FINAL

BASELINE RISK ASSESSMENT

DUPONT CHAMBERS WORKS FUSRAP SITE
DEEPWATER, NEW JERSEY

Contract Number: W912DQ-08-D-0003/CF02

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JUNE 2011

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ACRONYMS AND ABBREVIATIONS

ABS	constituent-specific absorption factor
ADD	average daily dose
ADR	automated data review
ADS	all depth soil
AEC	Atomic Energy Commission
AF	soil to skin adherence factor
ANL	Argonne National Laboratories
AOC	Area of Concern
Am-241	Americium-241
ASTM	American Society for Testing and Materials
AT	averaging time
ATSDR	Agency for Toxic Substances Disease Registry
Atm-m^3/mol	atmospheres per cubic meter/mole
AUF	area use factor
B	chemical-specific constant reflecting the partitioning properties
B	constant (3.14159)
BAF	bioaccumulation factor
BCF	bioconcentration factor
BCG	biota concentration guide
BEE	baseline ecological evaluation
BEIR	Biological Effects of Ionizing Radiation
Be-7	Beryllium-7
Bi-212	Bismuth-212
Bi-214	Bismuth-214
BRA	baseline risk assessment
BW	body weight
CABRERA	Cabrera Services Inc.
CEA	Classification Exception Area
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CDD	Central Drainage Ditch
cm^2	square centimeter
COCs	constituents of concern
COPCs	constituents of potential concern
COPECs	chemicals of potential ecological concern
CF	conversion factor
CFR	Code of Federal Regulations
C_s	concentrations of radionuclides in soil or sediment
Cs-137	Cesium-137
C_{sed}	concentrations of radionuclides in sediment
CSF	cancer slope factor
CSM	conceptual site model
C_{sw}	concentrations of radionuclides in surface water
C_w	concentrations of radionuclides in water
DAD	dermally absorbed dose
D^{air}	diffusion coefficient in air
DA_{event}	absorbed dose per event in water

D_{cap}^{eff}	effective diffusion coefficient through capillary zone
DC	dietary composition
DCF	dose conversion factor
DE	Delaware
DOE	Department of Energy
DQO	data quality objectives
D^{wat}	diffusion coefficient in water
D_{WS}^{eff}	effective diffusion coefficient between groundwater and soil
D_v^{eff}	effective diffusion coefficient through unsaturated zone
ED	exposure duration
EF	exposure frequency
EPC	exposure point concentration
ERA	ecological risk assessment
ERAGS	Ecological Risk Assessment Guide for Superfund
ESA	Endangered Species Act
EU	exposure unit
EV	event frequency
°F	Fahrenheit
FA	fraction absorbed water
FCM	food chain multiplying factor
FGR	federal guidance report
FI	contaminated plant fraction
FR	fraction
FS	Feasibility Study
ft	feet
FUSRAP	Formerly Utilized Sites Remedial Action Program
g/day	grams per day
g/mol	grams per mole
GI	gastrointestinal
GW	groundwater
GWS	gamma walkover survey
H	Henry's Law Constant
H_{air}	ambient air mixing zone height
hcap	height of capillary zone
HEAST	Health Effects Assessment Summary Tables
HHRA	Human Health Risk Assessment
HI	hazard index
HQ	hazard quotient
HR	home range
hv	height of unsaturated zone
I	chronic daily intake
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiologic Protection
IDW	investigative-derived waste
IEUBK	Integrated Exposure Uptake Biokinetic model
ILCR	incremental lifetime cancer risk
IR	ingestion rate
IRIS	Integrated Risk Information System
J&E	Johnson and Ettinger
K-40	Potassium-40
kg	kilogram
kg/yr	kilogram per year
km	kilometer

K_{ow}	octanol/water coefficient
Kp	permeability coefficient from water
L/day	liter per day
LG_W	depth to groundwater
LOAEL	lowest observed adverse effects level
µg/dl	micrograms per deciliter
µg/pCi	microgram per picoCurie
µg/L	microgram per liter
m^3	cubic meter
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MED	Manhattan Engineer District
MCL	Maximum Contaminant Level
mg	milligram
mg/cm^2	milligram per square centimeter
mGy/d	milliGray per day
mg/kg	milligrams per kilogram
mg/kg-d	milligrams per kilogram-day
mol	mole
mph	mile per hour
mrem/yr	millirem per year
MW	molecular weight
NAVD 88	North American Vertical Datum of 1988
NCP	National Contingency Plan
ND	not detected
NIR	normalized food ingestion rate
NJ	New Jersey
NJDEP	New Jersey Department of Environmental Protection
NOAEL	no observed adverse effect level
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
OSWER	Office of Solid Waste and Emergency Response
OU	Operable Unit
Pa-234	Protactinium-234
Pa-234m	Protactinium-234 isomer
PAH	polyaromatic hydrocarbon
Paragon	Paragon Analytics Inc
Pb-210	Lead-210
Pb-212	Lead-212
Pb-214	Lead-214
PCBs	polychlorinated biphenyls
pCi/g	picoCuries per gram
pCi/L	picoCuries per liter
PEF	particulate emission factor
PEST	pesticides
Po-210	Polonium-210
PPRTV	Provisional Peer Reviewed Toxicity Values
PRG	preliminary remediation goals
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
Ra-226	Radium-226
Ra-228	Radium-228

RAGS	Risk Assessment Guidance for Superfund
RBCA	Risk based corrective action
RCRA	Resource Conservation and Recovery Act
RESRAD	RESidual RADioactivity computer code
RfD	reference dose
RI	Remedial Investigation
RME	reasonable maximum exposure
ROPCs	radionuclides of potential concern
SA	skin surface area exposed to soil
SD	sediment
Site	DuPont Chambers Works
SLERA	screening level ecological risk assessment
SPUF	soil-to-plants uptake factors
STSC	Superfund Health Risk Technical Support Center
SS	surface soil
SSL	soil screening level
STL	Severn Trent Laboratories
SVOCs	semi-volatile organic compounds
SW	surface water
SWMU	solid waste management unit
t*	chemical-specific time to reach steady-state
TAL	target analyte list
TEL	tetraethyl lead
t_{event}	duration of event
Th-228	Thorium-228
Th-230	Thorium-230
Th-231	Thorium-231
Th-232	Thorium-232
Th-234	Thorium-234
Tl-208	Thallium-208
TRV	toxicity reference values
U_{air}	wind speed above the ground surface in the ambient mixing zone
UCL	upper confidence limit
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium2-38
UF	uptake factor
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
VD	varied diet
VF	volatilization factor
VOCs	volatile organic compounds
W	width of source area parallel to wind or groundwater flow direction
WIR	normalized water ingestion rate
wt	weight
yr	year
Θacap	volumetric air content in capillary fringe soils
Θas	volumetric air content
θ_T	total soil porosity

Θwcap	volumetric water content in capillary fringe soils
Θws	volumetric water content
ϑ	lag time per event

1.0 INTRODUCTION

This Baseline Risk Assessment (BRA) report presents the potential health impacts to human and ecological receptors from exposure to both radiological and chemical contamination present at three Operable Units (OUs) within the DuPont Chambers Works facility in Deepwater, New Jersey (NJ) (referred to as the "Site"). Past operations in support of the nation's early atomic energy program occurred in the OUs and have resulted in releases of chemicals and radionuclides to environmental media that may pose risks to human and ecological receptors.

The Site is currently being addressed under the Formerly Utilized Sites Remedial Action Program (FUSRAP) managed by the U.S. Army Corps of Engineers (USACE) under the legislative authority provided by the 2000 Energy and Water Development Appropriations Act, Public Law 106-60. This law establishes the authority of the USACE to conduct response actions for releases related to the nation's early atomic energy program subject to the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).

This report describes both the human health risk assessment (HHRA) and ecological risk assessment (ERA) that have been performed at the Site. Both assessments include separate evaluations for radiological and non-radiological (chemical) contaminants present at the Site. Although the scope of the FUSRAP investigation does not include any hazardous substances (chemicals) associated with Manhattan Engineer District (MED)/Atomic Energy Commission (AEC) processes, the USACE is conducting separate evaluations to assess potential risks for all Site contaminants (radiological and chemical), consistent with CERCLA requirements. The scope of the FUSRAP investigation and determination of contaminants eligible for cleanup under FUSRAP is discussed in Section 1 of the Sitewide Remedial Investigation (RI). Further information about the process used by the USACE to identify eligible contaminants for the Site is provided in the technical memorandum entitled USACE Determination of Eligible Contaminants for FUSRAP Investigation at DuPont Chambers Works Site (CABRERA 2011a).

The BRA is being conducted as part of the Sitewide RI, and is intended to provide an assessment of risks to human health and environment that will support the selection of a remedy to eliminate, reduce, or control those risks. The specific objectives of the BRA are to:

- Estimate potential human health and ecological risks associated with the Site if no remedial action occurs;
- Identify areas that pose no unacceptable risks to human health or the environment, and thus require no further action;
- Develop a list of constituents of potential concern (COPCs) that contribute to unacceptable risks to human health or the environment; and
- Quantify risks associated with FUSRAP-related contaminants for the no action alternative in the Feasibility Study (FS) that will be used to evaluate risk reduction for each proposed alternative.

1.1 Baseline Risk Assessment Approach

The general approach for conducting the risk assessment follows U.S. Environmental Protection Agency (USEPA) and USACE risk assessment guidance and the data quality objective (DQO) process. The DQO process consists of a series of planning steps, based on scientific method, that are designed to ensure that the type, quantity, and quality of environmental data used in decision-making are appropriate for their intended purpose. The approach focuses on clearly defining the problem to be resolved (identification and, as appropriate, remediation or control of unacceptable risk) by focusing on the decisions to be made and the overall quality of data necessary to make these decisions. The risk assessment process produces information necessary for making risk management decisions.

The DQO for this risk assessment was to identify any unacceptable risks to human health and ecological receptors. The risk assessment identified receptors who may be exposed to site contaminants, the exposure pathways through which receptors are potentially exposed to site contaminants, and the concentrations of chemical contaminants in environmental exposure media (e.g., soil) for each exposure area. Based on these elements, and the specific toxicity of the site contaminants, the non-cancer hazards and carcinogenic risks were calculated and the uncertainty associated with these calculations discussed. The risk assessment ultimately identifies those contaminants found at unacceptable levels of risk and provides information to be used by stakeholders for risk management decisions.

The risk assessment process, both for human health and ecological assessments, typically involves the following five steps:

- **Data Review and Evaluation** selects a data set for use in the risk assessment and summarizes the nature and known extent of environmental contamination at the site. COPCs are selected based on the risk assessment data set.
- **Exposure Assessment** evaluates the magnitude, frequency, duration, and routes of potential human exposure to site-related COPCs. The exposure assessment considers both current and potential future site uses under a range of potential exposure scenarios and is based on complete exposure pathways to either actual or hypothetical receptors (i.e., generalized groups that could come in contact with site-related COPCs). The exposure scenarios are summarized in the Conceptual Site Model (CSM), which includes the sources, affected media, release mechanisms, and exposure pathways for each identified receptor population.
- **Toxicity Assessment** provides a review of available information to identify the nature and degree of toxicity, and to characterize the dose-response relationship (the relationship between magnitude of exposure and magnitude of potential adverse health effects on each receptor) for each COPC.
- **Risk Characterization** is a synthesis of exposure and toxicity information to yield quantitative estimates of potential cancer risks and non-cancer hazards to defined receptor populations.
- **Assessment of Uncertainty** identifies and characterizes the uncertainties associated with each of the four previous steps to assist decision-makers in evaluating the risk assessment results in the context of the assumptions and variability in the data used.

1.2 Report Organization

The general format of this document is as follows:

- Section 1: Introduction. This section presents the general purpose and scope of the BRA, the overall approach to the BRA, and the BRA Report organization.
- Section 2: Site Information. This section provides the site description, site history, history of MED activities at the site, physical characteristics of the site, and designation of exposure units.

- Section 3: Data Collection and Evaluation. This section summarizes the site-related constituents, history of site investigations, sampling information, data evaluations, and collection of background reference area sample information.
- Section 4: HHRA. This section describes how COPCs were identified for quantitative risk assessment; presents the land use and potentially exposed receptors (people), conceptual site model, methodology for estimating exposure point concentrations, and intake equations and exposure factor parameter values; describes the approaches for evaluating radiological and chemical toxicity; describes the methodology used for the estimation of health hazard and cancer risk, and discusses sources and implications of uncertainty in the risk characterization.
- Section 5: Screening Level Ecological Risk Assessment (SLERA). This section describes when, how, and why particular ecological entities may be exposed to chemical and radiological stressors present at the site; describes the receptor, constituents sources, and exposure media, methodology for estimating intake equations and exposure factor parameter values; describes the approaches for evaluating chemical toxicity; describes the methodology used for the estimation of health hazard, and discusses sources and implications of uncertainty in the risk characterization.
- Section 6: References. This section lists the references cited in the HHRA and SLERA.

2.0 SITE DESCRIPTION

DuPont Chambers Works is a 700 acre active chemical plant located in Salem County, Pennsville and Carneys Point Townships, on the southeastern shore of the Delaware River, north of the Interstate-295 Delaware Memorial Bridge. The plant is adjacent to the community of Deepwater, NJ. Figure 2-1 shows the location of Chambers Works within the floodplain of the Delaware River, between Helms Cove to the north and the Salem Canal to the south.

The USACE, based on previous Department of Energy (DOE) investigations, initially identified six potentially impacted areas, referred to as Areas of Concern (AOCs). To facilitate further investigations and remedial decisions, the USACE organized the six AOCs into three OUs under the FUSRAP and include:

- OU 1: Former Building 845 (AOC 1) and F Corral (AOC 2) – These AOCs were production areas where uranium refinement processes occurred.
- OU 2: Central Drainage Ditch (CDD) (AOC 3) and Building J-26 Area (AOC 5) – These AOCs include the location of a former laboratory building (J-16) and drainage ditches through which processing wastes were discharged.
- OU 3: Historical Lagoon A (AOC 4) and East Area/East Burial Area (AOC 6) – These AOCs were disposal areas for building rubble, discarded equipment, and process wastes.

Figure 2-2 is an aerial view of the Chambers Works property outlining the OUs and the six corresponding AOCs.

2.1 Site History

The Chambers Works Complex traces its origins to 1892, when the Carneys Point Smokeless Gunpowder Plant was constructed at Carneys Point, just north of Chambers Works. By 1914, manufacturing operations had extended south into the Chambers Works facility. In 1917, dye and specialty chemical manufacturing began at Chambers Works. Freon® and tetraethyl lead (TEL) production began in the 1920s, followed by aromatic chemical manufacturing in the 1940s. By the 1960s, Chambers Works began elastomer production. As chemical

Figure 2-1: Location of DuPont Chambers Works FUSRAP Site

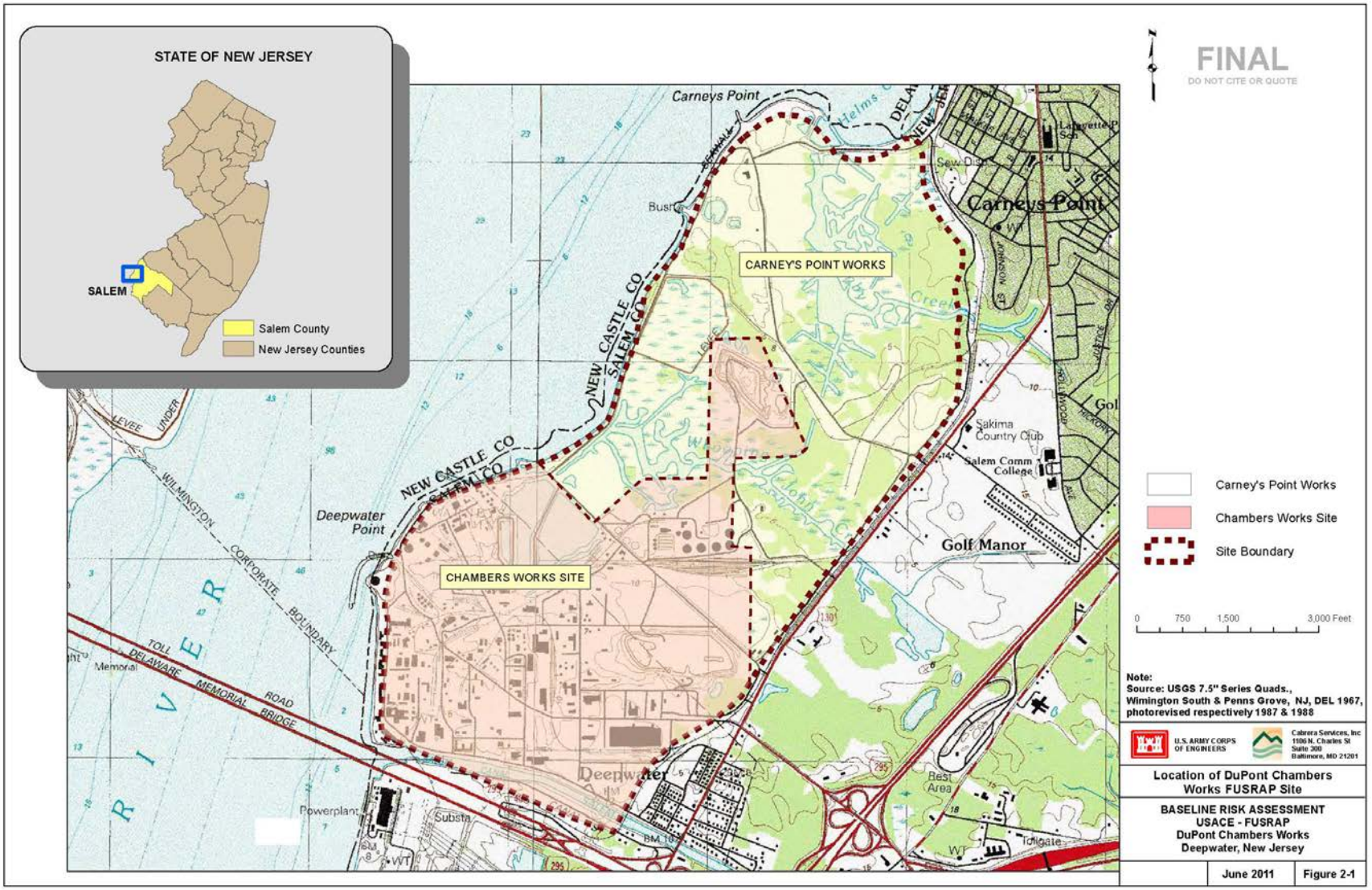
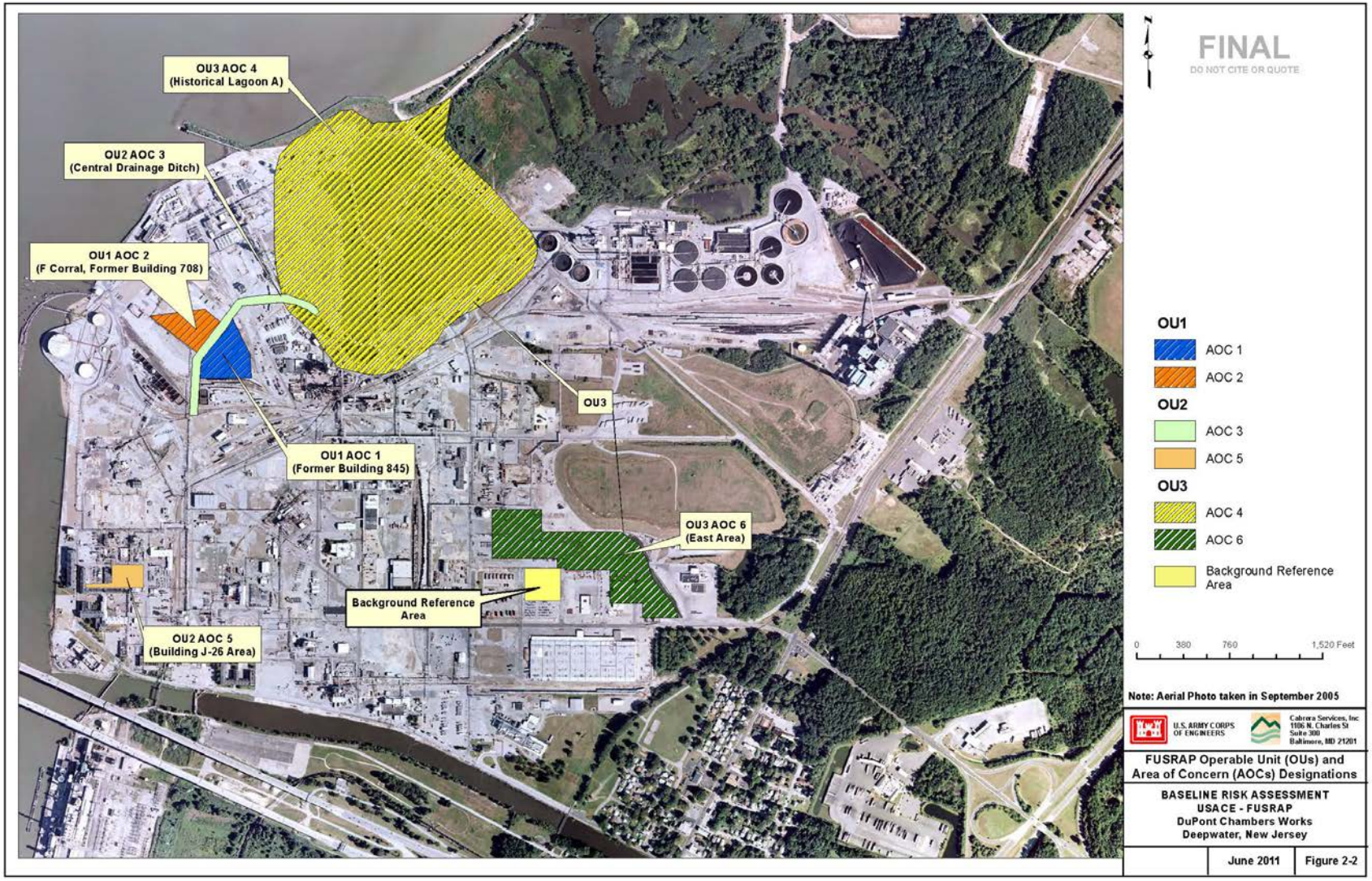


Figure 2-2: Designation of FUSRAP Operable Units (OUs) and Areas of Concern (AOCs)



manufacturing activities expanded, the low-lying areas were filled in with spoils from river dredging operations and construction debris to form consolidated subgrade for further development. By the late 1970s and early 1980s, the explosives and dye manufacturing divisions were shut down, leaving only chemical manufacturing.

Chambers Works' plant manufacturing history is summarized in Table 2-1. Commercial chemical materials produced at Chambers Works between 1920 and 1960 are presented in chronological order. Although this is not an all-inclusive listing of manufactured materials, the information is intended to provide a general representation of DuPont products (excluding MED materials) that have been manufactured at Chambers Works.

Currently, approximately 650 acres of Chambers Works are developed. The Chambers Works Complex produces approximately 600 products, employing more than 1,500 different processes in 44 manufacturing buildings. The general product manufacturing areas at Chambers Works currently include organic intermediates, aromatics, petroleum chemicals, fluorochemicals, polymers, elastomers, and specialty chemicals.

Table 2-1: DuPont Chambers Works Manufacturing History[1]

Date	Production Process
1920	Phthalic Anhydride developed.
1922	Tetra Ethyl lead developed.
1922	3-4 Acridine (Basic) dyes produced.
1924	Benzoic acid and sodium benzoate produced.
1924	Vulcone produced.
1925 to 1929	"Pink and Orange" Sulfanthrenes produced.
1926 to 1927	Gallopont and Luxol Dyes produced (Galloponts were discontinued in 1940. Luxols were transferred to New Brunswick Works in 1948-1949).
1930's	"Lithosol" fast yellow number produced. Discontinued in 1938.
1931	Sulfanthrene Brown G produced.
1931 to 1932	S.D.O (Special Drying Oil) paint produced.
1932	Antraquinone dyes (Ponsol dyes) produced.
1932 to 1937	Mercury Fungicides produced.
1933 to 1948	"Diagen' Colors produced; transferred to other areas in 1948.
1934	"White Products" produced.
1935 to 1949	Rubber chemicals (dimethoxydiphenylamine) produced.
1936 to 1948	Catalyst No. 3 Reduced produced.
1936 to 1949	Methrarols produced (transferred to New Brunswick plant in 1949).
1936 to 1949	"Monastral" Dyes or copper phthalocyanine colors produced.
1937 to 1946	Zelan A, Zelan AP water repellants produced.
1937/38 to 1947	Petroleum chemicals (known as Ortholeum) produced.
1939 to 1949	In-255 produced.
1941 to 1945	Monastral dyes, nickel catalysts, Zelans, In-2555 and other products produced.
1942 to 1945	Mustard gas antidote (1:2-dithioglycerol) produced.
1943 to 1950	Freon 1114 (Chlorotrifluoroethylene) produced.
1943 to 1952	Isocyanates produced (production suspended 1944-45).
1945 to 1957	Freon-13 produced. In 1957, it was produced at a rate of up to 56K lbs/year.
1946 to 1948	"Ceresan" M concentrate produced.
1949	Many manufacturing processes were moved to other plants. Chambers Works returned to a greater research and development role.
1950 to 1957	Fluoroalcohols produced.
1950 to 1959	"Teslar" film produced.
1951 to 1957	Freon-13B1 produced.
1953 to 1959	Polyac (rubber chemical) produced at a rate up to 50-80K lbs/year.
1953	"Zelec" NF (textile finishing agent) produced.
1954 to 1958	Hydrophobic fibers produced.
1956	"Zelec" NO (textile finishing agent) produced.
1957 to 1959	"Viton" A produced.
1959	Fluorowax (dispersed in Freon 113®) produced.
1959	Tetraisopropyl Titanate produced.

1 The manufacturing history is for commercial production processes and does not include MED/AEC materials or processes. MED/AEC process information is provided in Section 2-2 and Table 2-2.

2.2 History of MED Activities at the Site

Operations to refine uranium under contract to MED began in 1942 at the Site. In 1946 all MED activities were transferred to the AEC with DuPont continuing its research for AEC until late 1947. MED contracted with DuPont to perform several uranium-processing activities, as outlined in Figure 2-3. A summary of production activities under MED contracts is provided in Table 2-2. Uranium refinement and production of fluorocarbons were performed in an area referred to as the "Blue Products Area" (located in OU 1). These processes included the following:

- Brown oxide process
- Recovery process
- Green salt process
- Metal process

Chambers Works developed processes for converting uranium oxides to uranium tetrafluoride, uranium hexafluoride, and small quantities of uranium metal. DOE has estimated that more than half of the Chambers Works product came by processing uranium-bearing scrap (shipped from other sites) into uranium peroxide, which was then fed into the Brown Oxide Process (DOE 1997). Other research activities were also performed but no enrichment or depletion processes occurred at the Site.

Chambers Works converted scrap and dross into uranium peroxide dihydrate in Buildings 101 and 102. These buildings adjoined each other and were later collectively called Building 845. During processing, 5,486 tons of scrap material was converted to 982 tons of black oxide. Uranium peroxide and oxides were processed in Buildings 708 and 205, ultimately producing (through several steps) uranium tetrafluoride and uranium metal.

Chambers Works used a pilot plant located in Former Building J-16 to develop the processes used in the Blue Products Area. In addition to the small batch-scale versions of the processes listed above, DuPont conducted batch-scale testing of the Hexafluoride process at Former Building J-16.

As previously mentioned, six AOCs are presently being investigated to evaluate any residual contamination resulting from MED operations at Chambers Works (refer to Figure 2-2). A brief description of each AOC and former MED activities is provided below.

2.2.1 AOC 1 – Former Building 845

AOC 1 is the site of the Former Building 845, which was located in the northwest quadrant of the manufacturing complex, just east of the F Parking Corral Area. Work in Building 845 consisted of the recovery of uranium from scrap and other by-products. Some of the wastes from these recovery processes were discharged to the wooden trough located east of the building and ultimately discharged to the CDD.

AOC 1 is predominantly covered with six to 18 inches of crushed stone and asphalt. The area is bounded by a wooden trough to the east and northeast (which is a part of AOC 3). Rail lines are located adjacent to the wooden trough to the east-northeast. The northwest portion of AOC 1 is bounded by the portion of the CDD that is an open channel. The west side of AOC 1 is bounded by a slight depression (formerly the open channel of the CDD, now enclosed within two concrete culverts). The south side of the area is bounded by a rail yard. The adjacent land use is industrial. There is very little vertical relief in AOC 1. The wooden trough on the east and depression of the former CDD on the west convey surface water drainage to the open channel portion of the CDD along the northwest corner of the site.

Following completion of the Recovery Process operations in Building 845, equipment from the building was removed and either buried in the East Burial Area (OU 3-AOC 6) or sent to the Niagara Falls Storage Site within the Former Lake Ontario Ordnance Works. In 1948, Building 845 was surveyed and decontaminated by AEC, then released to DuPont. DuPont subsequently used Building 845 as a warehouse. The USACE surveyed and demolished Building 845 in 1996. The building rubble was then disposed offsite in a radiation-permitted landfill (Waste Control Specialists) due to the presence of residual levels of uranium fixed to metal surfaces. The only remaining portions of the building are the concrete slab and elevator shaft, which are covered with 12 to 18 inches of crushed stone.

Figure 2-3: Process Flow Diagrams for Uranium Refinement

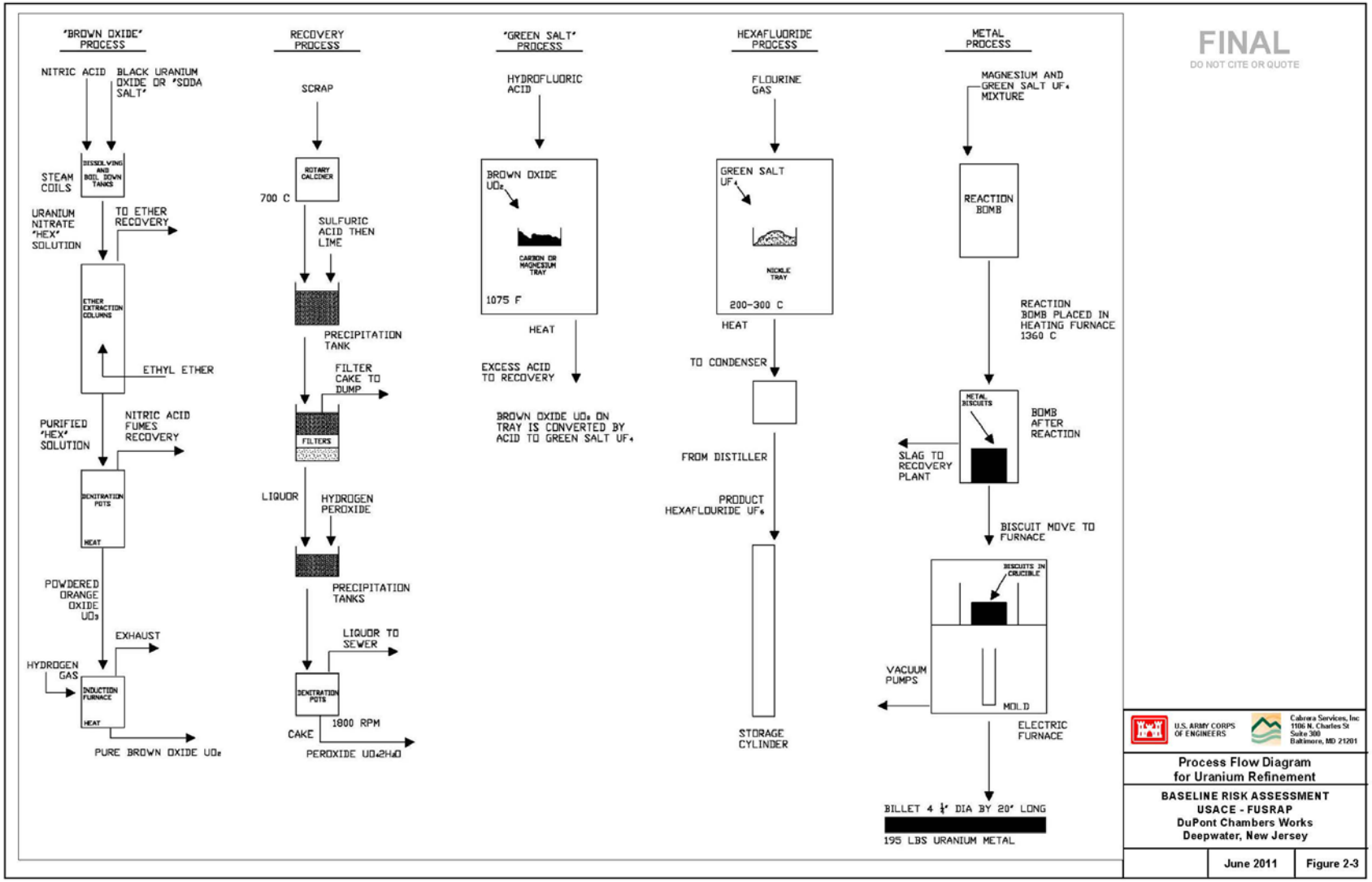


Table 2-2: DuPont Chambers Works MED Manufacturing History

Project/ Contract No.	Date (s)	AOC	MED Project Description
Project 9233 Contract W-7412-Eng. 8	Begins July 1943	n/a	Commercial production of hydrofluoric acid for use in the fluorine generators. Initial acid production 300,000 pounds/month. Production was a Kinetic Chemicals facility located north of AOC 3.
Project 9595 Contract W-7412-Eng. 2	Begins April 1943	1	Production of 117,032 pounds of n-perfluoroheptane in the Blue Products Area, referred to as Process Buildings A and B (OU 1).
Project 9634 Contract W-7412-Eng.3	April 1943 - May 1946	2	Converted sodium diuranate, commercial black oxide, and uranium peroxide dihydrate to brown oxide in Buildings 708 and 205 (AOC 2). The brown oxide was then converted to green salt, which, in turn, was converted to uranium metal. Green salt and uranium metal production were suspended in August 1944, and brown oxide production in May 1946. Total production had been 1,970 tons of brown oxide, 608 tons of green salt, and 232 tons of uranium metal.
Project 9757	Begins December 1943	6	This production was located on 21 acres in the East Area (AOC 6). Total production included 3.9 million pounds of hexadecafluoro-dimethylcyclohexane, 286,000 pounds of monochlorohexadecafluoro-dimethylcyclohexane, 8,200 pounds of fluorolube, and an unknown quantity of C_7F_{16}.
Project 9803 Contract W-7412-Eng.22	August 1943 - December 1945	1	This project was located in the "Blue Products" area (AOC 1), and included recovery of scrap uranium and by-products of other uranium process (uranium metal sludge, uranium metal dross and slag from the green salt/ magnesium reaction) and their conversion first into uranium peroxide dihydrate and then to the end product, black oxide. Approximately 982 tons (1,964,000 lbs) of black oxide was produced.
Contract W-7412-Eng.151	Unknown	5	Conducted research and development activities at the Former Building J-16 (AOC 5). The demolished Building J-16 was disposed of in the Historical Lagoon A area (AOC 4).
Contract W-7412-Eng.161	Unknown		Freon 113® produced under MED contract. Production of 79,850 pounds of Freon 113®.

n/a – Not Applicable (Outside of AOCs)

2.2.2 AOC 2 – F Corral

AOC 2 is the F Corral, currently a parking lot located directly west of Former Building 845. This parking lot is the former location of Building 708, which was used for the production of brown oxide, green salt, and uranium metal. AOC 2 is currently covered with asphalt. The area is bounded to the north by a portion of an open channel drainage ditch (which is part of AOC 3). The eastern portion of the area is bounded by the slight depression (formerly the open channel of the CDD, now enclosed within two concrete culverts). This feature defines the boundary between AOCs 1 and 2. The south side of AOC 2 is adjacent to a former storage area and DuPont's former TEL production area. The west portion of AOC 2 is next to a stone and asphalt lot. The depression of the former CDD on the east portion of the area, and drainage ditch on the north, convey surface water drainage to the open portion of the CDD. The adjacent land use is industrial. The topography of AOC 2 is flat with very limited change in elevation.

Building 708 housed operations for DuPont Project 9634, under contract W-7412-Eng. 3. Under this contract, DuPont converted sodium uranate, commercial black oxide, and uranium peroxide dihydrate to brown oxide. The brown oxide was then converted to green salt, which was then converted into uranium metal. The green salt was produced at a rate of 47 tons per month. Production began in April 1943. A total of 1,970 tons of brown oxide was produced through May 1946. When the green salt and metal production was suspended in the summer of 1944, 608 tons of green salt and 232 tons of uranium metal had been produced.

In 1945, part of Building 708 was demolished and removed from the Site as reported in the Phase I Records Review (Weston 2001). In 1953, the remainder of the building and some underlying soil were removed and disposed of in Historical Lagoon A (Weston 2001). The building is present in historical aerial photographs through 1954. The building is no longer present in the 1959 photograph, indicating that it was removed sometime between 1954 and 1959.

2.2.3 AOC 3 – The Central Drainage Ditch

AOC 3 consists of the CDD that runs between the former MED production areas (OU 1) and the Historical Lagoon complex (AOC 4). The general location of the CDD is shown on Figure 1-2. The CDD is part of a larger, plant-wide system of ditches used today to convey non-contact

cooling water and storm water runoff to DuPont's onsite wastewater treatment plant. The CDD has a nearly linear shape, and the investigated length between OU 1 and the lagoon is nearly 1,000 feet (ft) long and only 30 ft wide. Over time the configuration and route of the CDD has changed significantly, especially in relation to the settling basins and lagoon complex.

During MED operations the CDD received process wastes from the production areas in OU 1, specifically from Former Buildings 708 and 845 (Buildings 101 and 102) and conveyed the wastewater to the Historical Lagoon A (now AOC 4, part of OU 3). A historical aerial photo review was conducted in order to determine the location of the ditch from the 1940s to present (Weston 2001). During the 1940s, the CDD consisted of two streams that converged just west of Kinetic Road and then opened into a ponded area near the two railroad spurs located east of Kinetic Road. East of the railroad spurs the CDD then discharged into Lagoon A. The eastern, downstream reach of the CDD was significantly different from its present day course (see Figure 1-8 of the Sitewide RI).

A wooden trough is located along the eastern border of AOC 1 and was investigated as part of AOC 3. This drainageway connects with the CDD in the northern part of AOC 1. Historical aerial photos indicate that the wooden trough was in use during the MED era and that Former Building 845 may have been connected to it.

AOC 3 lies approximately 1,000 ft from the bank of the Delaware River. The CDD averages 30 ft in width at the top of its bank. It has an approximate elevation of zero ft North American Vertical Datum of 1988 (NAVD 88) at the base of the ditch. The water flow direction of the CDD is eastward toward the B basin. The CDD exhibits perennial water flow and water depth in the ditch averages one to two ft. During RI field activities groundwater seeps were noted on the banks of the CDD at elevations corresponding to the A Aquifer.

As part of DuPont's Resource Conservation and Recovery Act (RCRA) corrective action program for the Chambers Works Site, the Process Water Ditch System is in the process of being cleaned up for various chemical contaminants. The part of the CDD located between AOC 1 and AOC 2 was remediated in 1997 to remove organic and lead-contaminated soil. DuPont

conducted this action and disposed of the material in an onsite vault located in the closed former A settling basin (solid waste management unit (SWMU) 14).

2.2.4 AOC 4 - Historical Lagoon A

Lagoon A was located in the northern portion of the Site, bounded by the Delaware River to the north, Plant No.1 Road to the south, Kinetic Road to the west, and Boundary Road to the east. Lagoon A was later separated into three settling basins: Settling Basins "A", "B", and "C". The number and size of these basins varied significantly over time during the operational period of the facility. The lagoons were periodically dredged by DuPont as they filled with sediment. Historically, Lagoon A received wastewater from Chambers Works, including that generated by MED operations. The CDD provided the conduit for wastewater discharged from the MED production areas to the lagoon. It is believed that one or more of the fill areas, including the North Burial Area, received building debris and contaminated soil from buildings used in MED operations.

2.2.5 AOC 5 – Former Building J-16 (Building J-26 Area)

Former Building J-16 was used by Jackson Laboratory (a DuPont research and development subsidiary) to conduct batch experiments for uranium refinement. The Hexafluoride Process was conducted in Former Building J-16. Building J-16 was demolished in the mid-1950s and the foundation as well as several feet of underlying soil was removed. DuPont then constructed Building J-26 over the footprint of Former Building J-16.

AOC 5 is completely paved by concrete or asphalt. The drains surrounding Building J-26 are open-topped trenches that are covered with slotted steel gratings. The drains are approximately one ft wide. AOC 5 lies at an elevation of approximately five ft NAVD 88. The AOC 5 drains are used to collect storm water and direct it to the B Basin. The drains usually contain water. Surges in water flow are observable and indicate the use of pumps to feed water into the drain.

2.2.6 AOC 6 - The East Area

The East area was used to manufacture fluorinated hydrocarbons and fluorolube under contract with MED during World War II. The East Area includes the East Burial Area which received demolition debris and discarded equipment from MED projects conducted in the Blue Products Area (OU 1). The location of this burial area was adjacent to and north of East Road.

2.3 Physical Characteristics of Site

The following section summarizes the physical and environmental characteristics of the Chambers Works site that are relevant to identifying potential migration pathways, transport mechanisms, and potential current and future receptors.

2.3.1 Meteorology

Based on climatological data collected from National Weather Service Station at New Castle County Airport, Wilmington, Delaware (DE) for the period 1948 through 2000, the mean temperature in the site is 54 degrees Fahrenheit ($^{\circ}$ F), ranging from a minimum monthly mean temperature of 23° F in January to a maximum monthly mean temperature of 86° F in July. The average annual precipitation for this period is 41.5 inches, with a monthly average precipitation of 3.5 inches. The highest monthly mean precipitation is in July with 4.3 inches and the lowest monthly mean precipitation is in October with 2.9 inches. The prevailing winds come from the northwest at eight to 14 miles per hour (mph) during the spring, fall, and winter, and from the south at nine to 10 mph during the summer.

2.3.2 Land Uses

The Site is a 700 acre active chemical plant located in Salem County, NJ along the eastern shore of the Delaware River across from the city of Wilmington, DE. The village of Deepwater is adjacent to Chambers Works. Approximately 650 acres of Chambers Works are currently developed. The Site is zoned as industrial.

The Site is located in a moderately populated area consisting of light to heavy industry, recreational areas, community service areas, and residential neighborhoods. Situated south of the Site is the Atlantic Electric Power Plant. East of the site are light industrial, residential, and recreational areas. North of the Site are community service areas, and residential areas of Carneys Point Township.

The surrounding area is predominantly rural. Approximately 50% of the county's land is used for agriculture with an additional 25% of the land dedicated to environmental uses such as tidal and freshwater wetlands, marshland, lakes, ponds, flyways, and natural habitats. The developed lands make up only 13% of land use, and accommodate all types of uses including residential, commercial, and industrial.

2.3.3 Hydrology

The Delaware River is tidal and brackish at Deepwater and is not a potable water source in the area of the Site, but is a major supplier of potable water to communities north of the area.

2.3.4 Geology

Native site soils are of alluvial and palustrine (marsh) origin, but have been substantially modified by landfilling and construction activities. The land along the shoreline has most likely been accreted as point-bar deposits from the Delaware River, or possibly, from over-bank deposition during periodic flooding, which has resulted in the formation of a natural levee. Behind these shoreline deposits, which consist of sands and silty sands, there once existed a tidal marsh consisting of silty clays, with an elevation near sea level. The Site was gradually enlarged by filling in the marsh areas.

2.3.5 Hydrogeology

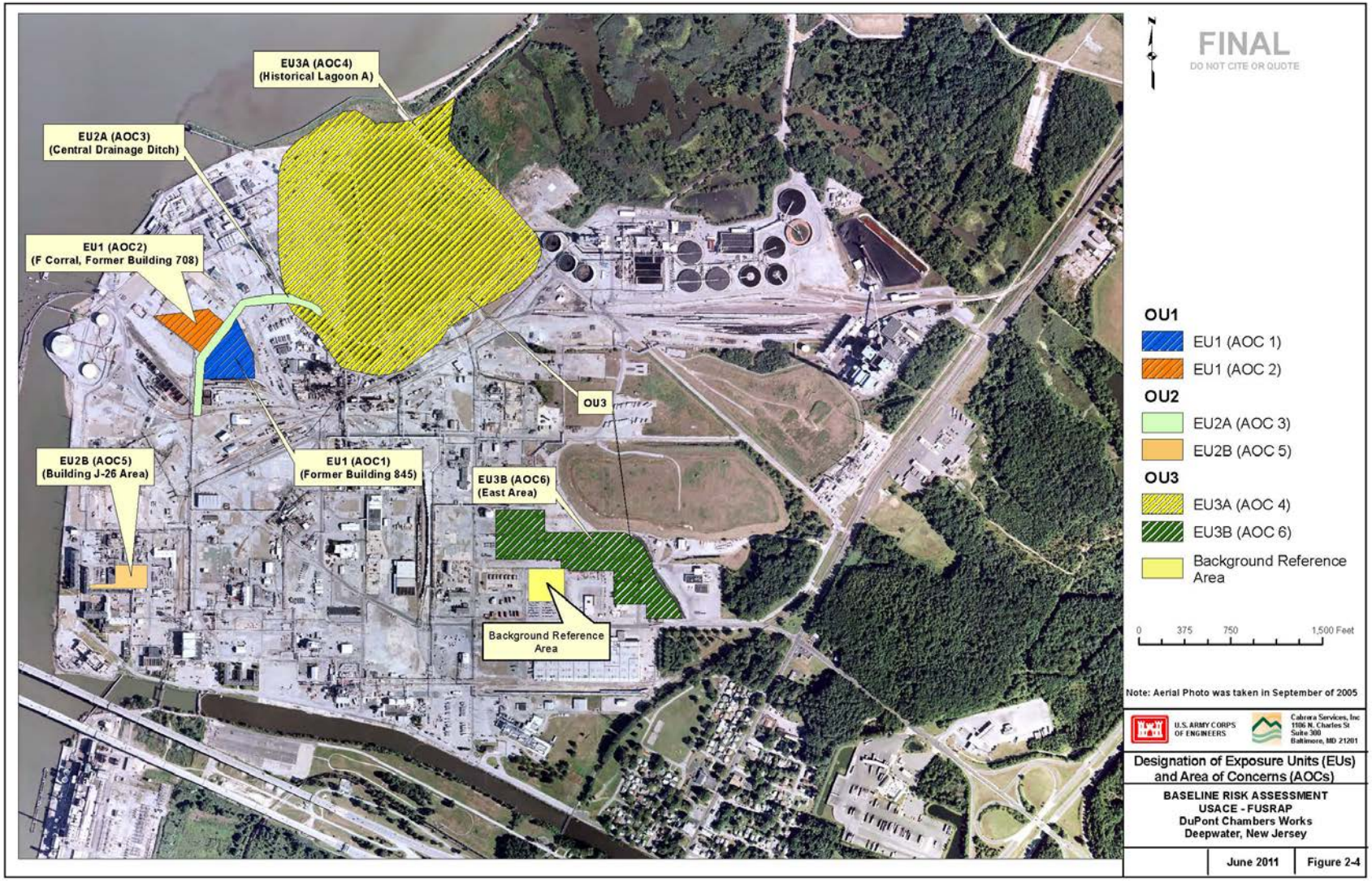
The sedimentary deposits beneath the Chambers Works can be divided into five major sequences (DERS 1993): (1) the A and B aquifer and the A-B and B-C aquitards. The A-B aquitard is discontinuous and thins to zero to the east and in areas where stream channels were once present. The A aquifer is the uppermost water-bearing zone at the Chambers Works facility. The B aquifer consists of sands that are interpreted to be Delaware River alluvium; (2) the C aquifer, which is composed mainly of Pleistocene-Age coarse-grained sands and gravels; (3) the C-D aquitard, which is composed of clays and silts of estuarine origin; (4) the D aquifer, consisting of coarse-grained sands and gravels. The D unit is valley-fill sediment that is incised in the underlying Potomac Group; and (5) the underlying D-E aquitard through the F Aquifer units are the Cretaceous-Age sediments of the Potomac Group. Although the surficial aquifers are not an important source of drinking water, the Potomac aquifer is widely used as a drinking water source in southern NJ and DE.

2.4 Designation of Exposure Units

Based on physical location within the Site, the six FUSRAP AOCs were grouped into five separate exposure units (EUs) for evaluation in the BRA. EUs, defined as areas in which a receptor is likely to average his/her exposure, were identified so as to correspond with the FUSRAP OU designations. EU 1 consists of the two adjacent areas, AOC 1 and AOC 2, which corresponds to the OU 1 designation. AOC 3 and AOC 5, which make up OU 2, were

designated as EU 2A and EU 2B, respectively. For OU 3, AOC 4 and AOC 6, were designated as EU 3A and EU 3B, respectively. Figure 2-4 presents all five EUs for the Site and shows the corresponding AOCs and OUs designations.

Figure 2-4: Designation of EUs and AOCs



3.0 DATA COLLECTION AND EVALUATION

In accordance with the RI Work Plans and the Sampling and Analysis Plans, samples were collected from the following media: soil, sediment, surface water, and groundwater. Samples were analyzed for radionuclides, inorganics (metals, anions), semi-volatile organic compounds (SVOCs), volatile organic compounds (VOCs), polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), and pesticides (PEST) depending on the specific AOC and media. The following sections of the report summarize information regarding site-related constituents, history of site investigations, medium-specific sampling analyses, and data evaluation processes performed during this BRA.

3.1 Site-Related Constituents

As mentioned earlier the USACE is authorized to conduct response actions for releases related to the nation's early atomic energy program. The following types of hazardous substances are considered eligible contaminants and within the scope of FUSRAP investigations and cleanup activities:

- Radioactive contamination (primarily uranium, thorium and associated radionuclides) resulting from activities performed for the MED or AEC, to include hazardous substances associated with these activities (e.g., chemical separation, purification);
- Other radioactive contamination or hazardous substances that are mixed or commingled with MED or early AEC radioactive contamination;
- At federally-owned FUSRAP sites, all radioactive contamination and hazardous substances are within the scope of the FUSRAP response action; and
- Other substances where specifically directed by Congress (USACE, 2003).

To determine specific eligible contaminants for Chambers Works the USACE reviewed historical site records, the use of specific compounds and feedstock materials at the Site, and general industry references describing similar processes at other facilities. After listing all radiological and chemical constituents listed in MED documents, the USACE utilized a screening process to identify those radiological and chemical constituents that may be eligible for investigation and cleanup under FUSRAP. As a result of the screening process five radionuclides and no hazardous substances or chemicals were determined to be eligible

contaminants (CABRERA 2011a). The radiological eligible contaminants are further discussed below.

3.1.1 Radiological Constituents

Earlier Site investigations indicated that MED-related radiological contamination is limited to isotopes of refined uranium (i.e., U-234, U-235, and U-238) and their short-lived decay progeny. The term "refined" in this context refers to processes undertaken at Chambers Works and elsewhere in the MED complex that altered the natural equilibrium condition of unrefined uranium ores.

Refined natural uranium, initially identified as the primary site contaminant, is in a state of secular equilibrium with its short-lived decay progeny, which consist of daughter radionuclides with half-lives short enough to allow them to decay at the same rate at which they are produced. Based on the assumption that the original uranium refinement processes were performed approximately 60 years ago, only the short-lived uranium decay progeny and the two parent isotopes (U-234 and U-238) would be expected to be present today in significant quantities.

These radionuclides include:

- Uranium-238 (U-238) short-lived decay progeny Thorium-234 [Th-234] (24-day half-life) and protactinium-234 isomer [Pa-234m] (1.17-minute half-life);
- Uranium-235 (U-235) short-lived decay progeny Thorium-231 [Th-231] (25-hour half-life); and
- Uranium-234 (U-234) has no significant decay progeny that are expected to be present.

Long-lived thorium isotopes have been identified as radionuclides of potential concern (ROPCs) at other FUSRAP sites where uranium ore or where ore concentrates were used as MED feedstock. The ore concentrate refining process was not used at Chambers Works. However, the Black Oxide (sodium uranate) feedstock was used at the site and based on USACE research, small amounts of radium and thorium contamination may be left behind in the feedstock as a by-product of the chemical separation process. The USACE performed a data evaluation by comparing site sampling results of Thorium-230 (Th-230) with respect to the potential in-growth

concentration of Th-230 from its parent products, U-234 and U-238. The results of the data evaluation showed that the observed Site concentrations for Th-230 are significantly higher than the expected in-growth concentration of Th-230. It is assumed that the excess concentrations of Th-230 are due to the presence of impurities within the sodium uranate feedstock. Therefore, Th-230 was added to the list of ROPCs for Chambers Works (CABRERA, 2011a).

Radium-226 (Ra-226) was also added as an ROPC since it is a daughter product in the decay chain of U-238 and is present in unrefined uranium ore. Like Th-230, a similar data evaluation was performed to compare the potential in-growth concentration of Ra-226 from its parent products, U-234 and U-238, with the observed Ra-226 concentrations at the Site. The Site concentrations for Ra-226 are again significantly higher than the calculated in-growth concentration of Ra-226. In addition, Ra-226 has been identified as a co-contaminant of uranium at other FUSRAP sites. Therefore, Ra-226 was identified as a potential contaminant in the Black Oxide feedstock and also added to the ROPC list for Chambers Works. Ra-226 appears to be a contaminant primarily where ore beneficiation has occurred (i.e., where ores or ore concentrates were initially processed) and may be present in MED wastes (CABRERA 2011a).

Therefore, five ROPCs have been identified as eligible contaminants for FUSRAP investigation and possible remediation at Chambers Works. They include U-234, U-235, U-238, Th-230, and Ra-226.

3.1.2 Chemical Constituents

No chemical constituent was identified as a FUSRAP eligible constituent for the Site (CABRERA 2011a). However, chemical samples were collected to assist in the characterization of chemical risks as part of the BRA. In addition, chemical analyses were performed to characterize geochemical conditions at the Site, to evaluate health and safety considerations, and to characterize investigative-derived waste (IDW) for possible disposal options. Target Analyte List (TAL) metals analysis for groundwater provided useful information for the interpretation of geochemical conditions as well as supporting data for the BRA. VOCs, SVOCs, PAHs, PCBs and PEST samples were also collected in support of the BRA.

3.2 History of Site Investigations

The OU 1 soil field investigation was conducted in 2002 by Weston while the OU 2 field investigation was conducted by Cabrera Services, Inc. (CABRERA) in 2003. Investigations at OU 3 were conducted in a phased approach from 2004 to 2006. In addition, soil sampling activities were conducted in 2007 to establish the relationship of Ra-226 and Th-230 with respect to MED uranium, as well as to provide information regarding the concentrations of chemical constituents.

Investigations of groundwater impact at all OUs were conducted from 2004 to 2007. Initial groundwater investigations were designed to investigate confirmed areas of groundwater impact and to evaluate the potential mobility of aqueous phase uranium in groundwater. Subsequent groundwater investigations were performed to determine the horizontal and vertical extent of contamination. Quarterly groundwater monitoring events were conducted as part of the overall groundwater investigation from July 2005 through May 2007. Although not present in OU 1 surface water and sediment were evaluated as part of the investigations at OU 2 and OU 3.

3.3 Sampling Information

Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) guidance was used to develop soil sampling strategies for the site. Initially, gamma walkover surveys (GWS) were conducted to map areas of potential radiological impact. Both biased and systematic soil samples were collected for each EU. In addition, sediment samples were collected from EU 2A and EU 3B. Samples were analyzed by both onsite and offsite laboratories. The onsite laboratory performed gamma spectroscopy to measure U-238 decay progeny. These results were used to identify potentially impacted areas and guide further investigations while in the field. However, onsite results were not used during this BRA. Eberline Services and Paragon Analytics Inc (Paragon) analyzed all offsite soil and sediment samples. The offsite laboratory utilized gamma spectroscopy for analyses of radium and uranium isotopes. However, alpha spectroscopy was performed for 10% of the earlier samples, and all samples collected during 2007. All thorium samples were analyzed via alpha spectroscopy. Table 3-1 presents the total number of samples for each EU utilized during this BRA.

Initially, groundwater samples were collected using temporary piezometers. Those sampling results were used to identify potential areas of groundwater contamination and plan subsequent

groundwater investigations including a monitoring well installation program. However, only the analytical results from the monitoring well program were used during this BRA. Based on the results from temporary piezometers, a total of 26 monitoring wells were installed in OU 1 in the A, B, and C aquifers. Thirteen monitoring wells were installed in Aquifer A and 12 wells were installed in Aquifer B. Only one well was installed in Aquifer C to assist in delineating the vertical extent of contamination in OU 1. In AOC 4 a total of five monitoring wells were installed in the A and B aquifers; in AOC 6 a total of seven monitoring wells were installed in Aquifer B. Only groundwater samples collected from Aquifer B were used during the BRA since the State of NJ identifies Aquifer B as the potential drinking water source for the Site.

Surface water samples, using a direct dipping method, were collected from EU 2A and 3B. A total of 13 and 12 surface water samples were collected from EU 2A and EU 3B, respectively. The sample container was dipped directly into the surface water for sample collection. After collection of groundwater and surface water samples, the samples were sent to Paragon for analysis. Groundwater and surface water samples were analyzed for isotopic uranium and thorium using American Society for Testing and Materials (ASTM) 3972-90 method. Ra-226 and Radium-228 (Ra-228) were analyzed by using USEPA method 903/904.

In addition to radiological constituents, media-specific sampling was conducted for chemical constituents. A detailed description of sample locations, sample types, analytical methods, and the necessary detection limit to meet project goals were presented in the *Baseline Risk Assessment Data - Gap Sampling: Field Sampling Plan* (CABRERA 2007).

Quality control (QC) samples were collected for 10% of the primary sample locations. Quality assurance (QA) split samples were collected at 5% of the primary locations. The QA/QC samples were analyzed by the USACE contract laboratory, Severn Trent laboratories (STL). However, only primary sampling results were used during this BRA. No QA/QC samples were included in the BRA dataset.

Table 3-1: Number of Samples for Each EU

EU	Analytes	Ra-226	Th-230	U Isotopes		Metal	VOC	SVOC	PAH	PCB	Pest
	Methodology/ Env. Medium	Gamma	Alpha	Alpha	Gamma	SW6010 ; SW7471	SW8260	SW8270	SW8270	SW8082	SW8081
1	Soil	39	41	U-234 = 50; U-238 = 50: U-235 = 50	U-235 = 233; Th-234 = 233	33	32	32	20	32	12
	Groundwater - Aquifer B	73	32	U-234 = 73; U-238 = 73; U-235 = 73	0	69	16	12	0	8	8
2A	Soil	72	45	U-234 = 18; U-238 = 18: U-235 = 18	U-235 = 76; Th-234 = 76	20	20	20	20	20	0
	Groundwater - Aquifer B	20	12	U-234 = 20; U-238 = 20: U-235 = 20	0	21	10	8	0	0	0
	Surface Water	13	10	U-234 = 14; U-238 = 14: U-235 = 14	0	10	10	10	0	0	0
	Sediment	17	20	U-234 = 10; U-238 = 10: U-235 = 10	U-235 = 18	10	10	10	10	10	0
2B	Soil	22	11	None	U-235 = 22; Th-234 =22	0	0	0	0	0	0
	Groundwater - Aquifer B	3	3	U-234 = 3; U-238 = 3: U-235 = 3	0	3	4	3	0	0	0
3A	Soil	50	30	U-234 = 20; U-238 = 20: U-235 = 20	U-235 = 50; Th-234 = 50	20	20	20	20	20	0
	Groundwater - Aquifer B	8	8	U-234 = 8; U-238 = 8: U-235 = 8	0	8	2	2	0	0	0
3B	Soil	91	28	U-234 = 20; U-238 = 20: U-235 = 20	U-235 = 91; Th-234 = 91	20	20	20	20	20	0
	Groundwater - Aquifer B	31	28	U-234 = 31; U-238 = 31: U-235 = 31	0	29	7	7	0	0	0
	Surface Water	12	12	U-234 = 12; U-238 = 12: U-235 = 12	0	10	10	10	0	0	0
	Sediment	13	13	U-234 = 10; U-238 = 10: U-235 = 10	U-235 = 13; Th-234 = 13	10	10	10	10	10	0

3.4 Collection of Background Reference Area Samples

A major step in assessing data is to distinguish between constituents that are likely related to past material- or waste-handling and/or disposal practices at the Site and those that may be present at naturally-occurring or background levels. USACE performed a background evaluation at the Site. The results of this background evaluation were utilized in the BRA in the following three ways and are further described in Section 4:

- Identification of COPCs - Under CERCLA, when the maximum detected concentration of a contaminant is less than its background concentration, no remedial action is required for that contaminant. Therefore, a background screen was performed for both radiological and chemical contaminants present at the site for identifying both radiological and chemical COPCs for the Site.
- Radiological Dose Assessment - Background concentration for each radiological COPC was subtracted from their corresponding exposure point concentrations during the radiological dose assessment. The subtraction was performed for comparing the radiological dose with respect to above background acceptable dose criteria.
- Radiological and Chemical Risk Assessment - Background concentrations were not subtracted in performing the radiological and chemical risk assessments.

As part of the background evaluation process, USACE selected an area to sample in order to characterize the background concentrations of naturally occurring radionuclides and metals present at the Site. Figure 2-4 shows the location of the background reference area. The selected area has the same characteristics as the site sampling locations, but did not receive any releases from the Site. This area is approximately 200 ft southwest of AOC 6, in a vacant lot of approximately two acres in size. Based on MED site history and review of historical documents it was concluded that no MED-related constituents are likely to be present within this area.

Section 9 of the Sitewide RI report provided a detailed summary of the background data collection and evaluation processes (CABRERA 2011b). A detailed description for site and background sample locations, sample types, analyses types, and the necessary detection limit to meet project goals are presented in the *Baseline Risk Assessment Data – Gap Sampling: Field Sampling Plan* (CABRERA 2007). Background samples were collected from the following media: soil, groundwater, surface water and sediment. The methodologies presented in USEPA's *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (USEPA 2002a) were used during the determination of background chemical concentrations. As a conservative approach in the BRA, no VOCs, SVOCS, PCBs, PAHs and PEST were assumed

to be present, so no background concentration was determined for those analytes. Appendix A presents the background sampling results for radiological COPCs and metals present in soil, groundwater, surface water and sediment.

3.5 Data Evaluation

Results of the RI sampling program constitute the analytical data set that was evaluated in the BRA. Radiological data were reviewed and verified using the USACE's Data Verification and Validation Worksheet developed by Argonne National Laboratory (ANL) for the Buffalo District. Chemical analytical data were audited for QA acceptance criteria using USACE's Automated Data Review (ADR) software in accordance with the approved RI Quality Assurance Project Plan (QAPP). The following sections of this report summarize the data evaluation process performed during the BRA.

Results flagged "J" (estimated) during the validation were used as reported. Results flagged "U" (not detected) were included in the database for statistical summaries. Results flagged "R" (rejected) in the validation process were excluded from the risk assessment summaries. More detailed information related to other data qualifiers used during various sampling events is provided in the Sitewide RI report (CABRERA 2011b). In addition, the information related to data verification and validation worksheets for radiological data, and ADR verification results for chemical data are provided in the Sitewide RI report. For radiochemical analyses, MARSSIM recommends that only reported sampling results be used in any statistical evaluations (USNRC 2000). In accordance with this guidance non-detect (ND) results for radiological constituents were used during the BRA. No data substitution methods were used for either radiological or non-radiological constituents in the BRA. Non-parametric statistics were utilized to include both detect and non-detect sampling results during statistical evaluations of data in this BRA.

Once data for each radiological and non-radiological constituent were determined to be useable, the data were tabulated for evaluation and were presented in all tables of Appendix B of the BRA. The following data are presented in tabular form in this BRA: frequency of detection; mean concentration; maximum and minimum concentration; distribution of data sets; 95% upper confidence limit (UCL) of the site data set; mean background concentrations; and risk-based screening concentrations.

4.0 HUMAN HEALTH RISK ASSESSMENT

The objective of the HHRA is to provide an analysis of baseline human health risks that will be used to determine the need for remedial action at the site. The risk assessment will also provide a basis for determining the concentrations of FUSRAP-eligible radiological and non-radiological constituents that can remain onsite and still be protective of human health. The technical approach for the risk assessment is consistent with guidelines established by the USEPA and the USACE for assessing risk to human health. The primary risk assessment guidance documents used in this HHRA report are listed below. Other guidance documents and scientific literature are cited as appropriate in the text.

- Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual: Part A (USEPA 1989a)
- Risk Assessment Guidance for Superfund (RAGS), Volume I, Human Health Evaluation Manual: Part B, Development of Risk-Based Preliminary Remediation Goals (PRGs) (USEPA 1991a)
- Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual: Part E, Supplemental Guidance for Dermal Risk Assessment (USEPA 2004)
- Guidance for Data Usability in Risk Assessment (Part A) (USEPA 1992a)
- Guidance for Data Usability in Risk Assessment (Part B) (USEPA 1992b)
- Soil Screening Guidance: Users Guide (USEPA 1996a)
- Supplemental Guidance for Developing Soil Screening Levels for Superfund Site (USEPA 2002b)
- Chemical Quality Assurance for HTRW Projects (USACE 1997)
- Integrated Risk Information System (IRIS) (USEPA 1998a)
- Health Effects Assessment Summary Tables and User's Guide (USEPA 1990a)
- Exposure Factors Handbook (USEPA 1997a)
- Guidance for the DQO Process for Hazardous Waste Site Investigation (USEPA 2000a)
- Soil Remediation Standards for Radioactive Materials (N.J.A.C. 7:28-12) - New Jersey Department of Environmental Protection (NJDEP 2000)

- USEPA Region 6 Medium Specific Screening Values (USEPA 2006a)
- Risk Assessment Handbook Volume 1: Human Health Evaluation (EM 200-1-4) (USACE 1999a)
- Risk Assessment Handbook Volume 2: Human Health Evaluation (EM 200-1-4) (USACE 1999b)

The HHRA methodology for both radiological and non-radiological constituents is presented in the following subsections of this report:

- Section 4.1 provides criteria that were used to evaluate and screen Site data and to determine the COPCs that were evaluated in the HHRA;
- Section 4.2 defines land use assumptions and receptors that were evaluated in the HHRA;
- Section 4.3 presents the methodology and guidance that were used to perform the toxicity assessment for both radiological and non-radiological constituents;
- Section 4.4 presents the methodology that was used to conduct the risk characterization for both radiological and non-radiological constituents as well as the results of the risk assessments; and
- Section 4.5 outlines the criteria and guidance that were used to evaluate the uncertainties associated with the HHRA.

4.1 Identification of Constituents of Potential Concern (COPCs)

The RI report provides data on the nature and extent of site constituents at each AOC. These site constituents were designated based on the operational history of each area, including the chemicals and radionuclides known or suspected to have been used at each specific area. In this section of the risk assessment report, the methodology to select COPCs is presented. COPCs differ from site constituents in that the COPCs are the constituents that have been detected at the site that have gone through an extensive screening process and then retained for quantitative analysis in the HHRA. No distinction of original source is made in selecting the COPCs. From the list of COPCs, those COPCs that are site and MED-related wastes and contribute the majority of the risk will be designated as constituents of concern (COCs) in the FS.

As a part of identifying COPCs, four different types of screens were performed to identify COPCs for the Site. The following sections summarize the screening processes.

4.1.1 Data Reduction

For radiological constituents, any daughter product with half life less than 180 days was not evaluated during this BRA. During this BRA, a six month cutoff half-life was selected in the radiological dose and risk model. The risk model assumes that these decays products (daughters) are in secular equilibrium with respect to the parent radionuclide. Therefore, their contributions are already incorporated in the dose conversion factor (DCF) and risk coefficients of the parent. Due to this,

- Ra-228 (half-life = 5.75 years) and Thorium-228 [Th-228] (half-life = 1.9 years), daughters of Thorium-232 (Th-232), were included during this BRA.
- Lead-210 [Pb-210] (half-life = 22 years), daughter product of Ra-226 was included during this BRA.
- Lead-214 [Pb-214] (half-life = 27 minutes) and Bismuth-214 [Bi-214] (half-life = 20 minutes), daughters of Ra-226 were not entered as a separate source term in the model.
- Lead-212 [Pb-212] (half-life = 11 hours), Bismuth-212 [Bi-212] (half-life = 61 minutes), and Thallium-208 [Tl-208] (half-life = 3 minutes), daughters of Th-228 were not entered as a separate source term in the model.
- Th-234 (half-life = 24 days), a surrogate of U-238, was evaluated to measure U-238. However, [mPa-234] (half-life = 1 minute) and protactinium-234 [Pa-234] (half-life = 7 hours) were not entered as a separate source term in the model.

Beryllium-7 [Be-7] (half-life = 53.3 days) and Polonium-210 [Po-210] (half-life = 138 days) were not evaluated as they are naturally occurring radionuclides. They are produced in the stratosphere as a result of cosmic ray reaction with oxygen and nitrogen atoms. Americium-241 (Am-241) and Cesium-137 (Cs-137) are manmade radionuclides (do not occur naturally) but may be detected worldwide as a result of fallout from past nuclear testing. Therefore, they were not included in the BRA. Potassium-40 (K-40) is naturally present in soil including uranium ores. However, there is no evidence that K-40 concentrations in any way relate to the concentrations of uranium and thorium found at the Site. In addition, potassium is an essential nutrient, therefore, it was not considered as a COPC for the Site.

Among chemical constituents, ubiquitous elements including calcium, magnesium, potassium, and sodium (USEPA 1989a) were screened from further consideration for the HHRA for the Site. These chemicals are considered to be human nutrients essential to a well-balanced diet, and as such are often added to foods as supplements. For this reason they typically are not considered hazardous to humans. Such chemicals are not addressed as chemicals of potential concern in the HHRA. In addition, iron is not a CERCLA hazardous substance per 40 Code of Federal Regulations (CFR) 302.4 and will not be a COPC for any EU.

4.1.2 Weight-of-Evidence Screening

The weight-of-evidence was performed for all radiological and chemical constituents that passed the data reduction screen. Under this screen, a review of the analytes with a low frequency of detection was performed. Radiological and non-radiological constituents that were detected in less than 5% of the samples from a given medium may be artifacts in the data due to sampling, analytical, or other problems, and may not be related to site activities or disposal practices (USEPA 1989a). These constituents were not included in the risk assessment.

4.1.3 Background Screening

The background screen was performed for all radiological and chemical constituents that passed the first two screens. This screen consisted of comparing the maximum detected concentration against background criteria. If the maximum detected concentration was below background criteria, the site constituent was not considered for risk screening. However, if the site constituent was present at concentrations above background criteria, that site constituent was retained for risk screening. As previously mentioned characterization of background concentrations was performed during the RI and results are presented in Section 9 of the Sitewide RI report (CABRERA 2011b) and in Appendix A of this document.

4.1.4 Risk-Based Screening

Risk-based screening was not performed for radionuclides present in soil at the Site. This is because no risk-based screening values are available from either NJDEP or USEPA Regions VI and IX for radionuclides in soil. However, risk-based screening was performed for radiological constituents that are present in the groundwater and surface water. Under the risk screen, the maximum detected concentration of the radionuclide was compared against their corresponding

USEPA maximum contaminant level (MCL). Any radionuclide that exceeded the MCL was retained as a COPC for the Site.

Chemical constituents detected above background concentrations were screened against the USEPA Region VI human health screening values. The Region VI PRGs table offers the most up-to-date human health screening values. Therefore, the Region VI PRG table (USEPA 2006) was selected for performing risk based screening for chemicals.

The following scenarios were evaluated for the Site using the Region VI PRGs. For carcinogenic chemicals, the maximum detected concentration for any constituent was compared against its corresponding PRG value. For non-carcinogenic chemicals, the maximum detected concentration of any constituent was compared with respect to 1/10 of its corresponding Region VI PRG value for screening purposes (USEPA 1993d). If the maximum detected concentration for any constituent did not exceed its corresponding PRG, then that constituent was not included in the risk assessment.

The maximum detected sampling results for both soil and sediment were compared against soil risk based screening values presented under the most conservative residential land use scenario, even though the Site is zoned as industrial. For both groundwater and surface water, the maximum detected concentration for any constituent was compared against the Region VI screening value for tap water, even though the Site is zoned as industrial.

Tables B-1-1, B-2-1, B-3-1, B-4-1, and B-5-1 of Appendix B present the screening process and identify the radiological COPCs for surface soil, soil at all depths, ground water, surface water, and sediment, respectively. Tables B-1-2, B-2-2, B-3-2, B-4-2, and B-5-2 of Appendix B present the screening process and identify the metal COPCs for surface soil, soil at all depth, ground water, surface water, and sediment, respectively. Tables B-1-3, B-2-3, B-3-3, B-4-3, and B-5-3 of Appendix B present the screening process and identify the VOC COPCs for surface soil, soil at all depth, ground water, surface water, and sediment, respectively. Tables B-1-4, B-2-4, B-3-4, B-4-4, B-5-4 of Appendix B present the screening process and identify the SVOC COPCs for surface soil, soil at all depth, ground water, surface water, and sediment, respectively. Tables B-1-5, B-2-5, and B-5-5 of Appendix B present the screening process and identify the PAH COPCs

for surface soil, soil at all depth and sediment, respectively. Tables B-1-6, B-2-6, B-3-6, and B-5-6 of Appendix B present the screening process and identify the PCBs COPCs for surface soil, soil at all depth, ground water, and sediment, respectively. Tables B-2-7, B-3-7, and B-5-7 of Appendix B present the screening process and identify the PEST COPCs for soil at all depth, ground water, and sediment, respectively.

No radiological COPCs were identified for soil in EU 2B (Appendix B, Tables B-1-1 and B-2-1). In addition, there are ongoing industrial operations conducted and controlled by DuPont at this location. For these reasons no chemical (non-radiological) soil samples were collected at EU 2B and no risk assessment performed. Table 4-1 summarizes the EU-specific COPC list for each environmental medium for the remaining four EUs (EU 1, EU 2A, EU 3A, and EU 3B).

Table 4-1: Summary of COPCS for Each Medium

Name of COPCs	EU 1	EU 2A	EU 3A	EU 3B
RADIOLOGICAL COPCS				
Ra-226	ADS, GW	SS, ADS, SW	SS, ADS	SS, ADS
Ra-228	GW	SS, ADS	SS, ADS	--
Th-228	SS, ADS	SS, ADS, SD	SS, ADS	--
Th-230	SS, ADS	SS, ADS, SW, SD	SS, ADS	SS, ADS
Th-232		SS, ADS, SW	SS, ADS	SW
U-234	SS, ADS, GW	SS, ADS, GW, SW, SD	SS, ADS	SS, ADS, GW, SW, SD
U-235	SS, ADS, GW	SS, ADS, GW, SW, SD	SS, ADS	SS, ADS, GW, SW, SD
U-238	SS, ADS, GW	SS, ADS, GW, SW, SD	SS, ADS	SS, ADS, GW, SW, SD
CHEMICAL COPCs				
ALUMINUM	GW	GW	--	--
ANTIMONY	SS, ADS	SS, ADS, GW, SW, SD	SS, ADS	SS, ADS, SD
ARSENIC	SS, ADS	SS, ADS, GW, SW, SD	SS, ADS	ADS, SD
BARIUM	--	SS, ADS, GW	--	--
BERYLLIUM	--	SD	--	--
CADMIUM	SS, ADS	SD		ADS, SD
CHROMIUM	SS, ADS, GW	SS, ADS	SS, ADS	ADS
COPPER	SS, ADS	SS, ADS		ADS
LEAD	SS, ADS, GW	SS, ADS, GW, SD	SS, ADS	GW
MANGANESE	GW	GW		ADS
MERCURY	SS, ADS	SS, ADS	SS, ADS	SS, ADS, SD
NICKEL	GW	GW	SS, ADS	
SELENIUM	--	SD	--	SD
SILVER	--	SD	--	SD

Table 4-1: Summary of COPCs for Each Medium (Cont'd)

Name of COPCs	EU 1	EU 2A	EU 3A	EU 3B
CHEMICAL COPCs				
VANADIUM	SS, ADS, GW	SS, ADS, SD	SS, ADS	
ZINC	--	--	--	ADS, SD
1,2-DICHLOROBENZENE	ADS, GW	GW, SW, SD	ADS, GW	ADS, GW
1,2-DICHLOROETHANE	GW	GW, SW	--	--
1,3-DICHLOROBENZENE	GW	GW	ADS, GW	GW
1,4-DICHLOROBENZENE	ADS, GW	GW, SW, SD	ADS, GW	GW
1,2,3-TRICHLOROBENZENE		SS, ADS	SS, ADS	SS, ADS, GW
1,2,4-TRICHLOROBENZENE	ADS, GW	GW	SS, ADS	GW
1,2,4-TRIMETHYLBENZENE	GW	GW, SW	ADS	SS, ADS
1,3,5-TRIMETHYLBENZENE	GW	GW	SS, ADS	ADS
1-METHYLNAPHTHALENE	SS, ADS	SS, ADS	SS, ADS	SS, ADS
2-BUTANONE	--			SW
2-CHLOROPHENOL	--	GW	GW	GW
2-CHLORONAPHTHALENE	--		SS, ADS	
2-METHYLNAPHTHALENE	SS, ADS, GW	SS, ADS, GW, SD	SS, ADS	SS, ADS, GW
3,3'-DICHLOROBENZIDINE	--	--	GW	--
3,4-METHYLPHENOL	--	GW	--	--
3-NITROANILINE	--	SD	--	--
4-CHLOROANILINE	--	GW	ADS, GW	GW
4-CHLOROTOLUENE	--	--	--	SS, ADS
ACENAPHTHENE	GW	--	--	SS, ADS
ACENAPHTHYLENE	SS, ADS	SS, ADS, GW, SD	ADS	ADS
ANILINE	--	GW	GW	--
ANTHRACENE	--	--	--	ADS
AZOBENZENE	--	--	--	ADS
BENZENE	ADS, GW	ADS, GW, SW, SD	ADS, GW	SW
BENZOIC ACID	--	SW	--	--
BENZO(A)ANTHRACENE	SS, ADS	SS, ADS, SD	SS, ADS	SS, ADS, SD
BENZO(A)PYRENE	SS, ADS	SS, ADS, SD	SS, ADS	SS, ADS, SD
BENZO(B)FLUORANTHENE	SS, ADS	SS, ADS, SD	SS, ADS	SS, ADS, SW
BENZO(G,H,I)PERYLENE	SS, ADS	SS, ADS, SD	SS, ADS	SS, ADS, SD
BENZO(K)FLUORANTHENE	ADS	SW	ADS	SS, ADS, SW
BROMODICHLOROMETHANE	--	SW	--	--
CARBON DISULFIDE	GW	--	--	--
CARBON TETRACHLORIDE	--	GW, SW, SD	--	GW, SW
CARBAZOLE	ADS	--	--	ADS

Table 4-1: Summary of COPCs for Each Medium (Cont'd)

Name of COPCs	EU 1	EU 2A	EU 3A	EU 3B
CHEMICAL COPCs				
CHLOROBENZENE	--	GW, SW	ADS, GW	GW
CHLOROETHANE	GW	GW	--	--
CHLOROFORM	GW	GW, SW, SD	--	SW
CHRYSENE	SS, ADS	--	ADS	SS, ADS
CIS-1,2-DICHLOROETHENE	GW	GW	--	--
DIBENZO(A,H)ANTHRACENE	SS, ADS	SS, ADS, SD	SS, ADS	SS, ADS, SD
DIBENZOFURAN	ADS, GW	GW	--	ADS, GW
DIBROMOCHLOROMETHANE	--	SW	--	--
DI-N-OCTYL PHTHALATE	--	SS, ADS	ADS	--
ETHYLBENZENE	GW	GW	--	--
FLUORANTHENE	--	--	--	SS, ADS
FLUORENE	ADS, GW	--	--	SS, ADS
HEXACHLOROBENZENE	--	ADS	ADS	--
INDENO(1,2,3-CD)PYRENE	SS, ADS	SS, ADS, SD	SS, ADS	SS, ADS, SD
ISOPROPYLBENZENE	GW	--	--	--
M+P-XYLENE	GW	--	GW	--
METHYLENE CHLORIDE	GW	GW		--
NAPHTHALENE	ADS, GW	GW, SW	ADS, GW	SS, ADS, GW, SW
N-BUTYLBENZENE	GW	GW	--	--
N-PROPYLBENZENE	GW	GW	--	--
NITROBENZENE	--	--	ADS	GW
PHENANTHRENE	SS, ADS, GW	SS, ADS, GW, SD	SS, ADS	SS, GW, SD
P-ISOPROPYLTOLUENE	ADS, GW	SS,ADS	SS, ADS	SS, ADS
PYRENE	--	--	--	SS, ADS
SEC-BUTYLBENZENE	GW	--	--	--
STYRENE	GW	--	--	--
TETRACHLOROETHENE	--	GW, SW	ADS	--
TOLUENE	GW	GW	ADS	--
TRICHLOROETHENE	--	GW, SW	--	--
TRICHLOROFLUOROMETHANE	GW	GW	--	--
VINYL CHLORIDE	GW	GW, SW	--	--
AROCLOR-1254	SS, ADS	--	--	--
AROCLOR-1260	SS, ADS	SS, ADS, SD	ADS	SD
AROCLOR-1268	ADS	--	ADS	--

SS = Surface soil; ADS = All depth soil; GW = Groundwater; SW = Surface water; SD = Sediment

4.2 Exposure Assessment

This section describes the receptors and exposure pathways that were evaluated in the risk assessment. The objectives of the exposure assessment were to estimate the magnitude, frequency, duration and routes of potential human exposures to COPCs at the Site. Potential receptor groups are identified in the exposure assessment and estimates of exposure or chemical intake are calculated based on assumptions regarding exposure pathways and exposure parameters.

The end product of the exposure assessment is a measure of chemical intake as an average daily dose (ADD) that integrates the exposure parameters for the receptors of concern (e.g., contact rates, exposure frequency, and duration) with exposure point concentrations for the media of concern. These ADDs are then used in conjunction with chemical-specific toxicity values (e.g., reference doses and cancer slope factors) to arrive at an estimate of potential health risks.

The exposure assessment was performed in two steps. Each of the steps is summarized in the following sections.

4.2.1 Development of Conceptual Site Model (CSM) for Each EU

The first step of the exposure assessment was to identify potentially complete pathways between sources and receptors by:

1) identifying a source of the constituents;
2) identifying media through which constituents may come in contact with the receptors, including soils, groundwater, sediment and surface water, and air;
3) identifying the routes of exposure or pathways through which the receptors may be exposed (i.e. external gamma radiation, ingestion, dermal contact, and inhalation); and
4) identifying current and future potential receptors.

The relationship among the above factors is presented in the CSM. The CSM provides an illustration of the site EUs, exposure pathways, potential receptors and routes of exposure that could lead to a human health dose and risk to potential receptors. The following sections of the reports provide a detail discussion of CSM developed for each EU.

Receptors Scenarios

The exposure assessment evaluates the risk to all receptor populations that are reasonably anticipated to be exposed to COPCs at each EU of the site. Only the reasonably maximally exposed (RME) scenario was evaluated in the HHRA. The exposure assessment evaluated the RME risk to all receptor populations to COPCs on the Site. Under the current land use scenario, the RME receptors include an adult industrial worker, an adult construction worker, a maintenance worker, and a utility worker. These receptors may come in contact with contaminated media while working at the Site. Physical barriers and access restrictions currently exist at the Site.

Only one RME receptor scenario was evaluated under a future land use scenario. The exposure was evaluated for an industrial worker receptor, assuming that the Site is maintained as an industrial property. The land use assumption is based on the fact that DuPont has used the site for industrial purposes for more than 100 years, and is expected to continue industrial operations well into the future. In addition, the BRA was also performed for a residential receptor. However, the results for a residential receptor were used only for comparison purposes. Tables C-1 and C-2 of Appendix C present the assigned values for the exposure parameters for each receptor scenario.

Exposure Scenarios

An exposure pathway is the physical course a contaminant takes from the source to the exposed receptor. The sources evaluated in this assessment include soil, groundwater, surface water, and sediments. Soil data is segregated into 1) surface soil and 2) surface plus subsurface soil for the purposes of risk characterization in relation to the exposure scenarios considered. It is assumed that only the industrial worker is exposed to surface soil, whereas the other four receptors may be exposed to both surface soil and subsurface soil. For the other four receptors, the soil data for both surface and subsurface samples were pooled into one population, named as “all depth soil”. Industrial workers are typically only exposed to surface soil (zero to six inches.).

For radiological constituents, external gamma is an important pathway of exposure and therefore, it was quantified in this evaluation. This pathway is not applicable for chemical constituents.

Humans routinely ingest small amounts of soil or soil-like materials each day primarily as a result of hand-to-mouth activity. As a rule, young children ingest greater quantities of such material than do older children and adults. Soil ingestion is frequently an important pathway of exposure and therefore, was quantified in this evaluation.

Dermal contact is also a likely route of exposure to chemicals in environmental media. Dermal contact with soils could result in the absorption of chemicals through the skin; therefore, dermal absorption of chemicals was evaluated in this HHRA.

Inhalation exposure may result from inhaling chemicals which have volatilized, as well as radiological contaminated soil particles. VOCs are generally those having reported Henry's Law constants greater than 1.0E-05 atmosphere per cubic meter/mole (atm-m^3/mol) and molecular weights less than 200 grams per mole (g/mol). Organic chemical constituents can also exist in air as associated with respirable size particulate matter. These particles can be emitted into the air either by wind erosion or as a result of mechanical disturbance. The inhalation of chemicals in soils was evaluated in this HHRA.

Groundwater is another media evaluated in this HHRA. Currently, there are no receptors utilizing the groundwater beneath the Site as their potable water source. It is also not likely that future receptors will be utilizing such water. However, as a means of providing information to risk managers, the groundwater ingestion pathway was evaluated for future adult and child residents. Groundwater samples were collected from both temporary and permanent monitoring wells. For this HHRA, groundwater samples collected from Aquifer B were evaluated for the determination of radiological and chemical intake and risk.

Surface water and sediment samples were collected from the CDD and in the ditch area located in EU 3B. The ditch at EU 3B may fill with water after storm events but remains dry for most of the year. Therefore, surface water and sediments were evaluated for EU 2A and EU 3B.

The process for identifying exposure pathways is similar for radionuclides and non-radionuclides except for the following three significant differences:

1) ***Radon pathway is suppressed during radiological HHRA:*** Radon is a radioactive noble gas that tends to accumulate in enclosed structures. In a Federal Register Notice (USNRC 1994), issued as a result of comments received from a radon workshop, the Nuclear Regulatory Commission (NRC) noted that "radon would not be evaluated when developing release criteria due to: the ubiquitous nature of radon in the general environment, the large uncertainties in the models used to predict radon concentrations; and the inability to distinguish between naturally occurring radon and that which occurs due to licensed activities." It is notable that radon limits are based on concentration and not risk or dose. This difference is due partly to the fact that background radon concentrations are highly variable and can produce risk estimates well above exposure-based limits.
2) ***Dermal pathway is not evaluated for radiological COPCs:*** Radiological constituents are typically metals and do not easily pass through the skin.
3) ***External exposure to radionuclides that emit gamma radiation or x-rays is evaluated:*** This external exposure pathway accounts for radionuclides that may produce a risk without any physical contact.

The receptor scenarios along with their corresponding exposure pathways are summarized in the following.

Industrial Worker: Under this scenario, the industrial worker may be exposed to the residual radioactive contamination that may be present in surface soil but is not expected to have regular contact with subsurface soil. The industrial worker is modeled as a typical site worker who spends most of the time indoors. The industrial worker is at the site for 250 days per year for 25 years (USEPA 1991a). During a typical working day, the worker is assumed to spend seven hours indoors and one hour outdoors and will ingest 50 milligram (mg) of soil (USEPA 1991b). The inhalation rate for the receptor is 20 cubic meter (m^3) per day (USEPA 1991a). Since workers are assumed to be adults, a body weight of 70 kilograms (kg) was used to assess exposure to chemical constituents.

Exposure pathways evaluated for the industrial worker scenario include:

- External gamma radiation from radionuclides in the surface soil;
- Incidental ingestion of surface soil;

- Inhalation of airborne contaminated dust or volatile emissions from surface soil; and
- Dermal exposure from chemicals in the surface soil.

Construction Worker: Since it is reasonable to assume that construction activities could occur at the Site, adult construction workers were identified as potential receptors. During construction activities these receptors could be exposed to residual contamination present in soil, surface water, and sediment. Construction workers were assumed to be on the job eight hours per day, 250 days per year over a one year period. During a typical working day, the construction worker is assumed to spend eight hours outdoors and will ingest 330 mg of soil (USEPA 2002f and 2002g). The inhalation rate for the receptor is 20 m^3 per day (USEPA 1991a). Since construction workers are assumed to be adults, a body weight of 70 kg was used to assess exposure to chemical constituents.

Exposure pathways evaluated for the construction worker scenario include:

- external gamma radiation from radionuclides in the soil;
- incidental ingestion of soil;
- inhalation of airborne contaminated dust or volatile emissions from soil;
- dermal exposure to chemicals in the soil; and
- inhalation of volatiles from groundwater.

Utility Worker: The utility worker may participate in utility work or other intrusive outdoor activities at the Site. It is assumed that the utility worker is exposed in a single event that takes place over an 80 hour period. Like the construction worker, the utility worker will ingest 330 mg of soil per day (USEPA 2002f and 2002g) and inhales 20 m^3 of air per day (USEPA 1991a). The utility worker is assumed to spend one hour per day and five days per year near the surface water bodies present at the Site. The worker is assumed to ingest 0.05 L/day (liter per day) of surface water (USEPA 1997a) while splashing during work in EUs where the worker is exposed to the surface water pathway (incidental ingestion). The worker is also assumed to ingest 33 mg of sediment (10% of soil ingestion rate) while being exposed to the contaminated sediment exposure pathway.

Exposure pathways evaluated for the utility worker scenario include the following:

- external gamma radiation from radionuclides in the soil;
- incidental ingestion of soil;
- inhalation of airborne contaminated dust or volatile emissions from soil;
- inhalation of volatiles from groundwater;
- dermal exposure to chemicals in soil;
- incidental ingestion of surface water (for EU 2A and EU 3B);
- dermal exposure to surface water(for EU 2A and EU 3B);
- incidental ingestion of sediment (for EU 2A and EU 3B); and
- dermal exposure to sediment (for EU 2A and EU 3B).

Maintenance Worker: This receptor is responsible for caretaker activities such as mowing the grass, clearing brush, and general site maintenance. It is assumed that the activities would require an average of one day every other week. It is likely that activity would be greater in the summer and less in the winter, but the yearly average is 26 times a year. The exposure duration for the maintenance worker is assumed to be 25 years, the same as that for industrial worker. The maintenance worker is assumed to spend four hours per day indoors and four hours per day outdoors. The adult maintenance worker is assumed to ingest 100 mg of soil and inhales 20 m^3 of air per day (USEPA 1991a).

Exposure pathways evaluated for the maintenance worker scenario include:

- external gamma radiation from radionuclides in the soil;
- incidental ingestion of soil;
- inhalation of airborne contaminated dust or volatile emissions from soil; and
- dermal exposure to chemicals in soil.

Residential Receptor: The onsite residential receptor is modeled as a potential future receptor in the event that the current land use for the area changes to residential. The residential receptor is assumed to live onsite for 350 days per year for 30 years (USEPA 2000b). The resident is assumed to spend 16.4 hours indoors and two hours outdoors at the site each day over the entire exposure area (USEPA 1997a).

Because child and adult ingestion rates, body weights, and exposure durations vary, exposure via ingestion of soil is based on a weighted average of the respective child and adult parameters. The assumptions used in calculating this weighted average are:

- The child weighs 15 kg and ingests 200 mg of soil or sediment per day, over six years.
- The adult weighs 70 kg and ingests 100 mg of soil or sediment per day, over 24 years.

This calculation results in a weighted average soil ingestion of 120 mg per day.

Based on the Exposure Factors Handbook, the inhalation rates for adult male and a child, one to five years old, are 15.2 and 7.55 m^3/day, respectively (USEPA 1997a). So, the time-weighted average for the residential receptor is calculated to be 13.7 m^3/day. In addition, the residential receptor uses groundwater as drinking water and is assumed to ingest two liters of water per day (USEPA 1997a).

NUREG/CR 5512 Volume 4 assigns 21.4 kilograms per year (kg/year (yr)) for leafy vegetable consumption rate for adult (NRC 1999). However, no value was assigned for the child. By using the child-to-adult body weight factor, the leafy vegetable consumption rate for child was calculated to be 4.59 kg/yr. So, the time-weighted average value of this exposure parameter for residential receptor is calculated to be 18 kg/yr.

Based on the Exposure Factor Handbook, by subtracting the leafy vegetable rate from total fruit and vegetable ingestion rate, the fruit, vegetable and grain consumption rate for adult male and child are calculated to be 551 and 118 kg/yr, respectively (USEPA 1997a). So, the time-weighted average fruit, vegetable and grain consumption rate for the residential receptor is calculated to be 464 kg/yr.

The onsite resident is assumed to spend one day every other week near the surface water bodies present at the site. The resident is assumed to ingest 0.05 L/day of water (USEPA 1997a) while being exposed to surface water pathway (incidental ingestion). The

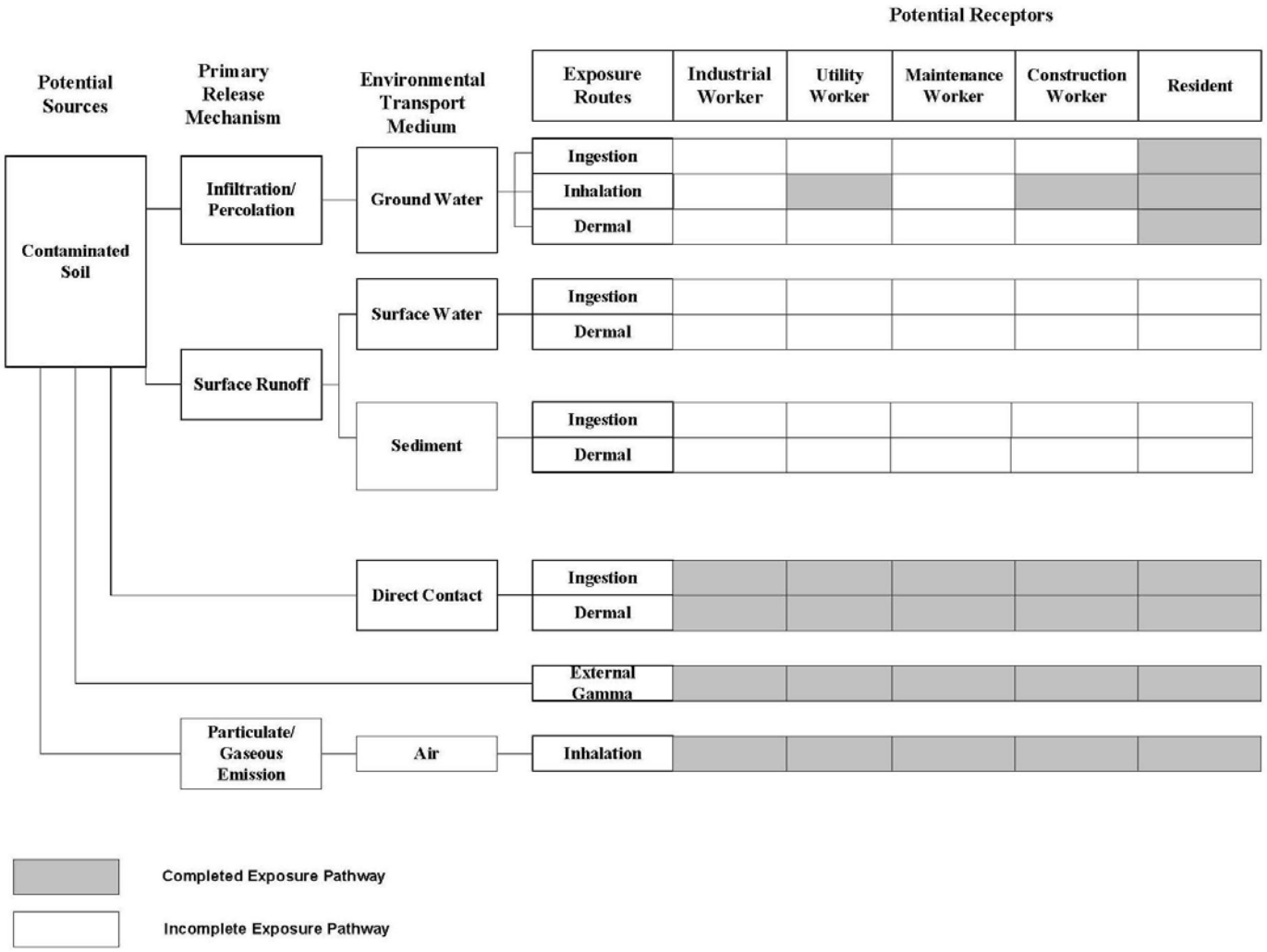
resident is also assumed to ingest 12 mg of sediment (10% of soil ingestion rate) while being exposed to contaminated sediment exposure pathway.

Exposure pathways evaluated for the residential scenario include the following:

- external gamma radiation from radionuclides in the soil;
- incidental ingestion of soil;
- inhalation of airborne contaminated dust or volatile emissions from soil;
- dermal exposure to soil;
- ingestion of foods from crops grown in the contaminated soil;
- incidental ingestion of surface water (for EU 2A and EU 3B);
- dermal exposure to surface water(for EU 2A and EU 3B);
- incidental ingestion of sediment (for EU 2A and EU 3B);
- dermal exposure to sediment (for EU 2A and EU 3B);
- ingestion of groundwater;
- inhalation of volatiles present in groundwater; and
- dermal exposure to groundwater..

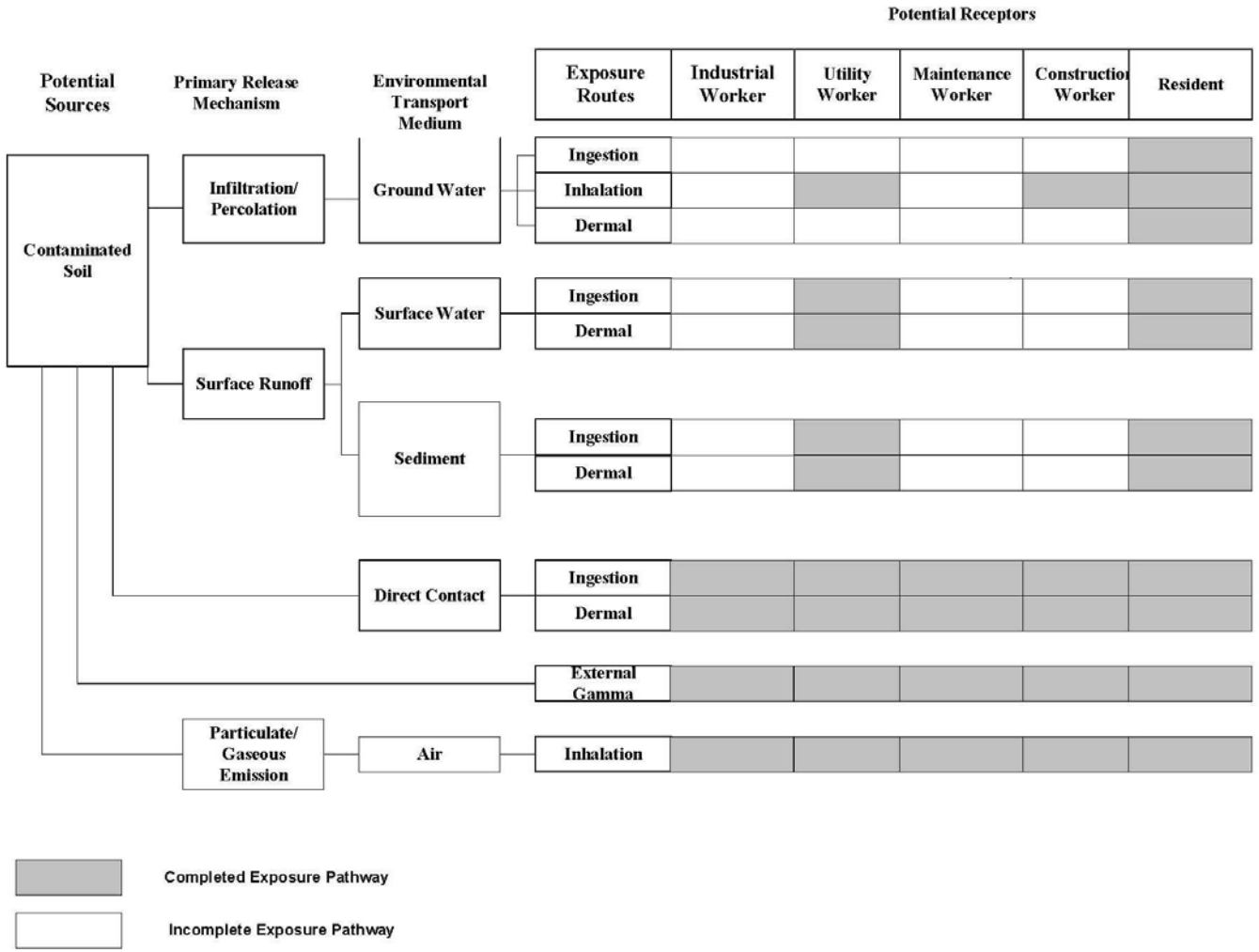
Appendix C-1 presents the assigned values for exposure parameters related to each receptor scenario. Those values were used during radiological dose and risk assessments. The same values were assigned (in different units) for non-radiological intake and risk assessment. Appendix C-2 presents those assigned values for exposure parameters to each receptor scenario in the chemical risk assessment. Figures 4-1 through 4-5 present the CSM for each EU. The models present the migration and exposure pathways for receptors at each EU.

Figure 4-1: Conceptual Site Model for Exposure Unit 1



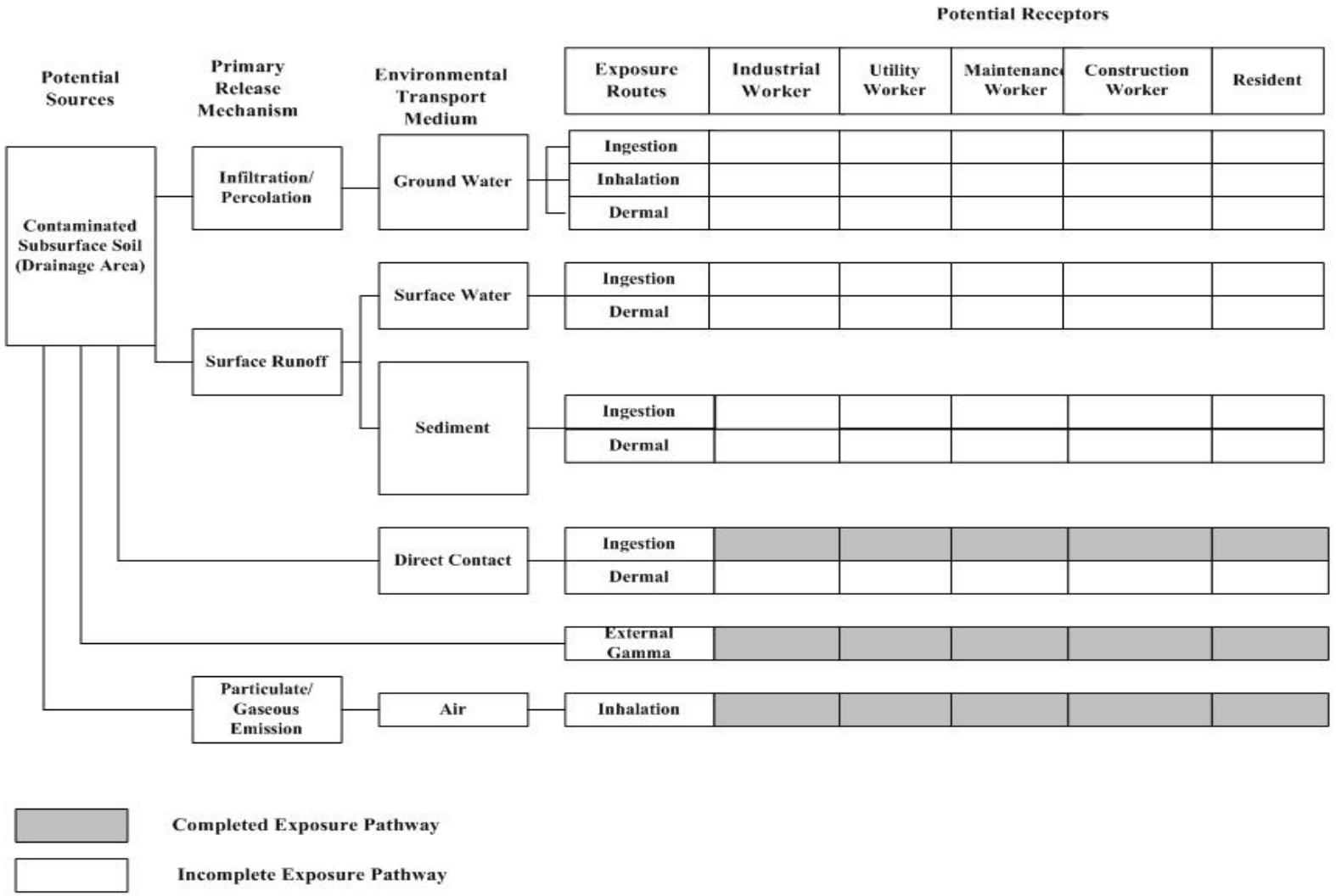
* All receptors except the industrial worker are exposed to both surface and subsurface soil; the industrial worker receptor is exposed to only surface soil.

Figure 4-2: Conceptual Site Model for Exposure Unit 2A



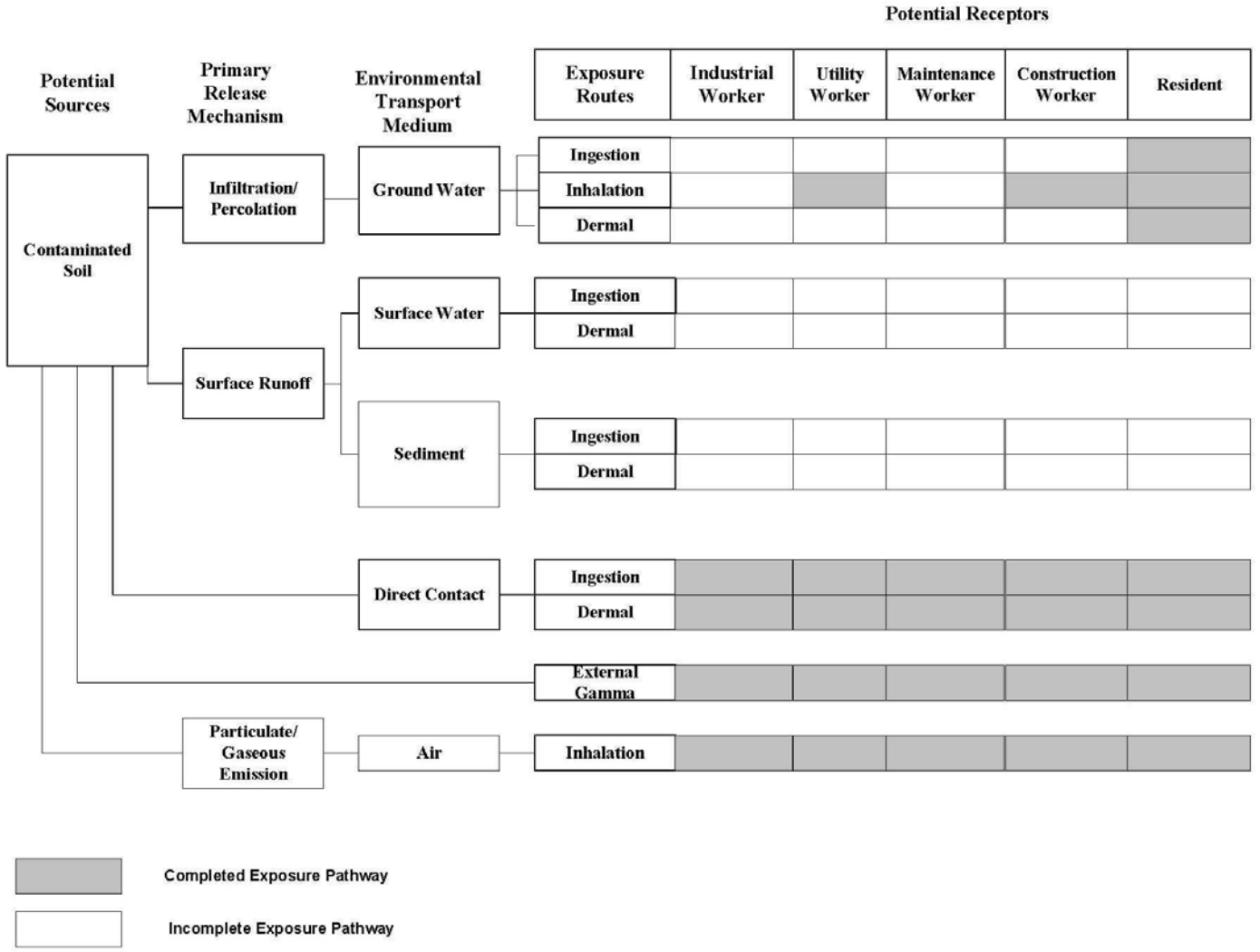
* All receptors except the industrial worker are exposed to both surface and subsurface soil; the industrial worker receptor is exposed to only surface soil.

Figure 4-3: Conceptual Site Model for Exposure Unit 2B



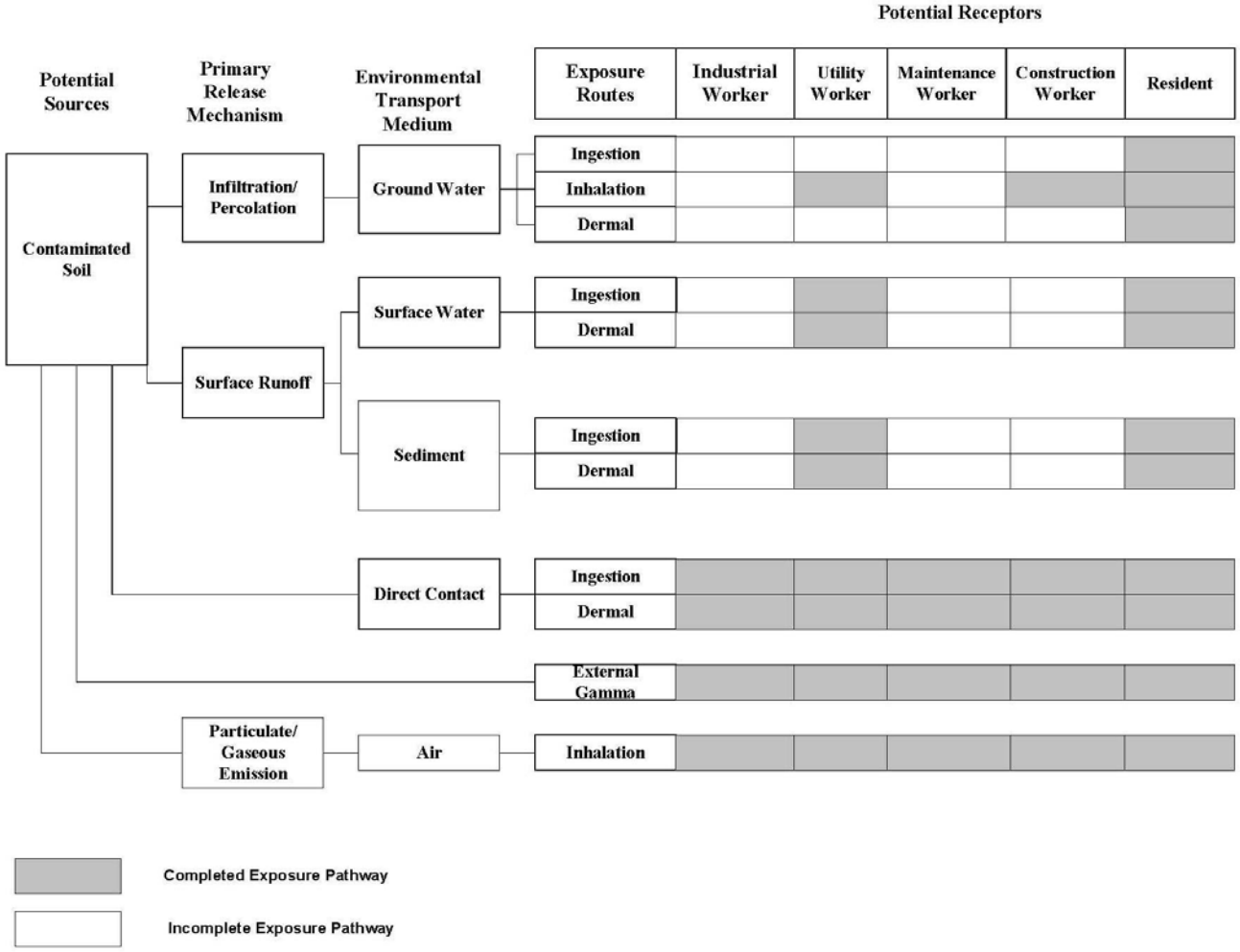
* All receptors except the industrial worker are exposed to both surface and subsurface soil; the industrial worker receptor is exposed to only surface soil.

Figure 4-4: Conceptual Site Model for Exposure Unit 3A



* All receptors except the industrial worker are exposed to both surface and subsurface soil; the industrial worker receptor is exposed to only surface soil.

Figure 4-5: Conceptual Site Model for Exposure Unit 3B



* All receptors except the industrial worker are exposed to both surface and subsurface soil; the industrial worker receptor is exposed to only surface soil.

4.2.2 Quantification of Exposure Concentration and Pathway Specific Intakes

To calculate a cancer risk or a non-cancer hazard, an exposure point concentration (EPC) or an estimate must be made of the chemical concentration in the environmental medium to which an individual may be exposed. In order to quantify exposure to each receptor, an EPC, or the estimate of the constituent concentration a receptor is likely to come in contact with over the duration of exposure, was calculated. The EPC was used to estimate the intake of each COPC by individual receptors via all pathways and media identified in the CSM. Intake is a measure of exposure expressed as the amount of a chemical that has come in contact (e.g., ingestion, inhalation, or dermal contact) with a receptor per kilogram body weight per unit of time (milligram/kilogram-day [mg/kg-d]).

EPCs were calculated on an EU-specific basis. For the conservative approach of evaluating the RME scenario, EPCs for soil were determined by calculating the 95% UCL of the mean following the procedures presented in USEPA's 2002 guidance document, *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites (OSWER 9285.6-10*) (USEPA, 2002a) . The intent of the RME scenario is to focus the assessment on a conservative exposure that is the maximum exposure that is reasonably expected to occur (USEPA 1989a). Because of the multiple conservative assumptions used in the risk assessment process, the RME is often a high-end estimate of exposure and risk.

USEPA issued the ProUCL program to assist in the determination of UCLs following the methodology described in their 2002 guidance. ProUCL program version 4.0 was utilized during the determination of appropriate UCL. When the percentage of non-detected samples in a data set is high, especially when multiple detection limits might be present, it is very difficult to reliably determine the distribution of the data set. In such situations, it is preferable to use a non-parametric method to determine the 95% UCL. Instead of substituting non-detected sample results, ProUCL (version 4.0) utilizes non-parametric statistics (Kaplan-Meier Method) to determine 95% UCL. The 95% UCL was used as the EPC, except in cases where the maximum detected value was less than the EPC. In these cases, the maximum detected value was used as the EPC, not the 95% UCL. However, an adjusted EPC was calculated for each radiological COPC during the radiological dose assessment. An adjusted EPC for a radiological COPC was

calculated by subtracting the average background concentration from the lower of its maximum detected concentration and the 95% UCL concentration.

All tables within Appendix B present the EPC for each medium-specific COPC. Uranium was evaluated for both radiological and chemical risk assessment due to its radioactive and chemical properties. As a result, for the chemical risk evaluation, it was necessary to convert the isotopic activity concentrations to a total mass concentration of uranium, represented in mg/kg. This value was calculated by summing the quotients of isotopic radioactivity divided by the specific activity constant for each respective uranium isotope, as follows:

$$U_{Total} = \left(\frac{^{234}U}{6{,}250\, pCi/\mu g} \right) + \left(\frac{^{235}U}{2.16\, pCi/\mu g} \right) + \left(\frac{^{238}U}{0.336\, pCi/\mu g} \right)$$

where:

U_{total} = Total mass concentration of uranium (mg/kg)
^{234}U, ^{235}U, and ^{238}U = Isotopic radioactivity concentration (picoCurie/gram [pCi/g])

For both surface water and groundwater, the total mass concentration of uranium was calculated by using the following formula:

U_{total} (microgram per liter [µg/L]) = U_{total} (picoCurie per liter [pCi/L]) / 0.677;

where: 0.677 (microgram per picoCurie[µg/pCi]) is the specific activity for Total Uranium where the three isotopes are present in a natural abundance.

Table 4-2 provides the EPCs for all radiological COPCs present at each EU.

Table 4-2: Results of EPCs for Radiological COPCs

EU	COPC	FOD[1]	Concentration[2]			Dist[3]	UCL_{95}[4]	EPC[5]
			Mean	Max	Min			
Surface Soil (Unit for concentration is pCi/g)								
1	Th-228	16/16	0.66	2.61	0.18	X	1.345	1.345
	Th-230	16/16	4.44	32.3	0.28	X	25.53	25.53
	U-234 mod[6]	48/53	26.29	347.2	0.77	L	71.87	71.87
				0.44	0.07			
	U-235	34/53	1.53	21.45	0.04	X	3.63	3.63
				0.23	-0.11			
	U-238 mod[7]	48/53	26.46	340.8	0.72	X	74.8	74.8
				0.44	0.07			
2A	Ra-228	4/9	0.72	1.09	0.5	N	0.74	0.74
				0.78	0.04			
	Th-228	22/22	1.17	3.42	0.05	G	1.72	1.725
	Th-230	22/22	0.62	1.37	0.12	N	0.74	0.74
	Th-232	22/22	0.59	1.13	0.04	N	0.72	0.72
	U-234 mod[6]	14/15	3.77	14.8	0.12	X	7.47	7.47
				0.1	0.10			
	U-235	8/15	0.20	1.02	0.03	X	0.38	0.38
				0.21	-0.33			
	U-238 mod[7]	14/15	4.05	14.8	0.10	X	7.59	7.59
				0.1	0.1			
3A	Th-230	11/11	0.51	1.33	0.20	G	0.691	0.69
	U-234 mod[6]	10/11	1.32	2.78	0.57	L	1.68	1.68
				1.3	1.3			
	U-235	9/11	0.10	0.213	0.06	G	0.124	0.12
				0.15	0.04			
	U-238 mod[7]	10/11	1.30	2.84	0.52	G	1.67	1.67
				1.3	1.3			
3B	Ra-226	10/11	1.49	9.8	0.54	X	5.115	5.115
				0.42	0.42			
	Th-230	10/10	7.44	69	0.3	X	75.5	69
	U-234 mod[6]	11/11	173.17	1770	0.76	L	487.1	487.1
	U-235	11/11	10.36	105	0.06	L	29.02	29.02
	U-238 mod[7]	11/11	179.21	1830	0.79	L	510	510

Table 4-2: Results of EPC for Radiological COPCS (Cont'd)

EU	COPC	FOD[1]	Concentration[2]			Dist[3]	UCL_{95}[4]	EPC[5]
			Mean	Max	Min			
All Depth Soil (Unit for concentration is pCi/g)								
1	Ra-226	36/39	1.06	2.87	0.37	X	1.54	1.54
				0.44	0.34			
	Th-228	41/41	1.37	5.8	0.18	X	2.33	2.33
	Th-230	41/41	3.87	64	0.19	X	21.14	21.14
	U-234 mod[6]	148/232	187	9640	0.62	X	605.3	605.3
				2.8	-2.2			
	U-235	71/229	10.51	508.6	0.04	X	32.67	32.67
				2.39	-0.23			
	U-238 mod[7]	148/232	182.2	10480	0.62	X	627.6	627.6
				2.8	-2.2			
2A	Ra-226	69/72	0.83	3.83	0.29	G	0.9	0.9
				0.37	0.3			
	Ra-228	11/18	0.64	1.41	0.49	G	0.81	0.81
				0.78	0.04			
	Th-228	45/45	1.21	4.31	0.05	G	1.53	1.53
	Th-230	45/45	1.24	11.1	0.12	X	2.21	2.21
	Th-232	45/45	0.62	1.45	0.04	G	0.74	0.74
	U-234 mod[6]	29/76	4.53	19.8	0.12	X	5.62	5.62
				2.9	-1.40			
	U-235	18/76	0.96	1.51	0.03	X	0.49	0.49
				0.32	-0.33			
	U-238 mod[7]	29/76	10.9	19.8	0.10	X	5.64	5.64
				2.9	-1.4			
3A	Ra-226	45/50	1.00	4.42	0.31	X	1.54	1.54
				0.43	0.16			
	Ra-228	8/20	0.64	2.66	0.61	G	0.87	0.87
				0.69	0.04			
	Th-228	30/30	0.66	2.31	0.13	G	0.805	0.81
	Th-230	30/30	2.13	26.4	0.09	X	12.12	12.12
	Th-232	30/30	0.63	2.19	0.13	L	0.806	0.806
	U-234 mod[6]	28/50	6.95	174	0.16	X	22.63	22.63
				3.7	-0.25			
	U-235	21/50	5.99	10.9	0.05	X	0.88	0.88
				0.68	-0.27			
	U-238 mod[7]	28/50	8.2	174	0.22	X	22.63	22.63
				3.7	-0.25			

Table 4-2: Results of EPC for Radiological COPCS (Cont'd)

EU	COPC	FOD[1]	Concentration[2]			Dist[3]	UCL_{95}[4]	EPC[5]
			Mean	Max	Min			
All Depth Soil (Unit for concentration is pCi/g)								
3B	Ra-226	86/91	1.18	14.3	0.37	X	1.96	1.96
				0.46	0.26			
	Th-230	28/28	2.99	69	0.172	X	27.32	27.32
	U-234 mod[6]	46/90	64.91	1910	0.55	X	193.9	193.9
				1.9	-1.2			
	U-235	39/91	3.91	121	0.04	X	11.76	11.76
				0.44	-0.42			
	U-238 mod[7]	46/90	67.28	1910	0.51	X	250.7	250.7
				1.9	-1.2			
Sediment (Unit for concentration is pCi/g)								
2A	Th-228	20/20	1.09	3.42	0.05	G	1.68	1.68
	Th-230	20/20	0.57	1.37	0.12	N	0.7	0.7
	U-234 mod[6]	15/18	4.15	30.4	3.5	L	9.285	9.285
				6	-3.2			
	U-235	8/17	0.16	1.02	0.03	X	0.5	0.5
				0.41	0.009			
	U-238 mod[7]	15/18	4.14	30.4	3.5	X	9.16	9.16
				6	-3.2			
3B	U-234 mod[6]	11/13	1.65	8.8	0.21	G	3.77	3.77
				0.12	0.01			
	U-235	7/13	0.09	0.71	0.03	X	0.629	0.629
				0.54	-0.07			
	U-238 mod[7]	11/13	1.67	9	0.15	X	5.04	5.04
				0.12	0.01			
Groundwater (Unit for concentration is pCi/L)								
1	Ra-226	44/73	0.29	0.84	0.13	X	0.414	0.414
				0.3	-0.02			
	Ra-228	18/73	1.07	36	0.72	X	3.19	3.19
				1.01	-0.13			
	U-234	53/73	1012	23600	0.09	X	5355	5355
				2.11	0.01			
	U-235	33/73	61.6	1940	0.03	X	195	195
				0.21	-0.02			
	U-238	59/73	1062	24400	0.06	X	1991	1991
				2.29	0.00			
	Uranium (Total)	59/73	2174	49900	0.12	X	4036	4036
				4.7	0.01			

Table 4-2: Results of EPC for Radiological COPCS (Cont'd)

EU	COPC	FOD[1]	Concentration[2]			Dist[3]	UCL_{95}[4]	EPC[5]
			Mean	Max	Min			
Groundwater (Unit for concentration is pCi/L)								
2A	U-234	14/20	1.1	10.8	0.14	L	2.27	2.27
				0.29	0.03			
	U-235	3/20	0.07	0.59	0.10	X	0.2	0.2
				0.11	-0.03			
	U-238	17/20	1.07	12.1	0.11	X	7.1	7.1
				0.12	0.03			
	Uranium (Total)	17/20	2.19	24.7	0.23	X	14.55	14.55
				0.24	0.05			
3B	U-234	27/31	14.49	252	0.17	X	97.96	97.96
				0.32	0.05			
	U-235	13/31	0.82	14	0.04	X	2.85	2.85
				0.08	-0.02			
	U-238	28/31	14.51	249	0.12	X	97.46	97.46
				0.25	0.06			
	Uranium (Total)	28/31	29.7	509	0.24	X	199.3	199.3
				0.51	0.11			
Surface Water (Unit for concentration is pCi/L)								
2A	Ra-226	4/9	0.28	0.35	0.2	N	0.21	0.21
			0.11	0.17	-0.003			
	Th-230	1/10	0.10	0.099	0.099	X	0.099	0.099
			0.00	0.08	-0.06			
	Th-232	2/10	0.03	0.031	0.023	X	0.031	0.031
			0.01	0.027	-0.021			
	U-234	14/14	0.47	1.26	0.082	G	0.71	0.71
	U-235	2/14	0.05	0.054	0.047	X	0.054	0.054
			0.02	0.078	-0.005			
	U-238	14/14	0.42	1.1	0.076	N	0.58	0.58
3B	Th-232	1/12	0.015	0.015	0.015	X	0.015	0.015
			0.008	0.032	-0.005			
	U-234	12/12	7.64	87	0.116	X	79.43	79.43
	U-235	2/12	2.24	4.4	0.082	X	4.4	4.4
			0.02	0.032	0.005			
	U-238	12/12	7.61	87	0.096	X	79.42	79.42

[1] FOD = Frequency of Detection (i.e., Detected/Total # of Samples)
[2] Max = Maximum; Min = Minimum
[3] Dist = Distribution of Sampling Results; N = Normal; L = Lognormal; G =Gamma; X = Non-parametric
[4] UCL_{95} = 95% of the upper confidence limit of the mean
[5] EPC = Exposure point concentration
[6] U-234 mod = EPC for U-234 was determined by combining samplings results of Th-234 and U-234.
[7] U-238 mod = EPC for U-238 was determined by combining samplings results of Th-234 and U-238

The following sections summarize the processes used to quantify exposure to receptors from radionuclides and chemical COPC present at the Site.

4.2.2.1 Pathway Specific Intakes for Radiological COPCs

The human health radiological dose and risk assessment for radiological constituents was conducted by utilizing the residual radioactivity computer code (RESRAD) Version 6.3 (ANL. 2005). While RESRAD uses methods consistent with those presented in the RAGS, the code has several advantages over standard RAGS methods including the following:

- RESRAD models future conditions taking into account source removal by radiological decay, leaching, erosion, etc., and radiological in growth;
- RESRAD considers site-specific variables such as rainfall, soil density, etc. that may impact results;
- RESRAD considers source geometry taking into account the thickness and surface area of soil contamination;
- RESRAD is an integrated code that accounts for all potential exposure pathways with a single calculation or "run"; and
- RESRAD provides both carcinogenic risk and radiological dose estimates for comparison to appropriate regulatory limits.

RESRAD 6.3 utilizes Federal Guidance Report (FGR) Nos. 11 and 12 DCFs for determining radiological dose assessment to various receptors present at the Site. Except for the differences identified above, the RESRAD calculations parallel the HHRA for non-radiological constituents. The same exposure parameters were utilized, the same exposure pathways were considered, and the same exposure scenarios were evaluated.

Specific parameter values were consistent with those provided in Appendix C. The RESRAD codes also require inputs that describe the physical characteristics of the contaminated media. Certain site-specific data such as evapotranspiration coefficients and air exchange rates may be limited, although as many as possible site-specific parameter values were used. The preference was to use site-specific data first, use values recommended or otherwise employed by USEPA second, and use RESRAD defaults last. Appendix C-1 presents the assigned value for each RESRAD input parameter.

The RESRAD model determines the radiological dose and risk caused by groundwater contamination that may occur due to leaching of radiological contamination that is present in the soil. It does not calculate the radiological dose and risk for existing groundwater contamination. Similarly, the RESRAD model does not determine the radiological dose and risk due to surface water contamination.

The following equation was used to determine the radiological dose due to incidental ingestion of existing groundwater and surface water contamination that may be present at the Site, for all those receptors identified in Section 4.2.1 that have incidental or other ingestion exposure to groundwater and/or surface water.

$$\text{Intake}_{\text{Ing}}\ (\text{pCi}) = C_w \times IR \times EF \times ED$$

where:

C_w	Concentration of radionuclides in water (pCi/L);
IR	Ingestion rate (L/day);
EF	exposure frequency (days/year); and
ED	exposure duration (years)

Aquifer B is considered a potential drinking water source for the hypothetical future residential receptor. The current RESRAD model can only evaluate one saturated zone. It is not capable of modeling the transport of constituents from soil to aquifer B through aquifer A. However, based on groundwater sampling results collected during the last four years, there has been a decreasing trend in concentrations of each COPC in groundwater. Therefore, it is likely that the dose and risk associated with future groundwater contamination will be less than that estimated for current groundwater contamination. For that reason no dose and risk assessment was performed for future groundwater contamination. However, as a conservative approach, the future dose and risk are assumed to be the same as those for current groundwater contamination.

Since there is no sediment ingestion pathway in the RESRAD model the following equation was used to determine the radiological dose resulting from incidental ingestion of contaminated sediment for applicable EUs:

$$\text{Intake}_{\text{Ing}}\ (\text{pCi}) = C_{sed} \times IR \times EF \times ED$$

where:

C_{Sed}	Concentration of radionuclides in sediment (pCi/g);

IR Ingestion rate (g/day);
EF exposure frequency (days/year); and
ED exposure duration (years)

Dose conversion factors presented in USEPA FGRs 11 and 12 (USEPA 1988, USEPA 1993a) were utilized to estimate radiological dose. The risk coefficient factors presented in USEPA's FGR No. 13 were utilized to estimate radiological risk (USEPA 2002b).

4.2.2.2 Pathway Specific Intakes for Chemical COPCs

The following subsections present the equations that were used to quantify exposure for receptors identified at the Site and the intake resulting from the exposure.

Soils, Sediments and Plant Exposure Pathways

Incidental ingestion of soils, sediments and plants were estimated for constituents by the following equation:

$$\textit{Constituent Intake (mg / kg - d)} = \frac{C_s \times IR_s \times EF \times ED}{BW \times AT}$$

where:

C_s = constituent concentration in soils or sediments (mg/kg)
IR_s = ingestion rate (kg/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
BW = body weight (kg)
AT = averaging time (days)

Incidental ingestion of plants that are grown in contaminated soil was estimated for constituents by the following equation:

$$\textit{Constituent Intake (mg / kg - d)} = \frac{C_s \times BAF \times FI \times IR_s \times EF \times ED}{BW \times AT}$$

where:

C_s = constituent concentration in soils (mg/kg)
BAF = bioaccumulation factor (soil to plant)
FI = contaminated plant fraction (unitless)
IR_s = ingestion rate (kg/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)

BW = body weight (kg)
AT = averaging time (days)

The dermally absorbed dose (DAD) from constituents in soils and sediments were calculated as follows:

$$Constituent\ DAD\ (mg/kg-d) = \frac{C_s \times CF \times SA \times AF \times ABS \times EF \times ED}{BW \times AT}$$

where:

DAD = dermally absorbed dose (mg/kg-d)
C_s = constituent concentration in soils or sediments (mg/kg)
CF = conversion factor (10^{-6} kg/mg)
SA = skin surface area exposed to soil (cm^2/event)
AF = soil to skin adherence factor (mg/cm^2)
ABS = constituent-specific absorption factor (unitless)
EF = exposure frequency (events/yr)
ED = exposure duration (years)
BW = body weight (kg), and
AT = averaging time (days)

Inhalation of constituent in soils was calculated as follows:

$$Constituent\ Intake\ (mg/kg-d) = \frac{C_s \times IR_a \times EF \times ED \times (VF^{-1} + PEF^{-1})}{BW \times AT}$$

where:

C_s = constituent concentration in soils or sediments (mg/kg)
IR_a = inhalation rate (m^3/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
VF = volatilization factor (constituent-specific m^3/kg)
PEF = particulate emission factor (1.32×10^9 m^3/kg)
BW = body weight (kg)
AT = averaging time (days)

Groundwater and Surface Water Exposure Pathways

Drinking water ingestion was estimated for constituents by the following equation:

$$Constituent\ Intake\ (mg/kg-d) = \frac{C_w \times IR_w \times EF \times ED}{BW \times AT}$$

where:

C_w = constituent concentration in water (mg/L)
IR_w = ingestion rate (L/day)

EF = exposure frequency (days/year)
ED = exposure duration (years)
BW = body weight (kg)
AT = averaging time (days)

The dermal absorbed dose from dermal contact with chemicals in surface water or groundwater was calculated as follows (USEPA 2004):

$$Chemical\ DAD\ (mg / kg - d) = \frac{DA_{event} \times EV \times EF \times ED \times SA}{BW \times AT}$$

where:

DAD = dermal absorbed dose (mg/kg-day)
DA_{event} = absorbed dose per event in water (mg/cm^2-event)
EV = event frequency (one event/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
SA = surface area of skin exposed (cm^2)
BW = body weight (kg)
AT = averaging time (days)

For inorganics, DA_{event} (mg/cm^2-event) is calculated as follows:

$$DA_{event} = K_p \times C_w \times t_{event}$$

where:

DA_{event} = absorbed dose per event in water (mg/cm^2-event)
K_p = permeability coefficient from water (chemical-specific, cm/hr)
C_w = concentration of chemical in water ($mg/cm^3 = 10^{-3}$ mg/L)
t_{event} = duration of event (hr/event)

For organics, DA_{event} (mg/cm2-event) is calculated as follows:

$$If\ t_{event} < t^*\ then:\ DA_{event} = 2\ FA \times K_p \times C_w \times (6\,t_{event}/B)^{1/2}$$

$$If\ t_{event} > t^*\ then:\ DA_{event} = FA \times K_p \times C_w\ [\{(t_{event}/(1+B)\} + 2\,\{(1+3B\,3B^2)/(1+B)^2\}]$$

where:

DA_{event} = absorbed dose per event in water (mg/cm^2-event)
FA = fraction absorbed water (dimensionless, chemical-specific)
K_p = permeability coefficient from water (chemical-specific, cm/hr)
C_w = concentration of chemical in water ($mg/cm^3 = 10^{-3}$ X mg/L)
t_{event} = duration of event (hr/event)
B = chemical-specific constant reflecting the partitioning properties

t*	=	chemical-specific time to reach steady-state (hour)
ϑ	=	lag time per event(hour)
B	=	constant (3.14159)

Values and equations for FA, K_p, t*, ϑ, and B can be found in RAGS, Part E (USEPA 2004). If a K_p is not found, it is calculated using the following empirical predictive formula:

$$\log (K_p) = -2.80 + 0.66 \log (K_{ow}) - 0.0056\, MW$$

where:

K_{ow}	=	octanol/water coefficient (chemical-specific)
MW	=	molecular weight (g/mole)

Inhalation of vapors and fugitive dust-containing volatile COPCs in ambient air is a consideration for groundwater exposures for a construction and utility worker. Potential migration of vapors from groundwater to ambient air was estimated using the volatilization factor presented in the ASTM Risk Based Corrective Action Standard (ASTM 2002). The volatilization factor was then multiplied by the groundwater concentration to derive the concentration of the volatile compound in the ambient air. The intake equation for inhalation of constituents in soil was then used to estimate the intake.

The ASTM model uses the following equation to calculate the volatilization factor from groundwater to ambient air, VFwamb:

$$VF_{wamb} = \frac{H \times 10^3 \ (mg/m^3 air)/(mg/L_{GW})}{1 + \frac{U_{air} \times H_{air} \times L_{GW}}{W \times D_{ws}^{eff}}}$$

where:

H	=	Henry's law constant (cm^3 H_20/cm^3 air)
U_{air}	=	wind speed above the ground surface in the ambient mixing zone (cm)
H_{air}	=	ambient air mixing zone height (cm)
LG_W	=	depth to groundwater (cm) (= h_{CAP}, height of capillary zone + hv, height of vadose zone)
W	=	width of source area parallel to wind or groundwater flow direction (cm)
D_{WS}^{eff}	=	effective diffusion coefficient between groundwater and soil (cm^2/s)

The diffusion coefficient, D_{WS}^{eff} is calculated using the following equation:

$$D_{WS}^{eff} = (hcap + hv) \times \left[\frac{hcap}{D_{cap}^{eff}} + \frac{hv}{D_S^{eff}} \right]^{-1}$$

where:

hcap = height of capillary zone (cm)
hv = height of unsaturated zone (cm)
D_{cap}^{eff} = effective diffusion coefficient through capillary zone (cm^2/s)
D_v^{eff} = effective diffusion coefficient through unsaturated zone (cm^2/s)

The diffusion coefficient, D_{cap}^{eff} is calculated using the following equation:

$$D_{cap}^{eff} = D^{air} \times (\theta acap^{3.33}/\theta_T^2) + (D^{wat} \times (\theta wcap^{3.33}/\theta_T^2)/H)$$

where:

D^{air} = diffusion coefficient in air (cm^2/s);
D^{wat} = diffusion coefficient in water (cm^2/s)
Θacap = volumetric air content in capillary fringe soils (cm^3-air/cm^3-soil)
Θwcap = volumetric water content in capillary fringe soils (cm^3- H_20/cm^3-soil)
θ_T = total soil porosity (cm^3/cm^3-soil)

The diffusion coefficient, D_s^{eff} is calculated using the following equation:

$$D_s^{eff} = D^{air} \times (\theta as^{3.33}/\theta_T^2) + (D^{wat} \times (\theta ws^{3.33}/\theta_T^2)/H)$$

where;

θas = volumetric air content (cm^3-air/cm^3-soil)
θws = volumetric water content (cm^3- H_20/cm^3-soil)

Exposure to indoor air vapor from groundwater was evaluated for residential scenarios. The indoor air exposure was evaluated primarily through application of the Johnson & Ettinger (J&E) vapor transport model (J&E 1991). The model, a series of spreadsheets developed by USEPA (EQM 2004), simulates the Site's shallow soil, deep soil, and groundwater data in order to predict indoor air concentrations. GW-ADV worksheet of "3 Phase System Models and Soil Gas Models" was utilized to determine the indoor air concentration and risks associated with inhalation through the indoor air pathway.

For J&E vapor model input parameters, site-specific soil properties, including bulk density, total porosity, air-filled porosity, and water filled porosity were used when possible. The depth below ground surface to the top of contamination was assumed to be three ft. Default building parameters (EQM 2004) were used for hypothetical future residential exposures. Additional chemical transport parameters were selected from ASTM (ASTM 2002) for chemicals under soil

conditions similar to this site. The predicted indoor air concentrations from the model were subsequently used as EPCs in the calculation of risk and hazard.

4.3 Toxicity Assessment

The toxicity assessment results in the selection of appropriate toxicity values to use in generating estimates of potential health risks associated with chemical and radiological COPCs exposure. The toxicity assessments for both radiological and chemical COPCs are summarized in the subsections below.

4.3.1 Toxicity Assessment for Radiological COPCs

With the exception of uranium, the toxicity criteria for radionuclides are limited to carcinogenic risk. That is, only uranium is considered as both a carcinogenic and non-carcinogenic hazard. The assessment for chemical constituents evaluated uranium's non-carcinogenic properties. RESRAD 6.3 utilizes FGR Nos. 11 and 12 DCFs for determining radiological dose assessment to various receptors present at the Site. Those DCFs are based on International Commission on Radiological Protection (ICRP) 30 publications.

To estimate radiological risk, the RESRAD code utilizes FGR No. 13 risk coefficient values. The risk coefficients derived in FGR No. 13 are based on methods and models that take into account the age- and gender-dependence of radionuclide intake, metabolism, dosimetry, radiogenic risk, and competing causes of death in estimating the cancer risk from low-level exposures to radionuclides in the environment. These risk coefficient slope factors are presented in units of risk per pCi (internal pathways) or risk per year per pCi/g (external pathways). Appendix D-1 provides the risk coefficients for each radiological COPC present at the site. Appendix D-2 provides the DCFs for each radiological COPC present at the site.

A Cancer Slope Factor (CSF) for a radionuclide is defined differently from a CSF for a chemical constituent. USEPA outlines these differences in *Radiation Exposure and Risk Assessment Manual* (USEPA 1996a). Major differences include the following:

- Radiological risk estimates are based primarily on human data – constituent risk estimates are based primarily on animal studies; and
- Radiological risk estimates are based on the central estimate of the mean – constituent risk estimates are based on 95% UCL of the mean.

4.3.2 Toxicity Assessment for Chemical COPCs

Toxicity Criteria Sources

In accordance with USEPA's Office of Solid Waste and Emergency Response (OSWER) Directive 9285.7-53 (USEPA 2003d) the following hierarchy of toxicological sources of information was used during the BRA to assign toxicity values for each COPC.

- Tier 1- USEPA's IRIS
- Tier 2- USEPA's Provisional Peer Reviewed Toxicity Values (PPRTVs) – The Office of Research and Development/National Center for Environmental Assessment/ Superfund Health Risk Technical Support Center (STSC) develops PPRTVs on a chemical specific basis when requested by USEPA's Superfund program.
- Tier 3- Other Toxicity Values – Tier 3 includes additional USEPA and non-USEPA sources (The California Environmental Protection Agency (Cal EPA) toxicity values, Agency for Toxic Substances and Disease Registry (ATSDR) Toxicology Profiles, Health Effects and Assessment Summary Tables (HEAST) toxicity values) of toxicity information. Priority should be given to those sources of information that are the most current, the basis for which is transparent and publicly available, and which have been peer reviewed.

Toxicity Criteria Definitions

The CSF is defined as a plausible upper-bound estimate of the probability of a response (e.g. cancer) per unit intake of a constituent over a lifetime (USEPA 1989a). Slope factors are specific for each constituent and route of exposure. The potential for non-carcinogenic health effects resulting from exposure to constituents is assessed by comparing an exposure estimate (intake or dose) to a reference dose (RfD). The chronic RfD is defined as an estimate of daily exposure level for the human population, including sensitive subpopulations, that are likely to be without an appreciable risk of deleterious effects during a lifetime (USEPA 1989a). An RfD is also specific to a constituent and route of exposure.

Oral and inhalation CSF and RfDs are currently available in above toxicological sources. Inhalation CSFs and RfDs take into consideration the fractional amount of a constituent absorbed into the blood. Dermal CSFs and RfDs were estimated from the oral toxicity values using

constituent-specific gastrointestinal (GI) factors to calculate the total administered dose by the following equations (USEPA 1992d):

$$CSF_{dermal} = CSF_{oral} / ABS_{gi} ,$$
$$RfD_{dermal} = RfD_{oral} \times ABS_{gi} ,$$

where:

CSF = constituent-specific cancer slope factors $(mg/kg\text{-}day)^{-1}$
RfD = constituent-specific reference doses (mg/kg-day)
ABS_{gi} = constituent-specific gastrointestinal factor (unitless)

GI factors provided in the USEPA RAGS Part E (USEPA 2004) were used to estimate dermal toxicity values.

CSFs and RfDs may not be available for some detected constituents at the Site because the carcinogenic and/or non-carcinogenic effects of the constituents have not yet been determined. Although these constituents may contribute to carcinogenic and non-carcinogenic effects from exposure to the contaminated media, their effects cannot be quantified at the present time. Appendix D-2 provides the toxicological and physical properties for each chemical COPC.

4.4 Risk Characterization

Risk characterization integrates the findings of the exposure assessment and toxicity assessment to estimate the likelihood that a receptor may experience an adverse effect as the result of exposure to COPCs (USEPA 1989a). Risks were calculated using toxicity information and the result of the exposure assessment. Total site risk referred to risks associated with all radiological and non-radiological COPCs, however risks from these two classes of COPCs were not summed. In addition to toxicity difference between radiological and chemical constituents as described in section 4.3.2, exposure point concentrations for radionuclides and non-radionuclides are specific to distinct models incorporating different assumptions, and so RAGS cautions against combining radiological and non-radiological risks. Given these differences, risk from non-radionuclides and radionuclides were assessed and presented separately.

For carcinogens, incremental lifetime cancer risks (ILCRs), or the increased lifetime probability of cancer, were calculated. The resulting ILCRs were compared to the range specified in the NCP (USEPA 1990) of 10^{-6} to 10^{-4}, or one in a million to one in 10,000 persons developing

cancer. ILCRs below 10^{-6} are considered acceptable risks whereas ILCRs above 10^{-4} are considered unacceptable risks. Risks between 10^{-6} and 10^{-4} are generally referred to as the "acceptable risk range". Any decisions to address the risk results further either by additional study or engineered control measures should account for uncertainty in the risk estimates.

The risk of developing cancer was determined as follows (USEPA 1989a):

$$ILCR = I \times CSF$$

where:

ILCR = incremental lifetime cancer risk (unitless probability)
I = chronic daily intake or DAD from exposure assessment (mg/kg-day)
CSF = cancer slope factor $(mg/kg\text{-}day)^{-1}$

For a given pathway with simultaneous exposure of a receptor to several carcinogens, the total risk to a receptor is the sum of the ILCRs for each carcinogen encountered in all sources and each pathway. The equation that was used to calculate the total ILCR is:

$$ILCR_{total} = \sum ILCR_i$$

where:

$ILCR_{total}$ = total incremental lifetime cancer risk (unitless probability)
$ILCR_I$ = ILCR for the i^{th} constituent

In addition to developing cancer from exposure to constituents, an individual may experience non-carcinogenic toxic effects from exposures to hazardous substances. The term "toxic effects" describes a wide variety of systemic effects, ranging from minor irritations such as skin irritation and headaches to more substantial effects such as kidney or liver disease and neurological damage. The risks associated with toxic constituents are evaluated by comparing an exposure level or intake to a reference dose. The reference dose is the threshold level below which no toxic effects are expected to occur in a normal population, including sensitive subpopulations. The ratio of intake or single constituent exposure level over a specified time period to a reference dose for that constituent derived from a similar exposure period is termed the Hazard Quotient (HQ) (USEPA 1989a) and is defined as:

$$HQ = \frac{I}{RfD}$$

where:

HQ = hazard quotient (unitless ratio)

I = chronic daily intake or dermally absorbed dose (mg/kg-day)
RfD = reference dose (mg/kg-day)

The HQs for each constituent are summed to obtain a hazard index (HI). An HI greater than one has been defined as the level of concern for potential adverse non-carcinogenic health effects (USEPA 1989a). This approach is different from the probabilistic approach used to evaluate carcinogens. A HQ of 0.01 does not imply a one in 100 chance of an adverse effect, but indicates only that the estimated intake is 100 times less than the threshold level at which adverse health effects may occur. For simultaneous exposure of a receptor to several constituents, an HI is calculated as the sum of the individual HQs for all non-carcinogens encountered for each pathway as follows:

$$HI = \sum HQi$$

where:
HI = hazard index
HQ_i = hazard quotient for the i^{th} constituent

An $ILCR_{total}$ and a total HI associated with each media for each receptor was estimated by summing pathway-specific values. If the segregated HIs still exceed one, it was concluded that the target risk level has been exceeded.

Lead, a non-carcinogen, is considered a special case for risk characterization. The traditional RfD approach to the evaluation of chemicals is not applied to lead because most human health effects data are based on blood lead concentrations, rather than external dose. Blood lead concentration is an integrated measure of internal dose, reflecting total exposure from site-related and background sources. A clear no observed adverse effects level (NOAEL) has not been established for such lead-related endpoints as birth weight, gestation period, heme synthesis and neurobehavioral development in children and fetuses, and blood pressure in middle-aged men. Dose-response curves for these endpoints appear to extend down to 10 micrograms per deciliter (µg/dl) or lower (ATSDR, 2007). USEPA guidance suggests that non-cancer effects from human exposure to lead contaminated media be evaluated by using the Integrated Exposure Uptake Biokinetic Model (IEUBK Model), for children's exposure (USEPA 2002g), and the Adult Lead Model for adult exposure (more specifically, for estimating fetal blood lead levels in women exposed to lead containing soil under non-residential scenarios) (USEPA 2003a). For this BRA,

Region VI risk based soil screening value of 800 mg/kg under an industrial worker scenario was used during risk screening for lead. It is presumed for this HHRA that concentrations of lead less than 800 mg/kg will be assumed to not pose an unacceptable risk to human health under an industrial use scenario, and concentrations greater than the screening level will be assumed at this point to have the potential to pose an unacceptable risk. As lead is not a FUSRAP-related COPC, no further risk characterization will be completed for lead at EUs where lead concentrations exceeded the risk based screening value.

The RESRAD code provides estimates of ILCR and radiological doses by radionuclide and pathway. Radiological dose estimates in millirem per year (mrem/yr) also were provided for comparison against dose-based goals. Based on *Soil Remediation Standards for Radioactive Materials* (N.J.A.C. 7:28-12) (NJDEP 2000), State of NJ identified a dose limit criterion of 15 mrem/yr. The radiological dose results for each EU under each receptor scenario were compared with respect to 15 mrem/yr dose criterion. A dose greater than 15 mrem/yr is considered unacceptable whereas one equal to or less than 15 mrem/yr is considered acceptable.

4.5 Results

The State of NJ has established a radioactivity above background dose criterion of 15 mrem/yr. Typically, the USEPA considers remedial action at a site when cumulative excess cancer risk to any current or future population exceeds a risk range of 1E-06 to 1E-04 (i.e., one case of cancer in one million to one case of cancer in 10,000) (USEPA 1991a). For non-carcinogenic risk, where the total HI is less than or equal to unity (i.e., one or 1.0E+00), it is believed that no appreciable risk or non-cancer adverse health effects will occur. However, if an HI exceeds one, there is some possibility, although not a certainty, that non-cancer adverse health effects could occur.

Appendix E presents EU-specific output radiological dose and risk assessment summary reports for each exposure scenario. Tables 4-3, 4-4, 4-5, 4-6 and 4-7 present the summary of radiological dose and risk assessments in a 1,000 year period for each EU under industrial worker, construction worker, utility worker, maintenance worker and residential receptor scenarios, respectively. The results showed that the maximum doses for radiological COPCs occurred at year zero or at year 1,000, so the tables present the results of radiological dose to an

EU for year zero and 1,000. In addition, the tables present the results of radiological risk assessments to an EU for year zero and 1,000. For any EU, whenever the cumulative dose and\or cancer risk exceed(s) either or both dose criteria or the CERCLA acceptable risk range, they are designated in **BOLD** font. The table also presents radionuclides that were the major dose and/or risk contributors for those bolded dose and risk results. If the total dose for a specified receptor and medium exceeds 15 mrem/yr, those individual COPCs with a dose greater than 1.5 mrem/yr were identified as maximum dose contributors for the site. If the total risk for a specified receptor and medium exceeds 1E-4, those individual COPCs with a risk greater than 1E-5 were identified as maximum risk contributors for the site. Major dose and/or risk contributors are only identified for an EU if the maximum dose and/or maximum risk are greater than the corresponding dose and risk limit, respectively. Additional attention will be given to those contributors during the selection of COCs for the site in the FS report.

Table 4-3: Results of Radiological Dose and Risk Assessment to Industrial Worker

EUs	Medium	Exposure Pathways	Total Dose (mrem/yr)		Total Risk		Major Contributors
			T=0	T=1000	T=0	T=1000	
1	Surface Soil	External	2.0	6.0	3E-05	1E-04	Not Identified
		Inhalation	0	0.0	1E-08	4E-09	
		Soil Ingestion	0.2	0.2	2E-06	3E-06	
		Cumulative	2.2	6.2	3E-05	1E-04	
2A		External	1.0	0	3E-05	3E-05	Not Identified
		Inhalation	0	0	2E-09	6E-10	
		Soil Ingestion	0	0	3E-07	2E-07	
		Cumulative	1.0	0	3E-05	3E-05	
2B		External	0.7	0	3E-06	0E+00	Not Identified
		Inhalation	0.0	0	6E-11	0E+00	
		Soil Ingestion	0.002	0	7E-09	0E+00	
		Cumulative	0.7	0	3E-06	0E+00	
3A		External	0.02	0	7E-07	3E-06	Not Identified
		Inhalation	0	0	4E-10	1E-10	
		Soil Ingestion	0	0	5E-08	7E-08	
		Cumulative	0.02	0	8E-07	3E-06	
3B		External	14.8	17.8	3E-04	3E-04	Ra-226, Th-230, and Uranium Isotopes
		Inhalation	0	0.0	7E-08	1E-08	
		Soil Ingestion	1.4	0.8	1E-05	8E-06	
		Cumulative	**16.3**	**18.5**	**3E-04**	**4E-04**	

Table 4-4: Results of Radiological Dose and Risk Assessment to Construction Worker

EUs	Medium	Exposure Scenario	Total Dose (mrem/yr)		Total Risk		Major Contributors
			T=0	T=1000	T=0	T=1000	
1	All Depth Soil	External	29.3	12.9	3E-05	1E-05	Th-230 and Uranium Isotopes
		Inhalation	30.2	3.5	6E-06	6E-07	
		Soil Ingestion	9.8	2.1	4E-06	9E-07	
		Cumulative	**69.3**	**18.5**	4E-05	1E-05	
2A		External	1.3	1	5E-06	3E-06	Not Identified
		Inhalation	0.3	0.1	1E-07	5E-08	
		Soil Ingestion	0.1	0.1	1E-07	1E-07	
		Cumulative	1.8	1	5E-06	3E-06	
2B		External	1.6	0	2E-06	0E+00	Not Identified
		Inhalation	0.04	0	3E-08	0E+00	
		Soil Ingestion	0.02	0	2E-08	0E+00	
		Cumulative	1.7	0	3E-06	0E+00	
3A		External	1.8	6.0	6E-06	7E-06	Not Identified
		Inhalation	2.0	0.9	4E-07	2E-07	
		Soil Ingestion	0.6	0.7	3E-07	4E-07	
		Cumulative	4.3	7.6	7E-06	8E-06	
3B		External	12.0	14.3	1E-05	1E-05	Th-230 and Uranium Isotopes
		Inhalation	11.2	2.3	2E-06	4E-07	
		Soil Ingestion	3.9	1.9	2E-06	8E-07	
		Cumulative	**27.1**	**18.5**	1E-05	1E-05	

Table 4-5: Results of Radiological Dose and Risk Assessment to Utility Worker

EUs	Medium	Exposure Scenario	Total Dose (mrem/yr)		Total Risk		Major Contributors
			T=0	T=1000	T=0	T=1000	
1	All Depth Soil	External	10.5	4.6	9E-06	4E-06	Uranium Isotopes
		Inhalation	11	1	2E-06	2E-07	
		Soil Ingestion	3.6	1	1E-06	3E-07	
		Cumulative	**25.0**	6.6	1E-05	4E-06	
2A	All Depth Soil	External	0.5	0.3	2E-06	1E-06	Not Identified
		Inhalation	0.1	0.05	4E-08	2E-08	
		Soil Ingestion	0	0.05	5E-08	4E-08	
		Total	0.6	0.5	2E-06	1E-06	
	Surface Water[1]	Ingestion	0	0	8E-11	8E-11	
	Sediment[2]	Ingestion	0	0	2E-7	2E-7	
	All Pathways	**Cumulative**	0.6	0.5	2E-06	1E-06	
2B	All Depth Soil	External	0.6	0	9E-07	0E+00	Not Identified
		Inhalation	0	0	1E-08	0E+00	
		Soil Ingestion	0	0	6E-09	0E+00	
		Cumulative	0.6	0	9E-07	0E+00	
3A	All Depth Soil	External	0.6	2.2	2E-06	3E-06	Not Identified
		Inhalation	0.7	0.3	1E-07	6E-08	
		Soil Ingestion	0.2	0.3	1E-07	1E-07	
		Cumulative	1.6	3	2E-06	3E-06	
3B	All Depth Soil	External	4.3	5.1	4E-06	4E-06	Not Identified
		Inhalation	4	0.8	8E-07	1E-07	
		Soil Ingestion	1.4	0.7	6E-07	3E-07	
		Total	9.8	6.7	0.0	0.0	
	Surface Water[1]	Ingestion	0	0	3E-09	3E-09	
	Sediment[2]	Ingestion	0	0	1E-10	1E-10	
	All Pathways	**Cumulative**	9.8	6.7	5E-06	5E-06	

[1,2] Dose and risk for surface water and sediment are assumed to be the same at T=0 year and T=1000 year.

Table 4-6: Results of Radiological Dose and Risk Assessment to Maintenance Worker

EUs	Medium	Exposure Pathways	Total Dose (mrem/yr)		Total Risk		Major Contributors
			T=0	T=1000	T=0	T=1000	
1	All Depth Soil	External	2.1	0.9	4E-05	2E-05	Not Identified
		Inhalation	0.0	0.0	1E-08	1E-09	
		Soil Ingestion	0.3	0.1	3E-06	7E-07	
		Cumulative	2.5	1.0	4E-05	2E-05	
2A		External	0.10	0.07	7E-06	6E-06	Not Identified
		Inhalation	0.00	0.00	2E-10	1E-10	
		Soil Ingestion	0.01	0.00	1E-07	9E-08	
		Cumulative	0.1	0	7E-06	6E-06	
2B		External	0.1	0	6E-07	0E+00	Not Identified
		Inhalation	0.0	0	1E-11	0E+00	
		Soil Ingestion	0.0	0	2E-09	0E+00	
		Cumulative	0.1	0	6E-07	0E+00	
3A		External	0.13	0	1E-05	1E-05	Not Identified
		Inhalation	0.00	0	9E-10	4E-10	
		Soil Ingestion	0.02	0	3E-07	3E-07	
		Cumulative	0.15	0	1E-05	1E-05	
3B		External	0.9	1.0	2E-05	2E-05	Not Identified
		Inhalation	0.0	0.0	5E-09	8E-10	
		Soil Ingestion	0.1	0.1	1E-06	6E-07	
		Cumulative	1.0	1.1	2E-05	2E-05	

Table 4-7: Results of Radiological Dose and Risk Assessment to Residential Receptor

EUs	Medium	Exposure Scenario	Total Dose (mrem/yr)		Total Risk		Major Contributors
			T=0	T=1000	T=0	T=1000	
1	All Depth Soil	External	43.9	19.3	1E-03	5E-04	Ra-226, Th-228, Th-230 and Uranium Isotopes
		Inhalation	0	0	2E-07	2E-08	
		Plant Ingestion	16.7	30.1	2E-04	4E-04	
		Soil Ingestion	11.6	2	1E-04	3E-05	
		Total	**72.2**	**51.8**	**1E-03**	**9E-04**	
	Groundwater	Ingestion	1475	1475	1E-02	1E-02	Uranium Isotopes
	All Pathways	**Cumulative**	**1547**	**1527**	**1E-02**	**1E-02**	
2A	All Depth Soil	External	2.0	1.1	2E-04	1E-04	Ra-226, Ra-228, Th-228, Th-230, Th-232 and Uranium Isotopes
		Inhalation	0.0	0	4E-09	2E-09	
		Plant Ingestion	0.1	0.8	5E-05	4E-05	
		Soil Ingestion	0.1	0.1	5E-06	4E-06	
		Total	2.3	2.0	**2E-04**	**2.0E-04**	
	Groundwater	Ingestion	0.3	0.3	2E-05	2E-05	Not Identified
	Surface Water[1]	Ingestion	0.001	0.001	1E-08	1E-08	Not Identified
	Sediment[2]	Ingestion	0.0	0.0	3E-08	3E-08	Not Identified
	All Pathways	**Cumulative**	2.6	2.3	**2E-04**	**2E-04**	
2B	All Depth Soil	External	2.4	0	1E-05	0E+00	Not Identified
		Inhalation	0	0	0E+00	0E+00	
		Plant Ingestion	0.01	0	7E-08	0E+00	
		Soil Ingestion	0.02	0	1E-05	0E+00	
	All Pathways	**Cumulative**	2.4	0.0	2E-05	0E+00	

Table 4-7: Results of Radiological Dose and Risk Assessment to Residential Receptor (Cont'd)

EUs	Medium	Exposure Scenario	Total Dose (mrem/yr)		Total Risk		Major Contributors
			T=0	T=1000	T=0	T=1000	
3A	All Depth Soil	External	2.7	9.0	3E-04	3E-04	Ra-226, Th-230 and Th-232
		Inhalation	0.0	0.0	2E-08	7E-09	
		Plant Ingestion	1.5	6.3	7E-05	1E-04	
		Soil Ingestion	0.7	0.9	1E-05	1E-05	
		Cumulative	4.9	**16.2**	**3E-04**	**5E-04**	
3B	All Depth Soil	External	18.0	21.4	5E-04	5E-04	Ra-226, Th-230 and Uranium Isotopes
		Inhalation	0	0.0	8E-08	1E-08	
		Plant Ingestion	7.3	20.4	1E-04	3E-04	
		Soil Ingestion	4.6	2.3	5E-05	3E-05	
		Total	29.9	44.1	**7E-04**	**8E-04**	
	Groundwater	Ingestion	**31**	**31**	**3E-04**	**3E-04**	Uranium Isotopes
	Surface Water[1]	Ingestion	0.1	0.1	5E-07	5E-07	Not Identified
	Sediment[2]	Ingestion	0.0	0.0	2E-08	2E-08	Not Identified
	All Pathways	**Cumulative**	**61.4**	**75.7**	**9E-04**	**1E-03**	

[1,2] Dose and risk for surface water and sediment are assumed to be the same at T=0 year and T=1000 year.
Ra-226 +D includes Ra-226 plus its daughter product of Pb-210.

The results of the radiological risk assessments for both current and future receptor scenarios presented in the above tables showed that the risks are often above the 10^{-6} point of departure, however except for industrial worker scenario at EU 3B, the risks are within the CERCLA target risk range. However, the results of the radiological dose assessments showed that for EU 1, the maximum doses exceeded the NJ dose limits under the industrial worker and construction worker scenarios. The maximum dose also exceeded the NJ dose limit for EU 3B under the construction and utility worker scenarios. The maximum dose and risk for maintenance workers at each EU are within the acceptable dose and risk range. The results also showed that Th-230 and uranium isotopes are major risk contributors for EU 1, whereas Ra-226, Th-230, and uranium isotopes are major contributors for EU 3B. The results of maximum dose and risks for residential receptors showed that both the doses and risks exceeded their corresponding dose and risk limits for each EU.

The results of radiological risk and dose assessments with respect to each EU show that the maximum risk and dose for EU 2A, EU 2B and EU 3A did not exceed their corresponding acceptable risk and dose criteria for both current and future RME receptors. Therefore, it can be concluded that no remedial action may be required for these three EUs due to radiological risk.

Appendix F presents EU-specific non-radiological intake and risk assessment for each exposure scenario. The J&E indoor vapor model input parameters and calculations are presented in Appendix G. Tables 4-8, 4-9, 4-10, 4-11 and 4-12 present the summary of chemical risk assessments for each EU under the industrial worker, construction worker, utility worker, maintenance worker and residential receptor, respectively. Whenever the cumulative cancer risk and/or hazard indices exceed either or both CERCLA acceptable risk range and HI of one, they are designated in **BOLD** font. The table also presents chemicals that were the major risk contributors for the corresponding bolded risk results. If the total risk for a specified receptor and medium exceeds 1E-4, those individual COPCs with a risk greater than 1E-5 were identified as carcinogenic maximum risk contributors for the site. If the total hazard for a specified receptor and medium exceeds one, those COPCs with a HQ greater than one, were identified as non-carcinogenic maximum risk contributors for the site. Major risk contributors are only identified for an EU if the maximum risks are greater than the corresponding risk limits. Additional attention will be given to the major risk contributors during the selection of COCs for the site in the FS report.

Table 4-8: Results of Chemical Risk Assessment to Industrial Worker

EUs	Medium	Exposure Pathway	Carcinogenic Risk	Hazard Indices	Risk Contributors
EU 1	Surface Soil	Ingestion	6.7E-06	1.6E-01	Not Identified
		Inhalation	3.1E-10	6E-05	
		Dermal Contact	1.3E-05	2.6E-01	
		Cumulative	2E-05	0.4	
EU 2A	Surface Soil	Ingestion	8.6E-06	5.8E-02	Not Identified
		Inhalation	2.7E-10	4E-05	
		Dermal Contact	9.9E-06	1.2E-02	
		Cumulative	2E-05	0.1	
EU 3A	Surface Soil	Ingestion	4.9E-06	2.9E-02	Not Identified
		Inhalation	1.6E-10	6E-05	
		Dermal Contact	1.1E-05	5.0E-03	
		Cumulative	2E-05	0.03	
EU 3B	Surface Soil	Ingestion	6.9E-05	4.5E-02	Benzo(a)pyrene, Benzo(a)anthracene
		Inhalation	2.9E-09	0E+00	
		Dermal Contact	1.9E-04	7.8E-02	
		Cumulative	**3E-04**	0.1	

Table 4-9: Results of Chemical Risk Assessment to Construction Worker

EUs	Medium	Exposure Pathway	Carcinogenic Risk	Hazard Indices	Risk Contributors
1	All Depth Soil	Ingestion	9E-06	3.9E+00	Aroclor-1254
		Inhalation	2E-10	9E-05	
		Dermal Contact	9E-06	1E+00	
		Total	1.8E-05	**4.8**	
	Groundwater	Inhalation	1.6E-08	0.0	
	Cumulative	All Pathways	2E-05	4.9	
2A	All Depth Soil	Ingestion	2E-06	0.6	Not Identified
		Inhalation	2E-10	0.0	
		Dermal Contact	9E-07	0.1	
		Total	3E-06	0.7	
	Groundwater	Inhalation	3.1E-09	0.00	
	Cumulative	All Pathways	3E-06	0.7	
3A	All Depth Soil	Ingestion	1E-05	2.9	Nickel
		Inhalation	2E-10	0.0	
		Dermal Contact	2E-06	0.2	
		Total	1E-05	**3.1**	
	Groundwater	Inhalation	5.0E-09	0.0	
	Cumulative	All Pathways	1E-05	**3.1**	
3B	All Depth Soil	Ingestion	2E-05	4.6	Antimony, Azobenze, Benzo(a) Anthracene, and Benzo(a) Pyrene
		Inhalation	2E-10	0.0	
		Dermal Contact	1E-03	1.1	
		Total	1.4E-03	5.7	
	Groundwater	Inhalation	4.1E-11	0.002	
	Cumulative	All Pathways	1.4E-03	5.7	

Table 4-10: Results of Chemical Risk Assessment to Utility Worker

EUs	Medium	Exposure Pathway	Carcinogenic Risk	Hazard Indices	Risk Contributors
1	All Depth Soil	Ingestion	3E-06	1.42	Aroclor-1254
		Inhalation	3E-09	0.00	
		Dermal Contact	3E-06	0.35	
		Total	6.6E-06	**1.8**	
	Groundwater	Inhalation	5.8E-09	0.009	Not Identified
	All Pathways	**Cumulative**	7E-06	**1.8**	
2A	All Depth Soil	Ingestion	8E-07	0.23	Not Identified
		Inhalation	5E-09	0	
		Dermal Contact	3E-07	0.02	
		Total	1.1E-06	0.25	
	Groundwater	Inhalation	7.1E-10	0.00	
	Surface Water	Ingestion	1.5E-09	0.00	
		Dermal Contact	5.2E-09	0.00	
		Total	6.7E-09	0.00	
	Sediment	Ingestion	2.6E-08	0.01	
		Dermal Contact	5.8E-08	0.00	
		Total	8.5E-08	0.01	
	All Pathways	**Cumulative**	1E-06	0.27	
3A	All Depth Soil	Ingestion	5E-06	1.0	Not Identified
		Inhalation	3E-09	0.00	
		Dermal Contact	6E-07	0.08	
		Total	5.3E-06	1.10	
	Groundwater	Inhalation	1.8E-09	0.01	
	All Pathways	**Cumulative**	5E-06	**1.1**	
3B	All Depth Soil	Ingestion	7E-06	1.7	Azobenzene
		Inhalation	3E-09	0.00	
		Dermal Contact	5E-04	0.37	
		Total	**5E-04**	2.02	
	Groundwater	Inhalation	1.5E-11	0.00	Not Identified
	Surface Water	Ingestion	8.0E-09	0.01	Not Identified
		Dermal Contact	2.4E-07	0.00	
		Total	2E-07	0.01	
	Sediment	Ingestion	2.7E-09	0.00	Benzo(a) anthracene
		Dermal Contact	**7.4E-04**	0.00	
		Total	**7E-04**	0.00	
	All Pathways	**Cumulative**	1E-03	**2.0**	

Table 4-11: Results of Chemical Risk Assessment to Maintenance Worker

EUs	Medium	Exposure Pathway	Carcinogenic Risk	Hazard Indices	Risk Contributors
EU 1	All Depth Soil	Ingestion	7.5E-06	0.1	Not Identified
		Inhalation	5.4E-10	0.0	
		Dermal Contact	2.9E-06	0.0	
		Cumulative	1E-05	0.1	
EU 2A	All Depth Soil	Ingestion	2E-06	0.02	Not Identified
		Inhalation	4E-10	0.0	
		Dermal Contact	3E-07	0.0	
		Cumulative	2.0E-06	0.02	
EU 3A	All Depth Soil	Ingestion	1.0E-05	0.1	Not Identified
		Inhalation	4.6E-10	0.0	
		Dermal Contact	5.8E-07	0.0	
		Cumulative	1.1E-05	0.1	
EU 3B	All Depth Soil	Ingestion	1.5E-05	0.1	Not Identified
		Inhalation	4.4E-10	0.0	
		Dermal Contact	7.2E-06	0.0	
		Cumulative	2E-05	0.2	

Table 4-12: Results of Chemical Risk Assessment to Residential Receptor

EUs	Medium	Exposure Pathway	Carcinogenic Risk	Hazard Indices	Risk Contributors
1	All Depth Soil	Ingestion	1.45E-04	2.01E+00	Arsenic, Benzo (a) Anthracene, Benzo(a) Pyrene, Benzo(b) Fluoranthene, Aroclor-1254
		Inhalation	1E-08	2E-04	
		Dermal Contact	1.84E-04	6.64E-01	
		Total	3.29E-04	2.68E+00	
	Groundwater	Ingestion	3.18E-03	1.21E+02	Manganese, Uranium, 1,2-Dichloroethane, 1,3-Dichlorobenzene, 1,4-Dichlorobenzene, 1,2,4-Trimethylbenzene, 1,3,5-Trimethylbenzene, Benzene, Carbon disulfide, Chlorobenzene, M+P-Xylene, Naphthalene, Toluene
		Inhalation	8.49E-04	3.67E+01	
		Dermal Contact	2.66E-05	3.40E+00	
		Total	4.06E-03	1.61E+02	
	Plant	Ingestion	3.86E-04	1.12E+01	Arsenic, Copper, Mercury, 1,4-Dichlorobenzene, Benzo (a) Anthracene, Benzo(a) pyrene, Naphthalene, Trichloroethene and Aroclor-1254
	All Pathways	**Cumulative**	**4.77E-03**	**1.75E+02**	
2A	All Depth Soil	Ingestion	3.25E-05	3.26E-01	Arsenic and Aroclor-1260
		Inhalation	1E-08	7E-07	
		Dermal Contact	1.91E-05	4.45E-02	
		Total	5.16E-05	3.70E-01	
	Groundwater	Ingestion	7.26E-03	9.08E+01	Arsenic, Antimony, Manganese, 1,2-Dichloroethane, 1,4-Dichlorobenzene, 1,2,4-Trimethylbenzene, 1,3,5-Trimethylbenzene, Aniline, Benzene, Carbon tetrachloride, Chloroethene, Chlorobenzene, Chloroform, cis-1,2 Dichloroethene, Naphthalene, Trichloroethene, Trichlorofluoromethane, and Vinyl Chloride
		Inhalation	2.80E-03	6.54E+01	
		Dermal Contact	1.16E-04	6.05E+00	
		Total	**1.02E-02**	**1.62E+02**	
	Surface Water	Ingestion	2.40E-07	4.85E-03	Not Identified
		Dermal Contact	2.23E-06	4.66E-02	
		Total	2.47E-06	5.15E-02	
	Sediment	Ingestion	1.49E-06	1.44E-02	Not Identified
		Dermal Contact	1.57E-05	2.45E-02	
		Total	1.72E-05	3.89E-02	
	Plant	Ingestion	6.90E-05	3.81E+00	Arsenic, Copper and Mercury
	All Pathways	**Cumulative**	**1.03E-02**	**1.66E+02**	

Table 4-12: Results of Chemical Risk Assessment to Residential Receptor (Cont'd)

EUs	Medium	Exposure Pathway	Carcinogenic Risk	Hazard Indices	Risk Contributors
3A	All Depth Soil	Ingestion	1.99E-04	1.45E+00	1,4-Dichlorobenzene, Benzo(a) Pyrene, Hexachlorobenzene and Tetrachloroethene
		Inhalation	1E-08	2E-04	
		Dermal Contact	3.71E-05	1.46E-01	
		Total	2.37E-04	1.60E+00	
	Groundwater	Ingestion	1.53E-02	1.05E+03	1,4-Dichlorobenzene, Aniline, Benzene, Chlorobenzene, and 4-Chloroaniline
		Inhalation	1.10E-03	1.32E+01	
		Dermal Contact	1.49E-04	5.88E+00	
		Total	1.65E-02	1.07E+03	
	Plant	Ingestion	8.07E-03	2.78E+01	Arsenic, Mercury, Nickel, 1,4-Dichlorobenzene, Hexachlorobenzene, Nitrobenzene and Tetrachloroethene
	All Pathways	**Cumulative**	**2.49E-02**	**1.10E+03**	
3B	All Depth Soil	Ingestion	2.93E-04	2.34E+00	Antimony, Azobenzene, Benzo(a) Anthracene, Benzo(a) Pyrene, Benzo(b) Fluoranthene, Dibenzo(a,h) Anthracene and Indeno (1,2,3-cd) Pyrene
		Inhalation	1E-08	6E-03	
		Dermal Contact	2.95E-02	9.92E-01	
		Total	2.98E-02	3.33E+00	
	Groundwater	Ingestion	1.52E-04	4.28E+01	Uranium, 1,2-Dichlorobenzene, 1,3-Dichlorobenzene, 1,4-Dichlorobenzene, 1,2,4-Trimethylbenzene, 4 Chloroaniline, Carbozole and Chlorobenzene
		Inhalation	0.00E+00	1.44E+01	
		Dermal Contact	9.38E-06	4.14E+00	
		Total	1.62E-04	6.14E+01	
	Surface Water	Ingestion	6.96E-08	4.12E-03	Benzo(b) Fluoranthene
		Dermal Contact	1.04E-04	1.56E-03	
		Total	1.04E-04	5.68E-03	
	Sediment	Ingestion	1.52E-07	7.10E-04	Not Identified
		Dermal Contact	3.44E-06	2.64E-03	
		Total	3.59E-06	3.35E-03	
	Plant	Ingestion	7.12E-03	2.53E+01	Antimony, Arsenic, Cadmium, Mercury, Zinc, Fluoranthene, Fluorene, Benzo(a) Anthracene, Benzo(a) Pyrene, Benzo(b) Fluoranthene, Carbazole, Chrysene, Dibenzofuran, and Naphthalene
	All Pathways	**Cumulative**	**3.72E-02**	**9.00E+01**	

The results of the chemical risk assessment for both current and future receptor scenarios presented in the above tables show that the maximum carcinogenic risks for the industrial worker, construction worker and utility worker exceed the CERCLA acceptable cancer risk

range at EU 3B. For all other EUs, the maximum carcinogenic risks are within the acceptable risk range for industrial, construction and utility workers. However, for non-cancer risk, the hazard indices exceeded one for both construction worker and utility worker at EU 1, EU 3A, and 3B. The maximum carcinogenic risks and hazard indices to maintenance workers are within the CERCLA acceptable risk range for all EUs. The maximum hazard indices for industrial and maintenance workers are within the acceptable risk level and do not exceed one for any EU. Two metals (antimony and nickel), three SVOCs (benzo (a) pyrene, benzo (a) anthracene, and azobenzene) and one PCB congener (aroclor 1254) were identified as the major risk contributors for the site. The results of chemical risk assessment for residential receptors showed that both the carcinogenic risk and hazard indices exceeded their corresponding acceptable risk limits for each EU.

The results of the chemical risk assessment show that the maximum chemical risk and HI for EU 2A did not exceed the corresponding CERCLA acceptable risk range. Therefore, no further remedial action may be performed for that EU. Remedial action for other EUs will depend upon the risks associated with FUSRAP-related contaminants for both current and future RME receptors. If the radiological and/or chemical risks exceed the acceptable risk criteria, remedial actions may be initiated for that EU. Otherwise, no further remedial action may be required for that EU.

4.6 Uncertainty Assessment

The methodology used in this risk assessment is consistent with USEPA and USACE risk assessment guidance documents. However, due to many assumptions that must be made about exposure and toxicity, there is uncertainty associated with every risk assessment. Assumptions built into the risk assessment in general, overestimate rather than underestimate potential risks, but occasionally can result in underestimating risk. In the following section, an evaluation is presented of the sources of uncertainty in the DuPont Site BRA and the relative influence of these sources on the results of the evaluation. Uncertainty is inherent in the selection of input parameters and in every step of the risk assessment process. Risk assessment of contaminated sites must not be viewed as yielding single value, invariant results. Rather, the results of risk assessment are estimates that span a range of possible values, and must be understood only in light of the assumptions and methods used in the evaluation.

The results of the BRA are presented in terms of the potential for adverse effects based upon a number of conservative assumptions. The tendency to be conservative is an effort toward protecting health. Uncertainty can be found at all phases in the risk assessment: in the analytical data, the exposure assessment, the toxicity assessment, and the risk characterization. Where uncertainty does exist, the BRA uses conservative assumptions to ensure that the outcome will be protective.

4.6.1 Uncertainties in Analytical Data

Uncertainty is introduced to the BRA when sample locations are selected and when samples are collected and analyzed. Based on the information regarding historical site operations, and GWS, samples were collected from areas of potential sources and releases. As a result, there is a conservative bias for EPC and associated risk estimates.

In the BRA, the long-term exposure concentrations were upper estimates of site concentrations (e.g., maximum detect or 95% UCL) rather than the sample mean to characterize each EU. The uncertainty from a relatively small sample size (less than five) requires a greater amount of conservatism during the estimation of mean, while a large sample size requires less conservatism during the estimation of mean. For either case, a conservative bias to overestimate potential exposure has been incorporated into the risk estimates. The uncertainty associated with the statistical analysis of environmental data is low, with little introduction of bias.

The limitations of chemical analytical methods introduced substantial uncertainty into the selection of COPC. The offsite laboratory occasionally could not achieve the required detection limit requirements for some sampling results. In such cases, the detection limits were above the toxicity screening values. These events resulted in a high uncertainty associated with the elimination of a COPC.

The BRA was performed for both MED-related wastes and wastes generated as a result of DuPont's historical and routine industrial operations. For example, EU 2A includes one sample that was determined to be fluorspar material used in the production of hydrofluoric acid (3-SS-28). This is not believed to have been generated during MED-related operations. However, as a conservative approach, the sampling results for non-MED related samples were included during

the determination of EPC for each COPC. This will result in an overestimate of actual dose and risks for FUSRAP eligible contaminants.

4.6.2 Uncertainties in Exposure Assessment

Exposure assessment may introduce considerable uncertainty in the risk assessment process. Exposure assumptions are based on speculation regarding potential land use, assumptions concerning contaminant fate and transport, and receptor behavior. The uncertainty associated with the exposure assumptions used in the risk assessment is low to moderate, and most likely overestimates the actual risks.

The exposure scenarios, receptors, exposure pathways, exposure parameters, and media included in this BRA were selected to conservatively represent a variety of exposure scenarios that could occur at the Site. The site is zoned as industrial. Therefore, four different types of workers - industrial, construction, utility, and maintenance were considered for the current and future RME receptors for the sites. Dose and risk assessments were also performed for a very conservative residential receptor scenario. Under that scenario, the resident would be exposed to two additional exposure pathways as compared to Site workers: 1) ingestion of groundwater as drinking water and 2) ingestion of home-grown fruits and vegetables as compared to other workers. However, the drinking water pathway may not be applicable for the following reasons.

- Current groundwater conditions preclude its present use as a potential drinking water source. The two uppermost aquifers beneath the Site exhibit high dissolved solids as well as high organic and metal contamination due to the long history of DuPont manufacturing operations;
- DuPont and the State designated the aquifers beneath the Site as a Classification Exception Area (CEA) as part of DuPont's groundwater remediation plan; and
- Chambers Works is not within the capture zone of current municipal drinking water well systems and it is unlikely that it will be in the future.

Fruits, vegetables, and grain consumption rate for residential receptor was calculated conservatively by using 95^{th} percentile of the total fruit intake, leafy vegetable intake, and actual body weight of the adult (70 kg) or child (15 kg). USEPA recommends that instead of using individual body for adult and child, a single weight of 60 kg should be used (USEPA 1997a) to calculate the total fruit, vegetable and grain consumption rate. In addition, the 95^{th} percentile intake rate for total fruit was derived based on a survey conducted over a period of one week,

and therefore may not be representative of the receptor's annual behavior. Both of those factors may result in overestimating dose and risk to the residential receptor for the plant ingestion pathway. Besides, NUREG/CR 5512 Volume 4 assigns 112 kg/yr for the fruits, vegetables, and grain consumption rate for a resident farmer (NRC 1999). NRC's consumption rate for fruits, vegetables, and grain is more than four times lower than the value used during this assessment. Since USEPA's assigned values were given first preference, the higher consumption rate was assigned for that intake parameter.

Assumptions regarding uniform contamination across the actual size of each EU with no soil cover are likely to produce conservative dose and risk results. The BRA also assumed that the receptors will be exposed equally at each location within each EU. The Sitewide RI report showed that the extent of radiological contamination covers a small area (which would lower dose estimates) and may only reasonably expose a subset of individuals (e.g., utility workers) (CABRERA 2011b). Therefore, equal exposures at each location are quite unlikely. Final status surveys and post-remediation risk/dose assessments for each EU will consider property-specific characteristics such as surface area and depth below ground surface.

Exposure parameters were selected to provide a conservative, yet reasonable, estimate of potential risks to each receptor. Site-specific measurements and data were used, as appropriate, to describe site conditions as accurately as possible. Where site-specific data were not available, parameter values were chosen to provide reasonably conservative estimates of risk, or standard default values recommended by the Exposure Factors Handbook (USEPA 1997a) were used. Intake parameters for the various exposure pathways (soil ingestion, dermal contact, inhalation, external gamma) were conservatively assumed to be upper bound estimates to take account the uncertainty associated with those parameters.

Another key area of uncertainty associated with exposure is the bioavailability of the chemicals present in soil and movement of the chemicals into the bloodstream, i.e., dermal penetration and GI absorption. Lipophilic chemicals are likely to present in soil for a long time, and are therefore less bioavailable than the same chemicals freshly added to the soil. The dermal or oral absorption rates for those lipophilic chemicals are much lower. However, the absorption rates used during this BRA were based on laboratory testing using freshly added chemicals. Higher

absorption rates were used during the calculation of intake, thus resulted in an overestimation of risk due to intake of chemicals.

The BRA failed to account for future environmental degradation of the organic chemicals present in the source area. Significant degradation of the chemicals is likely to occur over a 30 year exposure duration due to microbial degradation, photolysis, hydrolysis, and other processes which over time reduce the concentrations of chemicals present in soil. However, during this BRA, the EPC for any chemical COPC was assumed to remain the same over the exposure duration of the receptor.

The risk from gamma radiation is dependent on the source surface area and thickness. Slope factors for external gamma radiation assume that the source is a semi-infinite slab. This geometry may represent actual conditions resulting in an overestimate of risk. The radionuclide concentrations are spotty in nature. However, during this BRA, radionuclides are assumed to be uniformly contaminated across the thickness of the contaminated zone. This assumption resulted in an overestimation of dose and risk.

4.6.3 Uncertainties Related to Toxicity Information

Although USEPA approved toxicity values were used for the HHRA, a significant amount of uncertainty may surround these values. Identification of the sources of this uncertainty enables the risk assessor to establish the degree of confidence associated with the toxicity measures.

Uncertainty is inherent within the toxicity assessment and is primarily due to differences in study design, species, sex, routes of exposure, or dose-response relationships. A major source of uncertainty involves using toxicity values based on experimental studies that substantially differ from typical human exposure scenarios. The derivation of the toxicity values must take into account such differences as 1) using dose-response information from animal studies to predict effects in humans, 2) extrapolating dose-response information from high-dose studies to predict adverse health effects from low doses, 3) using data from short-term studies to predict chronic effects, and 4) extrapolating from uniform animal populations to variable human populations.

Uncertainty is inherent during the derivation of radiological DCF. This BRA utilizes FGR Nos. 11 and 12 DCFs. Those DCFs are based on ICRP 30 publications. A newer version of

RESRAD (version 6.4) is currently available. RESRAD version 6.4 includes ICRP 30 DCFs as well as ICRP 72 age-dependant (three months, one year, five year, 10 year, 15 year and adult) DCFs for the public. ICRP 72 DCFs could be used for resident child and resident adult. However, the residential receptor assumed for the Site is based on a combination of both child and adult. Therefore, ICRP DCFs may not directly apply for residential receptors. In addition, a comparison was performed between ICRP 72 and ICRP 30 DCFs (used in RESRAD 6.3) for inhalation and ingestion. DCFs for uranium isotopes based on ICRP 72 are less than that for ICRP 30. Since the uranium isotopes are major dose contributors for the Site, ICRP 30 dose results are more conservative than results from ICRP 72. By using ICRP 30 DCFs, the output dose assessment results will be the same for both versions of the RESRAD models. For this reason, RESRAD version 6.3 was used during this BRA.

The cancer slope factors in particular are based on studies that may differ greatly from realistic situations. Experimental cancer bioassays typically expose animals to very high levels of chemicals (i.e., the maximum tolerated dose) for their entire lifetime. After appropriate studies have been identified, the slope factor is calculated as the upper 95th percent confidence limit of the slope of the dose-response curve. This introduces conservatism into the risk assessment. In addition, carcinogens are assumed to be human carcinogens regardless of USEPA's weight -of - evidence classification.

The derivation of reference doses involves the use of animal studies. Uncertainty factors ranging from one to 1,000 are incorporated into the reference dose to provide an extra level of health protection. The factors used depend on the type of study from which the value has been derived (e.g., animal or human, chronic or acute, study design). The scientific basis for this practice is somewhat subjective. In general, high uncertainty factors are meant to bias the results conservatively so that exposures at the reference dose level will not result in adverse health effects.

Toxicity values derived from oral administered dose studies have been converted to absorbed dose toxicity values for use in evaluating the dermal contact pathway. This is considered a more accurate approach than using unadjusted oral toxicity values for the dermal pathway. Uncertainty is introduced in the use of the GI absorption factors. Limited information is

available on the GI absorption of some analytes and many have no information at all. In addition, no adjustments have been made for the medium of exposure (e.g., when the medium of exposure in the site differs from the medium of exposure assumed by the toxicity value). The uncertainty associated with using the absorbed dose toxicity values for the dermal pathway is moderate and the bias unknown.

Lifetime cancer risk estimates are provided for exposure to chemical constituents and are compared to the CERCLA target risk range of 10^{-6} to 10^{-4}. Radiological risk slope factors have been developed primarily using data from groups such as the Japanese atomic bomb survivors. These individuals received large doses of radiation over a short period of time. By contrast, potential receptors in this assessment receive relatively small radiological doses over a long period of time. Although cancerous effects have only been detected at doses several orders of magnitude larger than those estimated at the Site, it is assumed that the slope factors apply to both large and small radiological doses. Non-radiological CSFs are developed mostly from animal studies, and slope factors for radionuclides and non-radiological incorporate several differences that may result in incompatibility. USEPA, therefore, acknowledges a large (undefined) uncertainty in risk estimates and recommends that radiological and chemical risks be presented separately (USEPA 1996a).

A series of reports published by the National Research Council's Committee on the Biological Effects of Ionizing Radiation (BEIR) lists additional uncertainties resulting from the use of CSFs for radionuclides. BEIR reports point out that cancer risks from exposure to radionuclides at environmental levels (typical background radiation produces approximately 300 mrem/yr) are very difficult to distinguish from background cancer rates. In addition, the calculation of CSFs is based on radium dial painter studies, atomic bomb survivor studies, each considering doses many orders of magnitude higher than those received at environmental levels. The applicability of the linear no-threshold model has been debated by many professional societies. However, the linear no-threshold model (i.e., assuming risk is linear with exposure and is possible for even the smallest doses) has been adopted by all relevant United States regulating agencies. Using this model, risks at environmental levels are calculated even at dose levels a small fraction of background.

An additional area of uncertainty is exposure to multiple chemicals. Toxicological criteria are developed for individual chemicals. Potential interactions between chemicals could occur, leading to uncertainty in the risk estimates for multiple-chemical exposures. The risk assessment assumes that toxicity is additive across chemicals. This assumption would underestimate risk for chemicals that are synergistic or potentiometric with regard to toxicity, and overestimate risk for chemicals that are antagonistic with regard to toxicity. In addition, if chemical toxicological mechanisms differ or affect different organ systems, the assumption of additivity is conservative.

There are some chemicals for which no toxicity value exists and for which little information is available. Therefore, a quantitative risk estimate cannot be calculated for these chemicals. For example, many chemicals are not evaluated for the inhalation pathway because of limited inhalation-based toxicological information. The lack of toxicity information for some chemicals contributes to the underestimation of risks.

Cancer and non-cancer risks are summed in the risk characterization process (separately for carcinogens and non-carcinogens) to estimate potential risks associated with the simultaneous exposure to multiple chemicals. In the case of carcinogens, this gives carcinogens with a Class B or Class C weight-of-evidence the same weight as carcinogens with a Class A weight-of-evidence. It also equally weights slope factors derived from animal data with those derived from human data. Uncertainties in the combined risks are also compounded because RfDs and cancer slope factors do not have equal accuracy or levels of confidence and are not based on the same severity of effect.

In October 1999, Washington State University, under contract to the USACE, published a report titled *Determination of the In Vitro Dissolution Rates of Selected Radionuclides in Soils* and Subsequent ICRP 30 Solubility Classification for Dosimetry (sic) that may be used to support radiological dose and risk estimates. In vitro dissolution rates are broken into three Classes: D, W and Y with Class D being the most soluble and Class Y being the least soluble. RESRAD assumes by default that all radionuclides are present as Class Y because Class Y would cause the calculated dose and risk estimates to be higher. RESRAD models can be adjusted to reflect the site-specific conditions, if appropriate. Of the three radionuclides studied, Th-230 is found to be Class Y and only U-238 demonstrates Class W or D characteristics. However, U-238 also shows

some Class Y characteristics. To be conservative (i.e., to assure that the calculated dose and risk are not underestimated), all radionuclides including U-238 are modeled with a Class Y solubility (the RESRAD default).

4.6.4 Uncertainties in Risk Characterization

Uncertainties in the EPC estimation, exposure assessment, and toxicity assessment affect the degree of confidence in the assessment of risks. If the uncertainty in the EPC is low and the risk-driving chemical is a known human carcinogen (Class A), the corresponding uncertainty in the risk characterization is considered low. For cases where the EPC uncertainty is low, but the toxicity criteria are more uncertain, the corresponding uncertainty is considered low to moderate. Finally, if the EPC uncertainty is moderate to high, then the corresponding uncertainty in the risk characterization is considered moderate to high.

Combining the upper bound exposure assumptions, upper bound toxicity assumptions, and upper bound exposure concentrations, as in the RME approach, is a conservative approach typically utilized in risk assessment. This approach assumes, for example, that individuals who are most sensitive to the potential cancer effects of a chemical will also have a breathing rate and exposure duration (e.g., time at one residence) that exceeds most of the population. With numerous upper bound exposure assumptions combined, the risk is typically overestimated for the population. The corollary is that virtually all potentially exposed individuals will have a much lower level of potential risk than that which is estimated by the conservative assumptions employed in this assessment.

Uncertainties in any phase of the risk analysis are reflected in the risk estimates. Some uncertainty is associated with the summation of risks and HQs for multiple chemical constituents. As stated in RAGS (USEPA 1989a), “The assumption of dose additivity ignores possible synergisms or antagonisms among chemicals, and assumes similarity in mechanisms of action and metabolism”. However, summing risks and HQs for multiple substances in this risk assessment provides a conservative estimate.

4.7 Human Health Risk Assessment Summary

This BRA report presents the potential health impacts to human receptors from exposure to both radiological and chemical contamination present at DuPont Chambers Works Site. Past

operations at the Site have resulted in releases of chemicals and radionuclides to environmental media that may pose risks to human receptors. The risk assessment addresses potential exposures to industrial worker, construction worker, utility worker, maintenance worker and potential future hypothetical onsite residential receptors. Among them, the industrial worker scenario was considered as the potential future RME scenario for the site. The intent of the RME scenario was to focus the assessment on a conservative exposure that represents the maximum exposure that is reasonably expected to occur (USEPA 1989a). Potential exposures to radiological and chemical constituents detected in surface and subsurface soils, groundwater, surface water and sediment have been evaluated for various exposure pathways as presented in Section 4, Figures 4-1 through 4-5.

Review and analysis of the site data involved the following processes: (1) data validation and selection for use in the risk assessment; (2) selection of COPCs; and (3) calculation of EPCs for use in calculating both radiological and non-radiological dose and risk assessments.

For radiological COPCs, RESRAD (version 6.3) was used to perform radiological dose and risk assessment to all five receptors for contamination that are present in the soil. USEPA's RAGS equations were used to performed radiological dose and risk assessment for contamination that is present in surface water, sediment and groundwater. For chemical COPCs, standard USEPA's RAGS equations and ASTM Risk Based Corrective Action (RBCA) equations were used to perform chemical risk assessment for all five receptors present at the site.

The results of both radiological and chemical dose and risk assessments for each EU were then compared against their corresponding acceptable dose and risk criteria. The acceptable standards or acceptable dose and risk levels have been established by regulatory agencies. For example, the State of NJ established an acceptable dose limit of 15 mrem/yr for radiological constituents present at the site. The USEPA has established an acceptable risk range for Superfund sites. The NCP (40 CFR 300) indicates that lifetime incremental cancer risks posed by a site should not exceed a range of one in one million (1×10^{-6}) to one in 10,000 (1×10^{-4}) and noncarcinogenic chemicals should not be present at levels expected to cause adverse health effects (i.e., a HI greater than one).

Table 4-13 presented the results of maximum radiological dose and risk assessments for each receptor scenario at each EU. The results of dose and risk assessments were highlighted when they exceeded their corresponding dose and risk criteria.

Table 4-13: Results of Radiological Dose and Risk Assessment

Receptor Scenarios	Category	EU 1	EU 2A	EU 2B	EU 3A	EU 3B
Industrial Worker	Dose (mrem/yr)	6.2	1	0.7	0.02	**18.5**
	Risk	1E-04	3E-05	3E-06	3E-06	**4E-04**
Construction Worker	Dose (mrem/yr)	**69.3**	1.8	1.7	7.6	**27.1**
	Risk	4E-05	5E-06	3E-06	8E-06	1E-05
Utility Worker	Dose (mrem/yr)	**25**	0.6	0.6	3	10
	Risk	1E-05	2E-06	9E-07	3E-06	5E-06
Maintenance Worker	Dose (mrem/yr)	2.5	0.1	0.1	0.15	1.1
	Risk	4E-05	7E-06	6E-07	1E-05	2E-05
Residential Receptor	Dose (mrem/yr)	**1547**	2.6	2.4	**16.2**	**75.7**
	Risk	**1E-02**	**2E-04**	2E-05	**5E-04**	**1E-03**

The results of the radiological risk assessments for both current and future receptor scenarios showed that among all receptors, the maximum risk to industrial worker scenario at EU 3B exceeded the CERCLA acceptable target risk range. Furthermore, the results of the radiological dose assessments show that the maximum doses for construction worker and utility worker at EU 1, and the maximum doses for industrial worker and construction worker at EU 3B exceeded the NJ dose limits. Therefore, remedial action may be required for those two EUs. The results of radiological dose and risk assessments for both current and future receptor scenarios showed that the maximum dose and risk did not exceed their corresponding acceptable dose and risk criteria for EU 2A, EU 2B and EU 3A. Therefore, no further action will be required for those EUs. The results of maximum dose and risks for residential receptors show that both the doses and risks exceeded their corresponding dose and risk limit for all EUs. However, there is no current residential use or reasonably expected future residential use at the site. The results of assessments for the residential scenario were evaluated only for comparison purposes.

Table 4-14 presented the results of maximum chemical risk assessments for each receptor scenario at each EU. The results of risk assessments were highlighted when they exceeded their corresponding risk criteria.

Table 4-14: Results of Chemical Risk Assessment

Receptor Scenarios	Risk Type	EU 1	EU 2A	EU 3A	EU 3B
Industrial Worker	Carcinogenic Risk	2E-05	2E-05	2E-05	**3E-04**
	HI	0.5	0.1	0.03	0.1
Construction Worker	Carcinogenic Risk	2E-05	3E-06	1E-05	**1E-03**
	HI	**4.9**	0.7	**3.1**	**5.7**
Utility Worker	Carcinogenic Risk	7E-06	1E-06	5E-06	1E-03
	HI	**1.8**	0.3	**1.1**	**2**
Maintenance Worker	Carcinogenic Risk	1E-05	2E-06	1E-05	2E-05
	HI	0.1	0.02	0.1	0.2
Residential Receptor	Carcinogenic Risk	**5E-03**	**1E-02**	**2E-02**	**4E-02**
	HI	**175**	**166**	**1096**	**90**

The results of the chemical risk assessments for both current and future receptor scenarios showed that the maximum carcinogenic risks for industrial worker, construction worker and utility worker exceed the CERCLA acceptable cancer risk range at EU 3B. However, for non-cancer risk, the hazard indices exceeded the CERCLA acceptable risk limit of one for both construction worker and utility worker at EU 1, EU 3A, and 3B. Among all non-radiological COPCs, two metals (antimony and nickel), three SVOCs (benzo (a) pyrene, benzo (a) anthracene, and azobenzene) and one PCB congener (aroclor 1254) were identified as the major risk contributors for the site. For EU 2A, the maximum carcinogenic and HI did not exceed their corresponding acceptable risk criteria for all current and future receptor scenarios. Therefore, no further remedial action will be required for EU 2A. The results of chemical risk assessment for residential receptors showed that both the carcinogenic risk and hazard indices exceeded their corresponding acceptable risk limits for each EU. As mentioned earlier, the results of assessments for the residential scenario were evaluated for comparison purposes.

Lead is not a FUSRAP-related contaminant. Therefore, no chemical risk assessment was performed for lead, other than comparison to Region VI risk based screening value of 800 mg/kg during the chemical risk screening process.

There are a variety of factors that contribute to the uncertainty in risk estimates presented in this risk assessment. The use of site-specific factors can decrease uncertainty, but it persists in even the most site-specific risk assessments. This inherent uncertainty affects the level of confidence which can be placed in the final results; however, because the assumptions used in the exposure and toxicity assessments tend to be health-protective and conservative in nature, the estimated risks are likely to exceed the most probable risk posed to potential receptors at the site.

5.0 SCREENING LEVEL ECOLOGICAL RISK ASSESSMENT

A SLERA is a process for evaluating the likelihood that releases of chemicals from contaminated media may adversely affect ecological receptors. The scope of this SLERA is to determine the potential for adverse ecological impacts resulting from exposure to radionuclides and chemicals released to the environment through past site operations related to the DuPont Site. The SLERA provides information that is intended for use to determine: a) whether ecological risks at the site are negligible, b) if further information and evaluation are necessary to better define potential ecological risks at the site, or c) determine if mitigation should be done without further evaluation.

USEPA's Region VI developed an Ecological Exclusion Worksheet and Ecological Assessment Checklist to determine whether or not further ecological evaluation is necessary for an affected property. This report utilized that worksheet and checklist for each EU prior to performing any SLERA for any EU.

This SLERA has been developed to generate a preliminary quantitative estimate of risks posed by potentially contaminated on-site surface soil, surface water, and sediment to the ecosystems on and in the vicinity of the site. The SLERA identifies receptors that are particularly at risk and also provides information about the relative magnitude of risk from different analytes. For this SLERA, future risks are assumed to be the same as current risks presented here; however, for some chemicals, this may be overly conservative due to degradation.

The SLERA was prepared primarily in accordance with USEPA's *Ecological Risk Assessment Guidance for Superfund* (ERAGS) (USEPA, 1997b), USEPA's *Wildlife Exposure Factors Handbook* (USEPA, 1993c), and USEPA Region 5 supplemental ecological information and data. Additional guidance documents and information obtained from the scientific literature are cited as appropriate.

Generally, the SLERA consists of performing the following seven tasks:

- *Characterization of the Ecological Setting*: This step involves conducting a site visit to evaluate site conditions and the identification of potential habitat for terrestrial and

aquatic receptors, as well as review of pertinent guidance and published literature regarding the potential presence of certain sensitive species for the regional area.

- *Selection of Stressor*: This section of the SLERA identifies chemical constituents potentially originating from the site that may pose adverse impacts to the terrestrial and aquatic environments. Chemicals detected in environmental media are compared to published screening concentrations (also known as benchmarks) to derive a list of chemicals of potential ecological concern (COPECs) to be evaluated further in the SLERA process.
- *Screening-Level Problem Formulation*: This process includes a preliminary review of available information in order to identify the focus of the SLERA and develop a plan for ecological risk characterization. A CSM is the final product of the problem formulation step which identifies habitats and categories of potential receptors, as well as the potential exposure pathways to be further evaluated.
- *Screening-Level Ecological Exposure Assessment*: This process includes further identification of potential exposure pathways (i.e., the course a stressor takes from the source to the receptor) to be evaluated, selection of pertinent ecological receptors, and quantification of exposure (i.e., chemical intake).
- *Screening-Level Ecological Effects Assessment*: This process provides information on the toxicity of the chemical stressors to the selected ecological receptors based upon a review of pertinent guidance and the scientific literature.
- *Screening-Level Risk Characterization*: This process integrates the Exposure Assessment and Effects Assessment to develop an overall characterization of ecological risk.
- *Uncertainty Analysis*: This process addresses potential sources of uncertainty in the SLERA and discusses how assumptions used in the analyses may affect the conclusions.

5.1 Results of Ecological Exclusion Criteria and Ecological Assessment

Initially, an ecological exclusion criteria worksheet and ecological assessment checklist were completed for each EU. The process involves: 1) collecting information related to the EU, its operation, physical site characteristics, ecological habitats and receptors utilizing the Ecological

Exclusion Criteria Worksheet and determining if incomplete or insignificant exposure pathways exist at the EU that eliminate the need for further ecological evaluation, and 2) if an area cannot be excluded from further evaluation, collecting more detailed information about ecological areas utilizing the Ecological Assessment Checklist to assist in further ecological risk evaluations. If the affected property meets the exclusion criteria, no further evaluation of ecological risk will be required. If the affected property does not meet the exclusion criteria, then SLERA will be performed for the EU.

Appendix H presents the worksheet and checklist for each EU. The results of the ecological assessments for each EU showed that further ecological evaluations are required for two EUs – EU 2A (CDD) and EU 3A (Historical Lagoon A). A SLERA was performed for those EUs. The results also showed that no further ecological evaluation will be required for all other EUs. The reasons for exclusion for each EU were based on the absence of ecological habitat, and are summarized in the following.

- The EU 1 (AOC 1 and AOC 2) consists of an industrial area that is covered with gravel and pavement. The Former Buildings 845 and the 708 were demolished, and both areas are currently used as parking lot.
- The EU 2B (AOC 5) is completely covered by pavement or buildings. The Former Building J-16 was demolished and the soils underneath that building were excavated. Subsequently Building J-26 was built over the footprint of the former building in that same area.
- The EU 3B (AOC 6) was used as a disposal area for solvent and lubricant production. This area is bounded by truck maintenance yards, gravel lots, and warehouse area, and is currently used as a road way and for parking.

As mentioned earlier, the current land use for the site is industrial and the reasonably expected future land use will remain industrial. Each of the excluded EUs listed above do not provide undisturbed, natural, or vegetated habitat for ecological receptors. In addition, none of those EUs have been, is, or will be managed for ecological purposes. Because of the low probability of significant ecological effect on local populations, and the lack of unique, rare and critical

habitat at the site, these three EUs were excluded from further ecological evaluation and no SLERA was performed.

5.2 Characterization of the Ecological Setting

Ecological site reconnaissance was performed several times as part of the RI for the site. The reconnaissance included observations of plant and animal species at the site and some of the adjacent properties. Information also was collected during the reconnaissance that aided in the completion of the Ecological Exclusion Worksheet and Ecological Assessment Checklist. This ecologist checklist was also helpful in characterizing the site for problem formulation purposes. In addition, historical aerial photographs and anecdotal information gathered from the site visits and field investigation observations were utilized to define ecological settings for both EU 2A and EU 3A as summarized in the following sections.

The open portion of the CDD is approximately 1,600 ft long. Historically, the direction of flow along the ditch was eastward from a point west of Kinetic Road and the CDD discharged into Basin B. Water in the B Settling Basin is treated onsite and then discharged to the Delaware River via permitted Outfall D001. Lagoon A historically received wastewater from Chambers Works, including that from MED operations. The CDD connected the lagoon with MED operations areas. Lagoon A was comprised of three settling basins – A, B, and C. Basins A and C are no longer in use and have undergone RCRA closure. Basin A has been stabilized in-situ and Basin C has been drained and capped. Only a portion of Basin B is in current use. The lower half of Basin B, approximately eight acres, is currently being used for site storm-water collection. The B Basin is isolated by the outfall structure that prevents aquatic communities in the river from migrating into the basin. It is also a part of SWMUs 14 and 15 and has undergone remediation and received clean closure approval. However, the basin is located outside of the MED impacted area. No ecological evaluation was performed for the basin.

There is no surface water body present in EU 3A. No surface water or sediment samples were collected from EU 3A.

The surface soils present at both EU 2A and EU 3A support various types of microscopic algae and a variety of macrophytic species, primarily scrub vegetation, shrubs, and grasses. The upper

portion (approximately 700 ft) of the open CDD (EU 2A) has no riparian vegetation or other habitat features that would attract mammals or birds, other than occasional incidental visits. The lower portion (approximately 900 ft) of the CDD presents considerably different habitat. There is considerable streamside vegetation throughout this reach, including wetland vegetation. The CDD in this reach is narrow and relatively deep. Occasional visits from migratory birds and small mammals would occur in areas of EU 3A (SWMU 5 Area) because of its proximity to the River. Although SWMU 5 area is a capped area (clay) there are grasses and reeds between SWMU 5 and river. This area is infrequently maintained/ mowed. This area could provide temporary, occasional habitat for wildlife that is tolerant of disturbed environments.

Surface water and sediment at EU 2A support various types of aquatic vegetation, algae, invertebrates, fish, birds, and mammals. In the shallower, upper portion of the CDD, numerous small fish were observed that appeared to be mummichog (*Fundulus heteroclitus*), a killifish that is common and abundant in the mid-Atlantic region. No other animals were observed in the upper portion of the CDD, although bird and mammal tracks were noted on the bank of the ditch in one location. The Sitewide RI reported observations of frogs in the CDD as well as fish (CABRERA 2011b).

Typical bird species inhabiting the area around the CDD are the surface feeding predators such as herons that may feed on fish, invertebrates, and seed-eaters. Mallard ducks (*Anas platyrhynchos*) also feed on vegetation and invertebrates in these areas. A number of birds were observed in and near the lower reach of CDD. European starlings (*Sturnus vulgaris)* and mourning doves (*Zenaida macroura)* were common. A belted kingfisher (*Ceryle alcyon)*, a northern mockingbird (*Mimus polyglottos)*, and an Eastern phoebe (*Sayornis phoebe*) were observed in the riparian vegetation in the lowermost portion of the CDD. Outside of the immediate CDD, but in proximity, one, and possibly two, kestrels (*Falco sparverius)* were observed. Because of the proximity to a wooded marshy area to the north, transient predatory birds are expected to utilize the CDD from time to time.

Small mammals are seasonal inhabitants that feed on grasses, invertebrates, fish, and other small mammal and birds. Several small mammals such as the meadow vole, *Microtus pennsylvanicus*, a herbivore, are expected to occur in the drainage ditch. One predatory mammal that may forage

in the CDD and Basin B area is the omnivorous raccoon, *Procyon lotor*. Because of the limited terrestrial habitat in the area of the CDD and Basin B, the primary mammals of concern are limited to small mammals (such as the meadow vole) and the raccoon.

No census has been conducted for animal populations in the lagoon area. However, the areas likely would provide habitat for animals tolerant of disturbed environments. Some of the common mammals observed at the site are: short-tailed shrew (*Blarina brevicauda*), the Eastern Cotton-tailed Rabbit (*Sylvilagus floridanus*), white-footed mouse (*Peromyscus leucopus*) and white-tailed deer (*Odocoileus virginianus*). Some common birds include: American robin (*Turdus migratorius*), European starling (*Sturnus vulgaris*), Canada goose (*Branta canadensis*), mallard duck (*Anas platyrhynchos*), and great blue heron (*Ardea herodias*). In addition, numerous arthropod species (insects, spiders, etc.) are likely present.

According to the U.S. Fish and Wildlife Service (USFWS), the federally listed (threatened) sensitive joint-vetch (*Aeschynomene virginica*) plant has been known to exist in the vicinity of the project site (USDI 2007). Sensitive joint-vetch inhabits the inter-tidal zone of freshwater tidal river segments, typically in areas where sediments accumulate and extensive marshes are formed. These habitats are flooded twice daily by tidal action, and occur only along stretches of river close enough to the coast to be influenced by the tides, yet far enough upstream that river water is fresh or slightly brackish. Bare or sparsely vegetated substrate appears to be a habitat requirement for this species, which usually grows on river banks within two meters (6.6 ft) of the low water mark. The plant can also occur on accreting point bars and in sparsely vegetated microhabitats of freshwater tidal marsh interiors, such as low swales and areas of muskrat (*Ondatra zibethicus*) eat-out. This species is typically found in areas where plant diversity is high and annual species are prevalent. Available mapping shows freshwater tidal wetlands on the northern portion of the DuPont property. In addition, USFWS mentioned that there is a known nest site of the peregrine falcon (*Falco peregrinus*) immediately adjacent to the DuPont property (USDI 2007). While the USFWS removed the peregrine falcon from the List of Endangered and Threatened Wildlife and Plants in 1999, removing all protections provided to the species under the Endangered Species Act (ESA), the peregrine falcon continues to be protected by the Migratory Bird Treaty Act (40 Stat. 755; 16 U.S.C. 703-7I3), and under NJ

regulations as a State listed (endangered) species. The State listed (endangered) plant, Chickasaw plum (*Prunus angustifulia),* is also known to occur in the vicinity of the property.

DuPont performed a baseline ecological evaluation (BEE) for DuPont Chambers Works Site (DuPont Corporate Remediation Group 2006). The BEE was completed in accordance with the NJDEP Technical Requirements for Site Remediation (Tech Regs) 7:26E-3.11. DuPont's BEE evaluated both the Chambers Works facility and the former Carneys Point site. However, no data evaluation was performed in any of the FUSRAP AOCs. The evaluation did not provide any information regarding the presence of ecological receptors and habitat within these areas. The ecological evaluation identified no environmental sensitive areas in the Chambers Works manufacturing areas. The report concluded that the site does not contain appreciable ecological habitats, and no further ecological evaluation is required for the site.

5.3 Selection of Stressor

Four different types of screens – (1) initial data reduction, (2) weight-of-evidence, (3) background screen, and (4) ecological risk screens - were performed to identify COPECs for the site. The first three screens utilized the same procedures that were used for the HHRA.

No ecological risk screen was performed for radiological COPECs. Ecological screening values for radionuclides are not available. Ecological risk screen was only performed for chemical constituents. Under the ecological risk screen, the ecological EPC was determined for each chemical constituent that passed the three screens listed above. For detected constituents, either the maximum detected concentration, or the 95% UCL, whichever was less, was selected as the ecological EPC for the purposes of comparison to multiple published ecological screening/benchmark values. Ecological EPCs found to exceed the most conservative (i.e., lowest) published screening value, for each media, were retained for further evaluation in the SLERA.

Once the EPCs were determined, COPECs were selected for each potentially affected medium and population by calculating a preliminary HQ. The preliminary HQ was obtained by dividing the chemical EPC by the appropriate screening criterion, as represented by the following equation:

Preliminary HQ = EPC / Ecological Screening Value

For inorganic constituent, the latest versions of the USEPA's ecological screening values were utilized. However, USEPA's soil screening values are available for a very limited number of organics. Therefore, ecological screening values developed by USEPA's Region 3, 4, and 5 were used for those organic chemical constituents. A chemical was considered a COPEC and subject to a more detailed evaluation in the SLERA if the preliminary HQ exceeded one. COPECs were identified for each potentially affected medium (i.e., surface soils, sediment, and surface water) at the site. Published sources of ecological screening values utilized in this SLERA are presented below:

- USEPA Headquarters, 2005 (a – i). *Ecological Soil Screening Levels* (for various inorganics). Office of Solid Waste and Emergency Response (OSWER) Directives, Washington, D.C.
- USEPA Headquarters, 2006b. *National Recommended Water Quality Criteria*. Office of Water. Office of Science and Technology. Washington, D.C.
- USEPA Region 5, 2003c. *Ecological Screening Values and Freshwater Screening Benchmarks*. Chicago, IL.
- USEPA Region 4, 2001. *Supplemental Guidance to RAGS: Region 4 Bulletins, Ecological Risk Assessment.* Atlanta, GA.
- USEPA Region 3, 2006c. *Freshwater Screening Benchmarks and Sediment Screening Benchmarks*. Philadelphia, PA.

Appendix I presents the results of the screening for radionuclides, inorganics, volatile organics, semi-volatile organics, PAH, and PEST/PCBs in surface soil, surface water, and sediment. COPECs demonstrating preliminary HQs greater than one, for each media, were retained for further evaluation in the SLERA and are summarized in Table 5-1.

Table 5-1: List of COPECs for Various Environmental Media

COPECs	Surface Soil		Surface Water	Sediment
	EU 2A	EU 3A	EU 2A	EU 2A
RADIONUCLIDES				
Ra-226			✓	
Ra-228	✓			
Th-228	✓			
Th-230	✓	✓	✓	✓
Th-232	✓			✓
U-234	✓	✓	✓	✓
U-235	✓	✓	✓	✓
U-238	✓	✓	✓	✓
METALS				
Antimony	✓	✓		✓
Arsenic				✓
Barium	✓			
Cadmium	✓			✓
Copper	✓	✓		✓
Lead	✓	✓		✓
Mercury	✓	✓		✓
Nickel		✓		✓
Selenium	✓	✓		
Silver				✓
Vanadium	✓	✓		
Zinc	✓			✓
VOCs				
1,2,3-Trichlorobenzene		✓		
1,2,4-Trichlorobenzene		✓		
1,2-Dichlorobenzene	✓	✓	✓	✓
1,4-Dichlorobenzene	✓	✓		✓
Acetone				✓
Benzene		✓		✓
Carbon disulfide			✓	✓
Carbon tetrachloride			✓	✓
Chlorobenzene	✓	✓	✓	✓
Chloroform	✓		✓	✓
Ethylbenzene		✓		
Toluene		✓		
SVOCs				
2-Chloronaphthalene		✓		
4-Chloroaniline				
1,3-Dichlorobenzene				✓
2,4-Dinitrophenol				✓
2,4-Dinitrotoluene				✓
2-Methylnaphthalene				✓
Acenaphthene				✓
Acenaphthylene				✓
Anthracene	✓	✓		✓
Benzo(A) Anthracene				✓
Benzo(A) Pyrene	✓	✓		✓
Benzo (B) Fluoranthene				✓

COPECs	Surface Soil		Surface Water	Sediment
Benzo(G,H,I)Perylene				✓
Benzo(K) Fluoranthene				✓
Benzoic Acid				✓
Bis(2-Ethylhexyl) Phthalate		✓		✓
Chrysene		✓		✓
Dibenz(A,H) Anthracene				✓
Dibenzofuran				✓
Fluoranthene	✓	✓		✓
Fluorene				✓
Hexachlorobenzene				✓
INDENO(1,2,3-C,D)PYRENE				✓
Naphthalene	✓	✓		✓
Nitrobenzene				✓
Phenanthrene	✓	✓		✓
Pyrene	✓	✓		✓
PCBs				
PCB-1016 (Aroclor 1016)				✓
PCB-1260 (Aroclor 1260)	✓	✓		✓

5.4 Screening-Level Problem Formulation

This SLERA is concerned with evaluation of surface soils, surface waters and sediments. For that purpose, ecological reviews of the literature, and ecological observations were documented during site reconnaissance. While it seems likely that this particular site does not support high species densities, nor ecologically sensitive species, occasional use of these areas by species such as red-tailed hawks and raccoons, along with their prey, are possible. Therefore, potential terrestrial receptors for ecological consideration in the SLERA appear to be small terrestrial mammals and avian species.

Habitats included in this SLERA are the on-site surface soils comprised of short grasses. The development of naturally-appearing, disturbed and diverse vegetation type offers habitat, cover, and a food source necessary for a variety of animals.

Surface water and sediment samples collected from the CDD serve to provide preliminary information relative to potential constituents that may be observed in aquatic environments present at the Site. This area may be used by rodents, raccoons, opossums, small raptors (kestrels), and mammalian predators (e.g., foxes). Species typically associated with aquatic environments also may be present, such as fish, ducks, and birds which prey on aquatic species (e.g., belted kingfisher).

5.4.1 Scope of this SLERA

The scope and focus of this SLERA have been developed based on consideration of specific objectives of the RI. The level of effort for a SLERA may range from relatively simple to complex and resource intensive. However, as stated in the *Guidelines for Ecological Risk Assessment* (USEPA, 1998c), the most detailed assessment is neither applicable nor necessary for every site under investigation. Outlined below is a summary of information pertaining to the complexity of the SLERA.

Analytical Data to be Evaluated - This SLERA relied on analytical data collected during the RI field investigations of the Site.

Assessment Endpoints - This SLERA focused primarily at the individual level, as opposed to populations, communities, or ecosystems.

For radiological constituents, the decision rules associated with assessment endpoints are stated quantitatively in terms of absorbed dose to terrestrial and aquatic species. The International Atomic Energy Agency (IAEA 1992) established the chronic dose rates for terrestrial animals and aquatic invertebrates. If the absorbed dose due to ionization radiation does not exceed their corresponding dose limit, no further evaluation will be required for that site.

For chemicals, the decision rules associated with assessment endpoints are stated quantitatively in terms of HQs. If HQ is less than or equal to one, the risk is considered acceptable (protective of the ecological receptor). Any HQ greater than one indicates that the COPEC qualifies for further investigation of the actual likelihood of harm, i.e., a baseline risk assessment may be needed. The final ecological COCs are selected only after additional evaluation of the conservatism of exposure assumptions, toxicity thresholds, and uncertainties.

Tiered Assessment - This SLERA was performed using a tiered assessment approach. Constituents that potentially pose adverse impact to the environment (i.e., COPEC or stressors) were identified using a risk-based screening approach (described above in Section 5.3). Once the COPECs were selected, the following steps were performed sequentially to assess ecological risk:

- Conservative Approach - The conservative approach consists of evaluating the receptor's chemical intake as being from contact with the primary environmental media of concern (i.e., soil for terrestrial receptors and surface water/sediment for aquatic receptors) along with their primary food source being solely earthworms. Utilizing the earthworm as the primary food source ensures a conservative approach because the available uptake and bioconcentration factors for chemicals to earthworms result in earthworms being the most potentially contaminated food source. Receptors are also considered to spend their entire life cycle on site with no regard to their respective home ranges. An HQ for each COPEC was determined by dividing the average daily dose with respect to the NOAELs dose. At this step, chemicals which result in HQs less than one can be eliminated from further evaluation and those with HQs greater than one move up to the next tier.
- Varied Diet (VD) and Area Use Factor (AUF) Approach – For this evaluation, receptors were evaluated using the varied diet approach plus consideration of the duration of time they may be likely to spend on site by virtue of their respective home ranges. For this evaluation, receptors were evaluated with chemical intakes obtained from the more typical diets for each species. This tier of evaluation more closely resembles the receptors' food web/chain patterns. At this stage, a HQ for each COPEC was determined by dividing the average daily dose with respect to the lowest observed adverse effects levels (LOAELs) dose. Chemicals which result in HQs less than one at this step can be eliminated as not likely to pose an adverse risk to the pertinent ecological receptors. Those chemicals with HQs greater than one are retained as chemicals of ecological concern for which a decision point now exists in the SLERA process.

5.4.2 Ecological Conceptual Site Model

Figure 5-1 presents a graphical depiction of the ecological CSM developed for this SLERA to describe the relationships between stressors and receptors, including the pathways of concern to be evaluated. As shown, the media of concern for the Site include soil, surface water, and sediment.

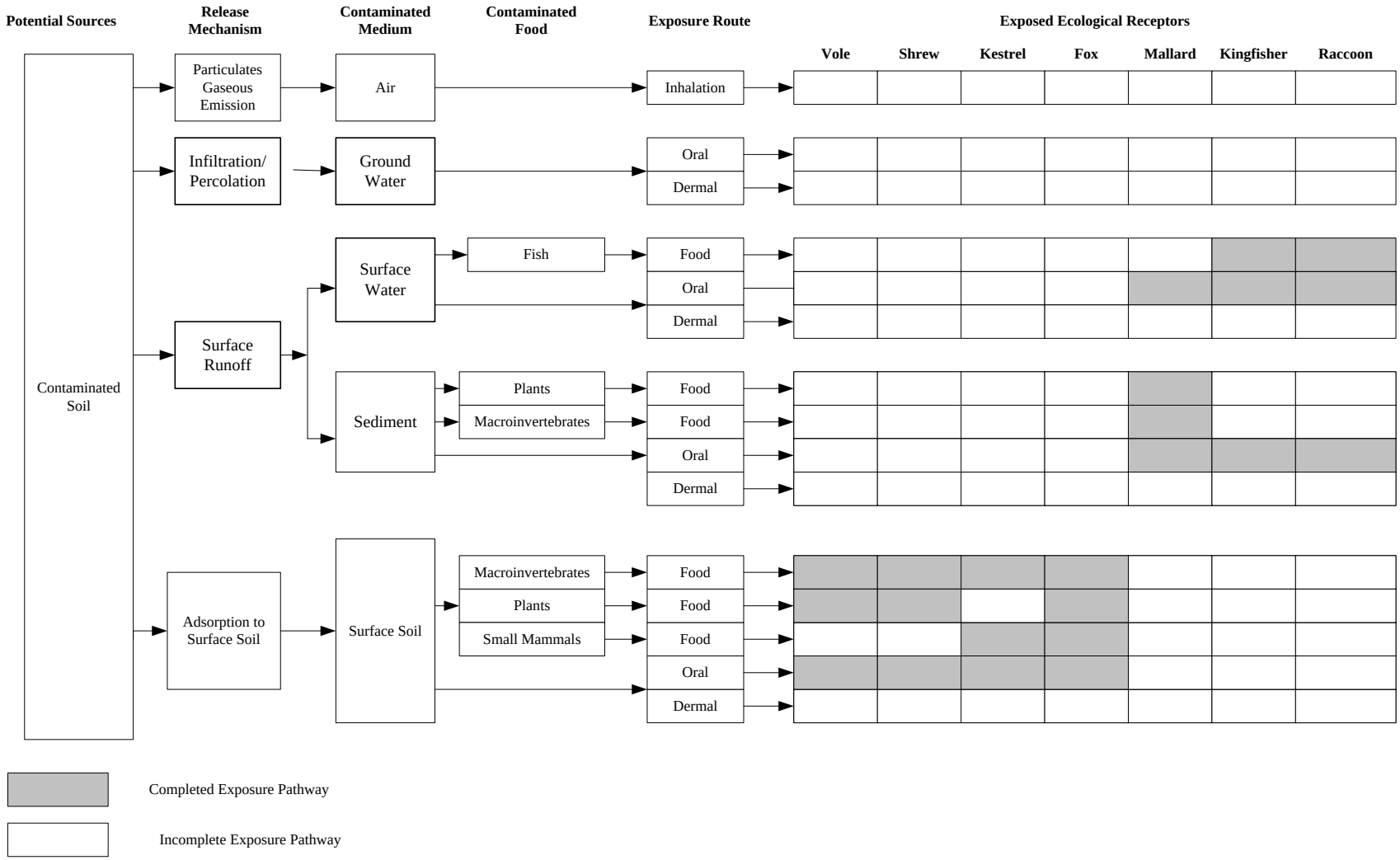
Exposure pathways for terrestrial receptors consist primarily of two components: soil and food webs/chains. Terrestrial receptors may potentially be exposed to COPECs in soils through inhalation; direct contact; incidental ingestion during feeding, burrowing, or grooming; and

ingestion of contaminated food/prey. It is unlikely that substantial amounts of chemicals would penetrate the dermal or chitinous layer of most organisms. In addition, information necessary for evaluating effects via dermal exposure is generally unavailable. Information necessary for evaluating effects via inhalation also is not generally available. Inhalation pathway is an insignificant pathway for ecological receptors. In addition, results of the HHRA showed that inhalation pathway is the least significant pathway for the media of concern associated with SLERA. Therefore the dermal exposure and inhalation pathways are shown as "incomplete" for all receptors in Figure 5-1.

Exposure pathways for aquatic receptors were assumed to consist primarily of three components: surface water, sediment, and food webs/chains. In the case of water column invertebrates (e.g., Daphnia, a zooplankton species), exposure to stressors in the water column is likely the primary exposure route. For this SLERA, it is assumed that benthic macro-invertebrates are exposed primarily to concentrations of stressors in sediment interstitial (pore) water. Although this is a simplifying assumption for benthic invertebrates, it is the basis employed by the USEPA for development of sediment quality criteria.

Potential exposure pathways for receptors inhabiting aquatic habitats may include respiration (uptake of stressors in surface water over the gill/water interface); ingestion of stressors in surface water; incidental ingestion of stressors in sediment when foraging; dermal contact with stressors in surface water and sediment; and ingestion of contaminated prey. Terrestrial species that prey on aquatic biota may be exposed to stressors in aquatic system through ingestion of contaminated prey, incidental ingestion of sediment when foraging, ingestion of surface water, and dermal contact with surface water. For this SLERA, it is assumed that the primary routes of exposure to stressors in aquatic habitats are through the ingestion of water, sediment, and food (either directly or through the food web).

Figure 5-1: Ecological Conceptual Site Model for DuPont Chambers Works Site



**Inhalation pathway was not evaluated in this SLERA.

5.5 Screening-Level Ecological Exposure Assessment

The exposure assessment of the SLERA more closely examines the potential pathways and routes of exposure of ecological receptors to stressors found in various environmental media. In addition, the exposure assessment addresses the magnitude, duration, and frequency of the exposure. The following sections include an evaluation of potential exposure pathways by which the ecological receptors may come in contact with chemical stressors, an evaluation of potential receptors; an overview of exposure profiles for receptors selected for this SLERA; and an estimation of magnitude of exposure.

5.5.1 Receptors and their Exposure

An ecological receptor is a species, or a group of species, that may potentially be affected by the presence of COPECs in the environment. The two types of ecological receptors evaluated in this SLERA include terrestrial receptors, based on exposure to COPECs detected in soils, and aquatic receptors, based on exposure to COPECs detected in sediment and/or surface water. While a multitude of ecological receptors were observed at Site, the selection of receptors for this SLERA was developed to represent a variety of potential feeding guilds, yet limited to species that are either potential prey species (e.g., voles and shrews), predator species at the top of a potential food chain (raccoon and red fox), and species in close association with the affected media (e.g., belted kingfisher and mallard).

Presented below are exposure profiles that have been prepared for species that have been selected as the focus of this SLERA based on available information provided in the *Wildlife Exposure Factors Handbook* (USEPA, 1993c). Information provided in the exposure profiles for each species includes qualitative descriptions of the species and available data necessary for exposure assessment. Life history parameters for the key receptor species are summarized in Table 5-2.

Meadow Vole (*Microtus pennsylvanicus*)

Habitat: Meadow Voles are small, herbivorous rodents that live in all areas of the United States with good grass cover. *Microtus* species are adapted to underground, terrestrial, and sometimes semi-amphibious habitats.

Food Habits: Meadow Voles consume green succulent vegetation, sedges, seeds, roots, bark, fungi, insects, and animals. Voles eat primarily green vegetation and only consume alternative foods when vegetation is less available. For the conservative approach, voles are evaluated as eating a diet consisting entirely of earthworms. However, the varied diet approach evaluation considers their diet to be mainly terrestrial plants.

Home Range: The vole's home range is dependent on season, habitat, population density, age and sex of the animal. The average home range, for both males and females, at varying times of the year, is 0.1 acre (0.066 hectares). Because of the small home range, they are evaluated as spending their entire life cycle in EU 2A and EU 3A and the area use factor approach for the vole is not necessary.

Short-Tailed Shrew (*Blarina brevicauda*)

Habitat: Shrews are small, insectivorous mammals that inhabit most regions of the United States. Shrews inhabit a variety of habitat types and are common in areas with abundant vegetative cover. They also need cool, moist habitats because of their high metabolic and water loss rates.

Food Habits: The shrew is primarily carnivorous; most species are primarily vermivorous (worm eating) and insectivorous, but some also eat small birds and mammals. As shrews have high metabolic rates, they can eat approximately their body weights in food each day. Stomach analyses indicate that insects, earthworms, slugs, and snails comprise most of the shrew's diet, while plants, fungi, millipedes, centipedes, arachnids, and small mammals are also consumed. Shrews were evaluated as eating a diet consisting entirely of earthworms, which represents the typical feeding patterns for shrews, therefore a varied diet approach evaluation is not necessary.

Home Range: The average home range, for both males and females at varying times of the year, is one acre (0.39 hectares). Because of the small home range, shrews are evaluated as spending their entire life cycle on EU 2A and EU 3A and the area use factor approach is not necessary.

Red Fox (*Vulpes vulpes*)

Habitat: Foxes inhabit many types of habitats: cropland, rolling farmland, brush, pastures, hardwood stands, and coniferous forests.

Food Habits: Foxes are primarily carnivorous, preying predominantly on mice, voles, other small mammals, birds, and insects. Foxes also feed on plant materials in summer and fall when fruits, berries, and nuts are abundant.

For the conservative approach, it was assumed that red foxes eat a diet consisting entirely of earthworms, assumed to be the most contaminated prey species. For chemicals requiring further evaluation, the varied diet approach considers the more typical diet of the fox as being comprised of 6% earthworms, 55% voles, 27% shrews, and 12% terrestrial plants (see Table 5-2).

Chemical concentrations in prey species (earthworms, voles, shrews, and plants) were estimated using equations and models developed by Oak Ridge National Laboratory (ORNL) (Sample et al., 1998). These prey species were selected for this SLERA since they represent various groups of potential prey species: Earthworms are representative of terrestrial invertebrates, voles are representative of small mammalian herbivores, shrews are representative of small mammalian insectivores/omnivores, and plants are representative of various terrestrial herbaceous species.

Home Range: The home range of individuals from the same family constitutes a family territory. Territory sizes range from less than 123 to over 7,410 acres (50 to over 3,000 hectares). The average home range of the red fox is approximately 250 acres (100 hectares) for an adult female in Wisconsin living in a diverse habitat. Male red foxes typically have home ranges five or more times greater than the female. The value of 250 acres was utilized as a conservative estimate of the home range of the red fox for this SLERA.

American Kestrel (*Falco sparverius*)

Habitat: The American Kestrel falcon inhabits in open and semi-open areas throughout North America, including open deserts, edges of groves, and even cities.

Food Habits: Kestrels prey on a variety of small animals, including invertebrates (worms, spiders, beetles and other large insects), amphibians, reptiles (frogs, lizards), and small- to medium-sized birds and mammals.

For the conservative approach, it was assumed that kestrels ate a diet consisting entirely of earthworms, the most contaminated prey species. For chemicals requiring further evaluation, the varied diet approach considers the more typical diet of the kestrel as being comprised of 50% earthworms, 25% voles, and 25% shrews.

Home Range: Foraging territories range from a few hectares in productive areas to hundreds of hectares in less productive areas. The average home range of a kestrel is approximately 370 acres (150 hectares). This value was selected for this SLERA, based on the results of a study conducted in agricultural areas in Illinois.

Mallard (*Anus platyrhynchos*)

Habitat: Mallards are aquatic birds that prefer areas which provide concealment from predators. The primary habitat requirement for nesting appears to be dense grassy vegetation at least a half meter high.

Food Habits: Mallards feed by dabbling and tipping up in shallow water, often filtering through soft mud for food. In winter they feed primarily on seeds and plant materials (leaves, buds, stems, and rootlets). In spring, females shift from a largely herbivorous diet to a more omnivorous diet, with a greater percentage of invertebrate food types.

For the conservative approach, it was assumed that the Mallards' diet consists entirely of invertebrates associated with surface water and sediment. For chemicals requiring further evaluation, the varied diet approach considers the more typical diet of the mallard as being comprised of 18.6% benthic macro-invertebrates and 81.4% aquatic plants.

Migration: Mallards tend to arrive at their wintering grounds in mid-September through early November and depart for their breeding grounds in March. For purposes of this risk assessment, mallards will be assumed to live in the vicinity of Site for the entire year.

Home Range: Each pair of mallards uses a home range. A value of 1,330 acres (468 hectares) is selected to represent the home range, based on the aforementioned study of mallards in potholes in south central North Dakota.

Belted Kingfisher (*Ceryle alcyon*)

Habitat: The Belted Kingfisher is typically found along rivers, streams, and along lake and pond edges. They nest in burrows in earthen banks that they dig using their bills and feet. They seem to prefer waters that are free of thick vegetation that obscures the view of the water and water that is not completely overshadowed by trees. They also prefer relatively clear water in order to see their prey and avoid waters that become turbid. Kingfishers also appear to prefer waters no deeper than two ft.

Food Habit: Kingfishers generally feed on fish that swim near the surface or in shallow water. Although they feed primarily on fish, they also sometimes consume large numbers of crayfish, and in fish shortages, have been known to consume crabs, mussels, lizards, toads, small turtles, snakes, insects, salamanders, newts, young birds, mice, and berries. For this SLERA, rather than evaluate the conservative approach with the kingfisher eating a diet consisting entirely of benthic macro-invertebrates, it was evaluated with a diet consisting entirely of fish. Since fish represents the typical food of the kingfisher, a separate evaluation for a varied diet was not necessary.

Home Range: Home range (territory size) for the kingfisher is measured in terms of length of aquatic shoreline. The average of reported territory size shoreline lengths for the kingfisher is 1.16 kilometer (km). As the approximate length of shoreline for the CDD is estimated at less than 0.5 km, the area use factor approach was evaluated for this SLERA.

Raccoon (*Procyon lotor*)

Habitat: The raccoon is the most abundant and widespread medium-sized omnivore mammal in North America. They are found near virtually all kinds of aquatic habitats including hardwood swamps, mangroves, floodplain forests, and freshwater and saltwater marshes. They use surface waters for both drinking and foraging.

Food Habits: Although primarily active from sunset to sunrise, raccoons will change their activity to accommodate the availability of food and water. They feed primarily on fleshy fruits, nuts, acorns, and corns but also eat grains, insects, frogs, crayfish eggs, and virtually any animal and vegetable matter. For the conservative approach, the raccoon was assumed to have a diet consisting entirely of fish.

Home Range: The home range of the raccoon encompasses both their foraging areas around waterways and their den. Adult male home ranges are generally larger than adult female home range. For purposes of this SLERA, the home range of raccoon are assumed to be approximately 385 acres (156 hectares), based on the average value reported for adult males and females in a study conducted in Michigan.

Table 5-2: Summary of Life History Parameters for Ecological Receptors [1]

RECEPTOR SPECIES	NIR (g/g-day)	WIR (g/g-day)	BW (kg)	$DC_{Soil/Sed}$	DC_{Invert}	DC_{voles}	DC_{Shrews}	DC_{Fish}	DC_{Plants}	HR (acres)
				(unitless)						
Meadow Vole	0.3	0.175	0.037	0.024	0.02	0	0	0	0.98	0.1
Short-tailed Shrew	0.6	0.223	0.015	0.05	1	0	0	0	0	1
American Kestrel	0.3	0.11	0.12	0.1	0.5	0.25	0.25	0	0	380
Red Fox	0.095	0.085	4.5	0.028	0.06	0.55	0.27	0	0.12	250
Mallard Duck	0.056	0.056	1.1	0.02	0.186	0	0	0	0.814	1330
Belted Kingfisher	0.5	0.11	0.147	0.1 - 0.6[2]	0	0	0	1.0	0	1.16[3]
Raccoon	0.286	0.08	6.25	0	0	0	0	1	0	385

(1) Source: USEPA, 1993c. *Wildlife Exposure Factors Handbook.*
(2) Range reported for shorebirds
(3) km of shoreline

NIR = normalized food ingestion rate; WIR = normalized water ingestion rate; BW = body weight
$DC_{Soil/Sediment}$ = proportion of soil or sediment in diet;
DC_{Invert} = proportion of invertebrates in diet; representative of terrestrial earthworms and aquatic benthic macroinvertebrates;
DC_{Voles} = proportion of voles (representative of small mammalian herbivores) in diet;
DC_{Shrews} = proportion of shrews (representative of small mammalian insectivores/omnivores) in diet;
DC_{Fish} = proportion of aquatic species (fish and invertebrates) in diet;
DC_{Plants} = proportion of plants in diet;
HR = home range.

5.5.2 Quantification of Exposure

5.5.2.1 Quantification of Exposure for Radiological COPECs

Exposure evaluation includes evaluating: (1) the exposure point concentrations in surface soil, surface water and sediment; and (2) the absorbed dose resulted from ionizing radiation exposures of receptors to radionuclides in those exposure media. RESRAD-Biota, version 1.21 was used to perform general screening and to determine receptor –specific absorbed dose associated with the ionizing radiation present at the Site (DOE 2004). The software was developed for implementing the DOE "Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" (DOE 2002).

The graded approach for evaluating radiation doses to aquatic and terrestrial biota is consistent with the standard ERA paradigm (USEPA 1998c). The first and simplest tier is a scoping assessment, which establishes the need for an SLERA. The second tier consists of a screening ERA, which is relatively simple and conservative in its application and assumptions. The third

tier is a definitive ERA, which provides a relatively detailed and realistic assessment of the nature and magnitude of risks. Level 1 ERA of RESRAD-Biota model was used for radiological ERA at DuPont Site.

The terrestrial and aquatic biota were selected as endpoints for the radiological assessment. Initially, under the level 1 ERA, the maximum detected concentration of the radiological COPEC was used as a source term. The maximum detected sampling results for different environmental media are divided by their corresponding media-specific biota concentration guides (BCGs) to determine the ratio of the contaminant concentration with respect to its BCG. A BCG is defined as the environmental concentration of a given radionuclide in soil or water that, under the assumptions of the model, would result in a dose rate less than one rad/day to aquatic animals or terrestrial plants or 0.1 rad/day to terrestrial animals. The resulting ratios were summed and compared to unity. If the sum of the ratio is less than one, the dose to the biota or terrestrial receptor is below the biota dose limit, indicating that the site has met the acceptability criteria and no further evaluation is required. However, if the sum of the ratios is greater than one, a Level 2 ERA analysis is performed.

Failure in a Level 1 ERA does not necessary imply harm to organisms. Instead, it is an indication that more realistic model assumptions may be necessary. For a Level 2 ERA, instead of maximum detected concentration, the minimum of either the maximum detected concentration or the 95% UCL of a radionuclide COPEC was used as source term. After applying the source term, if the sum of ratios is still greater than one, the graded approach recommends evaluating the next step. However, if the sum of ratios is less than one, no further evaluation is required. Appendix J presents the results of SLERA for radiological COPECs.

5.5.2.2 Quantification of Exposure for Chemical COPECs

The objective of exposure quantification is to describe the magnitude and pattern of exposure in a form that can be used in risk characterization (i.e., HQ) calculations. A summary of the parameters used in the exposure equations for each of the ecological receptor species is presented in Table 5-2 (Life History Parameters) and Table K-3-1 of Appendix K.

Information is provided below for methodology used to quantify chemical intake for terrestrial and aquatic pathways.

Terrestrial Pathways

For terrestrial pathways, the level of exposure was expressed in terms of the potential ADD using the following equation:

$$ADD_{pot} = ADD_{soil} + ADD_{food}$$

where:

ADD_{pot} = Potential Average Daily Dose from all sources (mg/kg-day)
ADD_{soil} = Average Daily Dose from soil (mg/kg-day)
ADD_{food} = Average Daily Dose from food (mg/kg-day)

Described below is the general equation that was used to estimate the daily intake dose through ingestion of soil:

$$ADD_{Soil} = C_{Soil} \times NIR \times FR_{Soil} \times DC_{Soil}$$

where:

C_S = Concentration in soil (mg/kg)
NIR = Normalized food ingestion rate (mg/kg-day)
FR_{Soil} = Fraction of the total soil intake from foraging area (unitless)
DC_{Soil} = Dietary composition, fraction of soil in diet (unitless)

Described below is the general equation used to estimate the daily intake dose through food consumption:

$$ADD_{food} = C_{food} \times NIR \times FR_{food} \times DC_{food}$$

where:

C_{food} = Concentration in food ($mg_{chemical}/kg_{food}$)
NIR = Normalized food ingestion rate (kg/kg-day) (see Table 5-2)
FR_{food} = Fraction of food intake from foraging area (unitless)
DC_{food} = Dietary composition, fraction of that type of food in diet (unitless)

In this SLERA, no actual analytical data exists for chemical concentrations in food from the Site, such as earthworms and plants. Therefore, estimates of chemical concentrations are derived by multiplying the soil chemical concentrations by the appropriate bioconcentration factor (BCF), for earthworms, or soil-to-plant uptake factors (SPUFs), for plants. Review of the scientific literature and regulatory guidance was performed to develop a list of pertinent BCFs and SPUFs, and are presented in Appendix K, Table K-3-2.

For terrestrial top predators, such as the fox, an estimation of the concentration of chemicals in prey species (i.e., vole and shrew) must be derived. This is accomplished by multiplying the soil chemical concentration by the appropriate, literature derived mammalian uptake factor (UF), as

reported by ORNL (Sample et al., 1998). UFs for voles and shrews are presented in Appendix K, Table K-3-2.

All calculations to obtain chemical intake in food for terrestrial receptor species are provided in Appendix K, Tables K-4-1 through K-4-5 for soil, earthworms, terrestrial plants, voles, and shrews, respectively.

Chemical intake for terrestrial species, from ingestion of contaminated surface soil and ingestion of food at EU 2A, are presented in Appendix K, Tables K-5 through K-8. Chemical intake for terrestrial species, from ingestion of contaminated surface soil and ingestion of food at EU 3A, are presented in Appendix K, Tables K-10 through K-13. These tables present estimated chemical intake calculations for the vole, shrew, kestrel, and fox using the conservative approach, the varied diet and the area use factor approach, as appropriate.

Aquatic Pathways

For the aquatic pathways, the level of exposure was calculated using the following equation:

$$ADD_{pot} = ADD_{SW} + ADD_{Sed} + ADD_{food}$$

where:

ADD_{pot} = Average Daily Dose from all sources (mg/kg-day)
ADD_{SW} = Average Daily Dose from surface water (mg/kg-day)
ADD_{Sed} = Average Daily Dose from sediment (mg/kg-day)
ADD_{food} = Average Daily Dose from food (mg/kg-day)

Described below is the general equation that was used to estimate the daily intake dose through ingestion of water (ADD_{SW}):

$$ADD_{SW} = C_{SW} \times WIR \times FR_{SW}$$

where:

C_{SW} = Concentration in surface water ($mg_{compound}/L_{water}$)
WIR = Normalized water ingestion rate (mg/kg-day)
FR_{SW} = Fraction of the total water intake from foraging area (unitless)

Described below is the general equation that was used to estimate the daily intake dose through ingestion of sediment (ADD_{Sed}):

$$ADD_{Sed} = C_{Sed} \times NIR \times FR_{Sed} \times DC_{Sed}$$

where:

C_{SW} = Concentration in sediment (mg/kg)
NIR = Normalized food ingestion rate (mg/kg-day)
FR_{Sed} = Fraction of the total sediment intake from foraging area (unitless)
DC_{Sed} = Dietary composition, fraction of sediment in diet (unitless)

Described below is the general equation used to estimate the daily intake dose through aquatic food consumption (ADD_{food}):

$$ADD_{food} = C_{food} \times NIR \times FR_{food} \times DC_{food}$$

where:

C_{food} = Concentration in food (mg $_{chemical}$/ kg $_{food}$)
NIR = Normalized food ingestion rate (kg/kg-day) (see Table 5-2)
FR_{food} = Fraction of the total diet comprised of that food type (unitless)
DC_{food} = Dietary composition, fraction of food in diet (unitless)

For evaluating the aquatic food chain pathway, concentrations in prey, such as fish, were calculated using the following equation:

$$\text{Concentration in prey} = C_{SW} \times BAF$$
$$= C_{SW} \times BCF \times FCM$$

where:

C_{SW} = Concentration in surface water (mg/L)
BAF = Bioaccumulation factor (L/kg); the ratio of the concentration of a stressor in tissue (mg/kg) to its concentration in water (mg/L) where both the receptor and its prey are exposed.
BCF = Bioconcentration factor (L/kg) (see Appendix K, Table K-3-2)
FCM = Food chain multiplying factor (unitless)

Estimated chemical concentrations in benthic macro-invertebrates were determined by using the EPCs in sediments multiplied by the appropriate BCF (see Appendix K Table K-3-2). Estimated concentrations in aquatic plants were determined by multiplying the exposure point concentration in sediments by SPUFs, derived by ORNL (Sample et al., 1998), and presented on Appendix K, Table K-4-11. Estimated chemical concentrations in fish were determined by using EPCs in surface water multiplied by a BCF (see Appendix K, Table K-4-8).

All calculations to obtain chemical intake into food for aquatic receptor species are provided in Appendix K, Tables K-4-7, K-4-9, K-4-10, for fish, benthic macro-invertebrates, and aquatic plants, respectively.

Chemical intake for aquatic species, from contact with contaminated environmental media (surface water and sediment) at EU 2A and ingestion of food, are presented in Appendix K, Tables K-15 through K-17. These tables present estimated chemical intake calculations for the mallard, kingfisher and raccoon using the conservative approach, the varied diet approach, and the area use factor approach, as appropriate.

5.6 Screening Level Ecological Effects Assessment

The purpose of the ecological effects assessment is to estimate and evaluate the response to chemical and physical stressors at the Site. Depending on the parameters of exposure, this effects assessment results in a profile of the response or toxicity reference value (TRV) of receptor populations to stressors at concentrations or doses (or other units of stress) to which they are exposed.

5.6.1 Effects Evaluation for Radionuclides

Because most ecological receptors neither live long enough to receive the high cumulative lifetime exposures experienced by humans nor are protected as stringently from cancer as humans, cancer risk was not evaluated in the SLERA. Instead, risks of population effects (e.g., reduction in fertility or lifespan) from radiological effects of chronic exposure were evaluated.

The IAEA (1992) reported that irradiation at chronic dose rates of one milliGray per day (mGy/d) (0.1 rad/day) or less do not appear likely to cause observable changes in terrestrial vertebrate animal populations. Therefore, the effects benchmark for terrestrial animals is set at 0.1 rad/day. Because aquatic biota, including invertebrates, appear not to be harmed by chronic doses of 10 mGy/d (one rad/day) or less (IAEA 1992), a benchmark of one rad/day was used for aquatic invertebrates.

5.6.2 Chemical Toxicity

Site-specific toxicological studies using the Site animal populations have not been conducted to determine whether the concentrations of COPECs at the site are toxic. Therefore, the effects assessment used TRVs obtained from compiled data in the literature [e.g., Will and Suter (1996) and Sample et al. (1996), which utilize USFWS and other toxicity studies]. Information on test concentrations, modes of exposure, and effects on similar species from published toxicity studies

were used to establish TRVs or thresholds for risk calculations. Examples of the kinds of toxicological data that are used to assess effects of site constituents on ecological receptors are:

- NOAEL – the highest concentration of a constituent in a study that causes no observable adverse effect on a test species, and
- LOAEL – the lowest concentration of a constituent in a study that causes an observable adverse effect on a test species.

Both NOAEL and LOAEL based dietary limits toxicity threshold were used in this SLERA when available. During initial risk calculation (conservative approach), screening benchmarks for the mammals and birds are doses (mg/kg body weight [wt]/day) associated with NOAELs derived from laboratory studies on test species (Sample et al., 1996). The test species NOAEL benchmark data were derived prior to performing risk calculation. Different studies are used for mammals and birds, and the test species vary among constituents. These test species' NOAELs were converted to NOAELs for both birds and mammals using a body-weight ratio scaling exponent of 1.2, and 0.94, respectively. Tables 1-1 and 1-2 of Appendix K present the NOAELs for both birds and mammals, respectively. During VD and AUF approach risk calculations, screening benchmarks were based on species specific LOAEL. Tables 2-1 and 2-2 of Appendix K present the species-specific LOAEL for birds and mammals, respectively based on the test species LOAEL.

5.7 Screening Level Risk Characterization

Risk characterization integrates exposure and stressor response on receptor organisms used in the assessment, summarizes risk or the likelihood of harm to animals, and interprets the ecological significance of these findings.

5.7.1 Risk Characterization for Radionuclides

Risk characterization for radionuclides was performed for both terrestrial and aquatic ecological receptors. Terrestrial animals and terrestrial plants evaluated as a part of terrestrial receptors, are exposed to surface soil present at EU 2A and EU 3A. During the Level 1 SLERA for each EU, the ratio of the maximum detected concentration for each surface soil COPEC to its corresponding BCG factor was determined. The resulting ratios were summed and compared to unity. Table J-1 and Table J-2 of Appendix J present the results of the radionuclide SLERA to terrestrial receptors for EU 2A and EU 3A, respectively. The results showed that the sum of the

ratios for surface soil present at both EUs are less than one, i.e., the absorbed doses to terrestrial receptors exposed to surface soil at both EUs are less than their corresponding dose limits. The terrestrial receptors do not appear to be sensitive to the radiological COPECs present at the site.

Both aquatic and riparian animals evaluated as part of aquatic ecological receptors are exposed to the surface water and sediment present at EU 2A. A Level 1 SLERA was performed by utilizing the maximum detected concentration for both surface water and sediment COPECs. The ratio of maximum detected concentration for each medium-specific COPEC to its corresponding BCG factor was determined. The resulting ratios were summed for each medium. Table J-3 of Appendix J present the results of the radionuclide SLERA to aquatic receptors for EU 2A. The results showed that the sum of the ratio for each medium is less than one, and the doses to the aquatic receptors are below the biota dose limit presented in section 5.6.1, indicating that the site has met the acceptability criteria and no further evaluation is required. Therefore, radionuclide COPECs are not a concern for the site.

5.7.2 Current Chemical Preliminary Risk to Ecological Receptors

The risk characterization step of the SLERA integrates the results of the exposure and toxicity assessments into a quantitative description of excess risks. The ADDs developed from the exposure assessment, and the TRVs derived from the effects assessment are utilized to derive risks for each receptor-COPEC scenario using the HQ approach. The resulting HQs can then be evaluated in order to determine the likelihood that COPECs detected in site samples pose any adverse impacts to ecological receptors.

An HQ greater than one indicates that the chemical of concern may be present in site media at a concentration that could potentially result in an adverse effect to the species, under that specific scenario evaluated. Further thresholds may be needed to make decisions. Accordingly, HQs in the range of one to 100 will be designated as low ecological risk, in the range of 100 to 1,000 as intermediate ecological risk and in excess of 1,000 as high ecological risk. The basis for these categories is professional judgment based on experience gained by completing numerous ERAs. The use of such a simple method to organize HQs is designed to help manage risk, not to supplant this responsibility that is related but different from risk assessment. However, full acknowledgement is given any constituent with an HQ of one or higher based on the SLERA.

Ecological risk calculations (i.e., HQ calculations) are presented in detail in Appendix K for all terrestrial receptors, and for aquatic receptors. The subsections below present a more detailed discussion of the HQ results for each receptor.

5.7.2.1 Risk Results for the Vole

For surface soil present at EU 2A, HQ calculations for voles are presented in Appendix K, Tables K-5-2 and K-5-4, for the conservative approach and the varied diet approach, respectively. For surface soil present at EU 3A, HQ calculations for voles are presented in Appendix K, Tables K-10-2 and K-10-4, for the conservative approach and the varied diet approach, respectively. Voles were evaluated for the conservative approach as being exposed to site soils and having a diet consisting entirely of earthworms. Chemicals with resulting HQs greater than one were re-evaluated by the varied diet approach, with a diet consisting of both earthworms and terrestrial plants. The area use factor approach was not utilized for voles as their home range is smaller than the Site. Table 5-3 summarizes the HQ results for voles, showing only those chemicals which demonstrated a HQ greater than one for the conservative approach.

Table 5-3: Results of Risk Characterization for Meadow Vole

Meadow Vole HQ Summary		
Chemical	**Conservative HQs (NOAEL)**	**Varied Diet Approach HQs (LOAEL)**
EU-2A Surface Soil		
Antimony	**2.2E+00**	6.7E-01
Arsenic	**2.2E+01**	2.8E-01
Barium	**8.2E+00**	**1.5E+00**
Cadmium	**2.0E+01**	6.6E-02
Chromium	**6.1E+00**	8.1E-02
Copper	**1.6E+01**	**3.6E+00**
Lead	**1.5E+02**	9.0E-01
Selenium	**4.2E+00**	**1.1E+00**
Vanadium	**4.1E+00**	7.0E-02
Zinc	**1.4E+01**	3.4E-01
Pyrene	**7.4E+00**	1.6E-02
EU-3A Surface Soil		
Antimony	**1.1E+00**	3.4E-01
Copper	**3.1E+00**	7.3E-01
Lead	**5.0E+01**	3.1E-01
Nickel	**9.2E+00**	1.6E-01
Vanadium	**4.0E+00**	7.2E-02
bis(2-Ethylhexyl) Phthalate	**2.3E+02**	4.8E-01
Pyrene	**3.8E+00**	8.8E-03

As shown in the above table, the HQs presented in **BOLD** text represent those chemicals that appear to present adverse risk to voles at Site from exposure to site soil and ingestion of food. When taking the varied diet of the vole into account, for EU 2A, three inorganic (barium, copper and selenium) demonstrated HQs greater than one. However, they are designated as low ecological risk. For EU 3A, none of soil COPECs exceeded HQ of one.

5.7.2.2 Risk Results for the Shrew

For surface soil present at EU 2A, HQ calculations for shrews are presented in Appendix K, Tables K-6-2 and K-6-3, for the conservative approach and the varied diet approach, respectively. For surface soil present at EU 3A, HQ calculations for shrews are presented in Appendix K, Tables K-11-2 and K-11-3, for the conservative approach and the varied diet approach, respectively. Only the conservative approach was evaluated as shrews diets typically consist entirely of insects (in this case, earthworms). The area use factor approach was not utilized for shrews as their home range is smaller than the Site. HQ results for shrews are summarized below in Table 5-4, only showing those chemicals which demonstrated an HQ greater than one.

Table 5-4: Results of Risk Characterization for Short-Tailed Shrew

Short-Tailed Shrew HQ Summary		
Chemical	**Conservative HQs (NOAEL)**	**Varied Diet Approach HQs (LOAEL)**
EU-2A Surface Soil		
Antimony	**5.8E+00**	5.8E-01
Arsenic	**4.4E+01**	**4.4E+00**
Barium	**1.7E+01**	**4.4E+00**
Cadmium	**3.8E+01**	**3.8E+00**
Chromium	**1.2E+01**	**2.9E+00**
Copper	**3.1E+01**	**2.4E+01**
Lead	**2.9E+02**	**2.9E+01**
Selenium	**8.1E+00**	**4.9E+00**
Vanadium	**9.0E+00**	9.0E-01
Zinc	**2.6E+01**	**1.3E+01**
Pyrene	**1.4E+01**	6.0E-02
EU-3A Surface Soil		
Antimony	**5.2E+00**	5.2E-01
Chromium	**1.7E+01**	**4.2E+00**
Copper	**6.7E+00**	**5.2E+00**
Lead	**1.1E+02**	**1.1E+01**
Nickel	**1.9E+01**	**9.4E+00**
Vanadium	**1.3E+01**	**1.3E+00**

As shown in the above table, the chemicals/HQs presented in **BOLD** text represent those chemicals that appear to present adverse risk to shrews, at EU 2A and EU 3A, from exposure to site soil and ingestion of food. When taking the varied diet of the shrew into account, for EU 2A, eight inorganics demonstrated HQs greater than one. For EU 3A, five inorganic soil COPECs exceeded HQ of one. However, for both EUs, they are designated as low ecological risk.

5.7.2.3 Risk Results for the American Kestrel

For surface soil present at EU 2A, HQ calculations for kestrels are presented in Appendix K, Tables K-7-2 and K-7-3, for the conservative approach and the varied diet approach, respectively. For surface soil present at EU 3A, HQ calculations for kestrels are presented in Appendix K, Tables K-12-2 and K-12-4, for the conservative approach and the varied diet approach, respectively. Kestrels were evaluated for the conservative approach as being exposed to site soils and having a diet consisting of 100% earthworms. Chemicals with resulting HQs greater than one were reevaluated by using the varied diet and the area use factor approach. HQ results for the kestrel are summarized below in Table 5-5, only showing those chemicals which demonstrated HQs greater than one for the conservative approach:

Table 5-5: Results of Risk Characterization for American Kestrel

American Kestrel HQ Summary		
Chemical	**Conservative HQs (NOAEL)**	**Varied Diet and Area Use Factor Approach HQs (LOAEL)**
EU-2A Surface Soil		
Antimony	**2.3E+00**	1.4E-03
Barium	**3.0E+00**	7.5E-03
Cadmium	**2.5E+01**	6.4E-03
Copper	**7.0E+00**	2.1E-02
Lead	**1.4E+03**	5.4E-01
Selenium	**3.1E+00**	8.1E-03
Zinc	**3.1E+02**	1.3E-01
Pyrene	**1.1E+00**	3.9E-04
Aroclor-1260	**1.5E+00**	2.9E-02
EU-3A Surface Soil		
Antimony	**1.2E+00**	6.9E-03
Copper	**1.4E+00**	4.1E-02
Lead	**1.1E+02**	**1.1E+01**
Nickel	**8.5E+00**	2.3E-01
bis(2-Ethylhexyl) Phthalate	**4.1E+03**	**1.4E+01**

As shown in the above table, when taking the kestrel's varied diet and home range into account, for EU 2A, none of soil COPECs exceeded HQ of one. For EU 3A, only lead and bis(2-Ethylhexyl) Phthalate exceeded HQ of one. However, both of those soil COPECs are considered as low ecological risk.

5.7.2.4 Risk Results for the Red Fox

For surface soil present at EU 2A, HQ calculations for red fox are presented in Appendix K, Tables K-8-2 and K-8-4, for the conservative approach and the varied diet approach, respectively. For surface soil present at EU 3A, HQ calculations for red fox are presented in Appendix K, Tables K-13-2 and K-13-4, for the conservative approach and the varied diet approach, respectively. Foxes were evaluated for the conservative approach as being exposed to site soils and having a diet consisting of 100% earthworms. Chemicals with resulting HQs greater than one were re-evaluated by the varied diet approach, with a diet consisting of earthworms, voles, shrews, and terrestrial plants and by using the area use factor approach. HQ results for the fox are summarized below in Table 5-6, only showing those chemicals which demonstrated HQs greater than one for the conservative approach:

Table 5-6: Results of Risk Characterization for Red Fox

Red Fox HQ Summary		
Chemical	**Conservative HQs (NOAEL)**	**Varied Diet and Area Use Factor Approach HQs (LOAEL)**
EU-2A Surface Soil		
Barium	**1.1E+02**	2.7E-03
Cadmium	**9.7E+00**	8.5E-04
Chromium	**3.2E+01**	1.4E-03
Copper	**1.2E+03**	8.6E-03
Lead	**4.8E+03**	1.4E-02
Zinc	**1.8E+05**	8.6E-03
Anthracene	**9.0E+02**	1.0E-05
Fluoranthene	**2.1E+02**	9.5E-06
Pyrene	**2.7E+00**	3.1E-04
EU-3A Surface Soil		
Chromium	**4.5E+01**	6.8E-02
Copper	**2.5E+02**	2.6E-02
Lead	**1.7E+03**	4.7E-01
Nickel	**7.6E+03**	8.6E-02
Anthracene	**7.0E+01**	8.0E-05
Bis(2-Ethylhexyl) Phthalate	**2.9E+04**	9.9E-01
Pyrene	**1.5E+00**	1.7E-02

As shown in the above table, when taking the red fox's varied diet and home range into account, for both EU 2A and EU 3A, none of the soil COPECs demonstrated a HQ greater than one.

5.7.2.5 Risk Results for the Mallard

HQ calculations for the mallard are presented in Appendix K, Tables K-15-2, and K-15-4, for the conservative approach, the varied diet with area use factor approach, respectively. Mallards were evaluated as an aquatic receptor for the conservative approach as being exposed to surface water, sediment, and having a diet consisting entirely of benthic macro-invertebrates. Chemicals with resulting HQs greater than one were re-evaluated using the varied diet and the area use factor approach, with a diet consisting of benthic macro-invertebrates and aquatic plants. HQ results for the mallard are summarized below in Table 5-7, only showing those chemicals which demonstrated HQs greater than one for the conservative approach:

Table 5-7: Results of Risk Characterization for Mallard Duck

Mallard HQ Summary		
Chemical	**Conservative HQs (NOAEL)**	**Varied Diet Approach HQs (LOAEL)**
Lead	**6.1E+01**	3.2E-03
Zinc	**2.6E+01**	1.3E-03
bis(2-Ethylhexyl) Phthalate	**1.4E+02**	5.2E-03
Fluoranthene	**5.6E+00**	2.1E-04
Pyrene	**4.9E+01**	1.8E-03
Aroclor-1260	**3.0E+05**	**1.1E+01**

As shown in the above table, when taking the mallard's varied diet and home range into account, HQ for only one PCB was greater than one. However, it is considered as low ecological risk.

5.7.2.6 Risk Results for the Belted Kingfisher

HQ calculations for the kingfisher are presented in Appendix K, Tables K-16-2, and K-16-4, for the conservative approach, the varied diet with area use factor approach, respectively. Kingfishers are known for a diet consisting entirely of fish and have relatively small territory size. As the range size is higher than that for EU, therefore, a varied diet approach and the area use factor approach was evaluated. HQ results for the kingfisher are summarized below in Table 5-8, only showing those chemicals which demonstrated HQs greater than one:

Table 5-8: Results of Risk Characterization for Belted Kingfisher

Belted Kingfisher HQ Summary		
Chemical	**Conservative HQs (NOAEL)**	**HQs (LOAEL)**
Antimony	**4.4E+00**	1.9E-01
Arsenic	**1.5E+00**	2.5E-01
Lead	**4.3E+02**	**1.8E+01**
Zinc	**1.6E+01**	7.5E-01
Aroclor-1260	**1.1E+02**	**4.7E+00**

As shown in the above table, lead, and one PCB soil COPECs have demonstrated HQs greater than one for the kingfisher under the scenario evaluated. However, they are considered as low ecological risk.

5.7.2.7 Risk Results for the Raccoon

HQ calculations for the raccoon are presented in Appendix K, Table K-17-2, for the conservative approach. Raccoon were evaluated as an aquatic receptor for the conservative approach as being exposed to site surface water, sediment, and having a diet consisting entirely of fish. Since resulting HQs are not greater than one, no further evaluation was performed based on varied diet approach.

5.8 Uncertainty Analysis

The objective of an uncertainty analysis is to provide risk managers with the uncertainties inherent to the SLERA, and the likely impact of these uncertainties on the risk estimates. Virtually every step in the risk evaluation process involves numerous assumptions that contribute to the total uncertainty in the final evaluation of risk.

5.8.1 Uncertainties Related to Problem Formulation

Onsite reconnaissance has established the nature and quality of habitat and has confirmed the presence of vegetation types and of active, visible animal species. Observations made during this reconnaissance justify assumptions about the presence of unobserved organisms that are essential to normal ecosystem functioning, such as soil dwelling worms and arthropods, and herbivorous insects. It is possible that one (or more) unobserved species at the Site is more sensitive than the ecological receptors for which toxicity data are available for use in the SLERA. It does not necessarily follow that these unevaluated species are at significantly greater risk of harmful ecological effects than that estimated in this SLERA because exposure point concentrations for the selected ecological receptors could be greater than those for more sensitive unevaluated receptors and the exposure concentrations could be generally overestimated.

5.8.2 Uncertainties Related to Exposure Assessment

Environmental concentrations of constituents in the surface soil, sediment, and surface water at and near the Site were based on a limited number of samples. A degree of uncertainty exists about the actual spatial distribution of constituents. Exposure concentrations could be overestimated or underestimated, depending on how the actual concentrations distribution differs from the measured data distribution. Because the estimated 95% UCL of the mean concentrations or maximum detected concentration were used as the EPC concentration to calculate HQs, the estimates of risk from COPECs were conservative (i.e., protective). Using 95% UCL or maximum concentrations decreases the likelihood of underestimating the risk posed by each COPEC and increases the likelihood of overestimating the risk.

Bioaccumulation refers to the tendency of a chemical constituent to increase in tissue concentrations in organisms because the organisms retain the constituent rather than metabolizing or excreting it. Chemicals with logarithm of the octanol-water partition coefficient greater than 3.5 have the potential to bioaccumulate in the food chain. Therefore, they can cause harm to the ecological population. This criterion is true for organic chemical constituents (herbicides/PEST, VOCs, SVOCs, and PAHs). The inorganic chemical constituents are not considered to be persistent bioaccumulative toxic compounds (Ohio EPA, 2003), therefore they are judged not to pose a risk to biota by accumulation from soil or sediment. Based on that criteria, 1,2-Dichlorobenzene, 1,4-Dichlorobenzene, 2,4-dinitrophenol, 2,4-dinitortoluene,

acetone, aniline, benzene, naphthalene, nitrobenzene, carbon disulfide, carbon tetrachloride, chlorobenzene and chloroform are less likely to bioaccumulate in the food chain and should not be considered as COPEC for the site. However, as a conservative, those chemicals constituents were not excluded from the list of COPEC for the site, and were included for further evaluation.

For all chemical analyses, total content was measured as opposed to chemical fractions or species. Subsequently, when calculating intake of chemicals for each food type (worms, fish, benthic invertebrates), it was assumed that 100% of the chemical was available for uptake. However, availability to organisms (i.e., bioavailability) varies with each chemical depending upon the inherent chemical and physical properties of the constituent, as well as the local environmental conditions. No adjustment was made in this SLERA to account for chemicals that may not be 100% bioavailable to the organisms. Therefore, uncertainty exists as to whether chemical intake should have been adjusted downward in some cases. Using total content is a more conservative approach and HQs are most likely higher than they would have been had bioavailability been taken into account.

The actual movements of constituents from source media to ecological receptors have not been measured for this SLERA. This introduces uncertainties about the actual modes and pathways of exposure and the actual exposure concentrations of these constituents to the ecological receptors. Exposure concentrations can differ from the measured environmental concentrations as a result of physical and chemical processes during transport from source to receptor and as a result of biomagnification through the food web. These processes were not evaluated quantitatively in this SLERA. Although bioaccumulation was estimated for those receptors ingesting food for which toxicity thresholds are available, it is possible that exposure to top predators may be underestimated because biomagnification of certain constituents in prey is overlooked.

The models and pathways to be used to characterize the exposure to ecological receptors are the most important ones for the relatively large and active species in terrestrial habitats. Soil dwelling terrestrial animals may be exposed to constituents in soil by way of inhalation following volatilization, but gaseous concentrations in soil interstices, cavities, and burrows were not available for the Site. Therefore, the exposure to burrowing organisms at the site from contaminated soil and soil interstitial water may be underestimated if gas concentrations are

larger than soil concentrations, which is unlikely. The estimate of risk also was underestimated if toxicity thresholds are lower for inhalation than they are for ingestion. Conservative exposure estimates were used for absorption of COPECs from soil and absorption from tissue. Overestimating exposure by using conservative exposure concentrations is thought to counter-balance the underestimation of exposure that results from neglecting certain exposure modes and pathways of lesser importance, such as inhalation. Additional uncertainties are inherent in ingestion rates and dietary fractions of plants and animals.

The scientific literature was consulted to obtain the BCFs and UFs for chemical movement into food sources (earthworms, fish, voles, shrews, and plants). The USEPA document, *Screening Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities* (USEPA, 1999), was consulted for many BCFs and UFs. Uncertainty exists for those chemicals for which there are no published BCFs and UFs. The fact that they do not exist in the scientific literature does not mean that uptake and bioconcentration do not occur; rather the rate at which it might occur has not been measured and published. Total risk to ecological receptors may therefore be unreasonably low if HQs cannot be calculated for chemicals lacking BCFs and UFs.

Another issue of uncertainty associated with BCFs and UFs is that generally, no upper-bounds for uptake are documented. It was assumed in the calculations for this SLERA that uptake into the earthworm, plant, fish, etc., will occur at the same rate regardless of the chemical concentration in the media, even if the concentration would be at a level toxic for the given receptor. It is also known that chemicals at high concentrations are toxic to earthworms, plants, etc., and uptake would be prevented because death, impedance of growth, or avoidance would certainly occur. Therefore, for some limited chemicals found at high concentrations, the HQs calculated for receptors that would consume the affected earthworm or plant, for example, would most likely be much higher than the actual HQ. If earthworms or plants are not available as a food source (due to death, impeded growth, or avoidance), exposure to the receptor (i.e., intake) would be much lower.

5.8.3 Uncertainties Related to Effects Assessment

Toxicity reference values were based on concentrations reported to have no or little effect on the test organism or was estimated conservatively from published toxicity data as provided in

Appendix I. Dietary limits used as threshold levels for soils were derived from NOAELs and LOAELs using multiplier factors of one or 10 (Opresko et al. 1994) with 10 being the most conventional one. These thresholds would underestimate the risks only to organisms at the Site that are considerably more sensitive than the study organisms. They are more likely to overestimate the risk to organisms that are equally or less sensitive than the study organisms. The possibility remains that some thresholds were set at levels at or above which some harm would occur to organisms at the Site.

The preferred guidance documents for the collection of data for use in ERAs would be those prepared by the USEPA as a first choice, with the ORNL as a good secondary source. Attachment 4-5 of USEPA's Guidance for Developing Ecological Soil Screening Levels (Eco-SSLs) (USEPA 1999) provides an example of deriving TRV value for cobalt. However, a USEPA source does not currently exist that contains a definitive list of ecological TRVs for all COPEC present at the site. Therefore, for all HQ calculations, TRVs were primarily obtained from the following ORNL publication: Sample, B.E., D.M. Opresko, and G.W. Suter II. 1996. *Toxicological Benchmarks for Wildlife*. Not all chemicals retained for evaluation in this SLERA have published TRVs, and so uncertainty exists for such chemicals. Total risk to ecological receptors may therefore be unreasonably low if HQs cannot be calculated for these chemicals without TRVs.

There are no available TRVs for some compounds, especially organics, for all ecological receptors considered. This, of course, contributes to uncertainty associated with the likely underestimation of risk.

The calculated risks to the ecological receptors at the Site are the risks from the individual constituents. The risks from exposure to multiple constituents depend on synergistic or antagonistic constituent interactions; effects could be greater or lesser than those from a single chemical. This SLERA provides findings for COPEC-specific risk estimates. An evaluation of risk from constituent mixtures cannot be conducted without additional data and evaluation of alternative models of constituent interaction.

Additional uncertainty exists as to the pertinence of individual organism toxicity for characterizing the risk to populations and ecosystems. It is possible that populations may

compensate for the loss of large numbers of juveniles or adults with increased survival or birth-rates, and habitats or ecosystems may possess functionally redundant species that are less sensitive to constituents. Although the Site habitats surely possess these buffering mechanisms, a conservative approach is still justified to risk assessment based on single organism toxicity thresholds (i.e., NOAELs).

5.8.4 Uncertainties Related to Risk Characterization

The uncertainties described above ultimately produce uncertainty in the quantification of current and future risks to terrestrial and aquatic animals at the Site. Two additional areas of uncertainty in the risk characterization exist: cumulative risk, and future risk.

Cumulative Risk: The SLERA estimates the risk to populations of ecological receptors from individual constituents. Yet, in nature, receptors are exposed simultaneously to mixtures of constituents. Generally, the methods used are sufficiently conservative resulting in individual risks that are overestimated. Nevertheless, cumulative risk is possible when several living plants and animals are affected simultaneously. Harmful effects in ecosystems (including effects on individual organisms) may cascade throughout the system and have indirect effects on the ability of a population to persist in the area even though individual organisms are not sensitive to the given constituents in isolation. Therefore, the ecological risk characterization for the Site may underestimate actual risks to plants and animals from cumulative risks.

Future Risk: A second area of uncertainty in the ecological risk characterization is the future risk to the plants and animals from contamination at the Site. The SLERA characterizes the current risk based on chronic exposure to measured concentrations of toxicants with the potential to persist in the environment for extended periods of time. HQs for animals estimate the risk to animal species that would be natural parts of future successional stages at these areas. Nevertheless, possible mechanisms exist that could significantly increase (e.g., erosion, leaching to surface water) or decrease (e.g., enhanced microbial degradation) the risk to future plants and animals at the sites.

5.8.5 Summary of Uncertainties

The most important uncertainties in the Site SLERA were those surrounding the estimates of the constituent concentrations to which ecological receptors are actually exposed (exposure concentrations) and the concentrations that present an acceptable level of risk of harmful effects (toxicity reference values or thresholds). These uncertainties arise from multiple sources, especially from the lack of site-specific data on constituent transport and transformation processes, organismal toxicity, animal behavior and diet, population dynamics, and the response of plant and animal populations to stressors in their environments. Despite these uncertainties, the available site-concentration data and published exposure and effects information allow COPECs (HQs greater than one) to be identified as risks characterized for EU 2A and EU 3A.

5.9 Summary of the Screening or Preliminary Ecological Risk Assessment

The purpose of this SLERA for the Site was to evaluate and quantify the potential adverse effects that radiological and chemical constituents of potential concern present in site media could have on the ecological receptors identified. RESRAD-Biota, version 1.21 was used to identify radiological constituents that could potentially impact the ecological receptors that are present at EU 2A and EU 3A. Level 1 of SLERA was utilized during the SLERA. Characterization of radiological SLERA showed that the terrestrial and aquatic ecological receptors were not likely to be affected by the radiological constituents of potential concern present at the site.

Characterization of the chemical ecological risks was performed in a tiered approach, beginning with the conservative approach, followed by the varied diet and area use factor approach for COPECs found to present excess risk at the conservative approach step. No chemicals were found to present excess risk (HQs greater than one) for the raccoon and fox, following all tiers of evaluation. The summary table below presents only those chemicals that present HQs greater than one for the vole, shrew, kestrel, fox, mallard, and kingfisher following all tiers of evaluation.

The results of HQs for all ecological receptors showed that all media specific COPECs resulted in low ecological risk to terrestrial and aquatic receptors present at the site. As a result, no chemicals of ecological concern may be present at the site.

Table 5-9: SLERA Summary Table

Chemical	Vole	Shrew	Kestrel	Mallard	Kingfisher
	Soil			Sediment[1]	
EU 2A					
Arsenic		✓			
Barium	✓	✓			
Cadmium		✓			
Chromium		✓			
Copper	✓	✓			
Lead		✓			✓
Selenium	✓	✓			
Zinc		✓			✓
PCB-1260				✓	✓
EU 3A					
Antimony		✓			
Copper		✓			
Lead		✓	✓		
Nickel		✓			
Vanadium		✓			
bis(2-Thylhexyl) Phthalate			✓		

✓ = HQ > 1.0
[1] Shaded areas indicate that the pathway is not applicable for that EU.

Continuing the ERA process for the Site is not recommended. No further evaluation of ecological risk for the surface soil present at EU 2A and EU 3A is recommended because these areas do not provide undisturbed, natural, or vegetated habitat for ecological receptors. The remaining evaluation steps of the USEPA ERA process (Steps 4 through 7) are not recommended because of low risk relative to uncertainty in risk estimates, low probability of significant ecological effect on local populations, and the lack of unique, rare and critical habitat at the site. If the decision is made to excavate soils at the Sites to address human health risk, the residual risk to ecological receptors would also be reduced without serious impacts to ecological habitat.

No further ecological risk evaluation is recommended for both surface water and sediment present in the CDD. The CDD does not represent unique, rare and critical habitat for ecological receptors. The lack of unique, rare, and critical habitat means excavation of sediments for purposes of reducing human health risk, if executed properly, would not have a severe impact on ecological resources and may reduce the residual risk to ecological receptors from contamination.

6.0 REFERENCES

American Society for Testing and Materials (ASTM) Standard E-1739-95 2002. Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (ASTM E-1739).

Agency for Toxic Substances and Disease Registry (ATSDR). 2007. Toxicological Profile for Lead *(Update).* Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service

Argonne National Laboratory (ANL) 2005. *RESRAD for Windows,* Version 6.3, Computer Code, Argonne National Laboratory, Environmental Assessment Division, August 25.

Cabrera Services, Inc (CABRERA) 2007. Baseline Risk Assessment Data – Gap Sampling: Field Sampling Plan.

Cabrera 2011a. Technical Memorandum, USACE Determination of Eligible Contaminants for FUSRAP Investigation at DuPont Chambers Works Site.

Cabrera 2011b. Final Sitewide Remedial Investigation Report, DuPont Chambers Works FUSRAP Site, for all Operable Units, June.

DuPont Environmental Remediation Services (DERS) 1993. Geologic Model Refinement and Well Screen Verification Program.

DuPont Corporate Remediation Group 2006. *Baseline Ecological Evaluation DuPont Chambers Works,* Delaware, March.

DOE 1997. *Report on the Remedial Investigation of Bear Creek Valley at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee*. DOE/OR/01-1455/V6&D2.

DOE 2002, *A Graded Approach for Evaluation Radiation Doses to Aquatic and Terrestrial Biota,* DOE-STD-1153-2002.

DOE 2004, RESRAD-Biota: *A Tool for Implementing a Graded Approach to Biota Dose Evaluation,* ISCORS Technical Report 2004-02, January.

Environmental Quality Management Inc. (EQM) 2004. User's guide for the Johnson and Ettinger (1991) model for subsurface vapor intrusion into buildings (revised). Prepared for E.H. Pechan and Associates Inc. Submitted to U.S. EPA.

International Atomic Energy Agency (IAEA). 1992. *Effects of Ionizing Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards*. IAEA Technical Report Series 332, Vienna, Austria.

Integrated Risk Information System (IRIS) 1999. National Center for Environmental Assessment, U.S. Environmental Protection Agency, 26 West Martin Luther King Drive, MS-190, Cincinnati, Ohio 45268. (513) 569-7254.

Johnson, P.C., and R. Ettinger. 1991. Heuristic model for predicting the intrusion rate of contaminant vapors into buildings. Environmental Science and Technology 25, no. 8: 1445–1452.

NJDEP 2000. Final Rule: Soil Remediation Standards for Radioactive Materials N.J.A.C. 7:28 Subchapter 12.

NRC 1999. *Comparison of the Models and Assumptions used in DandD 1.0, RESRAD 5.61, and RESRAD-Build 1.50 Computer Codes with Respect to the Residual Farmer and Industrial Occupant Scenarios*, Draft, Volume 4, NUREG/CR-5512, SAND99-2147, U.S. Nuclear Regulatory Commission, October.

Ohio EPA, 2003. *Ecological Risk Assessment Guidance Document*, DERR-00-RR-031, Division of Emergency and Remedial Response, State of Ohio Environmental Protection Agency, Columbus, Ohio.

Opresko, D. M., B. E. Sample, and G. W. Suter II 1994. Toxicological Benchmarks for Wildlife: 1994 Revision. ES/ER/TM-86/RI. Oak Ridge National Laboratory, Oak Ridge, TN.

Opresko, D. M., B. E. Sample, and G. W. Suter, II 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. ES/ER/TM-86/R3, Oak Ridge National Laboratory, Oak Ridge, TN.

Sample, B.E., D.M. Opresko, and G.W. Suter, II 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. ES/ER/TM-86/R3, Oak Ridge National Laboratory, Oak Ridge, TN.

Sample, B.E., J.J. Beauchamp, R.A. Efroymson, G.W. Suter, T.L. Ashwood. 1998. *Development and Validation of Bioaccumulation Models for Earthworms.* ES/ER/TM-220. Prepared for the U.S. Department of Energy by Lockheed Martin Energy Systems, Oak Ridge, TN.

Suter, G.W. II, and C.L. Tsao. 1996. Toxicological Benchmarks for Screening Potential Constituents of Concern for Effects on Aquatic Biota: 1996 Revision. ES/ER/TM96/R2. Lockheed Martin Energy Systems, Oak Ridge National Laboratory, Oak Ridge, TN.

U.S. Army Corps of Engineers (USACE) 1997. Chemical Quality Assurance for HTRW Project, EM 200-1-6, October.

USACE 1999a. Risk Assessment Handbook Volume I: Human Health Evaluation. EM 200-1-4, June.

USACE 1999b. Risk Assessment Handbook Volume II: Environmental Evaluation. EM 200-1-4, January.

USACE 2003. Formerly Utilized Sites Remedial Action Program (FUSRAP) – Site Designation, Remediation Scope, and Recovering Costs. ER 200-1-4.

U.S. Department of the Interior (USDI), Fish and Wildlife Service 2007. Reference 2008-I-0103, Response to Endangered Species Act (ESA), December.

U.S. Environmental Protection Agency (USEPA) 1988. Federal Guidance Report No. 11: Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion, EPA 520/1-88-020, September

USEPA 1989a. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A), EPA 540/1-89/002, December, 1989, PB90-155581.

USEPA 1989b. Risk Assessment Guidance for Superfund, Volume II: Environmental Evaluation Manual. EPA/540/1-89-001. U.S. Environmental Protection Agency.

USEPA 1990a. Health Effect Assessment Summary Tables and User's Guide. Environmental Criteria and Assessment Office. Prepared for Office of Emergency and Remedial Response, Washington D.C.

USEPA 1990b. "National Oil and Hazardous Substances Pollution Contingency Plan," Final Rule, FR Vol. 55, No. 46, March 8, 1990, available from U.S. Government Printing Office, Washington, D.C.

USEPA 1991a. "Risk Assessment Guidance for Superfund, Vol. I: Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals," OSWER Directive 9285.7-01B, Office of Emergency and Remedial Response, Washington, D.C.

USEPA 1991b. "Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Supplemental Guidance, Standard Default Exposure Factors, Interim Final," OSWER Directive 9285.6-03, EPA, Office of Emergency and Remedial Response, Washington, DC.

USEPA 1991c. Ecological Assessment of Superfund Sites: An Overview ECO Update 1(2), Office of Solid Waste and Emergency Response, Publ. 9345.0-051.

USEPA 1992a. "Guidance for Data Usability in Risk Assessment (Part A)", PB92-963356, April 1992. Office of Solid Waste and Emergency Response, Publ. 9285.7-09A.

USEPA 1992b. "Guidance for Data Usability in Risk Assessment (Part B)", PB92-963362, May 1992. Office of Solid Waste and Emergency Response, Publ. 9285.7-09B.

USEPA 1992c. "Supplemental Guidance to RAGS: Calculating the Concentration Term," PB92-963373, May, 1992. EPA, Office of Emergency and Remedial Response Toxics Integration Branch, Washington, DC.

USEPA 1992d. "Dermal Exposure Assessment: Principles and Applications," EPA/600/8-91/011b, Office of Health and Environmental Assessment, Washington, DC.

USEPA 1992e. "Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual Supplemental Guidance Dermal Risk Assessment Interim Guidance," EPA, Office of Emergency and Remedial Response Toxics Integration Branch, Washington, DC.

USEPA 1992f. Developing a Work Scope for Ecological Assessments. U.S. EPA Office of Emergency and Remedial Response. EcoUpdate 1 (4): 1-15.

USEPA 1992g. Framework for Ecological Risk Assessment. Risk Assessment Forum. EPA/630/R-92/001.

USEPA 1993a. *Federal Guidance Report No. 12, External Exposure to Radionuclides in Air, Water; and Soil*, EPA 402-R-93-081, Air and Radiation, September.

USEPA 1993b. "Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons," EPA/600/R-93/089, Office of Research and Development, Washington, D.C.

USEPA 1993c. Wildlife Exposure Factors Handbook. EPA/600/R93/187A,B. Office of Research and Development, Washington, D.C.

USEPA 1993d. Selecting Exposure Routes and Contaminants of Concern by Risk-Based Screening, EPA/903/R-93-001. Hazardous Waste Management Division, Office of Superfund Program, Philadelphia, PA. January.

USEPA 1995a. *Determination of Background Concentrations of Inorganics in Soils and in Sediments in Hazardous Waste Sites.* EPA/540-5-96/500. Washington D.C.

USEPA 1995b. "Health Effects Assessment Summary Tables," OHEA ECAO-CIN-909, Office of Research and Development and Office of Emergency and Remedial Response, Washington, D.C.

USEPA 1996a. Soil Screening Guidance: Users Guide, Office of Solid Waste and Emergency Response, EPA/540/R-96/018, Office of Research and Development and Office of Emergency and Remedial Response, Washington, D.C.

USEPA 1996b. *Radiation Exposure and Risks Assessment Manual (RERAM), Risk Assessment Using Radionuclide Slope Factors*, EPA 402-R-96-016, Air and Radiation, June.

USEPA 1996c. Proposed Guidelines for Ecological Risk Assessment. EPA/630/R-95/002B, Washington, DC.

USEPA 1996d. Integrated Risk Information System (IRIS) On-Line Database. Office of Environmental Criteria and Assessment Office, Cincinnati, OH. Washington, DC.

USEPA 1996e. ECO Update: Ecotox Thresholds. Intermittent Bulletin Vol. 3, No. 2, EPA 540/F-95/038.

USEPA 1996f. Recommendations of the Technical Review Workgroup for Lead for an Interim Approach to Assessing Risks Associated with Adult Exposure to Lead in Soil. December.

USEPA 1997a. "Exposure Factors Handbook," Volumes I, II, and III, EPA/600/P-95/002Fa-c, EPA, Office of Research and Development, Washington, DC.

USEPA 1997b. Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments. Interim Final. U.S. EPA Env. Response Team. Edison, NJ, June 1997.

USEPA 1998a. Integrated Risk Information System (IRIS), National Center for Environmental Assessment, U.S. Environmental Protection Agency, 26 West Martin Luther King Drive, MS-190, Cincinnati, Ohio 45268. (513) 569-7254.

USEPA 1998b. "Risk Assessment Guidance for Superfund: Volume I Human Health Evaluation Manual (Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments) Interim Guidance," OSWER Directive 9285.7-01D, Office of Emergency and Remedial Response, Washington, DC. January.

USEPA 1998c. Guidelines for Ecological Risk Assessment, EPA/630/R-95/002Fa.

USEPA 1998d. Region 9 Preliminary Remediation Goals. Supporting information for PRG tables. Updated June 3, 1998.

USEPA. 1999. *Screening Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities*. OSWER. EPA/530-D-99-001A.

USEPA 2000a. *Data Quality Objectives Process for Hazardous Waste Site Investigation.* EPA/600/R-00/007. Office of Environmental Information, Washington, DC. January.

USEPA 2000b. *Soil Screening Guidance for Radionuclides: User's Guide*, EPA/540-R-00-007, U.S. Environmental Protection Agency, October.

USEPA. Region 4. 2001. *Supplemental Guidance to RAGS: Ecological Risk Assessment*. Atlanta, GA.

USEPA 2002a. *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (EPA 540-R-01-003; OSWER 9285.7-41, September 2002

USEPA 2002b. *Supplemental Guidance for Developing Soil Screening Levels for Superfund Site.* OSWER 9355.4-24. U.S. Environmental Protection Agency, Washington, D.C. December.

USEPA, 2002c. *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites*. OSWER 9285.6-10. U.S. Environmental Protection Agency, Washington, D.C. December 2002.

USEPA, 2002d. *Federal Guidance Report No. 13: Cancer Risk Coefficients for Environmental Exposure to Radionuclides*. EPA-402/R-99-001. U.S. Environmental Protection Agency, Washington, D.C. April.

USEPA 2002e. National Recommended Water Quality Criteria. EPA 822-R-02-047.

USEPA. 2002f. *User's Guide for the Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK) Windows® 32-bit version.* EPA 540-K-01-005, OSWER 9285.7-42. Office of Solid Waste and Emergency Response, Washington, D.C.

USEPA. 2002g. *Recommendations of the Technical Review Workgroup for Lead for an Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil.* EPA-540-R-03-001. Washington, D.C.

USEPA. 2003a. *Guidance for Developing Ecological Soil Screening Levels*. November. Office of Solid Waste and Emergency and Remedial Response. OSWER Directive 92857-55.

USEPA 2003b. *Region 5 Media-Specific (soil, sediment, water and air) Ecological Screening Levels for RCRA Appendix IX Hazardous Constituents*. (http://www.epa.gov/reg5rcra/ca/ESL.pdf)

USEPA. Region 5. 2003c. *Ecological Screening Values and Freshwater Screening Benchmarks*. RCRA. Chicago, IL.

USEPA. 2003d. *National Primary Drinking Water Standards*. Office of Emergency Response, OSWER 9285.6-10. Washington, DC.

USEPA 2003e. *Human Health Toxicity Values in Superfund Risk Assessments*, OSWER 9285.7-53. Office of Solid Waste and Emergency Response, Washington, D.C.

USEPA 2004. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual: Part E, Supplemental Guidance for Dermal Risk Assessment, EPA 540/R/99/005, July, 2004, PB99-963312.

USEPA. 2005a. *Ecological Soil Screening Level for Antimony, Interim Final*, Office of Solid Waste and Emergency Response. OSWER Directives 9285.7-61.

USEPA. 2005b. *Ecological Soil Screening Level for Arsenic, Interim Final*, Office of Solid Waste and Emergency Response. OSWER Directives 9285.7-62.

USEPA. 2005c. *Ecological Soil Screening Level for Barium, Interim Final,* Office of Solid Waste and Emergency Response. OSWER Directives 9285.7-63.

USEPA. 2005d. *Ecological Soil Screening Level for Beryllium, Interim Final,* Office of Solid Waste and Emergency Response. OSWER Directives 9285.7-64.

USEPA. 2005e. *Ecological Soil Screening Level for Cadmium, Interim Final,* Office of Solid Waste and Emergency Response. OSWER Directives 9285.7-65.

USEPA. 2005f. *Ecological Soil Screening Level for Chromium, Interim Final,* Office of Solid Waste and Emergency Response. OSWER Directives 9285.7-66.

USEPA. 2005g. *Ecological Soil Screening Level for Cobalt, Interim Final,* Office of Solid Waste and Emergency Response. OSWER Directives 9285.7-67.

USEPA. 2005h. *Ecological Soil Screening Level for Lead, Interim Final,* Office of Solid Waste and Emergency Response. OSWER Directives 9285.7-70.

USEPA. 2005i. *Ecological Soil Screening Level for Vanadium, Interim Final,* Office of Solid Waste and Emergency Response. OSWER Directives 9285.7-75.

USEPA 2006a, *Region 6 Medium-Specific Screening Value*. U.S. Environmental Protection Agency Region 6, Dallas, TX, December.

USEPA. 2006b. *National Recommended Water Quality Criteria*. Office of Water. Office of Science and Technology. Washington, D.C.

USEPA. Region 3. 2006c. *Sediment Screening Benchmarks*. Philadelphia, PA.

U.S. Nuclear Regulatory Commission (USNRC) 1994. Federal Register Notice, Volume 59, Number 161, *Comments from Workshops: Radon,* U.S. Nuclear Regulatory Commission, August 22, 1994.

USNRC 2000. Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) Revision 1, NUREG-1575, Rev.1, EPA-402-R-97-016, Rev. 1, DOE/EH-0624, Rev. 1, *http://www/epa.gov/radiation/marssim/*

Weston Solutions, Inc. (Weston). 2001. Final Technical Project Planning Meeting Brief, Phase I Records Review, DuPont Chambers Works, Deepwater, New Jersey (an update from an original document prepared by URS Corporation, 13 June 2000).

APPENDICES

APPENDIX A

DETERMINATION OF BACKGROUND CONCENTRATIONS FOR RADIONUCLIDES AND METALS AT EACH MEDIUM

(On CD)

APPENDIX B

IDENTIFICATION OF COPCs AND DETERMINATION OF EXPOSURE POINT CONCENTRATION (EPC) FOR EACH COPC AT EACH MEDIUM

(On CD)

APPENDIX C
ASSIGNED VALUES FOR EXPOSURE PARAMETERS
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TOXICOLOGICAL AND PHYSICAL PROPERTIES FOR EACH COPC
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RADIOLOGICAL DOSE AND RISK ASSESSMENT SUMMARY REPORT
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OUTPUT SUMMARY FOR JOHNSON ETTINGER VAPOR INTRUSION MODEL

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ECOLOGICAL EXCLUSION WORKSHEETS AND ECOLOGICAL ASSESSMENT CHECKLISTS

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