</i>	Intake rate	20 m ³ /d
		<i>EF</i>	Exposure factor	250 d/year
		<i>ED</i>	Exposure duration	25 years
		<i>PEF</i>	Particulate emission factor	4.63×10^9 m ³ /kg
		<i>BW</i>	Body weight	70 kg
		<i>AT</i>	Averaging time	Noncarcinogen: $ED \times 365$ d/year Carcinogen: $70 \text{ yr} \times 365$ d/year
	Adult resident	<i>CS</i>	Exposure concentration	mg/m ³ (from values in Tables 3.6–3.13)
		<i>IR</i>	Intake rate	20 m ³ /d
		<i>EF</i>	Exposure factor	350 d/year
		<i>ED</i>	Exposure duration	24 years
		<i>PEF^a</i>	Particulate emission factor	4.63×10^9 m ³ /kg
		<i>BW</i>	Body weight	70 kg
		<i>AT</i>	Averaging time	Noncarcinogen: $ED \times 365$ d/year Carcinogen: $70 \text{ yr} \times 365$ d/year
External exposure to radionuclides	Building worker	<i>CS</i>	Exposure concentration	pCi/kg (from the values in Tables 3.6–3.13)
		<i>CF</i>	Conversion factor	1×10^{-3} kg/g

Table 3.5 (continued)

Equation	Receptor	Variable	Definition	Value and Units Used
		<i>ED</i>	Exposure duration	25 years
		$(1-S_e)$	Gamma shielding factor	Unitless
		T_e	Gamma exposure time factor	Unitless
	Adult resident	<i>CS</i>	Exposure concentration	pCi/kg (from values in Tables 3.6–3.13)
		<i>CF</i>	Conversion factor	1×10^{-3} kg/g
		<i>ED</i>	Exposure duration	24 years
		$(1-S_e)$	Gamma shielding factor	Unitless
		T_e	Gamma exposure time factor	Unitless
Ingestion of groundwater	Building worker	<i>CS</i>	Exposure concentration	mg/l (from values in Tables 3.6–3.13)
		<i>IR</i>	Intake rate	2 l/day
		<i>EF</i>	Exposure factor	250 d/year
		<i>ED</i>	Exposure duration	25 years
		<i>BW</i>	Body weight	70 kg
		<i>AT</i>	Averaging time	Noncarcinogen: $ED \times 365$ d/year Carcinogen: 70 yr $\times 365$ d/year
	Adult resident	<i>CS</i>	Exposure concentration	mg/l (from values in Tables 3.6–3.13)
		<i>IR</i>	Intake rate	2 l/day
		<i>EF</i>	Exposure factor	350 d/year
		<i>ED</i>	Exposure duration	24 years
		<i>BW</i>	Body weight	70 kg
		<i>AT</i>	Averaging time	Noncarcinogen: $ED \times 365$ d/year Carcinogen: 70 yr $\times 365$ d/year

*The particulate emission factor, PEF, relates the contaminant concentration in soil with the concentration of respirable particulates in air due to fugitive dust emissions from surface contamination sites [Section 3.3.2, Risk Assessment Guidance for Superfund, Vol. 1, Part A (EPA, 1989)].

3.3.2 Exposure Parameters

Two current and one future exposure scenarios were evaluated. The current exposure scenarios are a worst-case worker scenario and a more likely S&M worker exposure. The future exposure scenario is a residential scenario for an adult trespasser/squatter in the building. The exposure parameters used to quantify exposure for each exposure pathway evaluated for these three scenarios are described in the following text and summarized in Table 3.8. 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.

3.3.2.1 Current worst-case worker

Workers were assumed to ingest 50 mg of dust or sediment per day at the facility. For inhalation exposure, workers were assumed to have an inhalation rate of 20 m³/workday. A PEF of 4.63x10⁹m³/kg was assumed for dust and sediment resuspended by worker activities. For dermal contact, an exposed surface area of 3120 cm² representing the average adult's hands and arms was used. This was combined with a soil-to-skin adherence factor of 1.0 mg/cm² and absorption factors of 0.001 for metals and 0.01 for organic chemicals. The receptor was assumed to work at the facility 250 days/year for 25 years.

3.3.2.2 Current S&M worker

This receptor was assumed to work at the facility 2 days/year for 25 years. As previously described for the worst-case scenario, workers were assumed to ingest 50 mg of dust or sediment per day at the facility. For inhalation exposure, workers were assumed to have an inhalation rate of 20 m³/workday. A PEF of 4.63x10⁹ m³/kg was assumed for dust and sediment resuspended by worker activities. For dermal contact, an exposed surface area of 3120 cm² representing the average adult's hands and arms was used. This was combined with a soil-to-skin adherence factor of 1.0 mg/cm² and absorption factors of 0.001 for metals and 0.01 for organic chemicals.

3.3.2.3 Future trespasser

The receptor for this scenario was an adult who has taken up residence in the abandoned building at some time in the future. This receptor was assumed to ingest 100 mg of dust or sediment per day at the facility. For inhalation exposure, residence were assumed to have an inhalation rate of 20 m³/day. A particulate emission factor of 4.63x10⁹ m³/kg was assumed for dust and sediment resuspended by the trespasser's activities. For dermal contact, an exposed surface area of 3120 cm² representing the average adult's hands and arms was used. This was combined with a soil-to-skin adherence factor of 1.0 mg/cm² and absorption factors of 0.001 for metals and 0.01 for organic chemicals. The receptor is assumed to be in the facility 350 days/year for 30 years.

3.3.3 Exposure Concentration

The exposure concentrations for this BRE are derived for the ingestion, inhalation, dermal contact, and external exposure pathways using various data types. The types of data used are given in Tables 3.6 through 3.13.

Table 3.6. Alpha Smear Concentrations for Cells A through F

Location	Cells Alpha Smear Concentrations (pCi/kg)					
	Cell A	Cell B	Cell C	Cell D	Cell E	Cell F
East Wall	1.92e5	3.27e4	2.58e4	6.45e4	-	-
West Wall	5.42e4	1.64e4	1.03e5	1.42e5	-	-
North Wall	5.36e4	1.44e5	2.50e4	9.47e4	-	-
South Wall	9.31e4	2.88e4	9.47e4	1.21e5	-	-

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Table 3.6. (continued)

Location	Cells Alpha Smear Concentrations (pCi/kg)					
	Cell A	Cell B	Cell C	Cell D	Cell E	Cell F
Floor, NE, NW, SE, SW	4.81e6	1.78e6	4.83e4	5.96e5	-	-
Walls (gen)	-	-	-	-	1.90e6	1.84e8
Floor (Gen)	-	-	-	-	1.29e5	4.30e5

Table 3.7. Direct Alpha Probe Concentrations for Cells A through F

Location	Cells Alpha Probe Concentrations (pCi/kg)					
	Cell A	Cell B	Cell C	Cell D	Cell E	Cell F
East Wall	3.95e5	3.73e4	2.98e5	4.18e5	-	-
West Wall	4.97e4	4.47e4	1.04e6	8.95e5	-	-
North Wall	3.08e5	2.24e5	4.18e5	8.35e5	-	-
South Wall	9.63e4	2.98e4	1.04e6	2.68e5	-	-
Floor, NE, NW, SE, SW	1.4e6	1.52e6	-	-	-	-
Walls (gen)	-	-	-	-	1.44e5	1.09e4
Floor (Gen)	-	-	2.39e5	9.54e5	8.2e5	8.2e5

Table 3.8. Beta/Gamma Smear Concentrations

Location	Cells Beta/Gamma Smear Concentrations (pCi/kg)					
	Cell A ¹	Cell B ¹	Cell C	Cell D	Cell E	Cell F
East	7.55e4	7.42e4	-	-	-	-
West	1.32e5	7.16e5	-	-	-	-
North	1.08e5	1.25e5	-	-	-	-
South	6.14e4	1.97e5	-	-	-	-
Floor, NE, NW, SE, SW	5.17e6	3.84e7	-	-	-	-
Walls (gen)	-	-	-	-	3.12e4	-
Floor (gen)	-	-	-	-	1.14e5	-

¹ Provided as beta smears in intra-laboratory correspondence

Table 3.9. Beta/Gamma Probe

Location	Cells Beta/Gamma Smear Dose (mr/hr)					
	Cell A	Cell B	Cell C	Cell D	Cell E	Cell F
East Wall	68	12	-	-	-	-
West Wall	100	90	-	-	-	-
North Wall	146	35	-	-	-	-
South Wall	52	20	-	-	-	-
Inner Area	202	25	-	-	-	-

^a only half along the length of the wall

^b background reading @ waist level

^c sump

Table 3.10. Smear Results of the Electrical Gallery

Location	Alpha Smear Concentrations (pCi/kg)	
	Alpha	Beta
First Level	308	2498
Second Level	110	579

Table 3.11. Canal Beta/Gamma Dose Readings

Location	Canal Beta/Gamma Readings (mr/hr)	
	Probe	Smear
North Wall	12	-
Canal Top	<0.5-1.0	-
South Wall	15	-
South Walkway	450	-
South Fence	4	-
Canal Floor	1.3e4	700

Table 3.12. Smear Results of the Dissolver Room

Location	Smear Readings (mr/hr)	Alpha Smear Readings ^a (pCi/kg)	
	beta/gamma	Alpha	Beta/Gamma
Floor	5 / 0.38	9557	81978
East Wall	-	2083	4960
West Wall	-	3664	7119
North Wall	-	1486	150154
South Wall	-	719	10243

^a The first number in the cell is the average of the readings taken; the second number in the cell is that average converted to picocuries (pCi). If only one number exists, and is presented in a cell, this is the averaged readings converted to pCi.

Table 3.13. Smear Results of the Dissolver Pit

Location	Smear Readings (mr/hr)	Smear Readings (pCi/kg)	
	beta/gamma	Alpha	Beta/Gamma
Floor	1.2	-	-
East Wall	-	-	-
West Wall	-	62,950	8.1e5
North Wall	0.9	75,730	3.8e5
South Wall	-	5,415	26771

3.4 RESULTS OF THE EXPOSURE ASSESSMENT

The exposure assessment for Building 3505 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 3505, and the concentrations at which receptor populations may be exposed. The results of the quantitative exposure assessment are shown in Appendix C. Using the equations presented in Sect. 3.3.1, chronic daily intakes (CDI) were calculated for each receptor (current maintenance worker, current S&M worker, future trespasser) and contaminants present. These CDI values will be used along with toxicity values (Sect. 4) to derive excess cancer risk estimates for the carcinogenic contaminants and hazard quotients for noncarcinogenic contaminants in Sect. 5 of this BRE.

3.5 UNCERTAINTY

The objective of this exposure assessment is to estimate the type and magnitude of potential exposures to the radionuclides of potential concern that are present at Building 3505. Three major types of uncertainties should be considered when reviewing the results of the exposure assessment: uncertainties associated with predicting future land use, uncertainties 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 area and take up residence at the site is designed to provide an upper-bound estimate of exposure and risk. Uncertainty in the estimated exposure concentrations results from normal analytical error and because so few samples must be used to represent the contaminant concentrations over a large area.

Smear samples were collected from the floor as well as the walls of the cell. The data from the walls and floors were used to represent the entire cell. This assumption could underestimate the concentration of transferrable radionuclide contamination in the cell. The true distribution of radionuclides was not evaluated in these smear samples; therefore, it was assumed that the distribution of radionuclides detected in the smears was the same as that in the floor and wall cores. The smears were analyzed for plutonium-239, strontium-90; most of the radioactivity detected was plutonium-239.

Because of the lack of air monitoring data, a particulate emission factor was used to model the release of contaminants to the air. Using an emission factor increases the uncertainty in the inhalation exposure.

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

4. TOXICITY ASSESSMENT

The following contaminant-specific information provides a discussion of health effects associated with the COPCs for Building 3505. Data from human and laboratory animal research and data from occupational studies are used to characterize potential health effects resulting from exposure to the COPCs.

The carcinogenic and noncarcinogenic effects listed here may not necessarily be indicative of risks associated with exposure conditions at the site. This information does, however, give an indication of the kinds of potential health effects associated with these contaminants. For the purpose of this BRE, some contaminants were evaluated on a quantitative basis, while others were evaluated on a qualitative basis.

4.1 TOXICITY PROFILES

4.1.1 Contaminants Evaluated Quantitatively

4.1.1.1 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), both of which 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 or X rays) (ATSDR, 1989). Some radionuclides also emit protons or neutrons, but these are not of concern 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 the nuclei of ^4He atoms and consist of two protons and two neutrons. Alpha particles are emitted mostly in the decay of radioisotopes of elements with high atomic numbers (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 little penetrating power and lack the ability to pass through

a piece of paper or human skin. Therefore, external exposure to alpha particles is not a concern. 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 and its solid daughters, which are collected on dust in the air. In addition, the cancer incidence in smokers may be directly attributed to the naturally occurring alpha emitter polonium-210 common in tobacco products (BEIAS Toxicity Profiles).

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 charged electrons. Beta or positron radiations, like alpha radiation, are 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 DNA damage, causing hereditary defects.

Transformation of the atomic nucleus can result in gamma emissions or X rays. The resulting energy has 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 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.

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 (metastable), 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, such as 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.

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). No clear causal relationship exists between exposure and observed effect. Nonstochastic effects are those which the severity varies with dose, but a threshold for occurrence 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 injury 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, 1989d).

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; therefore, 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.

4.1.1.2 Americium-241

Americium was first discovered in 1944 at the Metallurgical Laboratory, the forerunner of Argonne National Laboratory. The isotope is named after America because europium, a similar rare-earth element, was named after the continent of its discovery. Americium-241 is used in high-precision devices and smoke detectors. It decays via alpha-particle emission to Neptunium-237.

Few data exist on the distribution of americium in humans, although measurable amounts have been distributed world-wide as a result of nuclear weapons testing. The limited data

gathered from experimental animals suggest that americium behaves like plutonium with regard to initial partition between liver and skeleton. For dosimetry purposes, all isotopes of americium are assumed to be uniformly distributed over bone surface at all times following their deposition to the skeleton.

4.1.1.3 Cesium-137

Cesium-137, a product of nuclear fission reactions, has a radioactive half-life of 30.2 years. In approximately 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 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 gastrointestinal tract and is distributed uniformly throughout the body. Because of its relatively short metabolic half-life (110 days), and 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.

4.1.1.4 Neptunium-239

Neptunium was artificially produced by Berkeley Laboratories in 1940 before it was discovered in nature. The isotope is named after the planet Neptune because it falls on the periodic chart immediately after uranium, which is named after the next closest planet Uranus. Neptunium is produced as a by-product of breeder reactors from uranium-235 and -238.

The major health effects resulting from exposure to neptunium are expected to be similar to those resulting from exposure to plutonium, discussed in the following subsection.

4.1.1.5 Plutonium-238, -239

Plutonium is a predominantly man-made, radioactive metal that is produced from nuclear reactions with uranium. Plutonium-238 has been used as a nuclear power source for satellites and in thermoelectric generation systems in spacecraft, cardiac pacemakers, and other power sources. Plutonium-239 is mostly associated with nuclear weapons production and testing. It is generated in irradiated uranium fuel when neutrons are captured by uranium-238 nuclei. Commerce and the military principally use plutonium-238 and plutonium-239 because of their ease of production and long radioactive half-lives (86 and 24,000 years, respectively). Both plutonium-238 and plutonium-239 are artificial, alpha-emitting isotopes of plutonium; plutonium-238 decays to radioactive uranium-234 via alphas of 5.5 million electron volts (MeV), and decays to radioactive uranium-235 via alpha of 5.1 MeV.

Atmospheric testing of nuclear weapons has been the main source of plutonium dispersion in the environment, while accidents and routine releases from weapons production facilities are the primary sources of localized contamination. Plutonium released to the atmosphere reaches the earth's surface through wet and dry deposition to the soil and surface water. Once in these media, plutonium can adsorb to soil and sediment particles or bioaccumulate in terrestrial and aquatic food chains.

Because of the low solubility of plutonium isotopes, inhalation of contaminated dust particles is considered to be the most harmful means of human exposure. Plutonium that has been inhaled may be absorbed through the lungs and deposited in other body tissues. Subsequent translocation of some of the plutonium from the lungs to tissues and organs distant from the site of entry results in radiation damage to these tissues as well as the lung. Liver and bone are the primary sites of plutonium deposition (ICRP, 1990). The assumed biological retention half-lives of plutonium isotopes accumulated in the liver and bone of the human body are 20 and 50 years, respectively (ICRP, 1990). Therefore, after a single exposure, plutonium isotopes reside in the body for a long time, resulting in prolonged exposure of body organs to alpha radiation. The permissible health levels for plutonium are the lowest of all the radioactive elements. This is occasioned by the concentration of plutonium directly on bone surfaces rather than the more uniform bone distribution shown by other heavy elements. This increases the possibility of damage from equivalent activities of plutonium and has led to adoption of extremely low permissible levels.

Inhaled plutonium-238 is solubilized and subsequently translocated from the lung to the bones and liver. Inhaled plutonium-239 dioxide is insoluble and retained primarily in the lungs and associated lymph nodes. In laboratory tests using plutonium on animals, the pattern of nonmalignant toxicity among the species tested was similar (i.e., radiation pneumonitis and pulmonary fibrosis occurred in the higher radiation dose groups in all species tested); however, species differences in the induction of cancer were apparent. With the exception of Syrian hamsters, cancer developed in animals in the lower exposure groups or in animals that survived initial radiation damage to the lungs (ATSDR, 1990).

4.1.1.6 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. For further information regarding the carcinogenicity and other properties of radionuclides, refer to Sect. 4.1.1.1, Radionuclides.

4.1.1.7 Technetium-99

Technetium-99 is an abundant, man-made radionuclide that is mobile in ecosystems. It is a beta emitter, emitting LET ionizing radiation, which is known to be carcinogenic to humans. As a pure beta emitter, it poses an insignificant external hazard. Assimilation of technetium following ingestion is high (50%), but retention in animal tissues appears low.

The potential health effects associated with exposure to low-level radiation include an increase in the probability of cancer induction and possible genetic effects. The major health concern associated with radiation is cancer induction; the risk of hereditary effects is much lower. Technetium-99 has been classified by the EPA as a Group A (human carcinogen) carcinogen.

4.1.1.8 Uranium-234, -238

Although uranium was first identified in 1789 by Martin Heinrich Klaproth, its radioactivity was not discovered until more than 100 years later by Henri Becquerel. The major uses of uranium are nuclear weapons and reactors, although small amounts are used in the production of ceramics, light bulbs, photographic chemicals, and household products (ATSDR 1990).

The study of uranium toxicity dates back to 1824 when C.G. Gmelin studied the toxic effects of uranium salts on dogs (Gmelin 1824). Toxicological effects from uranium result from the action of uranium as both a metal and as a radionuclide. The primary toxic chemical effect is in the kidney, although its radioisotope toxicity has been shown to cause lung cancer, apparently due to its decay into radon and its daughters.

4.1.2 Contaminants Evaluated Qualitatively

4.1.2.1 Asbestos

Asbestos is the name applied to a group of six different minerals that occur naturally in the environment. The most common mineral type is white (chrysotile), but others may be blue (crocidolite), gray (anthophyllite), or brown (amosite). These minerals are made up of long, thin fibers that appear somewhat similar to fiberglass. Asbestos fibers are very strong and resistant to heat and chemicals. Because of these properties, asbestos fibers have been used in a wide range of products, mostly in building materials, friction products, and heat-resistant fabrics. Because the fibers are so resistant to chemicals, they are also very stable in the environment (ATSDR, 1990d).

Studies of asbestos workers show an increased risk of developing two forms of cancer. These two forms are lung cancer and mesothelioma (a cancer of the membrane that surrounds the lung and other organs). There is also evidence of increased risk of cancer of the stomach, intestines, esophagus, pancreas, and kidneys. Inhalation of low doses of asbestos has been linked to a slow accumulation of scar-like tissue in the lungs and surrounding tissue which restricts the normal lung expansion and contraction. This condition is known as asbestosis (ATSDR, 1990d).

4.1.2.2 Mercury

Mercury is a naturally occurring element existing in multiple forms and various oxidation states. It is used in a wide variety of products and processes. In the environment, mercury may undergo transformations among its various forms and among its oxidation states. Exposure to mercury may occur in both occupational and environmental settings, the latter primarily involving dietary exposure (ATSDR, 1989e).

Absorption, distribution, metabolism, and excretion of mercury is dependent upon its form and oxidation state (ATSDR, 1989e). Organic mercurials are more readily absorbed than are inorganic forms. An oxidation-reduction cycle is involved in the metabolism of mercury and mercury compounds by both animals and humans (ATSDR, 1989e). The urine and feces are primary excretory routes. The elimination half-life is 35 to 90 days for elemental mercury and mercury vapor and about 40 days for inorganic salts.

Ingestion of mercury metal is usually without effect (BEIAS Toxicity Profiles). Ingestion of inorganic salts may cause severe gastrointestinal irritation, renal failure and death with acute lethal doses in humans ranging from 1–4 g (ATSDR, 1989e). Mercuric (divalent) salts are usually more toxic than are mercurous (monovalent) salts. Mercury is also known to induce hypersensitivity reactions such as contact dermatitis and acrodynia (pink disease). Inhalation of mercury vapor may cause irritation of the respiratory tract, renal disorders, central nervous system (CNS) effects characterized by neurobehavioral changes, peripheral nervous system toxicity, renal toxicity (immunologic glomerular disease), and death (ATSDR, 1989e; BEIAS Toxicity Profiles).

Toxicity resulting from subchronic and chronic exposure to mercury and mercury compounds usually involves the kidneys and/or nervous system, the specific target and effect being dependent on the form of mercury (ATSDR, 1989e). Organic mercury, especially methyl mercury, rapidly enters the CNS resulting in behavioral and neuromotor disorders (ATSDR, 1989e). The developing CNS is especially sensitive to this effect, as documented by the epidemiologic studies in Japan and Iraq where ingestion of methyl mercury-contaminated food resulted in severe toxicity and death in adults and severe CNS effects in infants. Blood mercury levels of $<10 \mu\text{g/dL}$ and $300 \mu\text{g/dL}$ corresponded to mild effects and death, respectively. Teratogenic effects due to organic or inorganic mercury exposure do not appear to be well-documented for humans or animals, although some evidence exists for mercury-induced menstrual cycle disturbances and spontaneous abortions (BEIAS Toxicity Profiles).

Methyl mercury is formed by biotic and abiotic methylation of mercury. Methyl mercury has been used as a fungicide and disinfectant and in industrial processes. Methyl mercury is highly toxic and is readily absorbed by the body following ingestion or inhalation. Methyl mercury may be metabolized to inorganic mercury by the liver and kidneys, with further transformation occurring to form the divalent cation (ATSDR, 1989e). Methyl mercury is excreted as inorganic mercury, primarily in the feces (BEIAS Toxicity Profiles).

The target organ for methyl mercury toxicity is the CNS, especially the brain, and may occur at doses as low as $3 \mu\text{g/kg}$ in humans. Methyl mercury is neurotoxic to several species of experimental animals and humans. The LD_{50} values for various rodent species range from 21 to 57.6 mg/kg . Manifestation of toxic effects (neurobehavioral alterations and degenerative changes in the central and peripheral nervous system) is probably a function of accumulation of critical levels of mercury. Histopathologic correlates have been identified in the brains of humans and animals prenatally exposed to methyl mercury (BEIAS Toxicity Profiles).

Exposure to methyl mercury in the diet (fish and contaminated grain) has caused epidemic poisonings in Iraq and Japan, characterized by severe developmental effects (impaired motor and cognitive functions) in infants of exposed mothers. The primary target organ for oral exposure to methyl mercury is the brain; the effects on this organ account for the developmental toxicity of the chemical.

4.2 TOXICITY VALUES

4.2.1 Toxicity Information for Noncarcinogenic Effects

The reference dose (RfD) is the toxicity value used to evaluate noncarcinogenic effects resulting from chemical exposure and is an estimate of the daily exposure to the human population, including sensitive subgroups likely to be without appreciable risk of harmful effects. It can be used to estimate a level of exposure at or below which no adverse effects are expected to occur. If the exposure level exceeds this threshold, concern for potential noncarcinogenic/systematic effects might arise. A reference dose, or RfD, is the toxicity value used in evaluating noncarcinogenic effects resulting from exposure at the Building 3505. Various type of RfDs are available depending on the exposure route (oral or inhalation), the critical effect (developmental or others), and the length of exposure being evaluated (chronic, subchronic, or single event). A chronic RfD is defined as an estimate of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime. Chronic RfDs are specifically developed to be protective for long-term exposure to a compound. These chronic RfDs are generally used to evaluate the potential noncarcinogenic effects associated with exposure periods between 7 years and a lifetime. Subchronic RfDs may be used to evaluate the potential noncarcinogenic effects associated with short-term exposure periods of 2 weeks to 7 years. Such short-term exposures can result when a particular activity is performed for a limited period of times or when a chemical with a short half-life degrades to negligible concentrations within several months. Therefore, RfDs are used to evaluate the potential effects on a organism following a single exposure event.

The EPA develops RfDs based on the period of contaminant exposure. The toxicity values are derived using EPA-approved methodology. For noncancer health effects, RfDs are derived as a benchmark for the amount of a chemical that can be ingested without an appreciable risk of deleterious effects; similarly, RfCs are derived for the concentrations that can be inhaled without deleterious effects. The basic formula for deriving the RfD and RfC is as follows

$$RfD/RfC = \frac{NOAEL}{UF \times MF}$$

where

NOAEL = No-observed adverse effect level

UF = Uncertainty factors

MF = Modifying factor

The NOAEL is selected from human data if possible, but it is more often obtained from studies using laboratory animals. For many noncarcinogenic effects, protective mechanisms are believed to exist that must be overcome before an adverse effect is manifested. Therefore, in developing a toxicity value for evaluating noncarcinogenic effects (i.e., RfD), the approach is to identify the upperbound of this tolerance range. Because variability exists in the human population, attempts are made to identify a subthreshold level protective of sensitive individuals in the population. For most chemicals, this level can only be estimated; the RfD incorporates

uncertainty factors indicating the degree or extrapolation used to derive the estimated values. Based on extrapolation of uncertainties, there are five possible uncertainty factors: (1) human to sensitive human, (2) animal to human, (3) subchronic to chronic toxicity extrapolation, (4) lowest observed adverse effect level (LOAEL) to NOAEL, and (5) incomplete to complete data base. Each of these factors can be 10, but to avoid the possibility of being too conservative, the EPA has established a maximum uncertainty factor of 3000 where four areas of uncertainty exist and a maximum of 10,000 for five areas of uncertainty. The modifying factor can be used in addition to uncertainty factor to account for some aspect of the study that is not covered by the five uncertainty factors described previously or the modifying factor can be < 1 which reduces the uncertainty associated with the selected study. The modifying factor most frequently used is 1 which is the default value.

Contaminant RfDs vary depending on the mode of intake (i.e., ingestion, inhalation, or dermal contact). The inhalation RfD was recently replaced with the inhalation reference concentration (RfC), expressed in units of milligrams per cubic meter (mg/m^3) (EPA, 1991a). Conversions between the inhalation RfC and RfD are made assuming that humans weigh 70 kg and breathe at a rate of 20 m^3/day . No RfDs are currently available for the dermal route of exposure. Noncarcinogenic risks associated with dermal exposure were evaluated by extrapolating from an oral RfD to a dermal RfD. Reference values that may be useful for evaluating potential adverse effects associated with oral exposures of shorter duration are known as One-day and Ten-day Health Advisories and these are issued as nonregulatory guidance. Health Advisory values are concentrations of contaminants in drinking water at which adverse health effects would not be expected to occur for an exposure of the specified duration. One-day and Ten-day Health Advisories do not consider any carcinogenic risk associated with the exposure even if the compound is a potential carcinogen.

4.2.2 Toxicity Information for Carcinogenic Effects

A slope factor and the accompanying weight-of-evidence determination are the toxicity data used to evaluate potential human carcinogenic risks. Carcinogenesis, unlike many noncarcinogenic health effects, is generally thought to be a phenomenon for which risk evaluation based on presumption of a threshold is inappropriate. The hypothesized mechanism for carcinogenesis is referred to as "nonthreshold" because there is believed to be essentially no level of exposure to such a chemical that does not pose a finite probability, however small, of generating a carcinogenic response. That is, no dose is thought to be risk-free; therefore, in evaluating cancer risks an effect threshold cannot be estimated.

For carcinogenic effects, EPA uses a two-part evaluation in which the substance is assigned a weight-of-evidence classification, and a slope factor is calculated. In the first step, data are evaluated to determine the likelihood that the agent is a human carcinogen. Based on this evaluation, EPA gives the agent a weight-of-evidence classification. The second step involves calculating a slope factor, which measures the relationship between dose and response.

In general, the slope factor is a plausible upperbound estimate of the probability of a response per unit intake of a chemical over a lifetime. The slope factor is used in this risk assessment to estimate an increased upper-bound lifetime probability of developing cancer as a result of exposure to a particular level of a potential carcinogen. Ingestion and inhalation slope

factors are best estimates (i.e., median or 50th percentile values) of the age-averaged, lifetime excess cancer incidence (fatal or nonfatal cancer) risk per unit of activity inhaled, or ingested, expressed as risk/pCi. External exposure slope factors are best estimates of lifetime excess cancer incidence risk for each year of exposure to external radiation from photon-emitting radionuclides distributed uniformly in a thick layer of soil, and are expressed as risk/yr per pCi/g of soil.

The toxicity values for the contaminants are listed in Tables 4.1. The data presented for each contaminant were taken from Integrated Risk Information System (IRIS) and/or the Health Effects Assessment Summary Table (HEAST) and are referenced appropriately in each table.

Table 4.1. Toxicity values: potential carcinogenic effects contaminants evaluated qualitatively

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
Radionuclides						
Americium-241	14596-10-2	2.4E-10	3.2E-08	4.9E-09	A	HEAST
Cesium-137	10045-97-3	2.8E+11	1.9E+11	2.0E-06	A	HEAST
Neptunium-237	13994-20-2	2.2E+10	2.9E-08	4.3E-07	A	HEAST
Plutonium-239	15117-48-3	2.3E+10	3.8E-08	1.7E+11	A	HEAST
Strontium-90	10098-97-2	3.6E+11	6.2E+11	0.0E+00	A	HEAST
Technetium-99	14133-76-7	1.3E-12	8.3E-12	6.0E-12	A	HEAST
Uranium-234	13966-29-5	1.6E+11	2.6E-08	3.0E+11	A	HEAST
Uranium-238	7440-61-1	2.0E+11	2.4E-08	5.1E-08	A	HEAST
Inorganic						
Mercury	7439-97-6	-	-	-	D	HEAST

Table 4.2. Toxicity values: potential noncarcinogenic effects for contaminants evaluated qualitatively

Analyte	CASRN	CHRONIC ORAL RfD (mg/kg/day)	DERMAL RfD (mg/kg/day)	INHALATION RfD (mg/kg/day)	CONFIDENCE LEVEL	MF	UF
Mercury, Inorganic	7439-97-6	3.0E-04	3.0E-08	8.6E-05	-	-	1000

Note: RfD source - IRIS

RfD basis (vehicle) - oral, inhalation

Critical effect - kidney damage; neurotoxicity

5. RISK CHARACTERIZATION

5.1 INTRODUCTION

The objectives of this section of the BRE are to present the results of the risk characterization. The risk characterization uses the results of the exposure assessment (Sect. 3) and toxicity assessment (Sect. 4) to estimate the potential risks associated with Building 3505. As discussed in preceding sections, this risk characterization is based on existing monitoring data for Building 3505 and was performed for contaminants in and on the surfaces of the structural components, walls, and floors of the building.

Risks for carcinogens are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the carcinogen. This incremental lifetime cancer risk (ILCR) (also referred to as excess cancer risk) is estimated as the product of the estimated exposure to a carcinogen and the carcinogen-specific, route-specific slope factor (the toxicity value that quantitatively defines the upperbound estimate of the probability of a response per unit intake of a carcinogen over a lifetime):

$$\text{ILCR} = \text{SF} \times \text{CDI}$$

where:

ILCR	=	incremental lifetime cancer risk (expressed as a unitless probability) over an assumed average lifespan of 70 years as the result of exposure to a specific, known carcinogen
SF	=	slope factor [in (mg/kg • d) ⁻¹] (Sect. 4)
CDI	=	chronic daily intake (in mg/kg • d) (Sect. 3)

In weighing exposures to potentially carcinogenic compounds, a reasonable level of risk must be identified. The EPA specifies a target risk range of 10^{-6} to 10^{-4} associated with the consideration and selection of remedial alternatives for Superfund sites (EPA, 1990). The lower end of this range is generally applied to residential risks while occupational risks may be considered acceptable at the higher end of this range. In the United States, the normal or background incidence of cancer occurrence is 3×10^{-1} or 0.30 (American Cancer Society, 1990). Therefore, an incremental lifetime cancer risk of one in one million (1×10^{-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 as the annual effective dose equivalent. This dose equates to a 25-year lifetime risk of 2×10^{-2} . Analogous protection standards for members of the public mandate a limit of 0.1 rem/year. This dose equates to a 70-year lifetime risk of 4×10^{-3} .

As stated in Sect. 3.1, two land use scenarios (current industrial and future trespasser residential) were explored for this BRE. Under the current industrial land use scenario, two exposure scenarios were evaluated. The receptor in the first of these exposure scenarios was a maintenance worker who is assumed to work 250 days/year in the building for 25 years; the second industrial receptor, the S&M worker, is assumed to work in the building for 2 days/year

for 25 years. Under the future land use scenario, the receptor was a possible adult trespasser who might live on the site at some future time when DOE no longer maintains institutional control of the facility (i.e., a squatter).

During 1993, one of the cells in the Metal Recovery Facility, Cell G, was decontaminated to determine the effectiveness of a dry decontamination technique and provide data about the use of this technique in the eventual decommissioning of the facility. Details of the procedure and analytical results are presented in *Decontamination Project for Cell G of the Metal Recovery Facility at Oak Ridge National Laboratory, Oak Ridge, Tennessee* (ORNL/ER-219). According to the report, the primary radioisotope of concern in Cell G was plutonium-239. However, americium-241, uranium-238, neptunium-237, cesium-137, strontium-90, and technetium-99 were also associated with the separation process which took place at the facility. The process was carried out in Cells A through G, the dissolver pit, the dissolver room, and the canal. Because no data were provided that analyze the distribution of the specific radionuclides in these areas, it is reasonable to assume that other alpha emitters (i.e., americium-241, neptunium-237 and uranium-238) might be present in addition to plutonium-239. The human health risks at Building 3505 might be underestimated if the potential risks from these other radionuclides were not considered.

Since any combination of the alpha and beta/gamma emitters could be present in a cell or other building area, it was decided that the risk from each of the 12 possible combinations of alpha and beta/gamma emitters should be evaluated. These combinations were called "alpha/beta pairs" in this study and comprised the following:

- americium-241 and strontium-90 (Am+Sr), americium-241 and technetium-99 (Am+Tc), americium-241 and cesium-137 (Am+Cs)
- neptunium-237 and strontium-90 (N +Sr), neptunium-237 and technetium-99 (Np+Tc), neptunium-237 and cesium-137 (Np+Cs)
- plutonium-239 and strontium-90 (Pu+Sr), plutonium-239 and technetium-99 (Pu+Tc), plutonium-239 and cesium-137 (Pu+Cs)
- uranium-238 and strontium-90 (U+Sr), uranium-238 and technetium-99 (U+Tc), and uranium-238 and cesium-137 (U+Cs)

The most conservative approach in evaluating the risk at this facility was determined to be the consideration of each alpha/beta pair (where both types of sampling data exist) and their contribution to the risk as if that pair were the only pair present. Risks were calculated as though:

- the alpha activity detected 1) by probe or 2) by smears were attributable to only americium-241, neptunium-237, plutonium-239, or uranium-238 and
- the beta/gamma activity detected 1) by probe or 2) by smears were attributable to only cesium-137, technetium-99, or strontium-90.

This approach to calculating risks precludes underestimating the potential risks posed by the contaminants in Building 3505 (as might be the case if, for example, risks from alpha-emitters were calculated only for plutonium-239) and highlights the estimated worst-case risk per exposure pathway.

The following subsection presents the results of the risk calculations for these three receptors in Cells A through F, the canal, dissolver room, dissolver pit, electrical gallery, locker room, office area, shop, and the building as a whole. The results, expressed as the risk posed by each of the 12 potential alpha/beta pairs, are summarized in this section in tabular form by exposure pathway and are displayed in histograms in Appendix D.

5.2 CURRENT LAND USE

5.2.1 Maintenance Worker

It is assumed that the hypothetical maintenance worker spends 8 hours/day, 250 days/year for 25 years working in the building. It is also assumed that the receptor spends all of his/her time in one specific area (i.e., a cell, the dissolver pit, etc.) for the entire exposure period. Incremental Lifetime Cancer Risk is determined by applying the excess cancer risks to the hypothetical maintenance worker which were based on smear survey data and probe survey data and are summarized in Tables 5.1 and 5.2, respectively. Smear samples for removable surface activity were used to indicate the amount of transferable contamination, as opposed to fixed. Table 5.1 summarizes the range of risks for the smear survey; probe data were used to estimate the amount of total (fixed and transferrable) contamination. Table 5.2 summarizes the range of potential risks for the probe data. The detailed results, by alpha/beta pair, are summarized in Appendix E.

Table 5.1 shows that the risk to the maintenance worker from ingestion or inhalation of transferable contamination (as detected by smear) are within EPA-specified levels of concern for the cells and rooms, regardless of the alpha/beta pair evaluated. However, external exposure to transferable contamination is outside of EPA's specified risk range. The highest risks were obtained for the beta/gamma emitters strontium-90 and cesium-137 at Cells A and B, the canal, and the dissolver room. The maximum risk for these areas exceeds both radiation protection standards and the EPA target risk range.

As shown in Table 5.2, the risks to the maintenance worker from ingestion or inhalation of contaminants, detected by probe (which includes both fixed or transferable), are within EPA risk range. For the canal, Cell A, and Cell B the external exposure to contamination exceeds the current radiation protection standard and is above the EPA-specified target risk range. The beta/gamma emitters are the dominant contributors to the risk (see Appendix E). Risks from the locker room, the office, and the shop exceed the EPA target risk range by an order of magnitude. The external exposure risks estimated from probe data are generally more representative of true risks than those estimated from smear samples.

Table 5.1. Range of incremental lifetime cancer risk risks to the maintenance worker for ingestion, inhalation, and external exposure pathways, determined from smear survey data

Location	Exposure Route		
	Ingestion	Inhalation	External
Cell A	4.2E-05 to 4.2E-04	4.1E-06 to 7.3E-06	1.0E+00
Cell B	5.9E-05 to 1.8E-04	1.5E-06 to 2.7E-06	1.9E-07 to 7.7E-01
Cell C ^a	6.2E+06 to 7.8E-05	7.6E-08 to 1.6E-06	1.0E-07 to 2.2E-04
Cell D ^a	8.4E-06 to 7.2E-05	3.6E-07 to 1.5E-06	9.3E-08 to 1.0E-03
Cell E	1.7E-05 to 1.3E-04	1.8E-06 to 2.9E-06	1.8E-07 to 6.0E-03
Cell F ^a	1.6E-03 to 1.4E-02	1.6E-6 to 2.8E-04	1.8E-05 to 3.7E-02
Canal ^b	-	-	1.0E+00
Dissolver Pit	9.9E-07 to 1.5E-05	7.1E-08 to 1.2E-07	4.3E-02
Dissolver Room	1.3E-07 to 2.4E-06	8.6E-09 to 1.4E-08	1.4E-09 to 1.7E-01
Electric Gallery	2.7E-09 to 5.1E-08	2.9E-10 to 4.7E-10	3.0E-11 to 7.6E-07
Locker Room	NA ^c	NA	NA
Office	NA	NA	NA
Shop	NA	NA	NA
Entire Building	9.7E-05 to 8.3E-04	9.4E-06 to 1.7E-05	1.0E+00

^a Indicates locations where only alpha smear data were available

^b Existing data permit determination of external exposure only (data provided in units of mrem/h)

^c NA—no smear data available

Table 5.2. Range of incremental lifetime cancer risk risks to the maintenance worker for ingestion, inhalation, and external exposure pathways, determined from probe survey data

Location	Exposure Route		
	Ingestion	Inhalation	External
Cell A ^a	9.1E-06 to 7.8E-05	9.7E-07 to 1.6E-06	1.0E-07 to 9.99E-01
Cell B ^a	1.3E-05 to 1.1E-04	1.4E-06 to 2.3E-06	1.5E-07 to 7.7E-01
Cell C	9.1E-06 to 7.8E-05	9.7E-07 to 1.6E-06	1.0E-07 to 2.1E-04
Cell D	8.4E-06 to 7.2E-05	8.9E-07 to 1.5E-06	9.3E-08 to 2.0E-04
Cell E	7.2E-06 to 6.4E-05	7.7E-07 to 1.2E-06	8.0E-08 to 1.7E-04
Cell F	7.2E-06 to 6.2E-05	7.7E-07 to 1.2E-06	8.0E-08 to 1.7E-04
Canal ^c	-	-	1.0E+00
Dissolver Pit	NA ^b	NA	NA
Dissolver Room	NA	NA	NA
Electric Gallery	NA	NA	NA
Locker Room ^c	-	-	3.2E-03
Office ^c	-	-	3.2E-03
Shop ^c	-	-	4.0E-03
Entire Building	1.1E-05 to 9.2E-05	1.2E-06 to 2.0E-06	1.2E-07 to 3.6E-05

^a Indicates only locations for which alpha and beta/gamma probe data were available

^b NA—no probe data available

^c Existing data permit determination of external exposure only (data provided in units of mrem/h)

5.2.2 Surveillance & Maintenance Worker

The second current exposure scenario, which considers a more realistic receptor, is represented by an S&M worker who spends two 8-hour days per year in the facility for 25 years. The estimated ILCRs for the S&M worker are summarized in Tables 5.3 and 5.4.

The risk to the hypothetical S&M worker estimated from smear data is summarized in Table 5.3. For the complete results tables, refer to Appendix E. The risks associated with ingestion and inhalation of transferable contamination are within EPA target risk range. However, for the external exposure pathways for Cell A, Cell B, and the canal, risk estimates are above the EPA level of concern of 10^{-6} to 10^{-4} , due to the presence of cesium-137, technetium-99, and strontium-90.

Table 5.4 summarizes the risk estimates based on the probe survey results. The ingestion and inhalation exposure pathway are below the EPA concern levels by an order of magnitude or greater for all areas. This trend is the same for the external exposure pathway with the exception of the canal, Cell A, and Cell B, where the beta/gamma emitters are the greatest contributors to risks that exceed EPA guidelines.

Table 5.3. Range of incremental lifetime cancer risk risks to the S&M worker for ingestion, inhalation, and external exposure pathways, determined from smear survey data

Location	Exposure Route		
	Ingestion	Inhalation	External
Cell A	3.4E-07 to 3.4E-06	3.3E-08 to 5.9E-08	3.9E-09 to 1.0E-00
Cell B	1.3E-07 to 1.4E-06	1.3E-08 to 2.2E-08	1.4E-09 to 7.7E-01
Cell C ^a	7.3E-08 to 6.3E-07	6.1E-10 to 1.3E-08	8.1E-10 to 1.7E-06
Cell D ^a	6.7E-08 to 5.7E-07	8.5E-09 to 1.2E-08	7.4E-10 to 8.3E-6
Cell E	1.3E-07 to 1.2E-06	1.4E-08 to 2.3E-08	1.5E-09 to 4.8E-05
Cell F ^a	1.3E-05 to 1.1E-04	1.4E-06 to 2.2E-06	1.4E-07 to 3.0E-04
Canal ^b	-	-	1.0
Dissolver Pit	7.9E-09 to 1.0E-07	5.2E-10 to 9.3E-10	8.1E-11 to 7.4E-05
Dissolver Room	1.1E-11 to 1.9E-08	6.1E-11 to 1.1E-10	6.9E-12 to 1.4E-05
Electric Gallery	3.0E-11 to 1.8E-10	2.3E-12 to 3.8E-10	2.4E-13 to 6.0E-09
Locker Room	NA ^c	NA	NA
Office	NA	NA	NA
Shop	NA	NA	NA
Entire Building	9.8E-06 to 8.4E-04	1.0E-07 to 1.4E-07	1.0

^a Indicates locations where only alpha smear data were available

^b Existing data permit determination of external exposure only (data provided in units of mrem/h)

^c NA—no smear data available

Table 5.4. Range of incremental lifetime cancer risk risks to the S&M worker for ingestion, inhalation, and external exposure pathways, determined from probe survey data

Location	Exposure Route		
	Ingestion	Inhalation	External
Cell A	7.3E-08 to 6.3E-07	7.8E-09 to 1.3E-08	8.1E-10 to 1.0
Cell B	1.1E-07 to 9.1E-07	1.1E-08 to 1.8E-08	1.2E-09 to 7.7E-01
Cell C ^a	7.3E-08 to 6.3E-07	7.8E-09 to 1.3E-08	8.1E-10 to 1.7E-06
Cell D ^a	6.7E-08 to 5.7E-07	7.1E-09 to 1.2E-08	7.4E-10 to 1.6E-06
Cell E	5.7E-08 to 4.9E-07	6.1E-09 to 1.0E-08	6.7E-10 to 1.4E-06
Cell F ^a	5.7E-08 to 4.9E-07	6.1E-09 to 1.0E-08	6.7E-10 to 1.4E-06
Canal ^b	-	-	1.0E-01
Dissolver Pit	NA ^c	NA	NA
Dissolver Room	NA	NA	NA
Electric Gallery	NA	NA	NA
Locker Room ^b	-	-	3.2E-03
Office ^b	-	-	3.2E-03
Shop ^b	-	-	4.0E-03
Entire Building	9.0E-08 to 7.4E-07	9.6E-09 to 1.6E-08	1.0E-09 to 2.1E-06

^a Indicates locations where only alpha probe data were available

^b Existing data permit determination of external exposure only (data provided in units of mrem/h)

^c NA—no probe data available

5.2.3 Future Land Use—Adult Resident (Trespasser)

As described in Sect. 3, this BRE provides exposure and risk estimates for a "no-action" (i.e., no-remedial-action) future land use scenario. The scenario assumes that:

- Building 3505 is abandoned by DOE at the start of the risk evaluation and
- DOE makes no attempt to prevent contaminant releases from the facility or restrict access to the facility.

For this risk evaluation, a hypothetical adult trespasser is assumed to live within the facility 24 hours/day, 350 days/year for 30 years. Tables 5.5 and 5.6 present summaries of the range of risk for transferable smear data and total probe data contamination, respectively. The ILCR for the adult resident is presented in Appendix E.

Table 5.5 summarizes the range of the risk to adult residents from ingestion, inhalation, and external exposure to transferable contamination. The EPA-specified target risk range is not exceeded for any of the cells or rooms for ingestion or inhalation with the possible exception of the ingestion pathway for Cell F whose estimated risk is 5.4×10^{-3} to 4.4×10^{-2} . The external exposure to transferable contamination exceeds the EPA limits at Cell A, Cell B, Cell F, the dissolver room, and the canal. The tables in Appendix E show that all combinations of alpha/beta pairs exceed the EPA limits for Cell A and Cell B.

As shown in Table 5.6, the risks to the adult resident from ingestion or inhalation of contaminants, detected by probe (total fixed and transferable), are within the EPA risk range. For the canal, Cell A, Cell B, and the shop area, the external exposure to contamination exceeds both the current radiation protection standard and the EPA-specified target range. The beta/gamma emitters are the dominant contributors to this risk (refer to Appendix E).

Table 5.5. Range of incremental lifetime cancer risk risks to the adult trespasser for ingestion, inhalation, and external exposure pathways, determined from smear survey data

Location	Exposure Route		
	Ingestion	Inhalation	External
Cell A	1.4E-04 to 1.4E-03	7.5E-06 to 1.2E-05	1.0
Cell B	5.2E-05 to 6.4E-04	2.8E-06 to 4.6E-06	1.0
Cell C ^a	3.1E-06 to 2.6E-04	1.3E-07 to 2.7E-06	5.1E-07 to 1.1E-03
Cell D ^a	2.8E-05 to 2.4E-04	1.5E-06 to 2.4E-06	4.7E-07 to 5.2E-03
Cell E	5.6E-05 to 4.8E-04	3.0E-06 to 4.8E-06	9.3E-07 to 3.0E-02
Cell F ^a	5.4E-03 to 4.5E-02	2.6E-04 to 4.7E-04	9.0E-05 to 1.7E-01
Canal ^b	-	-	1.0
Dissolver Pit	3.3E-06 to 5.0E-05	1.2E-07 to 2.0E-07	3.7E-08 to 4.5E-02
Dissolver Room	4.7E-07 to 8.0E-06	1.3E-08 to 2.3E-08	7.0E-09 to 6.0E-01
Electric Gallery	9.1E-09 to 1.7E-07	4.4E-10 to 7.9E-10	1.5E-10 to 3.8E-06
Locker Room	NA ^c	NA	NA
Office	NA	NA	NA
Shop	NA	NA	NA
Entire Building	3.3E-04 to 2.8E-03	1.6E-05 to 2.8E-05	1.0

^a Indicates locations where only alpha smear data were available

^b Existing data permit determination of external exposure only (data provided in units of mrem/h)

^c NA—no smear data available

Table 5.6. Range of incremental lifetime cancer risk risks to adult trespasser for ingestion, inhalation, and external exposure pathways, determined from probe survey data

Location	Exposure Route		
	Ingestion	Inhalation	External
Cell A	3.1E-05 to 2.5E-04	1.6E-06 to 2.7E-06	1.0
Cell B	4.5E-05 to 3.7E-04	2.8E-06 to 3.9E-06	9.9E-01
Cell C ^a	3.1E-05 to 2.5E-04	1.6E-06 to 2.7E-06	5.1E-07 to 1.1E-03
Cell D ^a	2.8E-05 to 2.3E-04	1.5E-06 to 2.4E-06	4.7E-07 to 1.4E-04
Cell E	2.4E-05 to 2.1E-04	1.3E-06 to 2.1E-06	4.0E-07 to 1.2E-04
Cell F ^a	2.4E-05 to 2.1E-04	1.3E-06 to 2.1E-06	4.0E-07 to 1.2E-04
Canal ^{a,b}	-	-	1.0
Dissolver Pit	NA ^c	NA	NA
Dissolver Room	NA	NA	NA
Electric Gallery	NA	NA	NA
Locker Room ^b	-	-	1.6E-02

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Table 5.6. (continued)

Location	Exposure Route		
	Ingestion	Inhalation	External
Office ^b	-	-	1.6E-02
Shop ^b	-	-	2.0E-01
Entire Building	3.3E-04 to 2.8E-03	1.7E-05 to 2.8E-05	1.0

^a Indicates locations where only alpha probe data were available

^b Existing data permit determination of external exposure only (data provided in units of mrem/h)

^c NA—no probe data available

Air monitoring data were available for the control room only and are presented in Appendix E. These data reveal that the ILCR associated with this room is within the EPA target risk range.

5.3 SUMMARY OF RISK CHARACTERIZATION

The lifetime excess cancer risk was found to exceed the EPA target risk range of 10^{-6} to 10^{-4} for the external exposure pathway for all three receptors (maintenance worker, S&M worker, and the adult trespasser) at Cells A and B, the canal, locker room, office, and shop regardless of the alpha/beta combination. However, it should be noted that current radiation protection standards for workers include a limit of 5 rem as the annual effective dose equivalent. This dose equates to a 25-year lifetime risk of 2×10^{-2} . Cell A and Cell B consistently exceeded the EPA risk range largely due to the beta/gamma emitters present, such as strontium-90, cesium-137, and technetium 99. Strontium-90 and cesium-137 were most often found to contribute to the elevated risk rather than technetium-99.

Table 5.7 provides a summary of the range of the total risk for the 12 alpha/beta pairs for the three receptors evaluated at this facility. The total ILCRs estimated for Cell A, the canal, and the entire building were 1 for both the smear and probe data, which indicates a probability of 1 chance in 1 of an individual developing cancer. This value applies for each of the alpha/beta pairs. The external exposure pathway is the dominant driver of the risk at the three locations.

Table 5.7. Total risk ranges for combinations of radionuclides at Building 3505

Location	Data Type	Receptors		
		Maintenance Worker	S&M Worker	Adult Resident
Cell A	Smear	1	3E-06 to 1	1
	Probe	1	1	1
Cell B	Smear	4.5E-03 to 8E-01	1E-6 to 8E-01	1
	Probe	8E-01	8E-01	1
Cell C	Smear	7E-05 to 2E-04	6E-07 to 2E-06	2E-04 to 1E-03
	Probe	8E-05 to 1E-04	9E-07 to 2E-06	4E-04 to 1E-03

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Table 5.7. (continued)

Location	Data Type	Receptors		
		Maintenance Worker	S&M Worker	Adult Resident
Cell D	Smear	7E-05 to 1E-03	6E-07 to 9E-06	2E-04 to 1E-03
	Probe	7E-05 to 1E-04	8E-07 to 2E-06	2E-04 to 1E-03
Cell E	Smear	1E-04 to 6E-03	1E-06 to 5E-05	8E-04 to 3E-02
	Probe	9E-05 to 2E-04	7E-07 to 1E-06	2E-04 to 9E-04
Cell F	Smear	1E-02 to 4E-02	3E-04 to 4E-3	7E-2 to 9E-1
	Probe	9E-05 to 2E-04	7E-07 to 1E-06	2E-04 to 9E-04
Canal	Smear	1	1	1
	Probe	1	1	1
Dissolver Pit	Smear	4E-02	5E-08 to 7E-05	3E-05 to 8E-05
	Probe	-	-	-
Dissolver Room	Smear	1E-06 to 2E-01	6E-09 to 1E-05	2E-06 to 6E-01
	Probe	-	-	-
Electrical Gallery	Smear	2E-08 to 7E-07	2E-10 to 6E-9	8E-08 to 4E-06
	Probe	-	-	-
Locker Room	Smear	-	-	-
	Probe	3E-03	3E-3	2E-02
Office Area	Smear	-	-	-
	Probe	3E-03	3E-03	2E-02
Shop	Smear	-	-	-
	Probe	4E-03	4E-03	2E-02
Control room	Air monitoring	1E-04 to 2E-04	1E-04 to 2E-04	2E-04 to 3E-04
Entire Building	Smear	1	1	1
	Probe	1	1	1

For the S&M worker receptor, the risks from Cells C, D, and E; the dissolver room; the electrical gallery; and the control room were determined to be within the acceptable range, as established by EPA, of 1×10^{-6} to 1×10^{-4} . This trend also applies to the maintenance worker receptor except for the exception of Cells D, E, and F and the dissolver room, where there is a slightly higher risk from the smear concentration at Cells D and E and a even higher risk for the same data type at Cell F and the dissolver room.

The risks associated with the locker room, office area, and shop area are below the lifetime risk of the current radiation standards of 2×10^{-2} , for maintenance worker and S&M worker; however, the EPA standard is exceeded for the residential receptor. As shown in Table 5.7, the lifetime risks for these areas were determined to be of 2×10^{-2} . The external exposure pathway is the lone contributor to the elevated risk.

Adequate data were unavailable to quantify the risks associated with asbestos and mercury at Building 3505. Due to the high toxicity of mercury via skin absorption and inhalation of vapor, mercury-contaminated soil outside the facility could present a risk to nearby receptors. The mercury is not enclosed; therefore, any agitation of the soil would likely cause the mercury to disperse to the atmosphere rather than concentrate in one area, as would be the case if the mercury was confined somewhere inside the building. This dilution effect will help to temper any potential risks. The asbestos risk is caused by asbestos located on the piping. Therefore, the risk associated with asbestos would be negligible to workers if proper precautions are taken, but a risk could exist for an adult resident in the facility if he or she comes into contact with the piping. It is important to note, however, that any D&D activity that would place workers in contact with the asbestos-contaminated piping would have to be controlled according to OSHA requirements.

5.4 UNCERTAINTY

Potential sources of uncertainty in the BRE include the radioisotope toxicity values, the averaging method used to estimate the radionuclide concentrations in the various rooms in Building 3505, the adequacy of the existing survey data, and the assumptions used in the worker and on-site adult resident exposure scenarios.

The dose-response relationship between cancer and ionizing radiation has been evaluated in many reports and is well established. The model most frequently used is the linear nonthreshold model. This is the most conservative model for evaluating radiation risk and 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 environmental or occupational dose range. Standard assumptions used in the exposure estimation equation such as body weight, exposure period, etc., may not be representative of the actual exposure situation. The potential magnitude of the over- or underestimation from these uncertainties could possibly affect estimates of risk by between one and two orders of magnitude.

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. 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.

6. PRELIMINARY ENDPOINT ANALYSIS

It is the objective of the Preliminary Endpoint Analysis (PEA) to consider endpoints that are likely to reduce the residual risk at the facility after remediation to particular endpoints is complete. The PEA will not result in an actual measure of residual risk associated with an endpoint; it will provide a gross estimate of residual risk sufficient for focusing the evaluation of alternatives on those endpoints most likely to adequately reduce risks to acceptable levels. It is the intent of the PEA to enable facility managers to evaluate the trade-offs between potential costs and benefits of various D&D endpoints and assist in focusing the evaluation of D&D alternatives. The conclusions from the PEA must be considered along with costs, other potential benefits of remediation, and potential worker risks in determining the endpoint for the facility.

6.1 SELECTED ENDPOINTS FOR ANALYSIS

The endpoints evaluated for this BRE are detailed in the following text.

Endpoint 1

- Remove portions of the concrete surface from cells, dissolver room, and dissolver pit; most of the radionuclide contamination resides in the first 0.25 in. of concrete.
- Dispose of removed, contaminated concrete waste; ninety-five percent of the activity exists in the waste.

Endpoint 2

- Perform tasks included in Endpoint 1.
- Clean the surfaces of the cells and rooms with sodium hydroxide, oxalic acid, and detergent (electropolishing).
- Fence the entire area and perform quarterly S&M.

6.2 IDENTIFICATION OF EXPOSURE PATHWAY

Table 6.1 identifies the exposure pathways by receptor.

Table 6.1. Exposure pathways identified by receptor

RECEPTOR	EXPOSURE PATHWAY
Current S&M Worker	Ingestion of contaminants from building surfaces
	Inhalation of airborne contaminants in building
	External contact from contaminated surfaces

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Table 6.1. (continued)

RECEPTOR	EXPOSURE PATHWAY
Adult resident	Ingestion of contaminants from building surfaces
	Inhalation of airborne contaminants
	External contact from contaminated surfaces

Endpoint 1

None of the pathways are completely eliminated. Exposure due to pathways will be reduced significantly due to this endpoint scenario. In addition, exposure will be reduced approximately 95% for the ingestion and inhalation pathways.

Endpoint 2

None of the pathways are completely eliminated. However, the potential for exposure by the pathways is greater than for the pathways in Endpoint 1.

6.3 EXPOSURE REDUCTION

Endpoint 1

The estimated reduction in exposure associated with Endpoint 1 is shown in Table 6.2.

Table 6.2. Exposure reduction for Endpoint 1

EXPOSURE PATHWAY	EXPOSURE REDUCTION
S&M Worker	
Ingestion of contaminants from building surfaces	95% reduction in activity - >95% reduced exposure
Inhalation of airborne contaminants in building	95% reduction in activity - >95% reduced exposure
External dermal contact from contaminated surfaces	95% reduction in activity - >95% reduced exposure
Adult Resident	
Ingestion of contaminants from building surfaces	95% reduction in activity - >95% reduced exposure
Inhalation of airborne contaminants	95% reduction in activity - >95% reduced exposure
External dermal contact from contaminated surfaces	95% reduction in activity - >95% reduced exposure

Endpoint 2

The estimated reduction in exposure associated with Endpoint 2 is presented in Table 6.3.

Table 6.3. Exposure reduction for Endpoint 2

EXPOSURE PATHWAY	EXPOSURE REDUCTION
S&M Worker	
Ingestion of contaminants from building surfaces	Reduced to as low as reasonably achievable
Inhalation of airborne contaminants in building	Reduced to as low as reasonably achievable
External dermal contact from contaminated surfaces	Reduced to as low as reasonably achievable
Adult Resident	
Ingestion of contaminants from building surfaces	Reduced to as low as reasonably achievable
Inhalation of airborne contaminants	Reduced to as low as reasonably achievable
External dermal contact from contaminated surfaces	Reduced to as low as reasonably achievable

6.4 SUMMARY

Endpoint 1 will significantly reduce worker exposure by removing a large part of the contamination via removal of the contaminated concrete level. Endpoint 2 will further reduce the risk to an overall acceptable level of risk.

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APPENDIX A

Conversion of dpm to pCi

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A. CONVERSION OF DPM TO PCI

A.1 INTRODUCTION

This appendix presents a brief list of the equations used to convert the Building 3505 radiological survey data to the units of measure needed for performing a risk characterization. In addition, it contains examples of how to apply the equations.

A.1.1 Radiation and Concentration Equations

Conversion of dpm to pCi:

$$\frac{dpm}{100cm^2} \times \frac{pCi}{2.2 dpm} = \frac{pCi}{100 cm^2} \quad (1)$$

Conversion of pounds per cubic feet to kilograms per cubic centimeter:

$$\frac{lbs}{ft^3} \times \frac{kg}{lbs} \times \frac{ft^3}{inches^3} \times \frac{inches^3}{cm^3} = \frac{kg}{cm^3} \quad (2)$$

Conversion of square feet to square centimeters:

$$ft^2 \times \frac{144 inches^2}{ft^2} \times \frac{6.452 cm^2}{inches^2} = cm^2 \quad (3)$$

Derivation of pCi per kilogram from pCi and volume of substrate:

$$pCi \times cm^3 \times \left(\frac{kg}{cm^3} \right)^{-1} = \frac{pCi}{kg} \quad (4)$$

A.1.2 Applications

Conversion of density of concrete in pounds per cubic feet to kilograms per cubic centimeter:

$$\frac{150 lbs}{ft^3} \times \frac{.453 kg}{lbs} \times \frac{ft^3}{1728 inches^3} \times \frac{inches^3}{16.387 cm^3} = \frac{kg}{cm^3} \quad (5)$$

Conversion of area of Building 3505 in square feet to square centimeters:

$$86780 \text{ ft}^2 \times \frac{144 \text{ inches}^2}{\text{ft}^2} \times \frac{6.452 \text{ cm}^2}{\text{inches}^2} = 8.06 \times 10^7 \text{ cm}^2 \quad (6)$$

A.1.3 Example Calculation: Converting Survey Data to pCi/kg for Use in Calculating Receptor Exposures

Following is a sample calculation for converting the Building 3505 radiological survey data to the proper units of measure for calculating receptor exposure. This example uses the dimensions and alpha smear survey data for the the East and West Walls of Cell A.

The east and west walls of Cell A are 17 ft high by 19 ft wide. Therefore, the total area of the two walls is:

$$17 \times 19 \times 2 = 646 \text{ ft}^2 = 6.1 \times 10^5 \text{ cm}^2$$

If 0.1 cm of transferable contaminated concrete dust covers the two walls, the volume of transferable contamination is:

$$(6.1 \times 10^5 \text{ cm}^2) \times (0.1 \text{ cm}) = 6.0 \times 10^4 \text{ cm}^3$$

Assuming per Equation (5) that the density of the contaminated concrete dust is $2.4 \times 10^{-3} \text{ kg/cm}^3$, the mass of transferable contamination on the east and west walls is:

$$(6.0 \times 10^4 \text{ cm}^3) \times (2.4 \times 10^{-3} \text{ kg/cm}^3) = 1.44 \times 10^2 \text{ kg}$$

The average measured concentration on the two walls is 10157.3 dpm/100 cm². Converting from dpm/100 cm² to pCi/cm² per Equation (1), the average activity detected by smear survey becomes:

$$(10157.3 \text{ dpm}/100\text{cm}^2) \times (\text{pCi}/2.2 \text{ dpm}) = 46.2 \text{ pCi/cm}^2$$

Multiplying the average activity per square centimeter by the area of the two walls yields the total transferable contamination expressed in pCi:

$$(46.2 \text{ pCi/cm}^2) \times (6.1 \times 10^5 \text{ cm}^2) = 2.8 \times 10^7 \text{ pCi}$$

The average concentration of contamination in the east and west walls can then be calculated from the mass of transferrable contamination and the total transferable contamination:

$$(2.8 \times 10^7 \text{ pCi}) \times (1.4 \times 10^2 \text{ kg}) = 195,579 \text{ pCi/kg}$$

APPENDIX B

Raw Data of the Smear and Probe Survey

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Table B.1 Alpha Smear Readings for Cells A through F

Location	Cells Alpha Smear Readings (d/m)					
	Cell A	Cell B	Cell C	Cell D	Cell E	Cell F
East Wall	19,000 8618 2854	3,800	3,000	7,500		
West Wall	3624 2418 2548	1900	12,000	16,500		
North Wall	4740 3860 1462 1272	4772 5372 12,600	2,900	11,000		
South Wall	2340 8000 4412	4430 26,000	11,000	14,000		
Inner Area	24,000 94,2000 86,000 36,000 94,000 280,000 96,000 130,000 600,000	246,000 98,000 57,420 42,000 27,300				
Walls (gen)					100,000 °	75,000
Floor, NE			4,000	40,000		
Floor, NW			1,600	35,000		
Floor, SE			4,000	30,000		
Floor, SW			600	21,000		
Floor (Gen)					15,000 °	50,000
Door			1,750			

° not generally

Table B.2 Direct Alpha Probe Readings for Cells A through F

Location	Cells Alpha Probe Readings (d/m)					
	Cell A	Cell B	Cell C	Cell D	Cell E	Cell F
East Wall	15,000 250,000	15,000 10,000	100,000	140,000		
West Wall	15,000 10,000 25,000	15,000	350,000	300,000		
North Wall	100,000 10,000 200,000	50,000 125,000 50,000	140,000	280,000		
South Wall	10,000 79,000 8000	15,000 5,000	350,000	90,000		
Inner Area	120,000 5000 500,000 250,000 200,000 100,000 100,000 750,000 125,000 200,000 1,500,000	150,000 2,000,000 450,000 100,000 200,000 150,000				
Walls (gen)					50,000 280,000 (spots)	10,000- 15,000
Floor, NE						
Floor, NW						
Floor, SE						
Floor, SW						
Floor (Gen)			80,000	320,000	50,000 500,000 (spots)	250,000- 300,000 ^b
Door						
1st Level						
2nd Level						

^b small area to right of door probed > 5000,000 d/p

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Table B.3 Beta/Gamma Smears

Location	Cells Beta/Gamma Smear Readings (dpm)					
	Cell A ¹	Cell B ¹	Cell C	Cell D	Cell E	Cell F
East	3700 4260 4000	3920				
West	1580 16,200 3200	37,800				
North	8040 7860 5000 1840	2760 10,200 6760				
South	3200 4800 1780	2800 18,000				
Inner	78,000 340,000 58,000 360,000 256,000 840,000 290,000 120,000 117,000	47,800 46,100 86,000 226,000 610,000				
Walls (gen)					30,000	
floor (gen)					6,000	

¹ Given as beta smears in correspondence

Table B.4 Beta/Gamma Probe

Location	Cells Alpha Smear Readings (mr/hr)						
	Cell A		Cell B	Cell C	Cell D	Cell E	Cell F
East Wall	45 90		12				
West Wall	55 45 50 50		90				
North Wall	70 *400 35 80		15 45				
South Wall	30 35 90		10 10				
Inner Area	60 300 35 80 80	100 65 250 450 600	35 20 *15 *20 10 50				

- * only half along the length of the wall
- * background reading @ waist level
- * sump

Table B.5 Smear Results of the Electrical Gallery

Location	Alpha Smear Readings (dpm)	
	Alpha	Beta
First Level	690	5600
Second Level	246	1300

Table B.6 Canal Beta/Gamma Reading

Location	Canal Beta/Gamma Readings (mr/hr)	
	Probe	Smear
North Wall	12	
Canal Top	<0.5- 1.0	
South Wall	15	
South Walkway	100 800	
South Fence	4	
Canal Floor	13 R/hr	700

APPENDIX C

Concentration Values Used in the Determination of the Incremental Lifetime Cancer Risk

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Table C1.1. Smear and Probe Concentration Results for areas located in Building 3505.

Method	Room Location	Directional Orientation	Concentration or Dose Rate Units	Concentration
a_smear	a	east	pCi/kg	192303.98
a_smear	a	west	pCi/kg	54209.68
a_smear	a	north	pCi/kg	53636.02
a_smear	a	south	pCi/kg	93091.54
a_smear	a	floor	pCi/kg	4808877.5
a_smear	b	east	pCi/kg	32709.83
a_smear	b	west	pCi/kg	16350.18
a_smear	b	north	pCi/kg	143533.63
a_smear	b	south	pCi/kg	28805.93
a_smear	b	floor	pCi/kg	1782389.62
a_smear	c	east	pCi/kg	25817.05
a_smear	c	west	pCi/kg	103268.75
a_smear	c	north	pCi/kg	24956.56
a_smear	c	south	pCi/kg	94662.94
a_smear	c	floor	pCi/kg	48278.1
a_smear	c	door	pCi/kg	33150
a_smear	d	east	pCi/kg	64542.9
a_smear	d	west	pCi/kg	141994.41
a_smear	d	north	pCi/kg	94662.94
a_smear	d	south	pCi/kg	120480.18
a_smear	d	floor	pCi/kg	596376.54
a_smear	e	wall	pCi/kg	1897000
a_smear	e	floor	pCi/kg	129086.18
a_smear	f	wall	pCi/kg	184000000
a_smear	f	floor	pCi/kg	430286.62
a_probe	a	east	pCi/kg	395113.3
a_probe	a	west	pCi/kg	49699.8
a_probe	a	north	pCi/kg	308138.57
a_probe	a	south	pCi/kg	96318.18
a_probe	a	floor	pCi/kg	1043695.5
a_probe	b	east	pCi/kg	37274.84

Method	Room Location	Directional Orientation	Concentration or Dose Rate Units	Concentration
a_probe	b	west	pCi/kg	44729.81
a_probe	b	north	pCi/kg	223649.04
a_probe	b	south	pCi/kg	29819.87
a_probe	b	floor	pCi/kg	1515744.06
a_probe	c	east	pCi/kg	298198.71
a_probe	c	west	pCi/kg	1043695.5
a_probe	c	north	pCi/kg	417478.2
a_probe	c	south	pCi/kg	1043695.5
a_probe	c	floor	pCi/kg	238558.97
a_probe	d	east	pCi/kg	417478.2
a_probe	d	west	pCi/kg	894596.14
a_probe	d	north	pCi/kg	834956.4
a_probe	d	south	pCi/kg	268378.84
a_probe	d	floor	pCi/kg	954235.88
a_probe	e	wall	pCi/kg	144200
a_probe	e	floor	pCi/kg	820046.46
a_probe	f	wall	pCi/kg	10930
a_probe	f	floor	pCi/kg	820046.46
b_smear	a	east	pCi/kg	75477.98
b_smear	a	west	pCi/kg	132401.27
b_smear	a	north	pCi/kg	107631.77
b_smear	a	south	pCi/kg	61720.24
b_smear	a	floor	pCi/kg	5168596.69
b_smear	b	east	pCi/kg	74215.75
b_smear	b	west	pCi/kg	715651.85
b_smear	b	north	pCi/kg	124450.15
b_smear	b	south	pCi/kg	196898.92
b_smear	b	floor	pCi/kg	3843315.49
bg_smear	e	wall	pCi/kg	31200
bg_smear	e	floor	pCi/kg	113595.53
bg_probe	a	east	mrem/hr	45

Method	Room Location	Directional Orientation	Concentration or Dose Rate Units	Concentration
bg_probe	a	east	mrem/hr	90
bg_probe	a	west	mrem/hr	55
bg_probe	a	west	mrem/hr	45
bg_probe	a	west	mrem/hr	50
bg_probe	a	west	mrem/hr	50
bg_probe	a	north	mrem/hr	70
bg_probe	a	north	mrem/hr	400
bg_probe	a	north	mrem/hr	35
bg_probe	a	north	mrem/hr	80
bg_probe	a	south	mrem/hr	30
bg_probe	a	south	mrem/hr	35
bg_probe	a	south	mrem/hr	90
bg_probe	a	floor	mrem/hr	60
bg_probe	a	floor	mrem/hr	300
bg_probe	a	floor	mrem/hr	35
bg_probe	a	floor	mrem/hr	80
bg_probe	a	floor	mrem/hr	80
bg_probe	a	floor	mrem/hr	100
bg_probe	a	floor	mrem/hr	65
bg_probe	a	floor	mrem/hr	250
bg_probe	a	floor	mrem/hr	450
bg_probe	a	floor	mrem/hr	600
bg_probe	b	east	mrem/hr	12
bg_probe	b	west	mrem/hr	90
bg_probe	b	north	mrem/hr	15
bg_probe	b	north	mrem/hr	45
bg_probe	b	south	mrem/hr	10
bg_probe	b	south	mrem/hr	10
bg_probe	b	floor	mrem/hr	35
bg_probe	b	floor	mrem/hr	20
bg_probe	b	floor	mrem/hr	15

Method	Room Location	Directional Orientation	Concentration or Dose Rate Units	Concentration
bg_probe	b	floor	mrem/hr	20
bg_probe	b	floor	mrem/hr	10
bg_probe	b	floor	mrem/hr	50
bg_probe	canal		mrem/hr	12
bg_probe	canal	top	mrem/hr	0.75
bg_probe	canal	south	mrem/hr	15
bg_probe	canal	south_wy	mrem/hr	100
bg_probe	canal	south_wy	mrem/hr	800
bg_probe	canal	fence	mrem/hr	4
bg_probe	canal	floor	mrem/hr	11388
bg_smear	canal	floor	mrem/hr	700
a_smear	gallery	lev1	pCi/kg	307.7
a_smear	gallery	lev2	pCi/kg	109.7
b_smear	gallery	lev1	pCi/kg	2497.9
b_smear	gallery	lev2	pCi/kg	579
a_smear	droom	east	pCi/kg	2082.58
a_smear	droom	west	pCi/kg	3663.46
a_smear	droom	north	pCi/kg	1486.21
a_smear	droom	south	pCi/kg	719.44
a_smear	droom	floor	pCi/kg	9557.17
bg_smear	droom	east	pCi/kg	4960.34
bg_smear	droom	west	pCi/kg	7118.65
bg_smear	droom	north	pCi/kg	150154.36
bg_smear	droom	south	pCi/kg	10242.53
bg_smear	droom	floor	pCi/kg	81978.11
bg_smear	droom	floor	mrem/hr	5
bg_smear	droom	floor	mrem/hr	0.38
a_smear	dpit	west	pCi/kg	62950.86
a_smear	dpit	north	pCi/kg	75730.35
a_smear	dpit	south	pCi/kg	5414.72
bg_smear	dpit	west	pCi/kg	804635.02

Method	Room Location	Directional Orientation	Concentration or Dose Rate Units	Concentration
bg_smear	dpit	north	pCi/kg	378651.77
bg_smear	dpit	south	pCi/kg	26770.68
bg_smear	dpit	floor	mrem/hr	1.2
bg_smear	dpit	north	mrem/hr	0.9
a_air	control	xxxx	pCi/m3	0.0257
b_air	control	xxxx	pCi/m3	0.0236
bg_probe	locker	xxxx	mrem/hr	0.0876
bg_probe	shop	xxxx	mrem/hr	0.1095
bg_probe	office	xxxx	mrem/hr	0.0876
a_air	all	xxxx	pCi/m3	0.00745
b_air	all	xxxx	pCi/m3	0.00358

APPENDIX D

Incremental Lifetime Cancer Risk Histograms

Table D.1 Ingestion Risk for Maintenance Worker in Cell A

Table D.2 Inhalation Risk for Maintenance Worker in Cell A

Table D.3. External Exposure Risk for Maintenance Worker in Cell A

Table D.4. Ingestion Risk for Maintenance Worker in Cell B

Table D.5. Inhalation Risk for Maintenance Worker in Cell B

Table D.6. External Exposure for Maintenance Worker in Cell B

Table D.7. Ingestion Risk for Maintenance Worker in Cell C

Table D.8. Inhalation Risk for Maintenance Worker in Cell C

**Industrial, External Exposure, Maintenance,
Cell C**

Table D.9. External Exposure Risk for Maintenance Worker in Cell C

Table D.10. Ingestion Risk for Maintenance Worker in Cell D

Table D.11. Inhalation Risk for Maintenance Worker in Cell D

Table D.12. External Exposure Risk for Maintenance Worker in Cell D

Table D.13. Ingestion Risk for Maintenance Worker in Cell E

Table D.14. Inhalation Risk for Maintenance Worker in Cell E

Table D.15. External Exposure for Maintenance Worker in Cell E

Table D.16. Ingestion Risk for Maintenance Worker in Cell F

Table D.17. Inhalation Risk for Maintenance Worker in Cell F

Table D.18. External Exposure Risk for Maintenance Worker in Cell F

Table D.19. Ingstion Risk for Maintenance Worker in Dissolver Pit

Table D.20. Inhalation Risk for Maintenance Worker in Dissolver Pit

Table D.21. External Exposure Risk for Maintenance Worker in Dissolver Pit

Table D.22. Ingestion Risk for Maintenance Worker in Dissolver Room

Table D.23. Inhalation Risk for Maintenance Worker in Dissolver Room

Table D.24. External Exposure Risk for Maintenance Worker in Dissolver Room

Table D.25. Ingestion Risk for Maintenance Worker in Whole Building

Table D.26. Inhalation Risk for Maintenance Worker in Whole Building

Table D.27. External Exposure Risk for Maintenance Worker in Whole Building

Table D.28. Ingestion Risk for Maintenance Worker in Electrical Gallery

Table D.29. Inhalation Risk for Maintenance Worker in Electrical Gallery

Table D.30. External Exposure for Maintenance Worker in Electrical Gallery

Table D.31. Ingestion Risk for S & M Worker in Cell A

Table D.32. Inhalation Risk for S & M Worker in Cell A

Table D.33. External Exposure for S & M Worker in Cell A

Table D.34. Ingestion Risk for S & M Worker in Cell B

Table D.35. Inhalation Risk for S & M Worker in Cell B

Table D.36. External Exposure Risk for S & M Worker in Cell B

Table D.37. Ingestion Risk for S & M Worker in Cell C

Table D.38. Inhalation Risk for S & M Worker in Cell C

Table D.39. External Exposure Risk for S & M Worker in Cell C

Industrial Ingestion, S&M, Cell D

Table D.40. Ingestion Risk for S & M Worker in Cell D

Industrial Inhalation, S&M, Cell D

Table D.41. Inhalation Risk for S & M Worker in Cell D

Table D.42. External Exposure Risk for S & M Worker in Cell D

Table D.43. Ingestion Risk for S & M Worker in Cell E

Table D.44. Inhalation Risk for S & M Worker in Cell E

External Exposure Inhalation, S&M, Cell E

Table D.45. External Exposure Risk for S & M Worker in Cell E

Table D.46. Ingestion Risk for S & M Worker in Cell F

Table D.47. Inhalation Risk for S & M Worker in Cell F

Table D.48. External Exposure Risk for S & M Worker in Cell F

Table D.49. Ingestion Risk for S & M Worker in Dissolver Pit

Table D.50. Inhalation Risk for S & M Worker in Dissolver Pit

Table D.51. External Exposure Risk for S & M Worker in Dissolver Pit

Table D.52. Ingestion Risk for S & M Worker in Dissolver Room

Table D.53. Inhalation Risk for S & M Worker in Dissolver Room

Table D.54. External Exposure for S & M Worker in Dissolver Room

Table D.55. Ingestion Risk for S & M Worker in Whole Building

Table D.56. Inhalation Risk for S & M Worker in Whole Building

Table D.57. External Exposure Risk for S & M Worker in Whole Building

Table D.58. Ingestion Risk for S & M Worker in Electrical Gallery

Table D.59. Inhalation Risk for S & M Worker in Electrical Gallery

Table D.60. External Exposure Risk for S & M Worker in Electrical Gallery

Table D.61. Ingestion Risk for Resident in Cell A

Table D.62. Inhalation Risk for Resident in Cell A

Table D.63. External Exposure Risk for Resident in Cell A

Table D.64. Ingestion Risk for Resident in Cell B

Table D.65. Inhalation Risk for Resident in Cell B

Table D.66. External Exposure Risk for Resident in Cell B

Table D.67. Ingestion Risk for Resident in Cell C

Table D.68. Inhalation Risk for Resident in Cell C

Table D.69. External Exposure Risk for Resident in Cell C

Table D.70. Ingestion Risk for Resident in Cell D

Table D.71. Inhalation Risk for Resident in Cell D

Table D.72. External Exposure Risk for Resident in Cell D

Residential Ingestion, Cell E

Table D.73. Ingestion Risk for Resident in Cell E

Residential Inhalation, Cell E

Table D.74. Inhalation Risk for Resident in Cell E

Table D.75. External Exposure Risk for Resident in Cell E

Table D.76. Ingestion Risk for Resident in Cell F

Table D.77. Inhalation Risk for Resident in Cell F

Table D.78. External Exposure Risk for Resident in Cell F

Table D.79. Ingestion Risk for Resident in Dissolver Pit

Table D.80. Inhalation Risk for Resident in Dissolver Pit

Table D.81. External Exposure Risk for Resident in Dissolver Pit

Table D.82. Ingestion Risk for Resident in Dissolver Room

Table D.83. Inhalation Risk for Resident in Dissolver Room

Table D.84. External Exposure Risk for Resident in Dissolver Room

Table D.85. Ingestion Risk for Resident in Electrical Gallery

Table D.86. Inhalation Risk for Resident in Electrical Gallery

Table D.87. External Exposure for Resident in Electrical Gallery

Residential Ingestion, Whole Building

Table D.88. Ingestion Risk for Resident in Whole Building

Residential Inhalation, Whole Building

Table D.89. Inhalation Risk for Resident in Whole Building

Table D.90. External Exposure Risk for Resident in Whole Building

APPENDIX E

Incremental Lifetime Cancer Risk Characterization Results for Building 3505

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Table E.1. ILCR associated with Building 3505 Cell A for the maintenance worker, based on alpha and beta/gamma smear survey data

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Air (alpha)	Entire building	Am-241	2.57E-02		1.03E-04		1.03E-04
Air (alpha)	Entire building	Pu-239	2.57E-02		1.22E-04		1.22E-04
Air (alpha)	Entire building	U-238	2.57E-02		1.67E-04		1.67E-04
Air (alpha)	Control room	Am-241	2.57E-02		1.03E-04		1.03E-04
Air (alpha)	Control room	Pu-239	2.57E-02		1.22E-04		1.22E-04
Air (alpha)	Control room	U-238	2.57E-02		1.67E-04		1.67E-04
Probe (alpha)	Cell A	Am-241	1.04E+03	7.83E-05	9.74E-07	2.92E-05	1.08E-04
Probe (alpha)	Cell A	Pu-239	1.04E+03	7.50E-05	1.16E-06	1.01E-07	7.63E-05
Probe (alpha)	Cell A	U-238	1.04E+03	9.13E-06	1.58E-06	2.14E-04	2.25E-04
Probe (alpha)	Entire building	Am-241	1.28E+03	9.62E-05	1.20E-06	3.59E-05	1.33E-04
Probe (alpha)	Entire building	Pu-239	1.28E+03	9.22E-05	1.42E-06	1.24E-07	9.37E-05
Probe (alpha)	Entire building	U-238	1.28E+03	1.12E-05	1.95E-06	2.64E-04	2.77E-04
Probe (alpha)	Cell B	Am-241	1.52E+03	1.14E-04	1.42E-06	4.24E-05	1.57E-04
Probe (alpha)	Cell B	Pu-239	1.52E+03	1.09E-04	1.68E-06	1.47E-07	1.11E-04
Probe (alpha)	Cell B	U-238	1.52E+03	1.33E-05	2.30E-06	3.11E-04	3.27E-04
Probe (alpha)	Cell C	Am-241	1.04E+03	7.83E-05	9.74E-07	2.92E-05	1.08E-04
Probe (alpha)	Cell C	Pu-239	1.04E+03	7.50E-05	1.16E-06	1.01E-07	7.63E-05
Probe (alpha)	Cell C	U-238	1.04E+03	9.13E-06	1.58E-06	2.14E-04	2.25E-04
Probe (alpha)	Cell D	Am-241	9.54E+02	7.16E-05	8.91E-07	2.67E-05	9.91E-05
Probe (alpha)	Cell D	Pu-239	9.54E+02	6.86E-05	1.06E-06	9.26E-08	6.97E-05
Probe (alpha)	Cell D	U-238	9.54E+02	8.35E-06	1.45E-06	1.96E-04	2.06E-04
Probe (alpha)	Cell E	Am-241	8.20E+02	6.15E-05	7.66E-07	2.29E-05	8.52E-05
Probe (alpha)	Cell E	Pu-239	8.20E+02	5.89E-05	9.09E-07	7.96E-08	5.99E-05
Probe (alpha)	Cell E	U-238	8.20E+02	7.18E-06	1.24E-06	1.69E-04	1.77E-04
Probe (alpha)	Cell F	Am-241	8.20E+02	6.15E-05	7.66E-07	2.29E-05	8.52E-05
Probe (alpha)	Cell F	Pu-239	8.20E+02	5.89E-05	9.09E-07	7.96E-08	5.99E-05

Table E.1. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Probe (alpha)	Cell F	U-238	8.20E+02	7.18E-06	1.24E-06	1.69E-04	1.77E-04
Smear (alpha)	Cell A	Am-241	4.81E+03	3.61E-04	4.49E-06	1.34E-04	5.00E-04
Smear (alpha)	Cell A	Pu-239	4.81E+03	3.46E-04	5.33E-06	4.67E-07	3.51E-04
Smear (alpha)	Cell A	U-238	4.81E+03	4.21E-05	7.30E-06	9.88E-04	1.04E-03
Smear (alpha)	Entire building	Am-241	1.11E+04	8.29E-04	1.03E-05	3.09E-04	1.15E-03
Smear (alpha)	Entire building	Pu-239	1.11E+04	7.94E-04	1.23E-05	1.07E-06	8.08E-04
Smear (alpha)	Entire building	U-238	1.11E+04	9.67E-05	1.68E-05	2.27E-03	2.38E-03
Smear (alpha)	Cell B	Am-241	1.78E+03	1.34E-04	1.66E-06	4.98E-05	1.85E-04
Smear (alpha)	Cell B	Pu-239	1.78E+03	1.28E-04	1.98E-06	1.73E-07	1.30E-04
Smear (alpha)	Cell B	U-238	1.78E+03	1.56E-05	2.70E-06	3.66E-04	3.85E-04
Smear (alpha)	Cell C	Am-241	8.97E+01	6.73E-06	8.38E-08	2.51E-06	9.32E-06
Smear (alpha)	Cell C	Pu-239	8.97E+01	6.45E-06	9.95E-08	8.71E-09	6.56E-06
Smear (alpha)	Cell C	U-238	8.97E+01	7.85E-07	1.36E-07	1.84E-05	1.94E-05
Smear (alpha)	Cell D	Am-241	4.20E+02	3.15E-05	3.92E-07	1.17E-05	4.36E-05
Smear (alpha)	Cell D	Pu-239	4.20E+02	3.02E-05	4.66E-07	4.08E-08	3.07E-05
Smear (alpha)	Cell D	U-238	4.20E+02	3.68E-06	6.37E-07	8.63E-05	9.06E-05
Smear (alpha)	Dissolver pit	Am-241	7.57E+01	5.68E-06	7.07E-08	2.12E-06	7.87E-06
Smear (alpha)	Dissolver pit	Pu-239	7.57E+01	5.44E-06	8.40E-08	7.35E-09	5.53E-06
Smear (alpha)	Dissolver pit	U-238	7.57E+01	6.63E-07	1.15E-07	1.56E-05	1.63E-05
Smear (alpha)	Dissolver room	Am-241	8.94E+00	6.71E-07	8.35E-09	2.50E-07	9.29E-07
Smear (alpha)	Dissolver room	Pu-239	8.94E+00	6.43E-07	9.91E-09	8.67E-10	6.53E-07
Smear (alpha)	Dissolver room	U-238	8.94E+00	7.82E-08	1.36E-08	1.84E-06	1.93E-06
Smear (alpha)	Cell E	Am-241	1.90E+03	1.42E-04	1.77E-06	5.31E-05	1.97E-04
Smear (alpha)	Cell E	Pu-239	1.90E+03	1.36E-04	2.10E-06	1.84E-07	1.39E-04
Smear (alpha)	Cell E	U-238	1.90E+03	1.66E-05	2.88E-06	3.90E-04	4.09E-04
Smear (alpha)	Cell F	Am-241	1.84E+05	1.37E-02	1.72E-04	5.15E-03	1.89E-02

Table E.1. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Smear (alpha)	Cell F	Pu-239	1.84E+05	1.31E-02	2.04E-04	1.79E-05	1.34E-02
Smear (alpha)	Cell F	U-238	1.84E+05	1.61E-03	2.79E-04	3.71E-02	3.89E-02
Smear (alpha)	Electrical gallery	Am-241	3.08E-01	2.31E-08	2.87E-10	8.61E-09	3.20E-08
Smear (alpha)	Electrical gallery	Pu-239	3.08E-01	2.21E-08	3.41E-10	2.99E-11	2.25E-08
Smear (alpha)	Electrical gallery	U-238	3.08E-01	2.69E-09	4.67E-10	6.32E-08	6.64E-08
Air (beta)	Entire building	Sr-90	2.36E-02		1.83E-07		1.83E-07
Air (beta)	Entire building	Tc-99	2.36E-02		2.45E-08		2.45E-08
Air (beta)	Control room	Sr-90	2.36E-02		1.83E-07		1.83E-07
Air (beta)	Control room	Tc-99	2.36E-02		2.45E-08		2.45E-08
Smear (beta)	Cell A	Sr-90	5.17E+03	5.81E-05	9.35E-09	0.00E+00	5.82E-05
Smear (beta)	Cell A	Tc-99	5.17E+03	2.10E-06	1.25E-09	1.77E-08	2.12E-06
Smear (beta)	Entire building	Sr-90	5.17E+03	5.81E-05	9.35E-09	0.00E+00	5.82E-05
Smear (beta)	Entire building	Tc-99	5.17E+03	2.10E-06	1.25E-09	1.77E-08	2.12E-06
Smear (beta)	Cell B	Sr-90	3.84E+03	4.32E-05	6.95E-09	0.00E+00	4.32E-05
Smear (beta)	Cell B	Tc-99	3.84E+03	1.56E-06	9.31E-10	1.32E-08	1.58E-06
Smear (beta)	Electrical gallery	Sr-90	2.50E+00	2.81E-08	4.52E-12	0.00E+00	2.81E-08
Smear (beta)	Electrical gallery	Tc-99	2.50E+00	1.01E-09	6.05E-13	8.55E-12	1.02E-09
Probe (beta/gamma)	Cell A	Cs-137	1.81E+02			9.99E-01	9.99E-01
Probe (beta/gamma)	Cell A	Sr-90	1.81E+02			9.99E-01	9.99E-01
Probe (beta/gamma)	Cell A	Tc-99	1.81E+02			9.99E-01	9.99E-01
Probe (beta/gamma)	Entire building	Cs-137	1.07E+03			1.00E+00	1.00E+00
Probe (beta/gamma)	Entire building	Sr-90	1.07E+03			1.00E+00	1.00E+00
Probe (beta/gamma)	Entire building	Tc-99	1.07E+03			1.00E+00	1.00E+00
Probe (beta/gamma)	Cell B	Cs-137	4.07E+01			7.73E-01	7.73E-01
Probe (beta/gamma)	Cell B	Sr-90	4.07E+01			7.73E-01	7.73E-01
Probe (beta/gamma)	Cell B	Tc-99	4.07E+01			7.73E-01	7.73E-01

Table E.1. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Probe (beta/gamma)	Canal	Cs-137	1.14E+04			1.00E+00	1.00E+00
Probe (beta/gamma)	Canal	Sr-90	1.14E+04			1.00E+00	1.00E+00
Probe (beta/gamma)	Canal	Tc-99	1.14E+04			1.00E+00	1.00E+00
Probe (beta/gamma)	Locker room	Cs-137	8.76E-02			3.20E-03	3.20E-03
Probe (beta/gamma)	Locker room	Sr-90	8.76E-02			3.20E-03	3.20E-03
Probe (beta/gamma)	Locker room	Tc-99	8.76E-02			3.20E-03	3.20E-03
Probe (beta/gamma)	Office	Cs-137	8.76E-02			3.20E-03	3.20E-03
Probe (beta/gamma)	Office	Sr-90	8.76E-02			3.20E-03	3.20E-03
Probe (beta/gamma)	Office	Tc-99	8.76E-02			3.20E-03	3.20E-03
Probe (beta/gamma)	Shop	Cs-137	1.10E-01			4.00E-03	4.00E-03
Probe (beta/gamma)	Shop	Sr-90	1.10E-01			4.00E-03	4.00E-03
Probe (beta/gamma)	Shop	Tc-99	1.10E-01			4.00E-03	4.00E-03
Smear (beta/gamma)	Entire building	Cs-137	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Entire building	Cs-137	8.05E+02	7.04E-06	4.46E-10	9.19E-03	9.19E-03
Smear (beta/gamma)	Entire building	Sr-90	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Entire building	Sr-90	8.05E+02	9.05E-06	1.46E-09	0.00E+00	9.05E-06
Smear (beta/gamma)	Entire building	Tc-99	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Entire building	Tc-99	8.05E+02	3.27E-07	1.95E-10	2.76E-09	3.30E-07
Smear (beta/gamma)	Canal	Cs-137	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Canal	Sr-90	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Canal	Tc-99	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Dissolver pit	Cs-137	1.20E+00			4.29E-02	4.29E-02
Smear (beta/gamma)	Dissolver pit	Cs-137	8.05E+02	7.04E-06	4.46E-10	9.19E-03	9.19E-03
Smear (beta/gamma)	Dissolver pit	Sr-90	1.20E+00			4.29E-02	4.29E-02
Smear (beta/gamma)	Dissolver pit	Sr-90	8.05E+02	9.05E-06	1.46E-09	0.00E+00	9.05E-06
Smear (beta/gamma)	Dissolver pit	Tc-99	1.20E+00			4.29E-02	4.29E-02

Table E.1. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Smear (beta/gamma)	Dissolver pit	Tc-99	8.05E+02	3.27E-07	1.95E-10	2.76E-09	3.30E-07
Smear (beta/gamma)	Dissolver room	Cs-137	5.00E+00			1.67E-01	1.67E-01
Smear (beta/gamma)	Dissolver room	Cs-137	1.50E+02	1.31E-06	8.32E-11	1.71E-03	1.72E-03
Smear (beta/gamma)	Dissolver room	Sr-90	5.00E+00			1.67E-01	1.67E-01
Smear (beta/gamma)	Dissolver room	Sr-90	1.50E+02	1.69E-06	2.72E-10	0.00E+00	1.69E-06
Smear (beta/gamma)	Dissolver room	Tc-99	5.00E+00			1.67E-01	1.67E-01
Smear (beta/gamma)	Dissolver room	Tc-99	1.50E+02	6.10E-08	3.64E-11	5.14E-10	6.16E-08
Smear (beta/gamma)	Cell E	Cs-137	1.14E+02	9.94E-07	6.30E-11	1.30E-03	1.30E-03
Smear (beta/gamma)	Cell E	Sr-90	1.14E+02	1.28E-06	2.05E-10	0.00E+00	1.28E-06
Smear (beta/gamma)	Cell E	Tc-99	1.14E+02	4.61E-08	2.75E-11	3.89E-10	4.66E-08
Air (alpha)	Entire building	Np-237	2.57E-02		9.32E-05		9.32E-05
Air (alpha)	Control room	Np-237	2.57E-02		9.32E-05		9.32E-05
Probe (alpha)	Cell A	Np-237	1.04E+03	7.18E-05	8.83E-07	2.56E-03	2.63E-03
Probe (alpha)	Entire building	Np-237	1.28E+03	8.82E-05	1.09E-06	3.15E-03	3.24E-03
Probe (alpha)	Cell B	Np-237	1.52E+03	1.04E-04	1.28E-06	3.72E-03	3.83E-03
Probe (alpha)	Cell C	Np-237	1.04E+03	7.18E-05	8.83E-07	2.56E-03	2.63E-03
Probe (alpha)	Cell D	Np-237	9.54E+02	6.56E-05	8.07E-07	2.34E-03	2.41E-03
Probe (alpha)	Cell E	Np-237	8.20E+02	5.64E-05	6.94E-07	2.01E-03	2.07E-03
Probe (alpha)	Cell F	Np-237	8.20E+02	5.64E-05	6.94E-07	2.01E-03	2.07E-03
Smear (alpha)	Cell A	Np-237	4.81E+03	3.31E-04	4.07E-06	1.17E-02	1.21E-02
Smear (alpha)	Entire building	Np-237	1.11E+04	7.60E-04	9.35E-06	2.68E-02	2.75E-02
Smear (alpha)	Cell B	Np-237	1.78E+03	1.23E-04	1.51E-06	4.37E-03	4.50E-03
Smear (alpha)	Cell C	Np-237	8.97E+01	6.17E-06	7.59E-08	2.20E-04	2.26E-04
Smear (alpha)	Cell D	Np-237	4.20E+02	2.89E-05	3.55E-07	1.03E-03	1.06E-03
Smear (alpha)	Dissolver pit	Np-237	7.57E+01	5.21E-06	6.41E-08	1.86E-04	1.91E-04
Smear (alpha)	Dissolver room	Np-237	8.94E+00	6.15E-07	7.56E-09	2.19E-05	2.26E-05

Table E.1. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Smear (alpha)	Cell E	Np-237	1.90E+03	1.30E-04	1.61E-06	4.66E-03	4.79E-03
Smear (alpha)	Cell F	Np-237	1.84E+05	1.26E-02	1.56E-04	3.63E-01	3.71E-01
Smear (alpha)	Electrical gallery	Np-237	3.08E-01	2.12E-08	2.60E-10	7.55E-07	7.77E-07

Table E.2. ILCR associated with Building 3505 Cell A for the maintenance worker, based on alpha and beta/gamma probe survey data

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Air (alpha)	Entire building	Am-241	2.57E-02		8.22E-07		8.22E-07
Air (alpha)	Entire building	Pu-239	2.57E-02		9.77E-07		9.77E-07
Air (alpha)	Entire building	U-238	2.57E-02		1.34E-06		1.34E-06
Air (alpha)	Control room	Am-241	2.57E-02		8.22E-07		8.22E-07
Air (alpha)	Control room	Pu-239	2.57E-02		9.77E-07		9.77E-07
Air (alpha)	Control room	U-238	2.57E-02		1.34E-06		1.34E-06
Probe (alpha)	Cell A	Am-241	1.04E+03	6.26E-07	7.80E-09	2.34E-07	8.68E-07
Probe (alpha)	Cell A	Pu-239	1.04E+03	6.00E-07	9.26E-09	8.10E-10	6.10E-07
Probe (alpha)	Cell A	U-238	1.04E+03	7.31E-08	1.27E-08	1.72E-06	1.80E-06
Probe (alpha)	Entire building	Am-241	1.28E+03	7.70E-07	9.58E-09	2.87E-07	1.07E-06
Probe (alpha)	Entire building	Pu-239	1.28E+03	7.38E-07	1.14E-08	9.96E-10	7.50E-07
Probe (alpha)	Entire building	U-238	1.28E+03	8.98E-08	1.56E-08	2.11E-06	2.21E-06
Probe (alpha)	Cell B	Am-241	1.52E+03	9.09E-07	1.13E-08	3.39E-07	1.26E-06
Probe (alpha)	Cell B	Pu-239	1.52E+03	8.72E-07	1.34E-08	1.18E-09	8.86E-07
Probe (alpha)	Cell B	U-238	1.52E+03	1.06E-07	1.84E-08	2.49E-06	2.62E-06
Probe (alpha)	Cell C	Am-241	1.04E+03	6.26E-07	7.80E-09	2.34E-07	8.68E-07
Probe (alpha)	Cell C	Pu-239	1.04E+03	6.00E-07	9.26E-09	8.10E-10	6.10E-07
Probe (alpha)	Cell C	U-238	1.04E+03	7.31E-08	1.27E-08	1.72E-06	1.80E-06
Probe (alpha)	Cell D	Am-241	9.54E+02	5.73E-07	7.13E-09	2.14E-07	7.93E-07
Probe (alpha)	Cell D	Pu-239	9.54E+02	5.49E-07	8.46E-09	7.41E-10	5.58E-07
Probe (alpha)	Cell D	U-238	9.54E+02	6.68E-08	1.16E-08	1.57E-06	1.65E-06
Probe (alpha)	Cell E	Am-241	8.20E+02	4.92E-07	6.12E-09	1.83E-07	6.82E-07
Probe (alpha)	Cell E	Pu-239	8.20E+02	4.72E-07	7.27E-09	6.37E-10	4.79E-07

Table E.2. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Probe (alpha)	Cell E	U-238	8.20E+02	5.74E-08	9.95E-09	1.35E-06	1.42E-06
Probe (alpha)	Cell F	Am-241	8.20E+02	4.92E-07	6.12E-09	1.83E-07	6.82E-07
Probe (alpha)	Cell F	Pu-239	8.20E+02	4.72E-07	7.27E-09	6.37E-10	4.79E-07
Probe (alpha)	Cell F	U-238	8.20E+02	5.74E-08	9.95E-09	1.35E-06	1.42E-06
Smear (alpha)	Cell A	Am-241	4.81E+03	2.89E-06	3.59E-08	1.08E-06	4.00E-06
Smear (alpha)	Cell A	Pu-239	4.81E+03	2.77E-06	4.27E-08	3.73E-09	2.81E-06
Smear (alpha)	Cell A	U-238	4.81E+03	3.37E-07	5.84E-08	7.91E-06	8.30E-06
Smear (alpha)	Entire building	Am-241	1.11E+04	6.63E-06	8.25E-08	2.47E-06	9.19E-06
Smear (alpha)	Entire building	Pu-239	1.11E+04	6.35E-06	9.80E-08	8.58E-09	6.46E-06
Smear (alpha)	Entire building	U-238	1.11E+04	7.74E-07	1.34E-07	1.82E-05	1.91E-05
Smear (alpha)	Cell B	Am-241	1.78E+03	1.07E-06	1.33E-08	3.99E-07	1.48E-06
Smear (alpha)	Cell B	Pu-239	1.78E+03	1.02E-06	1.58E-08	1.38E-09	1.04E-06
Smear (alpha)	Cell B	U-238	1.78E+03	1.25E-07	2.16E-08	2.93E-06	3.08E-06
Smear (alpha)	Cell C	Am-241	8.97E+01	5.38E-08	6.70E-10	2.01E-08	7.46E-08
Smear (alpha)	Cell C	Pu-239	8.97E+01	5.16E-08	7.96E-10	6.96E-11	5.25E-08
Smear (alpha)	Cell C	U-238	8.97E+01	6.28E-09	1.09E-09	1.47E-07	1.55E-07
Smear (alpha)	Cell D	Am-241	4.20E+02	2.52E-07	3.14E-09	9.40E-08	3.49E-07
Smear (alpha)	Cell D	Pu-239	4.20E+02	2.42E-07	3.73E-09	3.26E-10	2.46E-07
Smear (alpha)	Cell D	U-238	4.20E+02	2.94E-08	5.10E-09	6.91E-07	7.25E-07
Smear (alpha)	Dissolver pit	Am-241	7.57E+01	4.54E-08	5.66E-10	1.69E-08	6.29E-08
Smear (alpha)	Dissolver pit	Pu-239	7.57E+01	4.35E-08	6.72E-10	5.88E-11	4.43E-08
Smear (alpha)	Dissolver pit	U-238	7.57E+01	5.30E-09	9.19E-10	1.24E-07	1.31E-07

Table E.2. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Smear (alpha)	Dissolver room	Am-241	8.94E+00	5.36E-09	6.68E-11	2.00E-09	7.43E-09
Smear (alpha)	Dissolver room	Pu-239	8.94E+00	5.14E-09	7.93E-11	6.94E-12	5.23E-09
Smear (alpha)	Dissolver room	U-238	8.94E+00	6.26E-10	1.09E-10	1.47E-08	1.54E-08
Smear (alpha)	Cell E	Am-241	1.90E+03	1.14E-06	1.42E-08	4.24E-07	1.58E-06
Smear (alpha)	Cell E	Pu-239	1.90E+03	1.09E-06	1.68E-08	1.47E-09	1.11E-06
Smear (alpha)	Cell E	U-238	1.90E+03	1.33E-07	2.30E-08	3.12E-06	3.27E-06
Smear (alpha)	Cell F	Am-241	1.84E+05	1.10E-04	1.37E-06	4.12E-05	1.53E-04
Smear (alpha)	Cell F	Pu-239	1.84E+05	1.06E-04	1.63E-06	1.43E-07	1.08E-04
Smear (alpha)	Cell F	U-238	1.84E+05	1.29E-05	2.23E-06	3.02E-04	3.18E-04
Smear (alpha)	Electrical gallery	Am-241	3.08E-01	1.85E-10	2.30E-12	6.88E-11	2.56E-10
Smear (alpha)	Electrical gallery	Pu-239	3.08E-01	1.77E-10	2.73E-12	2.39E-13	1.80E-10
Smear (alpha)	Electrical gallery	U-238	3.08E-01	2.15E-11	3.73E-12	5.06E-10	5.31E-10
Air (beta)	Entire building	Sr-90	2.36E-02		1.46E-09		1.46E-09
Air (beta)	Entire building	Tc-99	2.36E-02		1.96E-10		1.96E-10
Air (beta)	Control room	Sr-90	2.36E-02		1.46E-09		1.46E-09
Air (beta)	Control room	Tc-99	2.36E-02		1.96E-10		1.96E-10
Smear (beta)	Cell A	Sr-90	5.17E+03	4.65E-07	7.48E-11	0.00E+00	4.65E-07
Smear (beta)	Cell A	Tc-99	5.17E+03	1.68E-08	1.00E-11	1.42E-10	1.69E-08
Smear (beta)	Entire building	Sr-90	5.17E+03	4.65E-07	7.48E-11	0.00E+00	4.65E-07
Smear (beta)	Entire building	Tc-99	5.17E+03	1.68E-08	1.00E-11	1.42E-10	1.69E-08
Smear (beta)	Cell B	Sr-90	3.84E+03	3.46E-07	5.56E-11	0.00E+00	3.46E-07
Smear (beta)	Cell B	Tc-99	3.84E+03	1.25E-08	7.45E-12	1.05E-10	1.26E-08

Table E.2. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Smear (beta)	Electrical gallery	Sr-90	2.50E+00	2.25E-10	3.61E-14	0.00E+00	2.25E-10
Smear (beta)	Electrical gallery	Tc-99	2.50E+00	8.12E-12	4.84E-15	6.84E-14	8.19E-12
Probe (beta/gamma)	Cell A	Cs-137	1.81E+02			9.99E-01	9.99E-01
Probe (beta/gamma)	Cell A	Sr-90	1.81E+02			9.99E-01	9.99E-01
Probe (beta/gamma)	Cell A	Tc-99	1.81E+02			9.99E-01	9.99E-01
Probe (beta/gamma)	Entire building	Cs-137	1.07E+03			1.00E+00	1.00E+00
Probe (beta/gamma)	Entire building	Sr-90	1.07E+03			1.00E+00	1.00E+00
Probe (beta/gamma)	Entire building	Tc-99	1.07E+03			1.00E+00	1.00E+00
Probe (beta/gamma)	Cell B	Cs-137	4.07E+01			7.73E-01	7.73E-01
Probe (beta/gamma)	Cell B	Sr-90	4.07E+01			7.73E-01	7.73E-01
Probe (beta/gamma)	Cell B	Tc-99	4.07E+01			7.73E-01	7.73E-01
Probe (beta/gamma)	Canal	Cs-137	1.14E+04			1.00E+00	1.00E+00
Probe (beta/gamma)	Canal	Sr-90	1.14E+04			1.00E+00	1.00E+00
Probe (beta/gamma)	Canal	Tc-99	1.14E+04			1.00E+00	1.00E+00
Probe (beta/gamma)	Locker room	Cs-137	8.76E-02			3.20E-03	3.20E-03
Probe (beta/gamma)	Locker room	Sr-90	8.76E-02			3.20E-03	3.20E-03
Probe (beta/gamma)	Locker room	Tc-99	8.76E-02			3.20E-03	3.20E-03
Probe (beta/gamma)	Office	Cs-137	8.76E-02			3.20E-03	3.20E-03
Probe (beta/gamma)	Office	Sr-90	8.76E-02			3.20E-03	3.20E-03
Probe (beta/gamma)	Office	Tc-99	8.76E-02			3.20E-03	3.20E-03
Probe (beta/gamma)	Shop	Cs-137	1.10E-01			4.00E-03	4.00E-03
Probe (beta/gamma)	Shop	Sr-90	1.10E-01			4.00E-03	4.00E-03

Table E.2. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Probe (beta/gamma)	Shop	Tc-99	1.10E-01			4.00E-03	4.00E-03
Smear (beta/gamma)	Entire building	Cs-137	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Entire building	Cs-137	8.05E+02	5.63E-08	3.57E-12	7.35E-05	7.35E-05
Smear (beta/gamma)	Entire building	Sr-90	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Entire building	Sr-90	8.05E+02	7.24E-08	1.16E-11	0.00E+00	7.24E-08
Smear (beta/gamma)	Entire building	Tc-99	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Entire building	Tc-99	8.05E+02	2.62E-09	1.56E-12	2.20E-11	2.64E-09
Smear (beta/gamma)	Canal	Cs-137	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Canal	Sr-90	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Canal	Tc-99	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Dissolver pit	Cs-137	1.20E+00			4.29E-02	4.29E-02
Smear (beta/gamma)	Dissolver pit	Cs-137	8.05E+02	5.63E-08	3.57E-12	7.35E-05	7.35E-05
Smear (beta/gamma)	Dissolver pit	Sr-90	1.20E+00			4.29E-02	4.29E-02
Smear (beta/gamma)	Dissolver pit	Sr-90	8.05E+02	7.24E-08	1.16E-11	0.00E+00	7.24E-08
Smear (beta/gamma)	Dissolver pit	Tc-99	1.20E+00			4.29E-02	4.29E-02
Smear (beta/gamma)	Dissolver pit	Tc-99	8.05E+02	2.62E-09	1.56E-12	2.20E-11	2.64E-09
Smear (beta/gamma)	Dissolver room	Cs-137	5.00E+00			1.67E-01	1.67E-01
Smear (beta/gamma)	Dissolver room	Cs-137	1.50E+02	1.05E-08	6.66E-13	1.37E-05	1.37E-05
Smear (beta/gamma)	Dissolver room	Sr-90	5.00E+00			1.67E-01	1.67E-01
Smear (beta/gamma)	Dissolver room	Sr-90	1.50E+02	1.35E-08	2.17E-12	0.00E+00	1.35E-08
Smear (beta/gamma)	Dissolver room	Tc-99	5.00E+00			1.67E-01	1.67E-01
Smear (beta/gamma)	Dissolver room	Tc-99	1.50E+02	4.88E-10	2.91E-13	4.11E-12	4.92E-10

Table E.2. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Smear (beta/gamma)	Cell E	Cs-137	1.14E+02	7.95E-09	5.04E-13	1.04E-05	1.04E-05
Smear (beta/gamma)	Cell E	Sr-90	1.14E+02	1.02E-08	1.64E-12	0.00E+00	1.02E-08
Smear (beta/gamma)	Cell E	Tc-99	1.14E+02	3.69E-10	2.20E-13	3.11E-12	3.73E-10
Air (alpha)	Entire building	Np-237	2.57E-02		7.45E-07		7.45E-07
Air (alpha)	Control room	Np-237	2.57E-02		7.45E-07		7.45E-07
Probe (alpha)	Cell A	Np-237	1.04E+03	5.74E-07	7.06E-09	2.05E-05	2.11E-05
Probe (alpha)	Entire building	Np-237	1.28E+03	7.05E-07	8.68E-09	2.52E-05	2.59E-05
Probe (alpha)	Cell B	Np-237	1.52E+03	8.34E-07	1.03E-08	2.98E-05	3.06E-05
Probe (alpha)	Cell C	Np-237	1.04E+03	5.74E-07	7.06E-09	2.05E-05	2.11E-05
Probe (alpha)	Cell D	Np-237	9.54E+02	5.25E-07	6.46E-09	1.87E-05	1.93E-05
Probe (alpha)	Cell E	Np-237	8.20E+02	4.51E-07	5.55E-09	1.61E-05	1.66E-05
Probe (alpha)	Cell F	Np-237	8.20E+02	4.51E-07	5.55E-09	1.61E-05	1.66E-05
Smear (alpha)	Cell A	Np-237	4.81E+03	2.64E-06	3.25E-08	9.44E-05	9.71E-05
Smear (alpha)	Entire building	Np-237	1.11E+04	6.08E-06	7.48E-08	2.17E-04	2.23E-04
Smear (alpha)	Cell B	Np-237	1.78E+03	9.80E-07	1.21E-08	3.50E-05	3.60E-05
Smear (alpha)	Cell C	Np-237	8.97E+01	4.93E-08	6.07E-10	1.76E-06	1.81E-06
Smear (alpha)	Cell D	Np-237	4.20E+02	2.31E-07	2.84E-09	8.25E-06	8.48E-06
Smear (alpha)	Dissolver pit	Np-237	7.57E+01	4.17E-08	5.13E-10	1.49E-06	1.53E-06
Smear (alpha)	Dissolver room	Np-237	8.94E+00	4.92E-09	6.05E-11	1.76E-07	1.81E-07
Smear (alpha)	Cell E	Np-237	1.90E+03	1.04E-06	1.28E-08	3.72E-05	3.83E-05
Smear (alpha)	Cell F	Np-237	1.84E+05	1.01E-04	1.25E-06	3.61E-03	3.72E-03
Smear (alpha)	Electrical gallery	Np-237	3.08E-01	1.69E-10	2.08E-12	6.04E-09	6.21E-09

Table E.3. ILCR associated with Building 3505 Cell A for the maintenance worker, based on alpha and beta/gamma smear survey data

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Air (alpha)	Entire building	Am-241	2.57E-02		1.73E-04		1.73E-04
Air (alpha)	Entire building	Pu-239	2.57E-02		2.05E-04		2.05E-04
Air (alpha)	Entire building	U-238	2.57E-02		2.81E-04		2.81E-04
Air (alpha)	Control room	Am-241	2.57E-02		1.73E-04		1.73E-04
Air (alpha)	Control room	Pu-239	2.57E-02		2.05E-04		2.05E-04
Air (alpha)	Control room	U-238	2.57E-02		2.81E-04		2.81E-04
Probe (alpha)	Cell A	Am-241	1.04E+03	2.63E-04	1.64E-06	1.47E-04	4.12E-04
Probe (alpha)	Cell A	Pu-239	1.04E+03	2.52E-04	1.94E-06	5.10E-07	2.55E-04
Probe (alpha)	Cell A	U-238	1.04E+03	3.07E-05	2.66E-06	1.08E-03	1.11E-03
Probe (alpha)	Entire building	Am-241	1.28E+03	3.23E-04	2.01E-06	1.81E-04	5.06E-04
Probe (alpha)	Entire building	Pu-239	1.28E+03	3.10E-04	2.39E-06	6.27E-07	3.13E-04
Probe (alpha)	Entire building	U-238	1.28E+03	3.77E-05	3.27E-06	1.33E-03	1.37E-03
Probe (alpha)	Cell B	Am-241	1.52E+03	3.82E-04	2.38E-06	2.14E-04	5.98E-04
Probe (alpha)	Cell B	Pu-239	1.52E+03	3.66E-04	2.82E-06	7.41E-07	3.70E-04
Probe (alpha)	Cell B	U-238	1.52E+03	4.46E-05	3.86E-06	1.57E-03	1.62E-03
Probe (alpha)	Cell C	Am-241	1.04E+03	2.63E-04	1.64E-06	1.47E-04	4.12E-04
Probe (alpha)	Cell C	Pu-239	1.04E+03	2.52E-04	1.94E-06	5.10E-07	2.55E-04
Probe (alpha)	Cell C	U-238	1.04E+03	3.07E-05	2.66E-06	1.08E-03	1.11E-03
Probe (alpha)	Cell D	Am-241	9.54E+02	2.40E-04	1.50E-06	1.35E-04	3.76E-04
Probe (alpha)	Cell D	Pu-239	9.54E+02	2.30E-04	1.78E-06	4.67E-07	2.33E-04
Probe (alpha)	Cell D	U-238	9.54E+02	2.81E-05	2.43E-06	9.88E-04	1.02E-03

Table E.3. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Probe (alpha)	Cell E	Am-241	8.20E+02	2.07E-04	1.29E-06	1.16E-04	3.24E-04
Probe (alpha)	Cell E	Pu-239	8.20E+02	1.98E-04	1.53E-06	4.01E-07	2.00E-04
Probe (alpha)	Cell E	U-238	8.20E+02	2.41E-05	2.09E-06	8.49E-04	8.75E-04
Probe (alpha)	Cell F	Am-241	8.20E+02	2.07E-04	1.29E-06	1.16E-04	3.24E-04
Probe (alpha)	Cell F	Pu-239	8.20E+02	1.98E-04	1.53E-06	4.01E-07	2.00E-04
Probe (alpha)	Cell F	U-238	8.20E+02	2.41E-05	2.09E-06	8.49E-04	8.75E-04
Smear (alpha)	Cell A	Am-241	4.81E+03	1.21E-03	7.54E-06	6.78E-04	1.90E-03
Smear (alpha)	Cell A	Pu-239	4.81E+03	1.16E-03	8.96E-06	2.35E-06	1.17E-03
Smear (alpha)	Cell A	U-238	4.81E+03	1.41E-04	1.23E-05	4.98E-03	5.13E-03
Smear (alpha)	Entire building	Am-241	1.11E+04	2.79E-03	1.73E-05	1.56E-03	4.36E-03
Smear (alpha)	Entire building	Pu-239	1.11E+04	2.67E-03	2.06E-05	5.40E-06	2.70E-03
Smear (alpha)	Entire building	U-238	1.11E+04	3.25E-04	2.82E-05	1.14E-02	1.17E-02
Smear (alpha)	Cell B	Am-241	1.78E+03	4.49E-04	2.80E-06	2.51E-04	7.03E-04
Smear (alpha)	Cell B	Pu-239	1.78E+03	4.30E-04	3.32E-06	8.72E-07	4.35E-04
Smear (alpha)	Cell B	U-238	1.78E+03	5.24E-05	4.54E-06	1.85E-03	1.90E-03
Smear (alpha)	Cell C	Am-241	8.97E+01	2.26E-05	1.41E-07	1.26E-05	3.54E-05
Smear (alpha)	Cell C	Pu-239	8.97E+01	2.17E-05	1.67E-07	4.39E-08	2.19E-05
Smear (alpha)	Cell C	U-238	8.97E+01	2.64E-06	2.29E-07	9.29E-05	9.58E-05
Smear (alpha)	Cell D	Am-241	4.20E+02	1.06E-04	6.59E-07	5.92E-05	1.66E-04
Smear (alpha)	Cell D	Pu-239	4.20E+02	1.01E-04	7.82E-07	2.05E-07	1.02E-04
Smear (alpha)	Cell D	U-238	4.20E+02	1.24E-05	1.07E-06	4.35E-04	4.48E-04

Table E.3. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Smear (alpha)	Dissolver pit	Am-241	7.57E+01	1.91E-05	1.19E-07	1.07E-05	2.99E-05
Smear (alpha)	Dissolver pit	Pu-239	7.57E+01	1.83E-05	1.41E-07	3.70E-08	1.85E-05
Smear (alpha)	Dissolver pit	U-238	7.57E+01	2.23E-06	1.93E-07	7.84E-05	8.08E-05
Smear (alpha)	Dissolver room	Am-241	8.94E+00	2.25E-06	1.40E-08	1.26E-06	3.53E-06
Smear (alpha)	Dissolver room	Pu-239	8.94E+00	2.16E-06	1.67E-08	4.37E-09	2.18E-06
Smear (alpha)	Dissolver room	U-238	8.94E+00	2.63E-07	2.28E-08	9.26E-06	9.54E-06
Smear (alpha)	Cell E	Am-241	1.90E+03	4.78E-04	2.98E-06	2.67E-04	7.48E-04
Smear (alpha)	Cell E	Pu-239	1.90E+03	4.58E-04	3.53E-06	9.28E-07	4.63E-04
Smear (alpha)	Cell E	U-238	1.90E+03	5.58E-05	4.83E-06	1.96E-03	2.03E-03
Smear (alpha)	Cell F	Am-241	1.84E+05	4.53E-02	2.89E-04	2.56E-02	7.00E-02
Smear (alpha)	Cell F	Pu-239	1.84E+05	4.35E-02	3.43E-04	9.00E-05	4.39E-02
Smear (alpha)	Cell F	U-238	1.84E+05	5.41E-03	4.69E-04	1.73E-01	1.78E-01
Smear (alpha)	Electrical gallery	Am-241	3.08E-01	7.75E-08	4.83E-10	4.34E-08	1.21E-07
Smear (alpha)	Electrical gallery	Pu-239	3.08E-01	7.43E-08	5.73E-10	1.50E-10	7.50E-08
Smear (alpha)	Electrical gallery	U-238	3.08E-01	9.05E-09	7.84E-10	3.19E-07	3.28E-07
Air (beta)	Entire building	Sr-90	2.36E-02		3.07E-07		3.07E-07
Air (beta)	Entire building	Tc-99	2.36E-02		4.11E-08		4.11E-08
Air (beta)	Control room	Sr-90	2.36E-02		3.07E-07		3.07E-07
Air (beta)	Control room	Tc-99	2.36E-02		4.11E-08		4.11E-08
Smear (beta)	Cell A	Sr-90	5.17E+03	1.95E-04	1.57E-08	0.00E+00	1.95E-04
Smear (beta)	Cell A	Tc-99	5.17E+03	7.06E-06	2.10E-09	8.92E-08	7.15E-06

Table E.3. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Smear (beta)	Entire building	Sr-90	5.17E+03	1.95E-04	1.57E-08	0.00E+00	1.95E-04
Smear (beta)	Entire building	Tc-99	5.17E+03	7.06E-06	2.10E-09	8.92E-08	7.15E-06
Smear (beta)	Cell B	Sr-90	3.84E+03	1.45E-04	1.17E-08	0.00E+00	1.45E-04
Smear (beta)	Cell B	Tc-99	3.84E+03	5.25E-06	1.56E-09	6.63E-08	5.31E-06
Smear (beta)	Electrical gallery	Sr-90	2.50E+00	9.44E-08	7.59E-12	0.00E+00	9.44E-08
Smear (beta)	Electrical gallery	Tc-99	2.50E+00	3.41E-09	1.02E-12	4.31E-11	3.45E-09
Probe (beta/gamma)	Cell A	Cs-137	1.81E+02			1.00E+00	1.00E+00
Probe (beta/gamma)	Cell A	Sr-90	1.81E+02			1.00E+00	1.00E+00
Probe (beta/gamma)	Cell A	Tc-99	1.81E+02			1.00E+00	1.00E+00
Probe (beta/gamma)	Entire building	Cs-137	1.07E+03			1.00E+00	1.00E+00
Probe (beta/gamma)	Entire building	Sr-90	1.07E+03			1.00E+00	1.00E+00
Probe (beta/gamma)	Entire building	Tc-99	1.07E+03			1.00E+00	1.00E+00
Probe (beta/gamma)	Cell B	Cs-137	4.07E+01			9.99E-01	9.99E-01
Probe (beta/gamma)	Cell B	Sr-90	4.07E+01			9.99E-01	9.99E-01
Probe (beta/gamma)	Cell B	Tc-99	4.07E+01			9.99E-01	9.99E-01
Probe (beta/gamma)	Canal	Cs-137	1.14E+04			1.00E+00	1.00E+00
Probe (beta/gamma)	Canal	Sr-90	1.14E+04			1.00E+00	1.00E+00
Probe (beta/gamma)	Canal	Tc-99	1.14E+04			1.00E+00	1.00E+00
Probe (beta/gamma)	Locker room	Cs-137	8.76E-02			1.60E-02	1.60E-02
Probe (beta/gamma)	Locker room	Sr-90	8.76E-02			1.60E-02	1.60E-02
Probe (beta/gamma)	Locker room	Tc-99	8.76E-02			1.60E-02	1.60E-02

Table E.3. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Probe (beta/gamma)	Office	Cs-137	8.76E-02			1.60E-02	1.60E-02
Probe (beta/gamma)	Office	Sr-90	8.76E-02			1.60E-02	1.60E-02
Probe (beta/gamma)	Office	Tc-99	8.76E-02			1.60E-02	1.60E-02
Probe (beta/gamma)	Shop	Cs-137	1.10E-01			1.99E-02	1.99E-02
Probe (beta/gamma)	Shop	Sr-90	1.10E-01			1.99E-02	1.99E-02
Probe (beta/gamma)	Shop	Tc-99	1.10E-01			1.99E-02	1.99E-02
Smear (beta/gamma)	Entire building	Cs-137	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Entire building	Cs-137	8.05E+02	2.37E-05	7.49E-10	4.52E-02	4.53E-02
Smear (beta/gamma)	Entire building	Sr-90	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Entire building	Sr-90	8.05E+02	3.04E-05	2.45E-09	0.00E+00	3.04E-05
Smear (beta/gamma)	Entire building	Tc-99	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Entire building	Tc-99	8.05E+02	1.10E-06	3.27E-10	1.39E-08	1.11E-06
Smear (beta/gamma)	Canal	Cs-137	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Canal	Sr-90	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Canal	Tc-99	7.00E+02			1.00E+00	1.00E+00
Smear (beta/gamma)	Dissolver pit	Cs-137	1.20E+00			1.98E-01	1.98E-01
Smear (beta/gamma)	Dissolver pit	Cs-137	8.05E+02	2.37E-05	7.49E-10	4.52E-02	4.53E-02
Smear (beta/gamma)	Dissolver pit	Sr-90	1.20E+00			1.98E-01	1.98E-01
Smear (beta/gamma)	Dissolver pit	Sr-90	8.05E+02	3.04E-05	2.45E-09	0.00E+00	3.04E-05
Smear (beta/gamma)	Dissolver pit	Tc-99	1.20E+00			1.98E-01	1.98E-01
Smear (beta/gamma)	Dissolver pit	Tc-99	8.05E+02	1.10E-06	3.27E-10	1.39E-08	1.11E-06

Table E.3. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Smear (beta/gamma)	Dissolver room	Cs-137	5.00E+00			6.01E-01	6.01E-01
Smear (beta/gamma)	Dissolver room	Cs-137	1.50E+02	4.41E-06	1.40E-10	8.64E-03	8.64E-03
Smear (beta/gamma)	Dissolver room	Sr-90	5.00E+00			6.01E-01	6.01E-01
Smear (beta/gamma)	Dissolver room	Sr-90	1.50E+02	5.68E-06	4.56E-10	0.00E+00	5.68E-06
Smear (beta/gamma)	Dissolver room	Tc-99	5.00E+00			6.01E-01	6.01E-01
Smear (beta/gamma)	Dissolver room	Tc-99	1.50E+02	2.05E-07	6.11E-11	2.59E-09	2.08E-07
Smear (beta/gamma)	Cell E	Cs-137	1.14E+02	3.34E-06	1.06E-10	6.54E-03	6.54E-03
Smear (beta/gamma)	Cell E	Sr-90	1.14E+02	4.29E-06	3.45E-10	0.00E+00	4.29E-06
Smear (beta/gamma)	Cell E	Tc-99	1.14E+02	1.55E-07	4.62E-11	1.96E-09	1.57E-07
Air (alpha)	Entire building	Np-237	2.57E-02		1.57E-04		1.57E-04
Air (alpha)	Control room	Np-237	2.57E-02		1.57E-04		1.57E-04
Probe (alpha)	Cell A	Np-237	1.04E+03	2.41E-04	1.48E-06	1.28E-02	1.31E-02
Probe (alpha)	Entire building	Np-237	1.28E+03	2.96E-04	1.82E-06	1.57E-02	1.60E-02
Probe (alpha)	Cell B	Np-237	1.52E+03	3.50E-04	2.15E-06	1.86E-02	1.89E-02
Probe (alpha)	Cell C	Np-237	1.04E+03	2.41E-04	1.48E-06	1.28E-02	1.31E-02
Probe (alpha)	Cell D	Np-237	9.54E+02	2.20E-04	1.36E-06	1.17E-02	1.20E-02
Probe (alpha)	Cell E	Np-237	8.20E+02	1.89E-04	1.17E-06	1.01E-02	1.03E-02
Probe (alpha)	Cell F	Np-237	8.20E+02	1.89E-04	1.17E-06	1.01E-02	1.03E-02
Smear (alpha)	Cell A	Np-237	4.81E+03	1.11E-03	6.84E-06	5.78E-02	5.88E-02
Smear (alpha)	Entire building	Np-237	1.11E+04	2.55E-03	1.57E-05	1.28E-01	1.30E-01
Smear (alpha)	Cell B	Np-237	1.78E+03	4.12E-04	2.53E-06	2.18E-02	2.22E-02

Table E.3. (continued)

Sampling Method	Sampling Location	Analyte	Concentration (pCi/kg)	Exposure Route			Total Risk for All Pathways
				Ingestion	Inhalation	External	
Smear (alpha)	Cell C	Np-237	8.97E+01	2.07E-05	1.28E-07	1.11E-03	1.13E-03
Smear (alpha)	Cell D	Np-237	4.20E+02	9.70E-05	5.97E-07	5.20E-03	5.29E-03
Smear (alpha)	Dissolver pit	Np-237	7.57E+01	1.75E-05	1.08E-07	9.37E-04	9.54E-04
Smear (alpha)	Dissolver room	Np-237	8.94E+00	2.07E-06	1.27E-08	1.11E-04	1.13E-04
Smear (alpha)	Cell E	Np-237	1.90E+03	4.38E-04	2.70E-06	2.32E-02	2.36E-02
Smear (alpha)	Cell F	Np-237	1.84E+05	4.16E-02	2.62E-04	8.97E-01	9.02E-01
Smear (alpha)	Electrical gallery	Np-237	3.08E-01	7.11E-08	4.37E-10	3.81E-06	3.88E-06

Table E.4. ILCR associated with Building 3505 Cell A for the maintenance worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am + Sr	4.19E-04	4.50E-06	1.00E+00
Pu + Sr	4.04E-04	5.34E-06	1.00E+00
Am + Tc	3.63E-04	4.49E-06	1.00E+00
Am + Cs	3.61E-04	4.49E-06	1.00E+00
Pu + Tc	3.48E-04	5.33E-06	1.00E+00
Pu + Cs	3.46E-04	5.33E-06	1.00E+00
U + Sr	1.00E-04	7.31E-06	1.00E+00
U + Tc	4.42E-05	7.30E-06	1.00E+00
U + Cs	4.21E-05	7.30E-06	1.00E+00
Np + Sr	3.89E-04	4.08E-06	1.00E+00
Np + Cs	3.31E-04	4.07E-06	1.00E+00
Np + Tc	3.33E-04	4.07E-06	1.00E+00

Table E.5. ILCR associated with Building 3505 Cell A for the maintenance worker, based on probe survey data

Isotope	Exposure Route		
	Ingestion	Inhalation	External
Am-241	7.83E-05	9.74E-07	2.92E-05
Pu-239	7.50E-05	1.16E-06	1.01E-07
U-238	9.13E-06	1.58E-06	2.14E-04
Np-237	7.18E-05	8.83E-07	2.56E-03
Cs-137	0	0	9.99E-01
Sr-90	0	0	9.99E-01
Tc-99	0	0	9.99E-01

Table E.6. ILCR associated with Building 3505 Cell B for the maintenance worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am + Sr	1.77E-04	1.67E-06	7.73E-01
Pu + Sr	1.71E-04	1.99E-06	7.73E-01
Am + Tc	1.36E-04	1.66E-06	4.98E-05
Am + Cs	1.34E-04	1.66E-06	7.73E-01
Pu + Tc	1.30E-04	1.98E-06	1.86E-07
Pu + Cs	1.28E-04	1.98E-06	7.73E-01
U + Sr	5.88E-05	2.71E-06	7.73E-01
U + Tc	1.72E-05	2.70E-06	3.66E-04
U + Cs	1.56E-05	2.70E-06	7.73E-01
Np + Sr	1.66E-04	1.52E-06	7.77E-01
Np + Cs	1.23E-04	1.51E-06	7.77E-01
Np + Tc	1.25E-04	1.51E-06	4.37E-03

Table E.7. ILCR associated with Building 3505 Cell B for the maintenance worker, based on probe survey data

Isotope	Exposure Route		
	Ingestion	Inhalation	External
Am-241	1.14E-04	1.42E-06	4.24E-05
Pu-239	1.09E-04	1.68E-06	1.47E-07
U-238	1.33E-05	2.30E-06	3.11E-04
Np-237	1.04E-04	1.28E-06	3.72E-03
Cs-137	0	0	7.73E-01
Sr-90	0	0	7.73E-01
Tc-99	0	0	7.73E-01

Table E.8. ILCR associated with Building 3505 Cell C for the maintenance worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	7.83E-05	9.74E-07	2.92E-05
Pu+Sr	7.50E-05	1.16E-06	1.01E-07
Am+Tc	7.83E-05	9.74E-07	2.92E-05
Am+Cs	7.83E-05	9.74E-07	2.92E-05
Pu+Tc	7.50E-05	1.16E-06	1.01E-07
Pu+Cs	7.50E-05	1.16E-06	1.01E-07
U+Sr	9.13E-06	1.58E-06	2.14E-04
U+Tc	9.13E-06	1.58E-06	2.14E-04
U+Cs	9.13E-06	1.58E-06	2.14E-04
Np+Sr	6.17E-06	7.59E-08	2.20E-04
Np+Cs	6.17E-06	7.59E-08	2.20E-04
Np+Tc	6.17E-06	7.59E-08	2.20E-04

Table E.9. ILCR associated with Building 3505 Cell C for the maintenance worker, based on probe survey data

Isotope	Exposure Route		
	Ingestion	Inhalation	External
Am-241	6.73E-06	8.38E-08	2.51E-06
Pu-239	6.45E-06	9.95E-08	8.71E-09
U-238	7.85E-07	1.36E-07	1.84E-05
Np-237	7.18E-05	8.83E-07	2.56E-03
Cs-137	0	0	0
Sr-90	0	0	0
Tc-99	0	0	0

Table E.10. ILCR associated with Building 3505 Cell D for the maintenance worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am + Sr	7.16E-05	8.91E-07	2.67E-05
Pu + Sr	6.86E-05	1.06E-06	9.26E-08
Am + Tc	7.16E-05	8.91E-07	2.67E-05
Am + Cs	7.16E-05	8.91E-07	2.67E-05
Pu + Tc	6.86E-05	1.06E-06	9.26E-08
Pu + Cs	6.86E-05	1.06E-06	9.26E-08
U + Sr	8.35E-06	1.45E-06	1.96E-04
U + Tc	8.35E-06	1.45E-06	1.96E-04
U + Cs	8.35E-06	1.45E-06	1.96E-04
Np + Sr	2.89E-05	3.55E-07	1.03E-03
Np + Cs	2.89E-05	3.55E-07	1.03E-03
Np + Tc	2.89E-05	3.55E-07	1.03E-03

Table E.11. ILCR associated with Building 3505 Cell D for the maintenance worker, based on probe survey data

Isotope	Exposure Route		
	Ingestion	Inhalation	External
Am-241	7.16E-05	8.91E-07	2.67E-05
Pu-239	6.86E-05	1.06E-06	9.26E-08
U-238	8.35E-06	1.45E-06	1.96E-04
Np-237	6.56E-05	8.07E-07	2.34E-03
Cs-137	0	0	0
Sr-90	0	0	0
Tc-99	0	0	0

Table E.12. ILCR associated with Building 3505 Cell E for the maintenance worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am + Sr	1.43E-04	1.77E-06	5.31E-05
Pu + Sr	1.37E-04	2.10E-06	1.84E-07
Am + Tc	1.42E-04	1.77E-06	5.31E-05
Am + Cs	1.43E-04	1.77E-06	1.35E-03
Pu + Tc	1.36E-04	2.10E-06	1.84E-07
Pu + Cs	1.37E-04	2.10E-06	1.30E-03
U + Sr	1.79E-05	2.88E-06	3.90E-04
U + Tc	1.66E-05	2.88E-06	3.90E-04
U + Cs	1.76E-05	2.88E-06	1.69E-03
Np + Sr	1.31E-04	1.61E-06	4.66E-03
Np + Cs	1.31E-04	1.61E-06	5.96E-03
Np + Tc	1.30E-04	1.61E-06	4.66E-03

Table E.13. ILCR associated with Building 3505 Cell E for the maintenance worker, based on probe survey data

Isotope	Exposure Route		
	Ingestion	Inhalation	External
Am-241	6.15E-05	7.66E-07	2.29E-05
Pu-239	5.89E-05	9.09E-07	7.96E-08
U-238	7.18E-06	1.24E-06	1.69E-04
Np-237	5.64E-05	6.94E-07	2.01E-03
Cs-137	0	0	0
Sr-90	0	0	0
Tc-99	0	0	0

Table E.14. ILCR associated with Building 3505 Cell F for the maintenance worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	1.37E-02	1.72E-04	5.15E-03
Pu+Sr	1.31E-02	2.04E-04	1.79E-05
Am+Tc	1.37E-02	1.72E-04	5.15E-03
Am+Cs	1.37E-02	1.72E-04	5.15E-03
Pu+Tc	1.31E-02	2.04E-04	1.79E-05
Pu+Cs	1.31E-02	2.04E-04	1.79E-05
U+Sr	1.61E-03	2.79E-04	3.71E-02
U+Tc	1.61E-03	2.79E-04	3.71E-02
U+Cs	1.61E-03	2.79E-04	3.71E-02
Np+Sr	1.30E-04	1.61E-06	4.66E-03
Np+Cs	1.30E-04	1.61E-06	4.66E-03
Np+Tc	1.30E-04	1.61E-06	4.66E-03

Table E.15. ILCR associated with Building 3505 Cell F for the maintenance worker, based on probe survey data

Isotope	Exposure Route		
	Ingestion	Inhalation	External
Am-241	6.15E-05	7.66E-07	2.29E-05
Pu-239	5.89E-05	9.09E-07	7.96E-08
U-238	7.18E-06	1.24E-06	1.69E-04
Np-237	5.64E-05	6.94E-07	2.01E-03
Cs-137	0	0	0
Sr-90	0	0	0
Tc-99	0	0	0

Table E.16. ICLR associated with the Building 3505 canal for the maintenance worker, based on smear survey data for alpha-emitters only

Alpha Emitters	External Exposure
Am-241	1.0E+00
Pu-239	1.0E+00
U-238	1.0E+00
Np-237	

Table E.17. ILCR associated with the Building 3505 dissolver pit for the maintenance worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	1.47E-05	7.22E-08	4.29E-02
Pu+Sr	1.45E-05	8.55E-08	4.29E-02
Am+Tc	6.01E-06	7.09E-08	4.29E-02
Am+Cs	1.27E-05	7.11E-08	4.29E-02
Pu+Tc	5.77E-06	8.42E-08	4.29E-02
Pu+Cs	1.25E-05	8.44E-08	4.29E-02
U+Sr	9.71E-06	1.16E-07	4.29E-02
U+Tc	9.90E-07	1.15E-07	4.29E-02
U+Cs	7.70E-06	1.15E-07	4.29E-02
Np+Sr	1.43E-05	6.56E-08	4.31E-02
Np+Cs	1.23E-05	6.45E-08	4.31E-02
Np+Tc	5.54E-06	6.43E-08	4.31E-02

Table E.18. ILCR associated with the Building 3505 dissolver room for the maintenance worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	2.36E-06	8.62E-09	1.67E-01
Pu+Sr	2.33E-06	1.02E-08	1.67E-01
Am+Tc	7.32E-07	8.39E-09	2.51E-07
Am+Cs	1.98E-06	8.43E-09	1.67E-01
Pu+Tc	7.04E-07	9.95E-09	1.38E-09
Pu+Cs	1.95E-06	9.99E-09	1.67E-01
U+Sr	1.76E-06	1.39E-08	1.67E-01
U+Tc	1.34E-07	1.36E-08	1.84E-06
U+Cs	1.38E-06	1.37E-08	1.67E-01
Np+Sr	2.31E-06	7.83E-09	1.67E-01
Np+Cs	1.93E-06	7.64E-09	1.67E-01
Np+Tc	6.76E-07	7.60E-09	2.19E-05

Table E.19. ILCR associated with the Building 3505 electrical gallery for the maintenance worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	5.12E-08	2.92E-10	8.61E-09
Pu+Sr	5.02E-08	3.46E-10	2.99E-11
Am+Tc	2.41E-08	2.88E-10	8.62E-09
Am+Cs	2.31E-08	2.87E-10	8.61E-09
Pu+Tc	2.31E-08	3.42E-10	3.85E-11
Pu+Cs	2.21E-08	3.41E-10	2.99E-11
U+Sr	3.08E-08	4.72E-10	6.32E-08
U+Tc	3.70E-09	4.68E-10	6.32E-08
U+Cs	2.69E-09	4.67E-10	6.32E-08
Np+Sr	4.93E-08	2.65E-10	7.55E-07
Np+Cs	2.12E-08	2.60E-10	7.55E-07
Np+Tc	2.22E-08	2.61E-10	7.55E-07

Table E.20. ICLR associated with the Building 3505 locker room, office, and shop for the maintenance worker, based on smear survey data for alpha-emitters only

Location	External Exposure
Locker room	3.2E-03
Office	3.2E-03
Shop	4.0E-03

Table E.21. ICLR associated with the Building 3505 locker room, office, and shop for the maintenance worker, based on probe survey data for beta/gamma-emitters only

Location	External Exposure
Canal	1.0E-01
Locker room	3.2E-03
Office area	3.2E-03
Shop	4.0E-03

Table E.22. Overall ILCR associated with Building 3505 for the maintenance worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am + Sr	8.38E-04	1.03E-05	1.00E+00
Pu + Sr	8.03E-04	1.23E-05	1.00E+00
Am + Tc	8.29E-04	1.03E-05	1.00E+00
Am + Cs	8.36E-04	1.03E-05	1.00E+00
Pu + Tc	7.94E-04	1.23E-05	1.00E+00
Pu + Cs	8.01E-04	1.23E-05	1.00E+00
U + Sr	1.06E-04	1.68E-05	1.00E+00
U + Tc	9.70E-05	1.68E-05	1.00E+00
U + Cs	1.04E-04	1.68E-05	1.00E+00
Np + Sr	7.69E-04	9.35E-06	1.03E+00
Np + Cs	7.67E-04	9.35E-06	1.03E+00
Np + Tc	7.60E-04	9.35E-06	1.03E+00

Table E.23. Overall ILCR associated with Building 3505 for the maintenance worker, based on probe survey data

Isotope	Exposure Route		
	Ingestion	Inhalation	External
Am-241	9.62E-05	1.20E-06	3.59E-05
Pu-239	9.22E-05	1.42E-06	1.24E-07
U-238	1.12E-05	1.95E-06	2.64E-04
Np-237	8.82E-05	1.09E-06	3.15E-03
Cs-137	0	0	1.00E+00
Sr-90	0	0	1.00E+00
Tc-99	0	0	1.00E+00

Table E.24. ILCR associated with Building 3505 Cell A for the S&M worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am + Sr	3.36E-06	3.60E-08	1.08E-06
Pu + Sr	3.24E-06	4.28E-08	3.73E-09
Am + Tc	2.91E-06	3.59E-08	1.08E-06
Am + Cs	2.89E-06	3.59E-08	9.99E-01
Pu + Tc	2.79E-06	4.27E-08	3.87E-09
Pu + Cs	2.77E-06	4.27E-08	9.99E-01
U + Sr	8.02E-07	5.85E-08	7.91E-06
U + Tc	3.54E-07	5.84E-08	7.91E-06
U + Cs	3.37E-07	5.84E-08	9.99E-01
Np + Sr	3.11E-06	3.26E-08	9.44E-05
Np + Cs	2.64E-06	3.25E-08	9.99E-01
Np + Tc	2.66E-06	3.25E-08	9.44E-05

Table E.25. ILCR associated with Building 3505 Cell A for the S&M worker, based on probe survey data

Isotope	Exposure Route		
	Ingestion	Inhalation	External
Am-241	6.26E-07	7.80E-09	2.34E-07
Pu-239	6.00E-07	9.26E-09	8.10E-10
U-238	7.31E-08	1.27E-08	1.72E-06
Np-237	5.74E-07	7.06E-09	2.05E-05
Cs-137	0	0	9.99E-01
Sr-90	0	0	9.99E-01
Tc-99	0	0	9.99E-01

Table E.26. ILCR associated with Building 3505 Cell B for the S&M worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am + Sr	1.42E-06	1.34E-08	3.99E-07
Pu + Sr	1.37E-06	1.59E-08	1.38E-09
Am + Tc	1.08E-06	1.33E-08	7.73E-01
Am + Cs	1.07E-06	1.33E-08	7.73E-01
Pu + Tc	1.03E-06	1.58E-08	7.73E-01
Pu + Cs	1.02E-06	1.58E-08	7.73E-01
U + Sr	4.71E-07	2.17E-08	2.93E-06
U + Tc	1.38E-07	2.16E-08	7.73E-01
U + Cs	1.25E-07	2.16E-08	7.73E-01
Np + Sr	1.33E-06	1.22E-08	3.50E-05
Np + Cs	9.80E-07	1.21E-08	7.73E-01
Np + Tc	9.93E-07	1.21E-08	7.73E-01

Table E.27. ILCR associated with Building 3505 Cell B for the S&M worker, based on probe survey data

Isotope	Exposure Route		
	Ingestion	Inhalation	External
Am-241	9.09E-07	1.13E-08	3.39E-07
Pu-239	8.72E-07	1.34E-08	1.18E-09
U-238	1.06E-07	1.84E-08	2.49E-06
Np-237	8.34E-07	1.03E-08	2.98E-05
Cs-137	0	0	7.73E-01
Sr-90	0	0	7.73E-01
Tc-99	0	0	7.73E-01

Table E.28. ILCR associated with Building 3505 Cell C for the S&M worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	6.26E-07	7.80E-09	2.34E-07
Pu+Sr	6.00E-07	9.26E-09	8.10E-10
Am+Tc	6.26E-07	7.80E-09	2.34E-07
Am+Cs	6.26E-07	7.80E-09	2.34E-07
Pu+Tc	6.00E-07	9.26E-09	8.10E-10
Pu+Cs	6.00E-07	9.26E-09	8.10E-10
U+Sr	7.31E-08	1.27E-08	1.72E-06
U+Tc	7.31E-08	1.27E-08	1.72E-06
U+Cs	7.31E-08	1.27E-08	1.72E-06
Np+Sr	4.93E-08	6.07E-10	1.76E-06
Np+Cs	4.93E-08	6.07E-10	1.76E-06
Np+Tc	4.93E-08	6.07E-10	1.76E-06

Table E.29. ILCR associated with Building 3505 Cell C for the S&M worker, based on probe survey data

Isotope	Exposure Route		
	Ingestion	Inhalation	External
Am-241	6.26E-07	7.80E-09	2.34E-07
Pu-239	6.00E-07	9.26E-09	8.10E-10
U-238	7.31E-08	1.27E-08	1.72E-06
Np-237	5.74E-07	7.06E-09	2.05E-05
Cs-137	0	0	0
Sr-90	0	0	0
Tc-99	0	0	0

Table E.30. ILCR associated with Building 3505 Cell D for the S&M worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am + Sr	5.73E-07	7.13E-09	2.14E-07
Pu + Sr	5.49E-07	8.46E-09	7.41E-10
Am + Tc	5.73E-07	7.13E-09	2.14E-07
Am + Cs	5.73E-07	7.13E-09	2.14E-07
Pu + Tc	5.49E-07	8.46E-09	7.41E-10
Pu + Cs	5.49E-07	8.46E-09	7.41E-10
U + Sr	6.68E-08	1.16E-08	1.57E-06
U + Tc	6.68E-08	1.16E-08	1.57E-06
U + Cs	6.68E-08	1.16E-08	1.57E-06
Np + Sr	2.31E-07	2.84E-09	8.25E-06
Np + Cs	2.31E-07	2.84E-09	8.25E-06
Np + Tc	2.31E-07	2.84E-09	8.25E-06

Table E.31. ILCR associated with Building 3505 Cell D for the S&M worker, based on probe survey data

Isotope	Exposure Route		
	Ingestion	Inhalation	External
Am-241	5.73E-07	7.13E-09	2.14E-07
Pu-239	5.49E-07	8.46E-09	7.41E-10
U-238	6.68E-08	1.16E-08	1.57E-06
Np-237	5.25E-07	6.46E-09	1.87E-05
Cs-137	0	0	0
Sr-90	0	0	0
Tc-99	0	0	0

Table E.32. ILCR associated with Building 3505 Cell E for the S&M worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am + Sr	1.15E-06	1.42E-08	4.24E-07
Pu + Sr	1.10E-06	1.68E-08	1.47E-09
Am + Tc	1.14E-06	1.42E-08	4.24E-07
Am + Cs	1.15E-06	1.42E-08	1.08E-05
Pu + Tc	1.09E-06	1.68E-08	1.47E-09
Pu + Cs	1.10E-06	1.68E-08	1.04E-05
U + Sr	1.43E-07	2.30E-08	3.12E-06
U + Tc	1.33E-07	2.30E-08	3.12E-06
U + Cs	1.41E-07	2.30E-08	1.35E-05
Np + Sr	1.05E-06	1.28E-08	3.72E-05
Np + Cs	1.05E-06	1.28E-08	4.76E-05
Np + Tc	1.04E-06	1.28E-08	3.72E-05

Table E.33. ILCR associated with Building 3505 Cell E for the S&M worker, based on probe survey data

Isotope	Exposure Route		
	Ingestion	Inhalation	External
Am-241	4.92E-07	6.12E-09	1.83E-07
Pu-239	4.72E-07	7.27E-09	6.37E-10
U-238	5.74E-08	9.95E-09	1.35E-06
Np-237	4.51E-07	5.55E-09	1.61E-05
Cs-137	0	0	0
Sr-90	0	0	0
Tc-99	0	0	0

Table E.34. ILCR associated with Building 3505 Cell F for the S&M worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	1.10E-04	1.37E-06	4.12E-05
Pu+Sr	1.06E-04	1.63E-06	1.43E-07
Am+Tc	1.10E-04	1.37E-06	4.12E-05
Am+Cs	1.10E-04	1.37E-06	4.12E-05
Pu+Tc	1.06E-04	1.63E-06	1.43E-07
Pu+Cs	1.06E-04	1.63E-06	1.43E-07
U+Sr	1.29E-05	2.23E-06	3.02E-04
U+Tc	1.29E-05	2.23E-06	3.02E-04
U+Cs	1.29E-05	2.23E-06	3.02E-04
Np+Sr	1.01E-04	1.25E-06	3.61E-03
Np+Cs	1.01E-04	1.25E-06	3.61E-03
Np+Tc	1.01E-04	1.25E-06	3.61E-03

Table E.35. ILCR associated with Building 3505 Cell F for the S&M worker, based on probe survey data

Isotope	Exposure Route		
	Ingestion	Inhalation	External
Am-241	4.92E-07	6.12E-09	1.83E-07
Pu-239	4.72E-07	7.27E-09	6.37E-10
U-238	5.74E-08	9.95E-09	1.35E-06
Np-237	4.51E-07	5.55E-09	1.61E-05
Cs-137	0	0	0
Sr-90	0	0	0
Tc-99	0	0	0

Table E.36. ILCR associated with the Building 3505 dissolver pit for the S&M worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am + Sr	1.18E-07	5.78E-10	1.69E-08
Pu + Sr	1.16E-07	6.84E-10	5.88E-11
Am + Tc	4.80E-08	5.68E-10	1.69E-08
Am + Cs	1.02E-07	5.70E-10	7.35E-05
Pu + Tc	4.61E-08	6.74E-10	8.08E-11
Pu + Cs	9.98E-08	6.76E-10	7.35E-05
U + Sr	7.77E-08	9.31E-10	1.24E-07
U + Tc	7.92E-09	9.21E-10	1.24E-07
U + Cs	6.16E-08	9.23E-10	7.36E-05
Np + Sr	1.14E-07	5.25E-10	1.49E-06
Np + Cs	9.80E-08	5.17E-10	7.50E-05
Np + Tc	4.43E-08	5.15E-10	1.49E-06

Table E.37. ILCR associated with the Building 3505 dissolver room for the S&M worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am + Sr	2.36E-06	8.62E-09	1.67E-01
Pu + Sr	2.33E-06	1.02E-08	1.67E-01
Am + Tc	7.32E-07	8.39E-09	2.51E-07
Am + Cs	1.98E-06	8.43E-09	1.67E-01
Pu + Tc	7.04E-07	9.95E-09	1.38E-09
Pu + Cs	1.95E-06	9.99E-09	1.67E-01
U + Sr	1.76E-06	1.39E-08	1.67E-01
U + Tc	1.34E-07	1.36E-08	1.84E-06
U + Cs	1.38E-06	1.37E-08	1.67E-01
Np + Sr	2.31E-06	7.83E-09	1.67E-01
Np + Cs	1.93E-06	7.64E-09	1.67E-01
Np + Tc	6.76E-07	7.60E-09	2.19E-05

Table E.38. ILCR associated with the Building 3505 electrical gallery for the S&M worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	4.10E-10	2.34E-12	6.88E-11
Pu+Sr	4.02E-10	2.77E-12	2.39E-13
Am+Tc	1.93E-10	2.30E-12	6.89E-11
Am+Cs	1.85E-10	2.30E-12	6.88E-11
Pu+Tc	1.85E-10	2.73E-12	3.07E-13
Pu+Cs	1.77E-10	2.73E-12	2.39E-13
U+Sr	2.47E-10	3.77E-12	5.06E-10
U+Tc	2.96E-11	3.73E-12	5.06E-10
U+Cs	2.15E-11	3.73E-12	5.06E-10
Np+Sr	3.94E-10	2.12E-12	6.04E-09
Np+Cs	1.69E-10	2.08E-12	6.04E-09
Np+Tc	1.77E-10	2.08E-12	6.04E-09

Table E.39. ICLR associated with the Building 3505 locker room, office, and shop for the S&M worker, based on smear survey data for alpha-emitters only

Location	External Exposure
Locker Room	3.2E-03
Office	3.2E-03
Shop	4.0E-03

Table E.40. ICLR associated with the Building 3505 canal, locker room, office, and shop for the S&M worker, based on data for beta/gamma-emitters only

Location	Data Type	External
Canal	Probe	1.0E+00
	Smear	1.0E+00
Locker room	Probe	3.2E-03
Office area	Probe	3.2E-03
Shop	Probe	4.0E-03

Table E.41. Overall ILCR associated with Building 3505 for the S&M worker, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	1.57E-05	8.40E-08	1.00E+00
Pu+Sr	1.54E-05	9.95E-08	1.00E+00
Am+Tc	6.96E-06	8.27E-08	1.00E+00
Am+Cs	1.37E-05	8.29E-08	1.00E+00
Pu+Tc	6.68E-06	9.82E-08	1.00E+00
Pu+Cs	1.34E-05	9.84E-08	1.00E+00
U+Sr	9.82E-06	1.35E-07	1.00E+00
U+Tc	1.10E-06	1.34E-07	1.00E+00
U+Cs	7.81E-06	1.34E-07	1.00E+00
Np+Sr	1.51E-05	7.63E-08	1.00E+00
Np+Cs	1.31E-05	7.52E-08	1.00E+00
Np+Tc	6.41E-06	7.50E-08	1.00E+00

Table E.42. Overall ILCR associated with Building 3505 for the S&M worker, based on probe survey data

Isotope	Exposure Route		
	Ingestion	Inhalation	External
Am-241	7.07E-07	9.58E-09	2.87E-07
Pu-239	7.38E-07	1.14E-08	9.96E-10
U-238	8.98E-08	1.56E-08	2.11E-06
Np-237	7.05E-07	8.68E-09	2.52E-05
Cs-137	0	0	1.00E+00
Sr-90	0	0	1.00E+00
Tc-99	0	0	1.00E+00

Table E.43. ILCR associated with Building 3505 Cell A for the adult trespasser, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	1.41E-03	7.56E-06	1.00E+00
Pu+Sr	1.36E-03	8.98E-06	1.00E+00
Am+Tc	1.22E-03	7.54E-06	1.00E+00
Am+Cs	1.21E-03	7.54E-06	1.00E+00
Pu+Tc	1.17E-03	8.96E-06	1.00E+00
Pu+Cs	1.16E-03	8.96E-06	1.00E+00
U+Sr	3.36E-04	1.23E-05	1.00E+00
U+Tc	1.48E-04	1.23E-05	1.00E+00
U+Cs	1.41E-04	1.23E-05	1.00E+00
Np+Sr	1.31E-03	6.86E-06	1.06E+00
Np+Cs	1.11E-03	6.84E-06	1.06E+00
Np+Tc	1.12E-03	6.84E-06	1.06E+00

Table E.44. ILCR associated with Building 3505 Cell A for the adult trespasser, based on probe survey data for alpha-emitters only

Alpha Emitter	Exposure Route		
	Ingestion	Inhalation	External
Am-241	2.63E-04	1.64E-06	1.00E+00
Pu-239	2.52E-04	1.94E-06	1.00E+00
U-238	3.07E-05	2.66E-06	1.00E+00
Np-237	2.41E-04	1.48E-06	1.28E-02

Table E.45. ILCR associated with Building 3505 Cell B for the adult trespasser, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	6.44E-04	2.82E-06	1.00E+00
Pu+Sr	6.25E-04	3.34E-06	1.00E+00
Am+Tc	4.56E-04	2.80E-06	1.00E+00
Am+Cs	4.49E-04	2.80E-06	1.00E+00
Pu+Tc	4.37E-04	3.32E-06	1.00E+00
Pu+Cs	4.30E-04	3.32E-06	1.00E+00
U+Sr	2.47E-04	4.56E-06	1.00E+00
U+Tc	5.95E-05	4.54E-06	1.00E+00
U+Cs	5.24E-05	4.54E-06	1.00E+00
Np+Sr	6.07E-04	2.55E-06	1.02E+00
Np+Cs	4.12E-04	2.53E-06	1.02E+00
Np+Tc	4.19E-04	2.53E-06	1.02E+00

Table E.46. ILCR associated with Building 3505 Cell B for the adult trespasser, based on probe survey data for alpha-emitters only

Alpha Emitter	Exposure Route		
	Ingestion	Inhalation	External
Am-241	3.82E-04	2.38E-06	9.90E-01
Pu-239	3.66E-04	2.82E-06	9.90E-01
U-238	4.46E-05	3.86E-06	9.92E-01
Np-237	3.50E-04	2.15E-06	1.86E-02

Table E.47. ILCR associated with Building 3505 Cell C for the adult trespasser, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	2.63E-04	1.64E-06	1.47E-04
Pu+Sr	2.52E-04	1.94E-06	5.10E-07
Am+Tc	2.63E-04	1.64E-06	1.47E-04
Am+Cs	2.63E-04	1.64E-06	1.47E-04
Pu+Tc	2.52E-04	1.94E-06	5.10E-07
Pu+Cs	2.52E-04	1.94E-06	5.10E-07
U+Sr	3.07E-06	2.66E-06	1.08E-03
U+Tc	3.07E-06	2.66E-06	1.08E-03
U+Cs	3.07E-06	2.66E-06	1.08E-03
Np+Sr	2.07E-05	1.28E-07	1.11E-03
Np+Cs	2.07E-05	1.28E-07	1.11E-03
Np+Tc	2.07E-05	1.28E-07	1.11E-03

Table E.48. ILCR associated with Building 3505 Cell C for the adult trespasser, based on probe survey data for alpha-emitters only

Alpha Emitter	Exposure Route		
	Ingestion	Inhalation	External
Am-241	2.63E-04	1.64E-06	1.47E-04
Pu-239	2.52E-04	1.94E-06	5.10E-07
U-238	3.07E-05	2.66E-06	1.08E-03
Np-237	2.41E-04	1.48E-06	1.28E-02

Table E.49. ILCR associated with Building 3505 Cell D for the adult trespasser, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	2.40E-04	1.50E-06	1.35E-04
Pu+Sr	2.30E-04	1.78E-06	4.67E-07
Am+Tc	2.40E-04	1.50E-06	1.35E-04
Am+Cs	2.40E-04	1.50E-06	1.35E-04
Pu+Tc	2.30E-04	1.78E-06	4.67E-07
Pu+Cs	2.30E-04	1.78E-06	4.67E-07
U+Sr	2.81E-05	2.43E-06	9.88E-04
U+Tc	2.81E-05	2.43E-06	9.88E-04
U+Cs	2.81E-05	2.43E-06	9.88E-04
Np+Sr	9.70E-05	5.97E-07	5.20E-03
Np+Cs	9.70E-05	5.97E-07	5.20E-03
Np+Tc	9.70E-05	5.97E-07	5.20E-03

Table E.50. ILCR associated with Building 3505 Cell D for the adult trespasser, based on probe survey data for alpha-emitters only

Alpha Emitter	Exposure Route		
	Ingestion	Inhalation	External
Am-241	2.40E-04	1.50E-06	1.35E-04
Pu-239	2.30E-04	1.78E-06	4.67E-07
U-238	2.81E-05	2.43E-06	9.88E-04
Np-237	2.20E-04	1.36E-06	1.17E-02

Table E.51. ILCR associated with Building 3505 Cell E for the adult trespasser, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am + Sr	4.80E-04	2.98E-06	2.67E-04
Pu + Sr	4.62E-04	3.53E-06	9.28E-07
Am + Tc	4.76E-04	2.98E-06	2.67E-04
Am + Cs	4.79E-04	2.98E-06	6.81E-03
Pu + Tc	4.58E-04	3.53E-06	9.30E-07
Pu + Cs	4.61E-04	3.53E-06	6.54E-03
U + Sr	6.01E-05	4.83E-06	1.96E-03
U + Tc	5.60E-05	4.83E-06	1.96E-03
U + Cs	5.91E-05	4.83E-06	8.50E-03
Np + Sr	4.42E-04	2.70E-06	2.32E-02
Np + Cs	4.41E-04	2.70E-06	2.97E-02
Np + Tc	4.38E-04	2.70E-06	2.32E-02

Table E.52. ILCR associated with Building 3505 Cell E for the adult trespasser, based on probe survey data for alpha-emitters only

Alpha Emitter	Exposure Route		
	Ingestion	Inhalation	External
Am-241	2.07E-04	1.29E-06	1.16E-04
Pu-239	1.98E-04	1.53E-06	4.01E-07
U-238	2.41E-05	2.09E-06	8.49E-04
Np-237	1.89E-04	1.17E-06	1.01E-02

Table E.53. ILCR associated with Building 3505 Cell F for the adult trespasser, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am/Sr	4.53E-02	2.89E-04	2.56E-02
Pu+Sr	4.35E-02	3.43E-04	9.00E-05
Am+Tc	4.53E-02	2.89E-04	2.56E-02
Am+Cs	4.53E-02	2.89E-04	2.56E-02
Pu+Tc	4.35E-02	3.43E-04	9.00E-05
Pu+Cs	4.35E-02	3.43E-04	9.00E-05
U+Sr	5.41E-03	4.69E-04	1.73E-01
U+Tc	5.41E-03	4.69E-04	1.73E-01
U+Cs	5.41E-03	4.69E-04	1.73E-01
Np+Sr	4.16E-02	2.62E-04	8.97E-01
Np+Cs	4.16E-02	2.62E-04	8.97E-01
Np+Tc	4.16E-02	2.62E-04	8.97E-01

Table E.54. Overall ILCR associated with Building 3505 Cell F for the adult trespasser, based on probe survey data for alpha-emitters only

Alpha Emitter	Exposure Route		
	Ingestion	Inhalation	External
Am-241	2.07E-04	1.29E-06	1.16E-04
Pu-239	1.98E-04	1.53E-06	4.01E-07
U-238	2.41E-05	2.09E-06	8.49E-04
Np-237	1.89E-04	1.17E-06	1.01E-02

Table E.55. ICLR associated with the Building 3505 canal for the adult trespasser, based on beta/gamma-emitter smear survey data only

Beta/Gamma Emitter	Exposure Route
	External
Cs-137	1.00E+00
Sr-90	1.00E+00
Tc-99	1.00E+00

Table E.56. ICLR associated with the Building 3505 canal for the adult trespasser, based on beta/gamma-emitter probe survey data only

Beta/Gamma Emitter	Exposure Route
	External
Cs-137	1.00E+00
Sr-90	1.00E+00
Tc-99	1.00E+00

Table E.57. ILCR associated with the Building 3505 dissolver pit for the adult trespasser, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	4.95E-05	1.21E-07	1.07E-05
Pu+Sr	4.87E-05	1.43E-07	3.70E-08
Am+Tc	2.02E-05	1.19E-07	1.07E-05
Am+Cs	4.28E-05	1.20E-07	4.52E-02
Pu+Tc	1.94E-05	1.41E-07	5.09E-08
Pu+Cs	4.20E-05	1.42E-07	4.52E-02
U+Sr	3.26E-05	1.95E-07	7.84E-05
U+Tc	3.33E-06	1.93E-07	7.84E-05
U+Cs	2.59E-05	1.94E-07	4.53E-02
Np+Sr	4.79E-05	1.10E-07	9.37E-04
Np+Cs	4.12E-05	1.09E-07	4.61E-02
Np+Tc	1.86E-05	1.08E-07	9.37E-04

Table E.58. ILCR associated with the Building 3505 dissolver room for the adult trespasser, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am + Sr	7.93E-06	1.45E-08	6.01E-01
Pu + Sr	7.84E-06	1.72E-08	6.01E-01
Am + Tc	2.46E-06	1.41E-08	1.26E-06
Am + Cs	6.66E-06	1.41E-08	6.01E-01
Pu + Tc	2.37E-06	1.68E-08	6.96E-09
Pu + Cs	6.57E-06	1.68E-08	6.01E-01
U + Sr	5.94E-06	2.33E-08	6.01E-01
U + Tc	4.68E-07	2.29E-08	9.26E-06
U + Cs	4.67E-06	2.29E-08	6.01E-01
Np + Sr	7.75E-06	1.32E-08	6.01E-01
Np + Cs	6.48E-06	1.28E-08	6.01E-01
Np + Tc	2.28E-06	1.28E-08	1.11E-04

Table E.59. ILCR associated with the Building 3505 electrical gallery for the adult trespasser, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	1.72E-07	4.91E-10	4.34E-08
Pu+Sr	1.69E-07	5.81E-10	1.50E-10
Am+Tc	8.09E-08	4.84E-10	4.34E-08
Am+Cs	7.75E-08	4.83E-10	4.34E-08
Pu+Tc	7.77E-08	5.74E-10	1.93E-10
Pu+Cs	7.43E-08	5.73E-10	1.50E-10
U+Sr	1.03E-07	7.92E-10	3.19E-07
U+Tc	1.25E-08	7.85E-10	3.19E-07
U+Cs	9.05E-09	7.84E-10	3.19E-07
Np+Sr	1.66E-07	4.45E-10	3.81E-06
Np+Cs	7.11E-08	4.37E-10	3.81E-06
Np+Tc	7.45E-08	4.38E-10	3.81E-06

Table E.60. ILCR associated with the Building 3505 locker room for the adult trespasser, based on probe survey data for alpha-emitters only

Alpha Emitter	Exposure Route
	External
Am-241	1.60E-02
Pu-239	1.60E-02
U-238	1.60E-02
Np-237	3.2E-03

Table E.61. ILCR associated with the Building 3505 office for the adult trespasser, based on probe survey data for alpha-emitters only

Alpha Emitter	Exposure Route
	External
Am-241	1.60E-02
Pu-239	1.60E-02
U-238	1.60E-02
Np-237	3.2E-03

Table E.62. ILCR associated with the Building 3505 shop for the adult trespasser, based on probe survey data for alpha-emitters only

Alpha Emitter	External Exposure
	External
Am-241	1.99E-02
Pu-239	1.99E-02
U-238	1.99E-02
Np-237	4.0E-03

Table E.63. Overall ILCR associated with Building 3505 for the adult trespasser, based on smear survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	2.82E-03	1.73E-05	1.00E+00
Am+Tc	2.79E-03	1.73E-05	1.00E+00
Am+Cs	2.81E-03	1.73E-05	1.00E+00
Pu+Sr	2.70E-03	2.06E-05	1.00E+00
Pu+Tc	2.67E-03	2.06E-05	1.00E+00
Pu+Cs	2.69E-03	2.06E-05	1.00E+00
U+Sr	3.55E-04	2.82E-05	1.00E+00
U+Tc	3.26E-04	2.82E-05	1.00E+00
U+Cs	3.49E-04	2.82E-05	1.00E+00
Np+Sr	2.58E-03	1.57E-05	1.13E+00
Np+Tc	2.55E-03	1.57E-05	1.13E+00
Np+Cs	2.57E-03	1.57E-05	1.13E+00

Table E.64. Overall ILCR associated with Building 3505 for the adult trespasser, based on probe survey data

Radionuclide	Exposure Route		
	Ingestion	Inhalation	External
Am-241	3.23E-04	2.01E-06	1.81E-04
Pu-239	3.10E-04	2.39E-06	6.27E-07
U-238	3.77E-05	3.27E-06	1.33E-03
Np-237	2.96E-04	1.82E-06	1.57E-02
Cs-137			1.00E+00
Tc-99			1.00E+00
Sr-90			1.00E+00

Table E.65. ILCR associated with the Building 3505 control room for the maintenance worker, based on probe survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	0.00E+00	1.03E-04	0.00E+00
Pu+Sr	0.00E+00	1.22E-04	0.00E+00
Am+Tc	0.00E+00	1.03E-04	0.00E+00
Am+Cs	0.00E+00	1.03E-04	0.00E+00
Pu+Tc	0.00E+00	1.22E-04	0.00E+00
Pu+Cs	0.00E+00	1.22E-04	0.00E+00
U+Sr	0.00E+00	1.67E-04	0.00E+00
U+Tc	0.00E+00	1.67E-04	0.00E+00
U+Cs	0.00E+00	1.67E-04	0.00E+00
Np+Sr	0.00E+00	9.34E-05	0.00E+00
Np+Cs	0.00E+00	9.32E-05	0.00E+00
Np+Tc	0.00E+00	9.32E-05	0.00E+00

Table E.66. ILCR associated with the Building 3505 control room for the S&M worker, based on probe survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	0.00E+00	8.23E-07	0.00E+00
Pu+Sr	0.00E+00	9.78E-07	0.00E+00
Am+Tc	0.00E+00	8.22E-07	0.00E+00
Am+Cs	0.00E+00	8.22E-07	0.00E+00
Pu+Tc	0.00E+00	9.77E-07	0.00E+00
Pu+Cs	0.00E+00	9.77E-07	0.00E+00
U+Sr	0.00E+00	1.34E-06	0.00E+00
U+Tc	0.00E+00	1.34E-06	0.00E+00
U+Cs	0.00E+00	1.34E-06	0.00E+00
Np+Sr	0.00E+00	7.46E-07	0.00E+00
Np+Cs	0.00E+00	7.45E-07	0.00E+00
Np+Tc	0.00E+00	7.45E-07	0.00E+00

Table E.67. ILCR associated with the Building 3505 control room for the adult trespasser, based on probe survey data

Alpha/Beta Pair	Exposure Route		
	Ingestion	Inhalation	External
Am+Sr	0.00E+00	1.73E-04	0.00E+00
Pu+Sr	0.00E+00	2.05E-04	0.00E+00
Am+Tc	0.00E+00	1.73E-04	0.00E+00
Am+Cs	0.00E+00	1.73E-04	0.00E+00
Pu+Tc	0.00E+00	2.05E-04	0.00E+00
Pu+Cs	0.00E+00	2.05E-04	0.00E+00
U+Sr	0.00E+00	2.81E-04	0.00E+00
U+Tc	0.00E+00	2.81E-04	0.00E+00
U+Cs	0.00E+00	2.81E-04	0.00E+00
Np+Sr	0.00E+00	1.54E-04	0.00E+00
Np+Cs	0.00E+00	1.54E-04	0.00E+00
Np+Tc	0.00E+00	1.54E-04	0.00E+00

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