FINAL

SCHOFIELD BARRACKS IMPACT RANGE

BASELINE HUMAN HEALTH RISK ASSESSMENT

FOR

RESIDUAL DEPLETED URANIUM

Contract No. W52P1J-06-D-0019
Delivery Order 0004

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Acronyms and Abbreviations

μg/L	microgram(s) per liter
^{234}Th	Thorium-234
^{234}U	Uranium-234
^{235}U	Uranium-235
^{238}U	Uranium-238
ac	acre
AEPI	U.S. Army Environmental Policy Institute
ADD	Average Daily Dose
ANL	Argonne National Laboratory
ASR	Archives Search Report
ATSDR	Agency for Toxic Substances and Disease Registry
BHHRA	Baseline Human Health Risk Assessment
CABRERA	Cabrera Services, Inc.
CDI	Chronic Daily Intake
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm	centimeter
CSF	Cancer Slope Factor
CSM	Conceptual Site Model
d	day
DQO	Data Quality Objective
DU	Depleted Uranium
ELCR	Excess Lifetime Cancer Risk
EPC	Exposure Point Concentration
FGR	Federal Guidance Report
Ft	foot (feet)
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HLA	Harding Lawson Associates
HQ	Hazard Quotient
IAEA	International Atomic Energy Agency
ITAM	Integrated Training Area Management
in.	inch
IRIS	Integrated Risk Information System
JMC	Joint Munitions Command
mg	milligram(s)
mg/kg	milligram per kilogram
mg/kg-d	milligram per kilogram-day
NCP	National Contingency Plan
NRC	Nuclear Regulatory Commission
pCi/g	picocuries per gram
PCOC	Potential Contaminant of Concern
PRG	Preliminary Remediation Goal
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
RESRAD	Residual Radioactivity
RfD	Reference Dose
RME	Reasonable Maximum Exposure
sec	second
SB	Schofield Barracks
SBIA	Schofield Barracks Impact Area
SRB	spotting round body
Sf	square foot (feet)
Th	Thorium
U	Uranium
UCL_{95}	95 Percent Upper Confidence Limit
USACE	U.S. Army Corps of Engineers
USAG-HI	U.S. Army Garrison, Hawaii
USEPA	U.S. Environmental Protection Agency
UXO	Unexploded Ordnance

EXECUTIVE SUMMARY

This *Baseline Human Health Risk Assessment (BHHRA) Report* has been developed to assess potential health impacts to human receptors from potential exposure to depleted uranium (DU) present at the Schofield Barracks Impact Area (SBIA), considering both chemical and radiological toxicity from DU. This document has been prepared in accordance with the provisions of the *Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)* and the *National Oil and Hazardous Substances Pollution Contingency Plan (NCP)*. Cabrera Services, Inc. (CABRERA) has prepared this report for the U.S. Army Joint Munitions Command (JMC), under Contract No. W52P1J-06-D-0019, Delivery Order 0004.

Site Description

Schofield Barracks (SB) is located near the town of Wahiawa in central Oahu in the Hawaiian Islands. It was declared a military reservation by Executive Order in 1899 and has remained under U.S. Army control since that date. The facility has been used for year round outdoor field training due to its mild weather conditions. The facility is currently the home of the United States Army 25th Infantry Division and the United States Army Garrison, Hawaii (USAG-HI). The site is approximately 22 miles northwest of Honolulu.

Project Background

According to the *Archives Search Report* (ASR) *On the Use of Cartridge, 20MM Spotting M101 For Davy Crockett Light Weapon* M28, *Schofield Barracks and Associated Training Areas, Islands of Oahu and Hawaii*[1] (USACE, 2007), training with the Davy Crockett weapons system was likely conducted at SB between 1962 and 1968. Historical documents contained no reference explicitly identifying a specific range used for Davy Crockett system training. However, the ASR identified the M79 grenade launcher range as the range that was likely used based on the location of the debris in its area and its designation as a secure range.

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[1] For a detailed description of the design and operation of the Davy Crockett Light Weapon System M28, please refer to the referenced report.

In August 2005, a tail assembly and partial spotter round body (SRB) from the Cartridge, 20mm Spotting M101 associated with the Davy Crockett Light Weapon M28 were discovered by Schofield personnel during routine activities in the SBIA. Depleted uranium (DU) fragments were found to be associated with the SRB at several locations throughout the range area. That discovery prompted the initial investigation of DU occurrence at the site by CABRERA, which ultimately led to site characterization work conducted during the summer of 2007. The results of that field study provided the data evaluated in this risk assessment.

Nature and Extent of Contamination

Results of environmental investigations conducted at SBIA have been used to identify contaminants of interest, identify the impacted media, and characterize the nature and extent of DU remaining on SBIA. Based on results of the field investigations conducted to date at similar impact areas, DU was identified as the primary contaminant of interest present at SBIA. DU fragments have been observed throughout SBIA as discrete metal fragments and as fine particulate matter. Sampling data from surface water samples indicates that the concentrations of uranium are less than the drinking water standard for uranium, and DU was not detected in the samples. The uranium alpha spec isotopic results were less than their respective minimum detectable concentrations for most of the samples, and the ^{234}U / ^{238}U activity ratios calculated were inconclusive for either DU or natural uranium. Therefore, there is no evidence that DU in soil has migrated to surface water bodies located in or adjacent to the SBIA. In addition, potential contamination of groundwater was considered, but not used in the risk assessment because the underlying aquifer (approximately 500 ft below ground surface) is not recharged from water from the SBIA.

Human Health Risk Assessment

A baseline human health risk assessment (BHHRA) was performed to evaluate the potential risk posed by DU the only site contaminant at SBIA. Reported concentrations of uranium and progeny in soil were evaluated to assess both toxicological and radiological risks from DU. Based on information obtained during site visits, review of historical records, and comparison of sampling results with respect to U.S. Environmental Protection Agency (USEPA) Region 9 Preliminary Remediation Goals (PRGs), DU was identified as the potential contaminant of concern (PCOC). For the purposes of this risk assessment, it was assumed that all uranium present at SBIA was depleted, and therefore DU is the sole contaminant considered in making the risk calculations presented herein.

Four exposure scenarios were evaluated for the purpose of quantifying risks to potential on-site receptors: current and future maintenance worker, future construction/remediation worker, future adult cultural monitor/trespasser/visitor, and future site worker. Complete exposure pathways were evaluated for each scenario and included a combination of the following: incidental ingestion of soil, inhalation of windblown fugitive dust, dermal contact with site contaminants, and direct exposure to external gamma radiation. Exposure point concentrations were calculated based on sample data from the soil.

Health risks were estimated for DU based on the chemical toxicity of uranium. The maximum hazard index (HI) of 2E-1 was calculated to quantify the non-carcinogenic effects of exposure for a future construction/remediation worker. This is below the USEPA's acceptable risk limit for non-carcinogenic effects of 1.0. These results for non-carcinogenic risks indicate that there are no adverse impacts expected due to chemical exposure to DU.

The *RESidual RADioactivity* (*RESRAD*) computer code, Version 6.3, developed by Argonne National Laboratory (ANL, 2005), was used to estimate risk due to the radiological toxicity of DU for each of the potential receptors. A maximum risk of 3E-5 was calculated to quantify the excess lifetime cancer risk (ELCR). This value falls within USEPA's acceptable risk range of 1E-4 to 1E-6, indicating that there are no likely adverse impacts expected from DU exposure based on its radiological toxicity, and the DU levels are safe.

An additional dose and risk evaluation was performed to evaluate the potential health impacts to an off-site subsistence farmer living 1500 meters from the SBIA. This is a highly conservative exposure scenario that would be considered the Maximally Exposed Individual for offsite receptors. RESRAD-OFFSITE, Version 2.1 (ANL 2007) was used to estimate radiological dose and risk, and USEPA's standard RAGS equations were used to determine the chemical risk due to the presence of DU at the site. The results of the dose and risk assessments showed that both the radiological and chemical risks are within the USEPA acceptable risk range. Hence, there are no likely adverse effects to off-site receptors resulting from the presence of DU at the SBIA and the DU levels are safe.

Conclusions

Investigations at the SBIA have determined that DU is the contaminant of interest for the purposes of this risk assessment. The results of the risk assessment presented in this document demonstrate that the presence of DU in soil at the SBIA results in radiological dose as well as chemical and radiological risk that falls within the EPA limits for what considered safe by the USEPA and NRC. No significantly increased risks exist at SB for the human receptors evaluated in this BHHRA. As a result, no adverse human health impacts are likely to occur as a result of exposure to uranium in soil. This is true for human receptors located on-site under current and potential future land use scenarios (e.g. range maintenance workers, cultural monitors, trespassers), as well as human receptors beyond the SBIA boundaries, as modeled by a subsistence farmer, representing an overly conservative exposure scenario.

1.0 INTRODUCTION

Cabrera Services, Inc. (CABRERA) has prepared this *Baseline Human Health Risk Assessment (BHHRA)* for the U.S. Army Joint Munitions Command (JMC), under Contract No W52P1J-06-D-0019, Delivery Order 0004. This BHHRA presents an evaluation of the potential health impacts to human receptors from exposure to depleted uranium (DU), and its potential radiological and chemical toxicity, found within limited areas on the Schofield Barracks Impact Area (SBIA). Specifically, this BHHRA considers the potential impacts related to DU fragments resulting from the confirmed presence of Davy Crockett spotter round bodies (SRB) on limited areas of the impact area. Based on previous evaluations of fragments associated with Davy Crockett SRB on other firing ranges (CABRERA, 2007), DU has been identified as the potential contaminant of concern (PCOC) that drives human health risk. This BHHRA report has been prepared in accordance with the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).

1.1 Purpose

During the removal of unexploded ordnance (UXO), Schofield Barracks (SB) in 2005, personnel discovered a number of 20 mm Davy Crockett DU spotter round fragments on a firing range. After a recent controlled grass burn on the range, Schofield personnel surveyed a portion of the range and discovered several additional DU fragments. This BHHRA has been developed to address DU associated with Davy Crockett SRB on SBIA.

The BHHRA is being undertaken as a part of a focused evaluation of the nature, extent, and potential effects of contamination resulting from the presence of DU from SRB at SBIA. The specific objectives of the BHHRA are to:

- Estimate potential human health risks and environmental impacts associated with SBIA under current conditions (i.e., if no remedial action occurs).
- Identify areas that pose human health risks in excess of CERCLA's acceptable risk range of 1E-4 to 1E-6 as prescribed in the Code of Federal Regulations (40 CFR 300.430, subpart E); and

- Estimate potential human health risks associated with SBIA under possible future land use conditions.

1.2 Baseline Risk Assessment Approach

The general approach for conducting this risk assessment follows U.S. Environmental Protection Agency (USEPA) *Risk Assessment Guidance for Superfund* (RAGS, 1989) and the data quality objectives (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 adverse 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 process followed in this risk assessment was to determine risk to human receptors. The risk assessment identified receptors who may be exposed to depleted uranium, the exposure pathways through which receptors are potentially exposed to the site contaminant, and the concentrations of the site contaminant in each environmental exposure media (e.g., soil). Based on these elements, and the specific toxicity of the site contaminants, both intakes and doses were calculated and the uncertainty associated with these calculations discussed. The risk assessment ultimately identifies locations of adverse levels of risk and provides information to be used by stakeholders for risk management decisions.

There are five steps involved in risk assessment:

- **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 SBIA. PCOCs 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 PCOCs. 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 PCOC). The exposure scenarios are summarized in the Conceptual Site Model (CSM Section 4.2.1), 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 the PCOC, DU.

- **Risk Characterization** is a synthesis of exposure and toxicity information to yield quantitative estimates of potential dose and risk 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 data variability.

1.3 Organization of the BHHRA Report

The general format of this document is as follows:

- Section 1: Introduction. Presents the general purpose and scope of the BHHRA, the overall approach to the BHHRA, and the BHHRA Report organization.

- Section 2: Site Information. Provides a general physical site description, specific information on areas of concern with respect to Davy Crockett spotter rounds, and history of Davy Crockett use on the firing ranges at SB.

- Section 3: Data Usability. Summarizes the overall process that was applied in evaluating data usability and a discussion of data collected to date that was incorporated into the risk calculations.

- Section 4: Baseline Human Health Risk Assessment (BHHRA). Describes how PCOCs were identified for quantitative risk assessment; presents the land use and potentially exposed populations (both on-site and off-site), conceptual site model, methodology for estimating exposure point concentrations, dose and risks, chemical hazard and cancer risk; and discusses sources and implications of uncertainty in the risk characterization.

- Section 5: Conclusions. Summarizes the findings of the BHHRA evaluation process for the purpose of supporting risk management decisions.
- Section 6: References. Lists the references cited in the BHHRA.

2.0 SITE DESCRIPTION

The SB comprises two sections - the East Range and the Main Post -- covering 17,725 acres on the island of Oahu in Hawaii, 22 miles northwest of the city of Honolulu. Most of the area surrounding the installation is rain forest or land used for agriculture. Wheeler Army Airfield lies adjacent to the installation to the south and the town of Wahiawa lies to the north. Schofield serves as headquarters for the 25th Infantry Division and 45th Support Group. As an active military installation and a residential community, Schofield's mission is to provide administration, training, and housing facilities (*Agency for Toxic Substances and Disease Registry* [ATSDR], 1998).

The subject of this report is the site located on the SBIA. The SBIA consists of approximately 2650 acres, of which 428 were surveyed to generate data on presence and concentrations of uranium isotopes, which were used in the risk calculations documented in this report.

2.1 Physical Characteristics

SB resides in a large valley with a ridgeline along the north, west and southwest boundaries. The valley faces east and extends into the central Schofield saddle. The SBIA is located in the northwest corner of the installation, butting up against the Waianae Mountain Range. The site under consideration for this assessment is approximately 428 acres of the SBIA (*Site Characterization Survey CABRERA, 2008*)

2.1.1 Topography

The majority of SBIA is of moderate slope with seasonally heavy vegetation. Beyond the SBIA to the west and southwest, the land rises steeply and is not considered usable for maneuvers. The steep area is used as a safety (buffer) zone for the impact area. The ridge of the Waianae Range has the highest point on Oahu, Mount Kaala, which has an elevation of over 4,000 feet (ft). The elevation of the maneuver areas vary between 800 and 1,400ft. Vegetation varies from dense woodlands on the steeper western slopes to open grasslands in the impact and range area. Several densely wooded gullies bisect the impact areas.

2.1.2 Geology

According to a United States Soil Conservation Service 1972 study, there are four soil associations that can be found at SBIA. The mountainous areas and low slopes of the Waianae Range reflect the volcanic history of the area and include Tropohumults-Dystrandepts soil types, commonly referred to as Andisols, typically of the Ultisol or Oxisol order, Soils in these areas are well-drained and often underlain by soft weathered rock, volcanic ash or colluvium. Soil erosion is significant in areas where natural drainage and gulches occur. Helemano Silty Clay, 30-90 percent slope, normally found on sides of gulches that cross the SBIA West Range, is highly erodible soil. However, the relative dry climate and lack of permanent streambeds reduce the amount of erosion, as well as in those areas where soils are not well developed on exposed lava. The Army's Integrated Training Area Management (ITAM) program uses land management practices and erosion control measures to stabilize and minimize soil erosion (US Army DPW, 2003).

2.1.3 Hydrogeology

The principal source of groundwater recharge on Oahu is rainfall, with recharge more predominant in the higher elevations Harding Lawson Associates (HLA) (1996). On Oahu, the fresh water percolating down through the ground into the saturated zone does not mix well with the denser salt water present in the subsurface environment, resulting in a lens-shaped fresh water body that rises where recharge occurs and thins where the fresh water discharges to the ocean.

The groundwater body that lies under the majority of SB is known as the Schofield High-Level Water Body. It lies approximately 270 to 275 feet above mean sea level and 500 to 600 feet below ground surface at Schofield. Groundwater from the Schofield High-Level Water Body flows south to the Honolulu-Pearl Harbor Basal Water Body and north to the Waialua Basal Water Body, both of which are at lower elevations than the Schofield High-Level Water Body. The Schofield High-Level Water Body overlies sea water and is naturally bounded on the north and south by groundwater dams (natural discharge zones, confined at their bases by the lenticular saline water lens) and on the east and west by dike-impounded water bodies within the mountain ranges (ATSDR, 1998). Surface runoff at SBIA during heavy rain events will pass through the unsaturated zone, in gravity-driven percolation downward into the Schofield high level aquifer. This would then run off eastward, towards lake Wilson.

2.1.4 Meteorology

The average rainfall at SBIA varies with elevation and exposure; the averages inland at higher elevations of SBIA are considered representative of the island averages and usually exceed 50 inches annually. The overall average for SBIA is 43.75 inches (in). The spring/summer (April-October) monthly average rainfall is 1.63 to 3.78in, and for fall/winter (November-March) months the range is 4.14 to 6.21in U.S. Army Corps of Engineers ([USACE] and Nakata Planning Group 2000). Prevailing winds are northeasterly trade winds from 4 to 12 miles per hour in the warmer summer months, and lighter southeasterly winds prevail in winter months. Droughts and the risk of fire danger increase in the summer and early fall on Oahu.

2.2 Project History

SB was declared a military reservation by Executive Order in 1899 and has remained under U.S. Army control since that date. The facility has been used for year-round outdoor field training due to its mild weather conditions. The facility is currently the home of the United States Army 25th Infantry Division and the United States Army Garrison, Hawaii (USAG-HI).

According to the *Archives Search Report* (ASR) *On the Use of Cartridge, 20MM Spotting M101 For Davy Crockett Light Weapon M28, Schofield Barracks and Associated Training Areas, Islands of Oahu and Hawaii* (USACE, 2007), training on the Davy Crockett weapons system was likely conducted at SB between 1962 and 1968. Although no range was specified for Davy Crockett system use in the available historical documents, the ASR identified the M79 grenade launcher range as likely, based on the location of the debris in the area and the designation of that range as a secure range.

In August 2005, tail fins and SRBs from the Cartridge, 20mm Spotting M101 associated with the Davy Crockett Light Weapon M28 were discovered by Schofield personnel during routine activities in the range impact area. DU fragments associated with the SRB were found at several locations throughout the western portion of the SBIA.

In November 2006, a scoping survey was performed by CABRERA. The purpose of the survey was to confirm the presence of DU at SBIA. That project is summarized in the *Schofield Barracks Firing Range Phase I Depleted Uranium Investigation,* CABRERA 2007. At that time SRBs were noted, and the presence of DU was confirmed through alpha spectroscopy analyses of both soil and metal fragment samples.

In preparation for the characterization survey, United States Army Garrison, Hawaii (USAG-HI) conducted a prescribed burn of the SBIA from July 30 to August 2, 2007. Davy Crocket debris was observed in the north/eastern portion of the SBIA during helicopter flyovers of the area. This finding indicated that the use of the Davy Crocket at SB may have impacted a larger area. A subsequent scoping survey was conducted in the north/eastern area and it was determined that SRB were present and the characterization survey area was expanded accordingly (See *Scoping Survey Technical Memorandum*, CABRERA 2008).

2.3 Land Use

SB is located in central Oahu, west of the town of Wahiawa. It is bordered to the east by Wahiawa’s Lake Wilson and Wheeler Army Airfield, to the north by private agricultural lands and the Mt. Kaala Natural Area Reserve, to the west by the Waianae Kai Forest Reserve on the Waianae Range crest, and to the south by Lualualei Naval Reservation, private agricultural lands, and state lands.

The Installation itself includes a main cantonment area, maneuver training areas, ranges, and impact areas. The cantonment area includes troop housing, operational facilities, family housing, warehouses, training facilities, and community service facilities. There are approximately 1,235 acres designated to support maneuver training (South Range); with an additional 1,506 acres to support range and indirect fire activities, and a 2,650 acre impact area (USACE and Nakata Planning Group 2000). The installation extends eastward from the ridge line to Kaukonahua Road. The upper portion of the training area lies within a Conservation District which is called the Schofield Forest Reserve. The conservation district extends to the northwest and is included in the central Oahu Agricultural District. Most of the district is used for growing pineapple. Urban districts adjacent to the training area include the SB developed area, Wheeler Army Air Field, and Wahiawa (Global Security, 2008).

SBIA is the primary range complex for individual weapons qualification with limited light maneuver training areas on the perimeter. Training and live-fire impact areas are situated west of the cantonment area. The wooded eastern slope of the Waianae Range is used primarily for tactical infantry maneuver training, including land navigation training. The SBIA, located on more rugged terrain west of the cantonment, is the main site for firing range practice on Oahu (USACE and Nakata Planning Group 2000). Small arms, machine gun, mortar, grenade, antitank, and limited short-range indirect fire artillery training are conducted on these firing ranges. The live-fire training facilities at SB are used year-round.

The western portion of the impact range includes the ridges and valleys where 15 SRBs containing DU were recovered by a contractor clearing UXO and scrap metal in August 2005. A scoping survey was completed for the western area in 2007 by CABRERA. The Site extends from the western part of the SBIA down into an area known as McCarthy Flats, and thus runs into the eastern portion of the SBIA and includes a smaller, isolated secondary area along the northern edge of the SBIA.

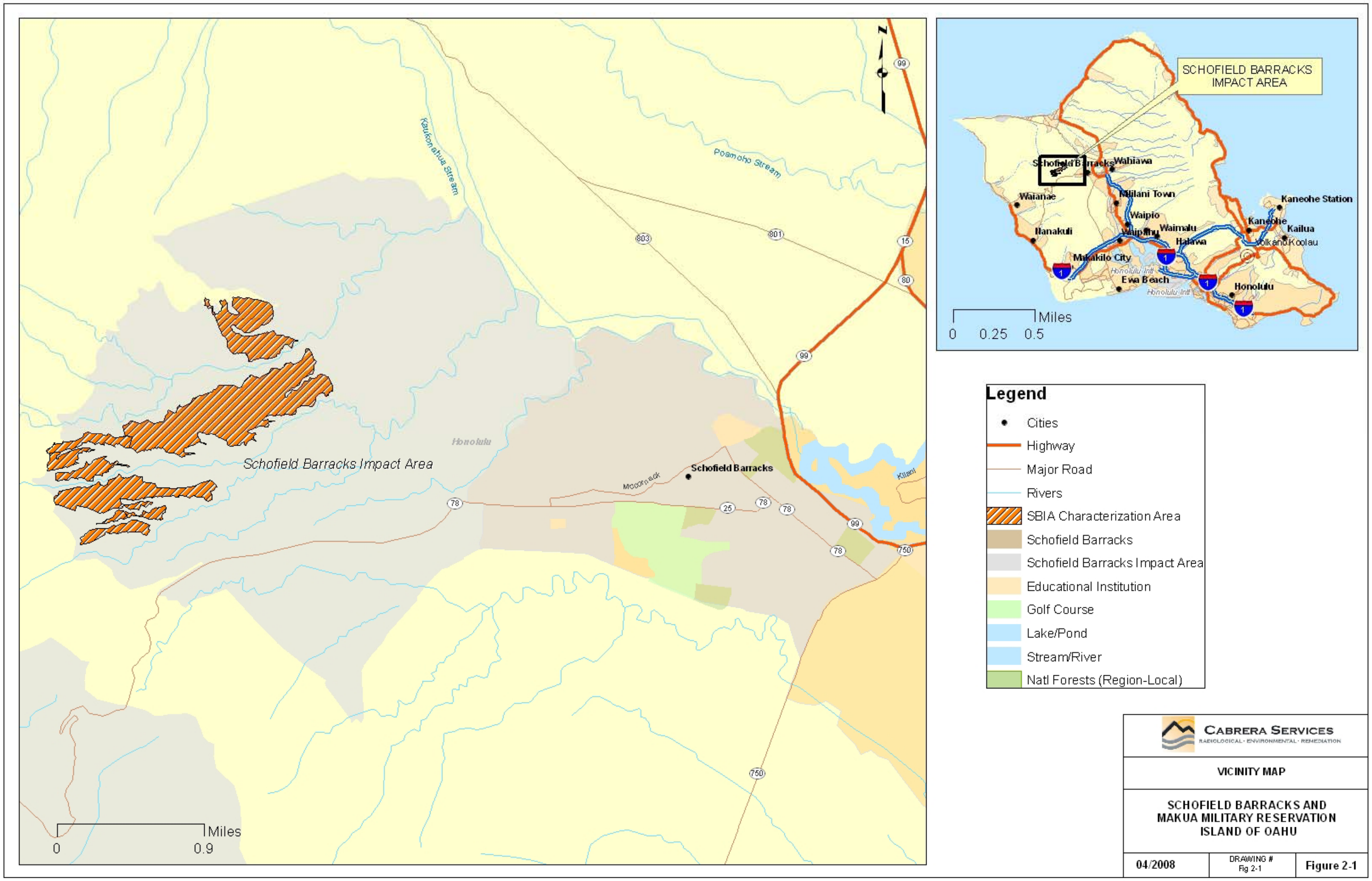

FIGURE 2-1: LOCATION OF SCHOFIELD BARRACKS

2.4 Source, Nature, and Extent of Contamination

A characterization survey was performed to obtain more detailed information regarding the location and extent of DU resulting from use of Davy Crockett weapons systems on parts of the firing range *(Site Characterization Survey* CABRERA*, 2008)*. The contaminant of concern is DU contained in the SRB found during previous investigations.

Use of the Davy Crockett weapons system as part of training exercises was identified during records searches conducted by USACE (2007). The presence of SRB on the firing range was confirmed visually during routine range maintenance and clearance activities. Characterization data were collected from a portion of the SBIA (approximately 428 acres) Figure 2-1 shows the location of SBIA.

Table 2-1: Number of Samples Collected[2]

	Systematic	**Biased[3]**
Gamma Spec Surface	416	165
Gamma Spec Sub-Surface	416	153
Alpha Spec Surface	0	52
Gamma Spec Surface: Reference Area	12	0
Gamma Spec Sub-Surface: Reference Area	12	

A total of 1,226 soil samples were collected at 645 sample locations, including the reference area (refer to *Site Characterization Survey* CABRERA*, 2008* for more details on the sample locations and results). Uranium isotope or progeny concentrations in soil were measured, and the Uranium-238/Uranium-234 (^{238}U/^{234}U) activity ratio was calculated for measurement. For Alpha Spec samples, the ratio of ^{238}U/^{234}U was determined from the measured results. For Gamma Spec samples, (^{234}Th is the progeny (i.e., decay product) of ^{238}U, and emits gamma radiation, and is measured by gamma spectroscopy. ^{234}Th and ^{238}U are in secular equilibrium, therefore ^{234}Th is a surrogate for ^{238}U. There are no progeny of ^{234}U that emit gamma radiation and are in

[2] *Schofield Site Characterization Survey* CABRERA, 2008.

[3] Locations of biased samples were selected based upon professional judgment.

secular equilibrium. Therefore, ^{234}U is not measured by gamma spectrometry. Given the assumption that all uranium at the site was DU, the ratio of $^{238}U/^{234}U$ was inferred for Gamma Spec samples by measuring the ^{234}Th. *Site Characterization Survey for Schofield Barracks Firing Site,* CABRERA 2008). A $^{238}U/^{234}U$ activity ratio significantly greater than one (>1) was used as an indicator of DU at SBIA. DU consists of the same three isotopes of uranium as natural uranium (U^{nat}); however, the percentages of the uranium isotopes are different than the percentages found in natural uranium. Therefore, DU is considered as the only PCOC for SBIA.

Based on the soil sample results (included in Appendix A), concentrations representative of background were determined to be less than 2.57 picocuries per gram (pCi/g) (1.65 ± 0.918 pCi/g at the 95% confidence level) for ^{238}U. Average concentrations of ^{238}U in both systematic and biased sample data were found to be similar to that of the reference area, with the exception of approximately three percent of the samples. These samples were found to contain DU or exhibit a DU influence (i.e., the reported ^{238}U concentration was above the naturally-occurring ^{238}U concentrations in the reference area). Concentrations ranged from 0.01 to 7,030 pCi/g without natural uranium background being subtracted from results.

The mobility and persistence of DU in the environment is influenced by the amount, form, and oxidation state of the metal, as well as by the composition and physicochemical properties of the affected media. In the metal form, DU tends to persist in the soil, and undergo few chemical changes other than oxidation due to weathering and exposure. Figure 2-2 illustrates the appearance of Davy Crockett round fragments found at SBIA. Note the oxidized state (bright yellow) of the fragments. The soil underlying and adjacent to the fragments is generally thin and poorly developed granular sand and silt-sized material resulting from the weathering of volcanic rock. The nature of the underlying soils, coupled with the relatively dry climate favors the retention and reduced solubility of metals, thereby reducing their mobility.

FIGURE 2-2: TYPICAL FORM OF DU AT SCHOFIELD BARRACKS

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3.0 DATA COLLECTION AND EVALUATION

The primary suspected contaminant associated with the SRB is D-38 uranium alloy (92% depleted uranium and 8% molybdenum). For the purposes of this report, we will refer to the alloy as DU. The DU was used in the SRB for the Davy Crockett weapon system because of its high density and weight. The SRB is approximately four inches in length and one inch in diameter and composed of DU. In accordance with the Characterization Survey Work Plan (CABRERA 2007), 1226 soil samples were collected as a part of the characterization of the SBIA. Samples were analyzed in accordance with the procedures developed by off-site laboratories. Off-site radiochemical analysis consisted of alpha spectrometry for uranium isotopes and gamma spectrometry analysis. The alpha spectrometry analyses were performed for 52 samples to quantify the target isotopes ^{234}U, ^{235}U, and ^{238}U. Gamma spectrometry analyses were performed for the remaining 1174 samples to quantify the target isotope Thorium-234 (^{234}Th), as it is the gamma-emitting progeny of ^{238}U. ^{238}U is not detectable with gamma spectrometry, whereas ^{234}Th is detectable with gamma spectrometry. As the activity of ^{234}Th and ^{238}U are in secular equilibrium, measurement of the ^{234}Th is the accepted method to infer the concentration of ^{238}U. All analytical results are included in Appendix A.

In addition, samples were also collected from a reference area. The reference area is approximately 40,000 square feet (sq ft) and was identified by Army personnel as an area where the Davy Crockett weapons system was never used. The reference area consisted of an earthen berm outside the surveyed areas, with heavy vegetation concentrated along the top and sides of the area.

Detection limits achieved during sample analyses were reviewed to ensure that required detection limits had been met[4]. Typically detection limit requirements are established to ensure that characterization has occurred to levels that are low enough to determine if constituents are

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[4] The applicable scan minimum detectable concentration (MDC) for DU is approximately 2.6 picocuries per gram (pCi/g). This scan MDC value is based on the assumption that uranium-235 is present at 0.35% by mass, and includes the sum of ^{234}U, ^{235}U, and ^{238}U. In addition, the calculation assumes that the DU is present as a 0.5pound (lb) slug with approximately 1 foot (ft) The applicable scan minimum detectable concentration (MDC) for DU is approximately 2.6 picocuries per gram (pCi/g). This scan MDC value is based on the assumption that uranium-235 is present at 0.35% by mass, and includes the sum of ^{234}U, ^{235}U, and ^{238}U. In addition, the calculation assumes that the DU is present as a 0.5pound (lb) slug with approximately 1 foot (ft) of soil cover, which is a conservative estimate of actual site conditions (See *Schofield Barracks Phase II Characterization and Scoping Surveys, Characterization Work Plan,* CABRERA 2007)

present at hazardous levels. These levels are constituent-specific and related to each constituent's toxicity.

Sample results were subjected to validation and verification using a checklist developed by CABRERA senior-level staff member with experience in radiochemistry, analytical quality assurance, and data evaluation. The radiological checklists were developed in accordance with accepted industry practices. The verifications and validations were performed according to the checklists. All radiological samples were subjected to data verification/review and radiological samples in 10% of the analytical batches received full data validation. Initial data verification was performed by the laboratory's quality control staff.

Data qualifiers are used to refine the description of precision and accuracy associated with data that meet the DQO for the project. An example is the "J+" qualifier. It indicates that while the sample result is acceptable, the actual concentration in the soil is likely slightly lower than reported, resulting in a conservative representation of actual soil concentrations.

No results were rejected as a result of the data quality assessments. The J+ qualifier (i.e., estimated, possibly biased high) was applied to all of the gamma spectrometry results unless they received qualifiers because of other quality parameters. The J+ qualifier was applied because the density of the samples was less than the density of the calibration standard (see Section 5.3.2 of *Site Characterization Survey CABRERA, 2008*) and the calibration geometries. In addition, data were qualified as estimated. A summary of data qualifiers is presented in Table 3-1.

Table 3-1: Summary of Qualifiers Applied to Indicator Radionuclides

Radionuclide	**Qualifier**				**Number of Samples**
	J+	J	DL	R	
^{234}Th	1147	14	41		1174
$^{233/234}$U		1			52
^{235}U					52
^{238}U					52

J+: result qualified as estimated; possible high bias

J: result qualified as estimated

DL: result qualified because of a failure to achieve the required minimum detectable concentration

R: The result was qualified as rejected.

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4.0 BASELINE HUMAN HEALTH RISK ASSESSMENT

To evaluate the risks posed by residual DU at SBIA, a BHHRA was performed in accordance with USEPA (*RAGS*; 1989). The Schofield Barracks risk assessment included evaluations of both chemical and radiological risks from DU to potential human receptors, both on-site and off-site, based on the exposure scenarios appropriate for SBIA. Consistent with USEPA guidance, the risk assessment presented below for on-site receptors includes the following components: contaminant identification, exposure assessment, toxicity assessment, and risk characterization (Subsections 4.1 through 4.4).

This assessment also includes a highly conservative (erring on the side of caution) evaluation of dose and risk resulting from potential exposure to DU for an off-site receptor. This off-site receptor evaluation has been included to address public concerns and makes use of both USEPA RAGS protocols to evaluate chemical risk related to potential exposure to DU, as well as a new model, *RESRAD OFF-SITE, V2.1* developed by Argonne National Laboratory (ANL, 2007) to evaluate radiological consequences to an off-site receptor. The methodologies, assumptions, and results of this off-site receptor evaluation are included in Subsection 4.5.

4.1 Potential Contaminant of Concern

The characterization survey was performed to obtain more detailed information regarding the location and extent of DU fragments in the affected area. The original form of residual fragments at SBIA is DU in the SRB from the M101 spotting round. During firing, the SRB struck the ground setting off an explosive charge, fragmenting the SRB. Hence, the distribution of DU in soils is non-homogeneous because of the variability in the projectiles trajectory and projectile fragmentation. The non-homogeneous deposition of DU in soils remains non-homogenous as the DU metal oxidizes with time. The highest concentrations of DU in soil have been from samples taken directly under SRB fragments. The DU concentrations decrease with depth, and at greater depth, DU concentrations are comparable to natural uranium concentrations. Hence, the uranium isotopes are considered as the PCOC for soil at SBIA.

The presence of uranium derived from DU in other environmental media at SBIA would be the result of transport from soil to other media, such as surface water. In addition to soil samples, 6 surface water samples were analyzed for uranium isotopes. The individual uranium isotopic results were summed to determine total uranium. The results of total uranium were compared with the USEPA's 30 microgram per liter (µg/L) total uranium drinking water concentration standard. The results showed that total uranium concentrations for all samples were found to be a factor of at least 10 times below its drinking water concentration limit.

4.2 Exposure Assessment

This section describes the receptors and exposure pathways that were evaluated in the risk assessment for on-site receptors. The objectives of the exposure assessment were to estimate the magnitude, frequency, duration and routes of potential human exposures to the PCOC at SBIA. 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 (EPC) 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.

4.2.1 Conceptual Site Model

The CSM identifies potential sources, release mechanisms, transport media, routes of migration through the environment, exposure media, and potential human receptors. Human receptors that may be potentially exposed to the PCOC are identified and the likelihood of their potential exposures assessed through consideration of the current and the anticipated future use of SBIA. The CSM for SBIA, illustrated in Figure 4-1, shows all potentially complete pathways for human exposures. Only human receptors were considered for the BHHRA.

The models present the migration and exposure pathways for receptors on SBIA. Only the reasonably maximally exposed (RME) exposure was evaluated in the BHHRA for onsite personnel. The exposure assessment evaluated the RME risk to all human receptor populations to the PCOC on SBIA. Due to presence of UXO, physical access to the range is highly restricted and relatively few human receptors are exposed to the DU present at SBIA. Under the current land use scenario (which is not expected to change), only one RME receptor, an adult range maintenance worker was considered for SBIA. The receptor may come in contact with contaminated media while working at SBIA. Installation security and administrative access controls prevent any other receptor to be exposed to the fragments present at SBIA.

Surface water pathways were considered for this assessment, however, sampling data from surface water samples indicates that the concentrations of uranium are less than the drinking water standard for uranium, and DU was not detected in the samples. The uranium alpha spec isotopic results were less than their respective minimum detectable concentrations for most of the samples, and the 234U / 238U activity ratios calculated were inconclusive for either DU or natural uranium. Therefore, it was determined that this represents an incomplete exposure pathway, and no analysis was performed (Section 4.1).

Similarly for the groundwater pathway, due to the lack of an active recharge zone in the impact area, the depth of the water table below the ground surface (500-600 feet), it was determined that it is an incomplete pathway, and no analysis was performed (Section 2.1.3 / ATSDR 1998).

Four RME receptor scenarios - range maintenance worker, construction/remediation worker, and adult cultural monitor/trespasser/visitor were evaluated under future land use scenarios. In addition, the BHHRA was also performed for a site worker. SBIA worker scenario was considered with the (very conservative) assumption that SBIA might be converted into conservation land following the completion of remediation. The receptor scenarios along with their corresponding exposure pathways are summarized in the following section.

Current and Future Maintenance Worker: This receptor is responsible for caretaker activities such as vegetation management or control burning of vegetation, clearing brush, and general site maintenance. It is assumed that these activities would likely require 10 days per year. The exposure duration for the maintenance worker is assumed to be 6.6 years. The maintenance worker is assumed to spend 8 hours per day outdoors. The adult maintenance worker is assumed to ingest 100 milligram (mg) of soil (USEPA 1989) and inhale 1.4 cubic meters per hour (m^3/hr) or 12,300 m^3 per year (m^3/yr) of air (ANL 1993, Section 4.4.2).

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 from soil; and
- dermal exposure to chemicals in soil.

Future Construction / Remediation Worker: Since it is reasonable to assume that construction/remediation activities could occur at the Site, adult construction workers were identified as potential receptors. During construction/remediation activities these receptors could be exposed to residual fragments present in soil. Construction workers were assumed to be on the job 8 hours per day, 180 days per year over a 1-year period. During a typical working day, the construction worker is assumed to spend 8 hours outdoors and will ingest 330 mg of soil (USEPA 2002). The inhalation rate for the receptor is 72 m^3 per day or 26,300 m^3/yr (ANL 1993, see Section 4.4.2). Since construction workers are assumed to be adults, a body weight of 70-kilogram was used to assess exposure to chemical contaminants.

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 from soil; and
- dermal exposure to chemicals in the soil.

Future Adult Cultural Monitor/Trespasser/Visitor: The adult cultural monitor/trespasser /visitor would, on average, spend one day every other week for performing other outdoor activities at SBIA. Under this scenario, the cultural monitor/trespasser/visitor may be exposed to the residual radioactive fragments that may be present in surface soil but are not expected to have regular contact with subsurface soil. This receptor will ingest 100 mg of soil per day (USEPA 1991a) and inhales 20 m3 of air per day (USEPA 1989). The receptor is assumed to spend 8 hours per day outdoors at SBIA.

Exposure pathways evaluated for the receptor scenario include:

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

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

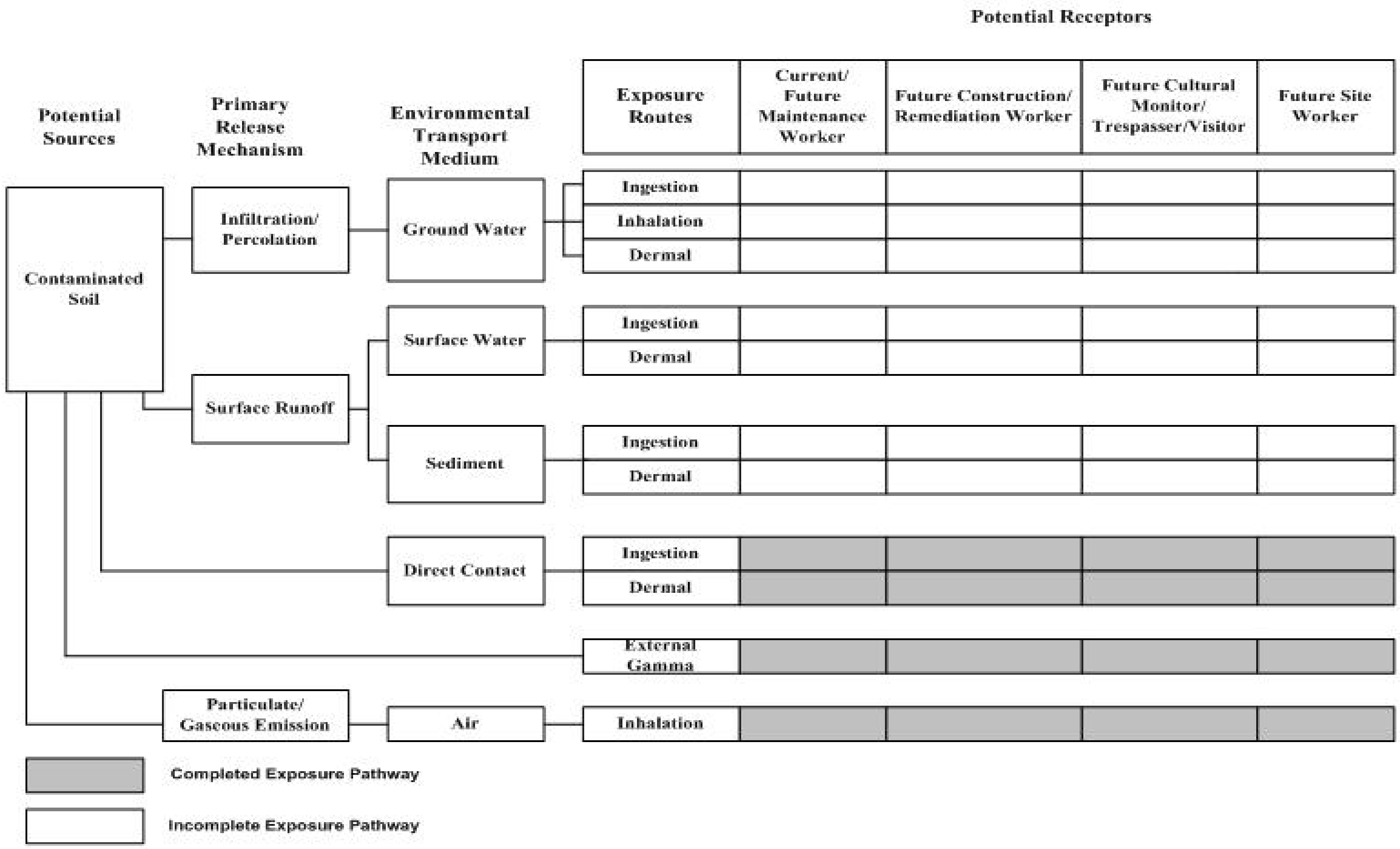
Future Site Worker: While this scenario is considered highly unlikely, it has been included as an extremely conservative estimation. Under this scenario, the site worker may be exposed to the residual radioactive fragments that may be present in surface soil but are not expected to have regular contact with subsurface soil. The worker is modeled as a typical site worker who spends all of the time indoors. The industrial worker is at SBIA for 250 days per year for 25 years (USEPA 1991a). During a typical working day, the worker is assumed to spend 8 hours indoors and will ingest 50 mg of soil (USEPA 1991b). The inhalation rate for the receptor is 20 m^3 per day (USEPA 1989, see Section 4.4.2). Since workers are assumed to be adults, a body weight of 70-kilogram was used to assess exposure to chemical contaminants.

Exposure pathways evaluated for the site worker scenario include:

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

Tables B-1 and B-2 of Appendix B present default values and the assigned values for non-default exposure parameters related to each receptor scenario, respectively. Those values were utilized during the radiological dose and risk assessment for each receptor scenario. The same values were assigned (in different units, as appropriate) for chemical risk assessment. Table 4-1 presents the assigned values for exposure parameters to each receptor scenario used for non-radiological intake and risk assessments.

FIGURE 4-1: CONCEPTUAL SITE MODEL FOR SCHOFIELD BARRACKS IMPACT AREA



- Maintenance and Construction/remediation workers are exposed to both surface and subsurface soil; whereas site worker and cultural monitor/trespasser/visitor are exposed to only surface soil.

Table 4-1: Exposure Pathways and Variables for Schofield Barracks Impact Area Receptors

Receptor	Exposure Duration			Soil Ingestion Rate		Inhalation Rate	
	Years	Days/Yr	Hrs/Day	(mg/d)	(g/Yr)	(m^3/hr)	(m^3/Yr)
Current/Future Maintenance Worker	6.6	10	8	100	36.5	1.4	12,330
Future Construction/ Remediation Worker	1	180	8	330	120.4 5	3	26,300
Future Adult Cultural Monitor/Trespasser/ Visitor	30	26	8	100	36.5	0.83	7,300
Future Site Worker	25	250	8	50	18.25	0.83	7,300

4.2.2 Exposure Point Concentrations

The EPC represents a reasonable estimate of the average contaminant concentration likely to be encountered at the point of exposure over the exposure period. To address the uncertainty associated with estimating a true average concentration based on a limited data set, the 95 percent upper confidence limit (UCL_{95}) of the mean is generally recommended for use in establishing a conservative (overly cautious) estimate of the EPC (USEPA, 1989 and 2002a). Determination of the UCL_{95} for any contaminant depends on the distribution of the sampling results. For example, data may follow parametric (e.g., normal, gamma, or lognormal) or non-parametric distributions. To determine the distribution patterns for Schofield Barracks data, USEPA's *ProUCL, Version 4.0,* software was used.

The EPC for chemical contaminants is defined as the minimum of either the maximum detected concentration or the UCL_{95}. However, for radiological contaminants, the EPC is defined as the minimum of either the maximum detected concentration or the UCL_{95}, both of which should be adjusted to account for background. Even though background samples were collected from an on-site reference area, no background concentrations were determined for individual uranium isotopes. Hence, background was not subtracted in the EPC calculations for radiological contaminants at SBIA. This adds more conservatism to this BHHRA (erring on the side of caution).

Appendix A presents sampling results and EPC for each PCOC. The soil sampling results were segregated into two different soil data sets – surface soil (less than 6 inches below surface) and all depth soil for the purposes of risk characterization to the types of human receptors evaluated. Trespasser and site workers are likely exposed to surface soil only. All depth soils include samples collected from both surface and subsurface soils. All other receptors are assumed to be exposed to all depth soils.

The data sets used to derive EPCs for DU at SBIA included both alpha and gamma spectroscopy analyses for surface soil and all depth soil. For radiological PCOCs, analytical results reported as estimated values were assumed to be present at the reported concentrations.

Uranium Isotopes and Depleted Uranium

The data sets used in the EPC calculations for uranium isotopes in surface and all soil depths are presented in Appendix A, Tables A-2-1 and A-3-1, respectively. ^{234}Th is a short-lived radioactive progeny of ^{238}U, and is assumed to be in secular equilibrium with the ^{238}U[5]. Thus, the activity concentrations reported in pCi/g for ^{234}Th are assumed to be representative of the activity concentrations of ^{238}U, as well. According to the U.S. Army Environmental Policy Institute (USAEPI) report, DU consists of uranium isotopes in the following activity percentages: 15.55% ^{234}U, 1.07% ^{235}U, and 83.38% ^{238}U (USAEPI 1995). For gamma spectroscopy results, the concentration for ^{234}U was determined using the AEPI ratio of ^{238}U to ^{234}U. ProUCL version 4.0 determined the UCL_{95} of each uranium isotope based on the distribution of the data set for both surface and all depth soil. The UCL_{95} results for each

[5] During the refinement process that generates DU, the uranium progeny are separated and removed the uranium isotopes. However, within one year of separation, equilibrium is reached in the ^{238}U decay chain with ^{234}Th, its immediate progeny. The DU in SB has likely been present for more than 40 years; therefore, it is assumed that the current activity concentrations of the two isotopes are equivalent.

uranium isotope at surface and all depth soil are presented in Appendix A, Table A-4. For the purpose of this BHHRA, it is assumed that all uranium found is DU.

However, for the chemical risk evaluation, it was necessary to convert the isotopic activity concentrations to a total mass concentration of uranium, represented in milligrams per kilogram (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 (pCi/g)

Thus, the EPC for total uranium mass concentration in the all depth soil data set was calculated to be 168.81 mg/kg, as indicated in Appendix A, Table A-4. The EPC for total uranium mass concentration in surface soil samples was calculated to be 347.74 mg/kg, as indicated in Appendix A, Table A-4. These values were used in the chemical risk (toxicity) evaluation presented in Section 4.3.

4.3 Toxicity Assessment

For chemical contaminants, the assessment of toxicity is based on two general effects: carcinogenic and non-carcinogenic. For radionuclides, however, the toxicity assessment is based only on carcinogenic effects. The benchmark value for describing toxicity due to non-carcinogenic effects is the reference dose (RfD), and for carcinogenic effects it is the cancer slope factor (CSF). These values are listed and described in various USEPA publications, including the *Integrated Risk Information System* (*IRIS*; USEPA, 2006), the *Health Effects Assessment Summary Tables* (*HEAST*; USEPA, 2001), the *Region 9 PRG Tables* (USEPA, 2004), and the ATSDR (2006).

In general, toxicity values are only available for ingestion and inhalation pathways. Oral RfD values of 3.0E-3 milligram per kilogram-day (mg/kg-d), as specified in IRIS 2006, was used for evaluating the non-carcinogenic effects of exposure to soluble uranium (see Section 4.6 Uncertainty Analysis) by ingestion. No inhalation RfD for uranium exists in IRIS. USEPA's National Center for Environmental Assessment (NCEA) is the main source of provisional toxicity values for chemicals without IRIS values. Recently, NCEA has recommended ATSDR chronic minimum risk levels (MRLs) for some chemicals (such as uranium), consistent with their description in OSWER Directive 9285.7-53 as Tier 3 toxicity values. Therefore, an inhalation RfD of 8.6E-5 mg/kg-day was used for evaluating the non-carcinogenic effects of exposure to soluble uranium by inhalation. To account for dermal exposure, the ingestion RfD was multiplied by the gastrointestinal absorption factor to derive an adjusted toxicity value (USEPA 1989).

Since uranium has not been found to be carcinogenic by inhalation, oral, or dermal exposure routes, the carcinogenic effects of exposure to uranium is not relevant to the chemical risk assessment. Rather, the carcinogenic effects of uranium nuclides were evaluated as part of the radiological risk assessment (Subsection 4.4.2).

4.4 Risk Characterization

Results of the exposure assessment and toxicity evaluation were combined to assess overall human health risk due to exposure to DU at SBIA.

4.4.1 Chemical Risk

The chemical toxicity risk characterization quantifies the potential carcinogenic risks and non-carcinogenic hazards associated with the DU identified for SBIA. For chemical contaminants, potential human health risks are generally characterized by combining exposure assumptions and toxicity data to derive excess lifetime cancer risks (ELCRs) for carcinogens, and hazard quotients (HQs) for constituents with non-carcinogenic effects. For SBIA, risks due to uranium chemical toxicity were evaluated by deriving hazard index (HI) for uranium, as described later in this section.

<u>Hazard Quotient for Uranium</u>

The HQ is a unitless term that is calculated as a ratio of exposure to toxicity, using the following formula:

$$HQ = CDI / RfD$$

where: CDI = Chronic Daily Intake (mg/kg-d)

RfD = Reference Dose (mg/kg-d)

CDI is the critical point estimate for determining the extent of the hazard associated with the PCOC. For each exposure pathway, the CDI represents the average daily dose of a PCOC ingested or inhaled by a receptor, and is expressed in terms of mg/kg-d. The CDI is a function of the concentration of the contaminant in the exposure medium, the dose received during an exposure event, and the lifetime frequency of exposure events.

For constituents with established RfDs for both ingestion and inhalation exposure routes, an HQ is generally calculated for each exposure pathway and summed to determine the HI for the constituent. Results of the ingestion, inhalation, and dermal HQ calculations were summed for each potential receptor to derive the HI for that receptor.

CDI and HI calculations for the four receptors evaluated in this risk assessment are presented in Appendix C. The HIs calculated for each receptor are summarized in Table 4-2. As indicated in the table, the highest HI was exhibited by the future construction/remediation worker receptor.

Table 4-2: Summary of Hazard Index Calculations

Receptor	Pathway-Specific Hazard Quotient [1]			Hazard Index
	Ingestion	Inhalation	Dermal Contact	
Current/Future Maintenance Worker	2E-3	2E-5	3E-6	2E-3
Future Construction/Remediation Worker	1E-1	3E-2	4E-4	2E-1
Future Adult Cultural Monitor/Trespasser/Visitor	1E-2	5E-5	5E-5	1E-2
Future Site Worker	6E-2	5E-4	4E-4	6E-2

NA = Not Applicable due to no inhalation toxicity value for uranium

[1] Hazard quotients calculated based on non-carcinogenic effects of exposure to uranium.

When assessing aggregate health effects due to several non-carcinogenic constituents, an HI is calculated by summing the HQs, as appropriate, considering the target organs and toxic modes of action. A HI of greater than 1.0 indicates that the receptor may be subject to adverse health effects and that further evaluation should be undertaken.

The maximum HI for SBIA is less than 1.0 (highest HI is 0.2). Thus, the chemical risk evaluation results indicate that no adverse human health impacts are likely to occur as a result of potential exposure to uranium in the soil.

4.4.2 Radiological Dose and Risk Assessment

The *RESidual RADioactivity* (*RESRAD)* computer code, Version 6.3 (ANL, 2005), was used to estimate the radiological dose and total ELCR for each of the potential receptors. This software was developed by ANL, in coordination with DOE, USEPA, and Nuclear Regulatory Commission (NRC), as a tool for predicting human health risks due to residual radioactivity in soils. The code uses radionuclide CSFs presented in *Federal Guidance Report (*FGR*) No. 13* (USEPA, 2002b), which incorporate HEAST 2001 risk coefficient values.

To determine the dose and total excess cancer risk per unit concentration of DU (i.e., risk per pCi/g), one pCi/g was used as the source term for each uranium isotope. As mentioned earlier, the *RESRAD* default parameters listed in Appendix B, Table B-1, were used as model input values for all receptors evaluated. The exposure variables listed in Appendix B, Table B-2, for soil ingestion rate, inhalation rate, and exposure time were applied to each receptor, as indicated, to model receptor-specific risks. The assigned values for RESRAD intake parameters (soil ingestion rate and inhalation rate) as presented in Appendix B, Table B-2, were based on 24 hours/day and 365 days/year. The model then multiplies the indoor and outdoor time fractions for each receptor with the assigned values of intake parameters to calculate actual soil ingestion rates and inhalation of airborne dust rates for the receptors.

In evaluating dose and risk due to the external gamma pathway, it was assumed that all receptors except the site worker received their exposure while outdoors. Under the site worker scenario, the individual was assumed to incur external gamma risk while working in a building situated on top of contaminated soil. The *RESRAD* default parameter, which assumes that the building structure’s shielding properties reduce external gamma risk by a factor of 0.7, was used to model this scenario.

For each receptor, the maximum dose-to-source ratios and risk-to-source ratios over a period of 1,000 years were obtained from the corresponding *RESRAD* dose and health risk output report. These values were multiplied by the EPC calculated for each uranium isotope (Section 4.2.2) to determine the individual dose and risk for each isotope. The dose and risks for all isotopes were summed to obtain the total risk for each receptor. Results of the dose and risk calculations are presented in Appendix B tables for each receptor. Table 4-4 summarizes the results of radiological dose and risk assessments for each receptor scenario.

Table 4-3: Summary of Radiological Dose and Risk Estimates

Receptor Type	Medium	Exposure Pathways	Total Dose (mrem/yr)		Total Risk	
			T=0	T=1000	T=0	T=1000
Current/Future Maintenance Worker	All Depth Soil	External Gamma	0.1	0.003	4E-07	2E-08
		Inhalation	0	0.001	2E-08	8E-10
		Soil Ingestion	0.0	0	2E-08	7E-10
		Total	**0.1**	**0.004**	**4E-07**	**2E-08**
Future Construction/ Remediation Worker		External Gamma	1.4	0.1	1E-06	4E-08
		Inhalation	0.5	0.02	9E-08	3E-09
		Soil Ingestion	0.4	0.01	2E-07	6E-09
		Total	**2.2**	**0.1**	**1E-06**	**5E-08**
Future Adult Cultural Monitor/Trespasser/Visitor	Surface Soil	External Gamma	0.4	0	5E-06	0
		Inhalation	0.05	0	2E-07	0
		Soil Ingestion	0.03	0	2E-07	0
		Total	**0.5**	**0**	**5E-06**	**0**
Future Site Worker		External Gamma	2.7	0	3E-05	0
		Inhalation	0.2	0	5E-07	0
		Soil Ingestion	0.2	0	1E-06	0
		Total	**3**	**0**	**3E-05**	**0**

The table illustrates that the future site worker incurs the highest radiological dose and risk due to DU fragments at SBIA. A detailed report of the *RESRAD* model results for this receptor is presented at the end of Appendix D. As shown on page 6 of the detailed report, the external gamma exposure pathway represents more than 90% of the total risk. This characteristic is common to the *RESRAD* results for all potential receptors, implying that the total radiological dose and risk is approximately proportional to exposure time.

4.5 Dose and Risk Evaluation for an Off-site Human Receptor

Dose and risk evaluation was performed to determine the impact of DU to a potential off-site receptor using highly conservative assumptions (all other offsite scenarios would be significantly less than this scenario). A subsistence farmer, as defined by USEPA (1994) was used as the model receptor for evaluation of chemical effects and risk. The receptor is assumed to live at this location for 365 days per year for 40 years (USEPA 1994). The farmer is assumed to spend 8 hours indoors and 16 hours outdoors at SBIA each day over the entire exposure area and time period.

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 6 years.
- The adult weighs 70 kg and ingests 100 mg of soil or sediment per day, over 34 years.

This calculation results in a weighted average soil ingestion of 115 mg per day. Based on USEPA's RAGS guidance, the farmer is assumed to inhale 20 m^3 of air per day (USEPA 1989).

NUREG/CR 5512 volume 4 assigns 21.4 kg/yr for leafy vegetable consumption rate for adult (NRC 1999). However, no value was assigned for a child receptor. By using the child-to-adult body weight factor, the leafy vegetable consumption rate for a child was calculated to be 4.59 kg/yr. So, the time-weighted average value of this exposure parameter for the subsistence farmer is calculated to be 18.9 kg/yr.

Based on the exposure factor handbook (USEPA 1997), by subtracting the leafy vegetable rate from the total fruit and vegetable ingestion rate, the fruit, vegetable and grain consumption rate for an adult male and a child are calculated to be 551 and 118 kg/yr, respectively (USEPA 1997b). So, the time-weighted average fruit, vegetable and grain consumption rate for the off-site receptor is calculated to be 486 kg/yr.

Exposure pathways evaluated for the subsistence farmer 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; and
- Ingestion of foods from crops grown in the contaminated soil;

Both groundwater and surface water pathways were not considered during this evaluation, as they are not pathways of concerns for DU present at SBIA, as discussed in Section 4.1.

RESRAD-OFFSITE model, Version 2.1 was used to determine the radiological dose and risk assessment (ANL 2007), whereas USEPA's standard RAGS equations were utilized to assess the chemical risk. The RESRAD-OFFSITE model, an extension of the original RESRAD model, was designed for evaluation of radiological consequences to a receptor located on-site or outside the area of primary contamination. It calculates radiological dose and excess lifetime cancer risk with the predicted radionuclide concentrations in the environment, and derives soil cleanup guidelines corresponding to a specified dose limit. The code is sponsored by DOE's Office of Health, Safety and Security, and the Office of Environmental Management, with support from the U.S. Nuclear Regulatory Commission. It was developed by ANL. Code and version control are currently maintained by DOE through ANL.

All depth soil concentrations of three uranium isotopes were used as source terms for the RESRAD-OFFSITE model. Like the RESRAD model, the RESRAD-OFFSITE model does not include a concentration output report. Therefore, in order to derive the source term for chemical risk assessment, the soil concentrations of the uranium isotopes at the off-site receptor site were derived from the graphical output of the RESRAD-OFFSITE model. Even though the maximum concentrations for all three uranium isotopes were occurred at year 1000, as a conservative (overly cautious) measure, those highest concentrations were selected to carry through the total uranium concentration in soil was then calculated using the equation presented in Section 4.2.2. The source terms, along with the assigned values of the exposure parameter, defined above were inputted into the RESRAD-OFFSITE and RAGS equations to determine both radiological dose and risk, and chemical risk, respectively.

The results of the radiological dose assessment demonstrated that the maximum dose for the model subsistence farmer receptor occurred at year 0 and the dose is less than 1 mrem/yr. The results of the radiological risk assessment indicate that the risk is well within USEPA's acceptable risk range. The results of the chemical risk assessment indicated an HI of less than 0.1. The results for both radiological and chemical risk assessments showed that the presence of DU at SBIA does not pose any adverse health impact to any potential off-site receptor and the projected dose is safe.

4.6 Uncertainty Analysis

As with all evaluations of human health risk, there are uncertainties associated with the SBIA risk assessment. First, with respect to the exposure assessment, it is not known what types of future activities may be conducted at SBIA that would involve regular exposure to contaminants. Currently, access to the SBIA is highly restricted due to its location within a very active training range. There are no plans to take the range out of active use. Only authorized personnel are allowed access to the impact areas. To account for the uncertainty in future exposure scenarios, the exposure variables used in the risk assessment were selected to ensure conservatism in the results.

Second, there is uncertainty in the EPCs used to represent average conditions due to the inherent uncertainties associated with using sampling data to represent a heterogeneous population. The magnitude of this uncertainty has been reduced as much as possible by using robust data sets that contain large numbers of sample results. These robust data sets include results for both surface and subsurface samples from across the entire footprint of SBIA, providing contaminant concentrations for samples from throughout the entire volume of soil and minimizing uncertainty regarding the representativeness of the data.

Both systematic and biased samples were collected from the site to estimate DU in soil concentrations present at the site. A systematic sample represents a larger area as compared to that for a biased sample. However, as a conservative (overly cautious) approach, the biased samples were given the same weight as that of the systematic samples. As a result, the EPC determined for each uranium isotope was higher, resulting in an overestimation of radiological dose and risk.

Uncertainty also exists in the methodology used to derive isotopic uranium concentrations from the gamma spectroscopy analyses. The isotopic ratios used in the risk assessment were based on the ratios presented in the USAEPI report (1995). Additional research has been conducted since this report was published. Both the International Atomic Energy Agency (IAEA, 2003) and the Battelle Memorial Institute (2004) have established isotopic ratios for DU that indicate percentages of ^{234}U that are lower than those set forth by USAEPI. Thus, the ratios used in the

SBIA risk assessment likely overestimate the radioactivity concentration of ^{234}U in DU, resulting in a conservative representation of risk in the radiological analysis.

There are also uncertainties related to the toxicity assessment for uranium. Toxicity parameters have been derived based on dose-response information from laboratory studies, and there is uncertainty involved with using these data to predict actual health effects in the general population. The sources of uncertainty include: using data from animal studies to predict effects in humans; using data from studies based on high-level exposures to predict effects at lower level exposures, using data from short-term exposure studies to predict effects due to long-term exposure; and using data from homogeneous healthy populations to predict effects to heterogeneous populations with a wide range of sensitivities. Scientific consensus is that these uncertainties err on the side of protection and safety (a reference would be nice).

The potential presence of soluble and non-soluble form of uranium compounds results in another source of uncertainty in the chemical risk assessment. For oral ingestion, insoluble uranium compounds are less toxic than the soluble compounds. Hence, risk due to oral ingestion was determined by using oral RfD for soluble uranium. On the other hand, insoluble uranium compounds are more toxic than the soluble compounds for inhalation exposure. ATSDR developed MRLs for both forms of uranium compounds (1999). However, MRL for insoluble uranium was derived based on intermediate duration (15 to 364 days) whereas MRL for soluble uranium was derived based on chronic duration (365 days and longer). Since USEPA risk assessments are based on lifetime risks, MRL for soluble uranium was used during the derivation of risk due to inhalation exposure.

The results of the characterization sampling showed that most of the uranium (assumed to be DU) is present at the surface (zero to 6 inches in depth). Lower concentrations of U-238 were generally observed as the sampling depth increased. However, as a conservative approach, the dose and risk assessment assumes that the DU was uniformly distributed across the thickness of the effected zone. As a result, this assumption overestimated both the dose and risk present at SBIA, and errors on the side of caution.

Finally, there are uncertainties involved with using the selected algorithms to characterize risks. One uncertainty is the degree to which the selected model input parameters accurately reflect the potentially exposed population. The ranges of values recommended by the model developers allow for flexibility and the application of professional judgment. This BHHRA used conservative (overly cautious) assumptions.

In general, the human health risk assessment was designed to provide conservative (overly protective) results based on the current and expected future use of SB. Due to presence of UXO at the site, the U.S. Army has restricted access to the site. The U.S. Army will continue to retain the title to the site, and will impose and maintain access and land use restrictions for the site. It is conceivable, however, that training range operations may cease at some point in the future, the perimeter may no longer be controlled, and the site may be used for other purposes. If this occurs, three additional receptor scenarios (future land use) were considered in this report. However, if the land use scenario is changed to something other than the scenarios defined in this report, a new risk assessment may need to be performed at that time based on contemporary site conditions and the revised potential exposure scenarios.

5.0 CONCLUSIONS

Investigations at the SBIA have determined that DU is the contaminant of interest for the purposes of this risk assessment. The results of the risk assessment presented in this document demonstrate that the presence of DU in soil at the SBIA results in radiological dose as well as chemical and radiological risk that falls within the EPA limits for what considered safe by the USEPA and NRC. Therefore, no significantly increased risks for the human receptors considered in this document exist at SB. As a result, no adverse human health impacts are likely to occur as a result of exposure to the uranium present in the soil at SBIA. This is true for human receptors located on-site under current and potential future land use scenarios (e.g. range maintenance workers, cultural monitors, trespassers), as well as human receptors beyond the SBIA boundaries, as modeled by the highly conservative scenario of a subsistence farmer.

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APPENDIX A

RADIOLOGICAL AND CHEMICAL SAMPLING RESULTS

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APPENDIX B

RADIOLOGICAL DOSE AND RISK ASSESSMENT

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APPENDIX C

CHEMICAL RISK ASSESSMENT

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APPENDIX D

OUTPUT RADIOLOGICAL DOSE AND RISK ASSESSMENT SUMMARY REPORT FOR VARIOUS RECEPTORS

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APPENDIX E

INTAKE AND CHEMICAL RISK ASSESSMENT SUMMARY REPORT FOR OFFSITE SUBSISTENCE FARMER

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APPENDIX F

OUTPUT DOSE SUMMARY REPORT FOR OFFSITE SUBSISTENCE

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