FINAL
POHAKULOA TRAINING AREA FIRING RANGE
BASELINE HUMAN HEALTH RISK ASSESSMENT
FOR
RESIDUAL DEPLETED URANIUM

Submitted to:

Department of the Army

Headquarters, U.S. Army Sustainment Command

Procurement Directorate, Environmental Contracting Division

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CABRERA SERVICES

RADIOLOGICAL • ENGINEERING • REMEDIATION

June 2010

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ACRONYMS AND ABBREVIATIONS

µg/L	microgram(s) per liter
^{234}U	Uranium-234
^{235}U	Uranium-235
^{238}U	Uranium-238
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
BMI	Batelle Memorial Institute
CA	Chemical Concentration in Air
CABRERA	Cabrera Services, Inc.
CDI	Chronic Daily Intake
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm	centimeter
Conc	Concentration
COPC	Contaminant of Potential Concern
CSF	Cancer Slope Factor
CSM	Conceptual Site Model
d	day
DandD	Decontamination and Decommissioning
DOD	**[U.S.]** Department of Defense
DQO	Data Quality Objective
DU	Depleted Uranium
ELCR	Excess Lifetime Cancer Risk
EPC	Exposure Point Concentration
FGR	Federal Guidance Report
FIDLER	Field Instrument for the Detection of Low Energy Radiation
Ft	foot (feet)
g	gram
G-M	Geiger-Müller (or Mueller) detector
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HQ	Hazard Quotient
hr.	hour
IAEA	International Atomic Energy Agency
ILCR	Incremental Lifetime Cancer Risk
in.	inch
IRIS	Integrated Risk Information System
JMC	Joint Munitions Command
Kg	Kilogram
m^2	square meter
m^3	cubic meter
mg	milligram(s)
mg/kg	milligram per kilogram
mg/kg-d	milligram per kilogram-day
MMR	Makua Military Reservation
mrem	millirem (see Rem, below)
MRL	Minimum Risk Levels
NCEA	National Center for Environmental Assessment
NCP	National Contingency Plan
NELAP	National Environmental Laboratory Accreditation Program
NRC	Nuclear Regulatory Commission
OSWER	Office of Solid Waste and Emergency Response

pCi/g	picocuries per gram
RAGS	Risk Assessment Guidance for Superfund
RDX	Cyclonite (Cyclotrimethyl-enetrinitramine, with many synonyms, generically any formulation of this material as a castable explosive)
Rem	Roentgen Equivalent Man
RESRAD	Residual Radioactivity
RfD	Reference Dose
RME	Reasonable Maximum Exposure
sec	second
PETN	Pentaerythrite tetranitrate
PTA	Pohakuloa Training Area
SRB	spotter round body
Sf	square foot (feet)
U	Uranium
UCL_{95}	95 Percent Upper Confidence Limit
USACE	U.S. Army Corps of Engineers
USAEPI	U.S. Army Environmental Policy Institute
USEPA	U.S. Environmental Protection Agency
UXO	Unexploded Ordnance
WHO	World Health Organization
yr	year

Executive Summary

The Baseline Human Health Risk Assessment (BHHRA) presents an evaluation of the potential health impacts to persons from exposure to depleted uranium (DU) resulting from the presence of Davy Crockett spotter round bodies (SRB) found on the Pohakuloa Training Area (PTA). The result of this evaluation is that all potential upper bound risks to hypothetically exposed people are well below US Environmental Protection Agency (USEPA) acceptable risks.

All potential upper bound risks at PTA to hypothetically exposed persons are below EPA acceptable risk range.

The BHHRA was prepared in accordance with provisions of the Comprehensive Environmental Response, Compensation, and Liability Act and the National Oil and Hazardous Substances Pollution Contingency Plan. The BHHRA identified multiple aspects of exposure: 1) the people who may be exposed to site contaminants (i.e., receptors), 2) the ways in which people may be exposed to the contaminants (i.e., exposure pathways), and 3) the concentrations of contaminants in environmental media (i.e., soil) that may be taken in to or adversely affect receptors. Based on these elements of exposure and the toxicity of the contaminants, the degree of hazard and risk were calculated for both current and future scenarios. The BHHRA also discusses uncertainties associated with these calculations.

A BHHRA is an assessment of potential exposures to hypothetical people. In the assessment, the amount of material potentially present on site is evaluated with an eye toward how that material might be ingested, inhaled, or otherwise exposed to a people. As part of this assessment, the various ways under which people might be exposed are called exposure scenarios (or pathways) that are described by conceptual site models (CSM). A CSM describes the physical and environmental pathways that link the source material with the potentially (hypothetically) exposed people. Five receptor scenarios (identified in Table ES-1) were evaluated under future land use scenarios..

A conceptual site model (CSM) was developed for the PTA Firing Range that summarizes the pathways that chemicals may take to reach potential receptors. The CSM demonstrates those pathways that are complete for each receptor and that are retained for further evaluation in the BHHRA. It was determined that soil is the only environmental media needed to be evaluated.

The BHHRA for the PTA Firing Range represents a unique challenge as only limited site-specific data are available from which to make a determination of an exposure point concentration (EPC) of uranium activity in surface soil. Since the appropriate information regarding the number of DU projectiles fired at the range and/or the exact footprint of the area of affected soil could not be reliably ascertained, the approach described by the St. Louis District of the USACE, in *Draft Final Range Operations Report No. 9* (RO-9) (2005) was used to derive a site-specific EPC (source term) for uranium.

Table ES-1, adapted from Table 5-2 in the BHHRA, summarizes radiological dose and risk estimates assuming 714 SRB rounds are present on the PTA ranges. The maximum risk is 4×10^{-9}, which is well below the USEPA acceptable risk range of 10^{-6} to 10^{-4}. Therefore, the results of the BHHRA demonstrate that the presence of DU in PTA soil results in radiological risk well below the limits that the USEPA considers safe.

TABLE ES-1 ESTIMATES OF RADIOLOGICAL DOSE AND RISKS FOR 714 SPOTTING-ROUND BODIES FOR VARIOUS RECEPTOR SCENARIOS

Receptor Scenario	Maximum Annual Dose (millirems)	Maximum Risk
Current/future maintenance worker	1×10^{-5}	5×10^{-11}
Future construction/remediation worker	4×10^{-4}	6×10^{-10}
Future adult cultural monitor/trespasser/visitor	3×10^{-5}	6×10^{-10}
Future site worker	2×10^{-4}	3×10^{-9}
Current/future soldier	3×10^{-4}	4×10^{-9}

Table ES-2, adapted from Table 5-4 in the BHHRA, summarizes hazard index results assuming 714 SRB rounds are present on the PTA range. A hazard index is the sum of the hazard quotients for substances that effect the same receptor scenario. The maximum hazard index is 2 × 10-5, which is well below the USEPA acceptable value of 1 indicating the sum of the hazard quotients for all pathways to the specified receptor scenario are also within the acceptable value specified by the EPA. Therefore, the results of the BHHRA demonstrate that the presence of DU in soil at the PTA results in chemical risk well below the limits that the USEPA considers safe.

No significantly increased risks for the human receptors considered in the BHHRA exist at PTA and no adverse human health impacts are likely to occur as a result of exposure to SRB uranium present in the soil at PTA.

TABLE ES-2 SUMMARY OF HAZARD INDEX CALCULATIONS FOR 714 SPOTTING ROUND BODIES FOR VARIOUS RECEPTOR SCENARIOS

Receptor Scenario	Pathway-Specific Hazard Quotient		Hazard Index
	Ingestion	Inhalation	
Current/future maintenance worker	3×10^{-7}	2×10^{-9}	3×10^{-7}
Future construction/remediation worker	2×10^{-5}	1×10^{-7}	2×10^{-5}
Future adult cultural monitor/trespasser/visitor	7×10^{-7}	3×10^{-9}	7×10^{-7}
Future site worker	3×10^{-6}	3×10^{-8}	3×10^{-6}
Current/future soldier	7×10^{-6}	5×10^{-8}	7×10^{-6}

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). 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 Pohakuloa Training Area (PTA). Specifically, this BHHRA considers the potential impacts related to DU fragments resulting from the presence of Davy Crockett spotter round bodies (SRB) on the impact area. Based on previous evaluations of fragments associated with Davy Crockett SRB on other firing ranges (Cabrera, 2008), DU has been identified as the contaminant of potential concern (COPC) 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

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 PTA. The specific objectives of the BHHRA are to:

- Estimate potential human health risks and environmental impacts associated with PTA 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 10^{-6} to 10^{-4} as prescribed in the Code of Federal Regulations (40 CFR 300.430, subpart E); and
- Estimate potential human health risks associated with PTA 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 followed in this risk assessment was to determine risk to human receptors. The BHHRA identified multiple aspects of exposure: 1) the people who may be exposed to site contaminants (i.e., receptors), 2) the ways in which people may be exposed to the contaminants (i.e., exposure pathways), and 3) the concentrations of contaminants in environmental media (i.e., soil) that may be taken in to or adversely affect receptors. Based on these elements of exposure and the toxicity of the contaminants, the degree of hazard and risk were calculated for both current and future scenarios and the uncertainty associated with these calculations discussed.

1.3 Pertinent Guidance

The technical approach for the BHHRA is consistent with guidelines established by the U.S. Environmental Protection Agency (USEPA), the Department of Defense (DOD), and the U.S. Nuclear Regulatory Commission (NRC) which are pertinent to assessing risk to human health and the environment. Guidance documents deemed most likely to be appropriate for this project include, but are not limited, to the following:

- Risk Assessment Guidance for Superfund (RAGS), Volume I, Human Health Evaluation Manual (Part A) (USEPA, 1989)
- Soil Screening Guidance for Radionuclides: User's Guide (USEPA, 2000)
- Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites (USEPA, 2002a)
- Exposure Factors Handbook (USEPA, 1997)
- Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil (ANL, 1993).
- Users Manual for RESRAD for Windows, Version 6.0 (ANL, 2005)
- Comparison of the Models and Assumptions used in the [Decontamination and Decommissioning] 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 (NRC, 1999)
- Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes, NUREG/CR-6697, ANL/EAD/TM-98 (NRC, 2000)

1.4 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 PTA.
- Section 3: Summary of Existing Site Data and Selection of Chemicals of Potential Concern Methodology. Presents a discussion of data collected to date at the site.
- Section 4: Baseline Human Health Risk Assessment (BHHRA). Describes how CPOCs 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, presents the land use and potentially exposed people, a graphic Conceptual Site Model (CSM), methodology for estimating exposure point concentrations (EPCs), including intake equations and exposure factor parameter values suggested for use in the risk assessment, describes the approaches for evaluating chemical toxicity in the risk assessment, and describes the methodology used for the estimation of health hazard and cancer risk, and how uncertainty were characterized in the risk assessment.
- 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

Pohakuloa Training Area (PTA) is located on the island of Hawaii between Mauna Loa, Mauna Kea and the Hualalai Volcanic Mountains. It extends up the lower slopes of Mauna Kea to approximately 6,800 feet in elevation and to about 9,000 feet on Mauna Loa. The training area is about midway between Hilo, on the east coast and the Army landing site at Kawaihae Harbor. The area is the largest Department of Defense (DOD) installation in Hawaii. The area is accessible by military helicopter or land via Saddle Road from Hilo. The locations of the PTA range are shown in Figure 2-1.

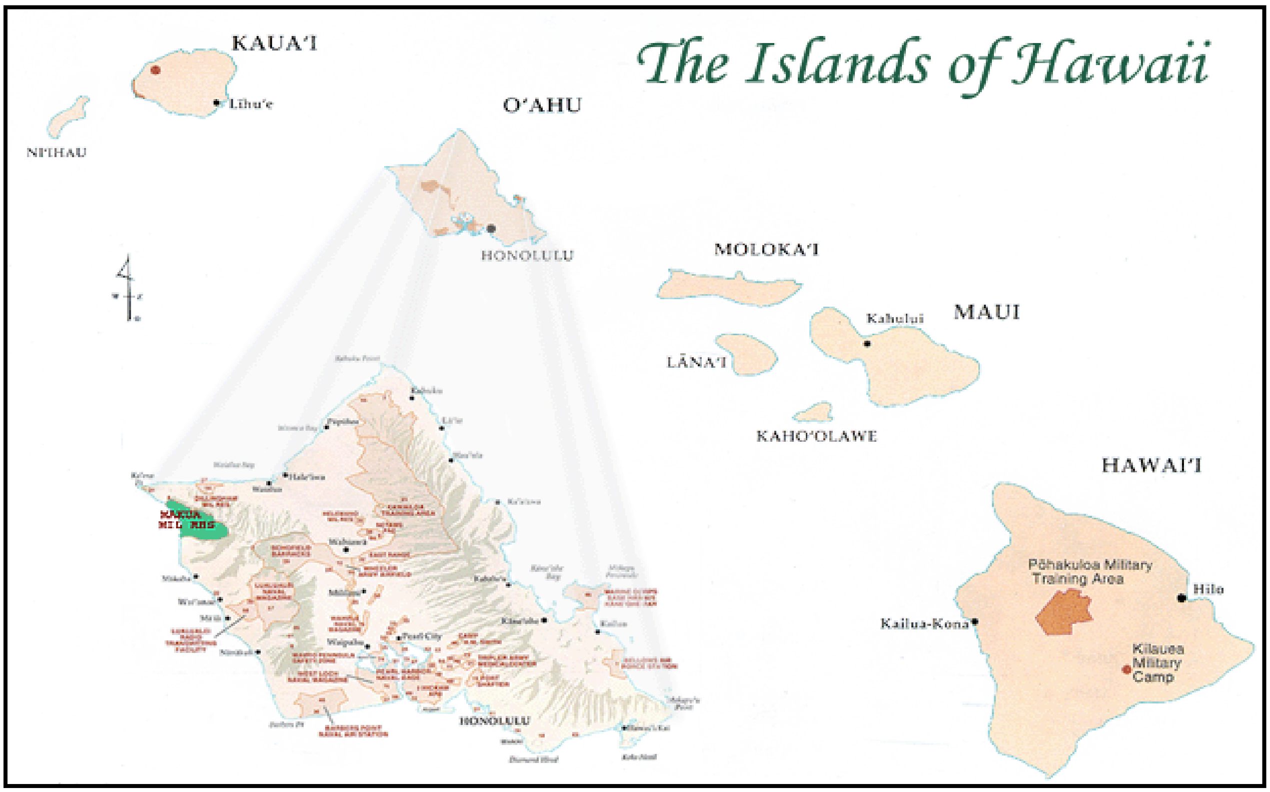


FIGURE 2-1: LOCATION OF POHAKULOA TRAINING AREA (HAWAII)

(Map reference: ://www.25idl.army.mil/makua/, accessed 3 July 2007.)

2.1 Site Background Information

In August 2005, tail fin components and spotter round bodies (SRB) from the Cartridge, 20mm Spotting M101 associated with the Davy Crockett Light Weapon M28 were discovered during routine activities at Schofield Barracks. As a result of archive searches conducted by the U.S. Army Corps of Engineers (USACE) regarding the potential for contamination resulting from the firing of spotter rounds for the Davy Crockett weapons system at Schofield Barracks, suspicion arose that this weapons system may have been used at other firing ranges in the Hawaiian Islands. The suspected ranges include Makua Military Reservation (MMR) on Oahu, PTA on Hawaii, and Schofield Barracks Impact Area on Oahu. For MMR and PTA, the St. Louis District of the USACE prepared *Archives Search Report on the Use Of Cartridge, 20MM Spotting Round M101, Davy Crockett Light Weapon M28, Schofield Barracks and Associated Training Areas, Islands of Oahu and Hawaii* (USACE, 2007).

According to the *Archives Search Report* (ASR), training on the Davy Crockett weapons system was likely conducted at PTA between 1962 and 1968. The ASR identified that the primary suspected contaminant associated with the SRB is D-38 uranium alloy, also called depleted uranium (DU). The DU was used in the SRB of training rounds for the Davy Crockett weapon system because of its high density and weight. According to the ASR, the Pohakuloa Impact Area is bounded on the north by Lava Road, on the east by Redleg Road, on the south by the Kon-Hilo Trail, and on the west by Bobcat Trail. Although the use of the Davy Crockett weapons system was not explicitly identified in the available historical documents, the ASR identified four ranges at PTA that may have potentially been used for that system. Three of these ranges (Features 10, 13, and 14 on Plate 6 of the ASR) are located in a more secure area, and are identified as the more likely ranges used for training, while the fourth (Feature 4) does not meet all the requirements for a secure range. The four ranges encompass a potential contamination area of approximately 560 acres.

During 2008, Cabrera performed additional scoping and characterization surveys at the Makua and Pohakuloa Ranges as identified in the USACE-St. Louis ASR. The surveys were performed to assess the presence of DU fragments that might have originated from past training activities involving Davy Crockett SRB. The objectives of the scoping surveys were to:

- Use historical knowledge, real-time radiation detection instruments, laboratory analytical results from shallow soil samples, and visual identification of Davy Crockett weapons system components (pistons, SRBs, tailfin assemblies, base plates, etc.) to confirm that SRBs containing DU were fired and remain on the ranges, and
- Provide a summary of the scoping data along with recommendations and conclusions to the Army for future decision making regarding investigation or closure of the DU issue.

Based upon the locations of the pistons, the Cabrera field team determined that Range 11T offered the best prospects for locating a Davy Crockett spotter round on the ground. The impacted area was calculated based upon the location of the pistons, the operational range of the Davy Crockett system, and the likely firing points. A total of 10 biased surface soil and sediment samples were collected from areas where sediment had accumulated from past runoff/erosion events and around the perimeter of the suspected impact areas where visual and radiological indicators of the Davy Crockett weapons system were identified. All samples were sent to a National Environmental Laboratory Accreditation Program (NELAP) accredited laboratory for analysis of uranium nuclide activity concentrations by alpha spectrometry. Activity concentrations were reported for the three naturally occurring uranium radionuclides; uranium-234 (^{234}U), uranium-235 (^{235}U), and uranium-238 (^{238}U). All of the results are consistent with naturally occurring concentrations of uranium. None of the results indicate uranium depletion, where the ^{234}U activity concentration is significantly lower than the ^{238}U activity concentration.

2.2 Davy Crockett Weapon Systems and Spotter Round Characteristics

Essential to the risk assessment to be performed for the PTA Site, is an understanding of the Davy Crockett Weapon Systems and the source of the site DU: the Spotter Rounds. The Davy Crockett weapon system was a battalion level weapon used by infantry, armored, and mechanized divisions which was first fielded in the late 1950's and withdrawn from service in the late 1960's.

The Davy Crockett weapon system consisted of two types of recoilless rifle weapons: the Davy Crockett Light Weapon XM28 and the Davy Crockett Heavy Weapon XM29. Both the XM28 and XM29 were constructed as open-breech, smooth bore, single shot, low-angle fire, muzzle loaded weapons. They differed in their barrels and mode of use. The XM28 consisted of a 120-millimeter (mm) barrel with a 20-mm spotting rifle attached. The XM29 consisted of a 155-mm barrel mounted on a tripod for ground use (USACE, 2005).

Each weapon system utilized its own set of standard ammunition. Ammunition for the Davy Crockett Weapon System consisted of three major components: the warhead projectile, the propellant charge, and the spotting projectile. There were three types of warhead projectiles, including: the primary nuclear projectile, a high explosive filled practice version, and an inert filled dummy version. There were two propellant charges for both the 120 mm (XM28) and the 155 mm (XM29) weapon systems. The associated chemical constituents of the standard ammunition components included cyclonite (RDX), trinitrotoluene, polyisoluctylene, nitrocellulose, nitroglycerin, barium nitrate, potassium nitrate, ethyl centralite, graphite, black powder (sodium nitrate or potassium nitrate plus charcoal and sulfur), lead azide, tetryl, lead styphnate, pentaerythrite tetranitrate (PETN), DU, tin, diphenylamine, dinitrotoluene, red phosphorus, and magnesium (USACE, 2005).

While the Davy Crockett systems are comprised of multiple chemicals and explosive compounds, the focus of the BHHRA to be performed at the PTA specifically addresses the risk associated with the DU component of the weapons system. The portion of the Davy Crockett system containing DU is the XM101 20 mm spotting round. The XM101 projectile was approximately 7.5 inches long, 20 mm in diameter, and weighed approximately one pound. It was a low velocity cartridge used to determine the impact point for the 279 mm projectile fired from the XM28 Davy Crockett weapon system. Upon impact, the XM101 spotting round emitted a puff of white smoke. They were fired prior to firing the XM390 Practice Projectile for the XM28 system with the purpose of making corrections and adjustments, by observing the puff of smoke, until fire was on target. The projectile body of the XM101 spotting round was made from a D-38 uranium alloy and filled with 90 grains of incendiary mix LCOP-1 and 25 grains of PETN. It contained an electric, point detonating fuse (M538) to detonate the projectile and produce the white smoke puff on impact (USACE, 2005).

Each Davy Crockett Spotting Round projectile body was comprised of approximately 8 oz (226.8 g) of the D-38 uranium alloy. The alloy was manufactured with 92% DU and 8% molybdenum (Rubin, 2008), resulting in approximately 7.36 oz (208.6 g) of DU per projectile. This information is useful in determining the approximate source term (also described as the EPC) for calculating risk.

3.0 SUMMARY OF EXISTING SITE DATA

The first step in the routine BHHRA process is to evaluate all existing data to determine whether they are of adequate quality and quantity for use in quantifying risks. The presence of DU at PTA been the subject of recent scoping investigations, and Characterization Surveys completed in 2007 by CABRERA and described in *Technical Memorandum, Depleted Uranium Scoping Investigations Makua Military Reservation, Pohakuloa Training* Area, *Schofield Barracks Impact Area, Islands of Oahu and Hawaii* (CABRERA, 2008A) and *Technical Memorandum for Pohakuloa Training Area (PTA) Aerial Surveys* (CABRERA, 2009).

Historical records searches and map analyses identified at least twelve present and past range locations at the PTA. Based on criteria known to have been regulated for Davy Crockett ranges (e.g., size of area, security provisions) the USACE identified four potential Davy Crockett Ranges (Range 10, 11T, 14 and Range 17). Based upon the locations of the pistons, the 2007 scoping survey conducted by the Cabrera field team determined that Range 11T offered the best prospects for locating a Davy Crockett spotter round on the ground. Therefore, the area of the Range 11T was considered during the BHHRA of the Site.

The 2007 and 2008 surveys and characterization efforts consisted of site visits and reconnaissance, radiological surveys to measure levels of alpha, beta, and gamma radiation using Ludlum Model 43-93 alpha-beta probe, Ludlum 44-9 Geiger-Müller (GM) Pancake Probe, and Field Instrument for the Detection of Low Energy Radiation (FIDLER), and surface soil and sediment sampling and analysis. Results are summarized as follows:

- The visual and scanning surveys identified no distinct surface areas with yellow, oxidized DU metal fragments.
- The visual and scanning surveys did identify non-oxidized metal fragments, partial spotter round bodies, and Davy Crockett system components on Range 11T consistent with DU and the Davy Crockett weapons.
- Pistons associated with the Davy Crockett system were identified on Ranges 11T, 10, 14 and 17.

- The results of ten soil samples were collected during the scoping survey are consistent with naturally occurring concentrations of uranium. None of the results indicate uranium depletion, where the 234U activity concentration is significantly lower than the 238U activity concentration.

While the soil samples collected around the perimeter and impacted areas of the range did not indicate the presence of DU, these data do not represent a statistically significant data set. A statistical field sampling design focused on the suspect Davy Crockett impact areas would hopefully yield more representative results. However, due to the general lack of the presence of traditional well developed soil, slightly weathered or unweathered volcanic rock predominates in some locales; thus, obtaining traditional soil samples typically used for risk assessment purposes will be problematic. CABRERA recommends that the Army attempt to conduct a characterization survey of the most impacted range (11T), with an emphasis on statistical sampling, defining the environmental characteristics of the impacted area, eliminating pathways, where possible, from further evaluation, and developing better statistically based data.

4.0 BASELINE HUMAN HEALTH RISK ASSESSMENT

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

4.1 Selection of Chemicals of Potential Concern Methodology

As the scope of this BHHRA project is limited specifically to depleted uranium, a selection process involving multiple screening activities and data reduction are not deemed to be warranted. The only known source of radionuclides is DU contained in the spotter round bodies of training rounds found during previous investigations at PTA. Depleted uranium is the waste product of U enrichment processes and is defined as U containing less than 0.711 percent (%) ^{235}U. Depleted uranium consists primarily of ^{238}U with smaller amounts of ^{234}U and ^{235}U from both a mass and activity perspective. Natural U that is present in the environment consists of approximately equal activities of ^{234}U and ^{238}U.

The DU was U metal-molybdenum alloy when it was released to the environment. The DU fragments identified at PTA are largely intact; however some of the metal has oxidized and is present as uranium oxide in the surface soils. The DU is expected to be intact or present as large and small fragments of U metal, and very little in the form of oxides in surface soils due to the environmental conditions at PTA. Therefore, DU is the only COPC for the BHHRA to be performed for the PTA.

4.2 Exposure Assessment

To evaluate potential risks to human health at a given site, exposure must first be evaluated and quantified. Exposure may occur when there is contact between a human and a constituent in the environment. The exposure assessment is performed to estimate the magnitude, frequency, duration, and route of the potential exposure of the human receptors to COPCs present in environmental media at the site, and typically consists of the following elements:

- Site setting,

- Current and future land use and potentially exposed people,
- Pathways by which people may be exposed,
- How EPCs (also referred to as source terms) of COPCs will be derived, and
- Intake equations and exposure factors that will be used to quantify the intake for each COPC, exposure pathway, and receptor.

4.2.1 Identification of Land Use and Potentially Exposed People

The BHHRA focused on those receptors that may be potentially exposed to radiologically contaminated media under current and future exposure scenarios. This approach ensures that all potential receptors will be adequately protected. The PTA military installation and firing range is currently active, and it is not anticipated that it will be closed at any time in the near future. Therefore, for the BHHRA, current and future use scenarios are the same. Presently, the firing range is still being used for munitions training; therefore a current receptor that may be potentially exposed to site DU would include the current and future military trainees.

In the future, if live fire weapons training activities should be discontinued at the range, and construction activities performed to provide buildings for Industrial Workers, it may be prudent to evaluate a Future Construction Worker receptor. Currently there are no residences on the Firing Range

4.2.2 Conceptual Site Model

A Conceptual Site Model (CSM) is a graphical representation of exposure pathways and intake routes identified for potential receptor populations at a contaminated site. A CSM has been developed for the PTA Firing Range and included as Figure 4-1. The CSM summarizes the pathways that chemicals may take to reach potential receptors. The CSM will demonstrate those pathways which are complete for each receptor and will be retained for further evaluation in the BHHRA. A complete exposure pathway for a receptor includes all of the following elements:

- A historical source/operation which contributed to the contamination at the site,
- A primary contaminant release mechanism,
- A secondary source and/or secondary release mechanism,
- A transport or contact medium (e.g., soil, air), and

- An exposure route, such as ingestion, inhalation, dermal contact, or external gamma.

The absence of any one of the above elements results in an incomplete exposure pathway. Where there is no exposure, there is no risk. In addition, USEPA's risk assessment and risk characterization guidance does not require that all plausible exposure scenarios and exposure pathways be assessed. Pathways that are incomplete or only potentially complete, but deemed to be negligible, do not require evaluation. Potentially complete but negligible pathways are identified on the CSM but will not be evaluated quantitatively because these pathways would be unlikely to measurably impact risk estimates or risk management decisions. Some pathways cannot be quantified even if they are potentially complete and significant because key information is lacking.

4.2.3 Exposure Pathways to be Quantitatively Evaluated

Pathways deemed to be significant for the BHHRA are presented in this section. Importantly to note, for this BHHRA, soil is the only environmental media to be evaluated. Currently, there is no information to show that either groundwater or surface water near the site may have been affected by historical activities at the PTA. Additionally the size of the DU fragments and the depth of ground water is sufficiently deep so as to preclude migration; therefore, these media are excluded from further evaluation in the BHHRA. Two shallow bores were drilled

within PTA-controlled properties in the 1960s for the purpose to investigate water resources

within the boundaries of PTA lands; the first, Pohakuloa Test Hole (TH) #1, was drilled in 1965 from an elevation of 1,943 m to an elevation of 1,939.5 meters (m) above mean sea level (amsl) [1,001 feet (ft) deep]. The second, Pohakuloa TH#2, was drilled from an elevation of 1,828.7 m to an elevation of 1,722 m amsl (350 ft deep). Neither test hole was deep enough to encounter the saturated zone. Groundwater monitoring and production wells that have been drilled closest to the PTA properties suggest that freshwaters may be elevated by as much as 800 m above sea level within Mauna Kea but are at least 300 m below ground surface (USGS, 2009).

In addition:

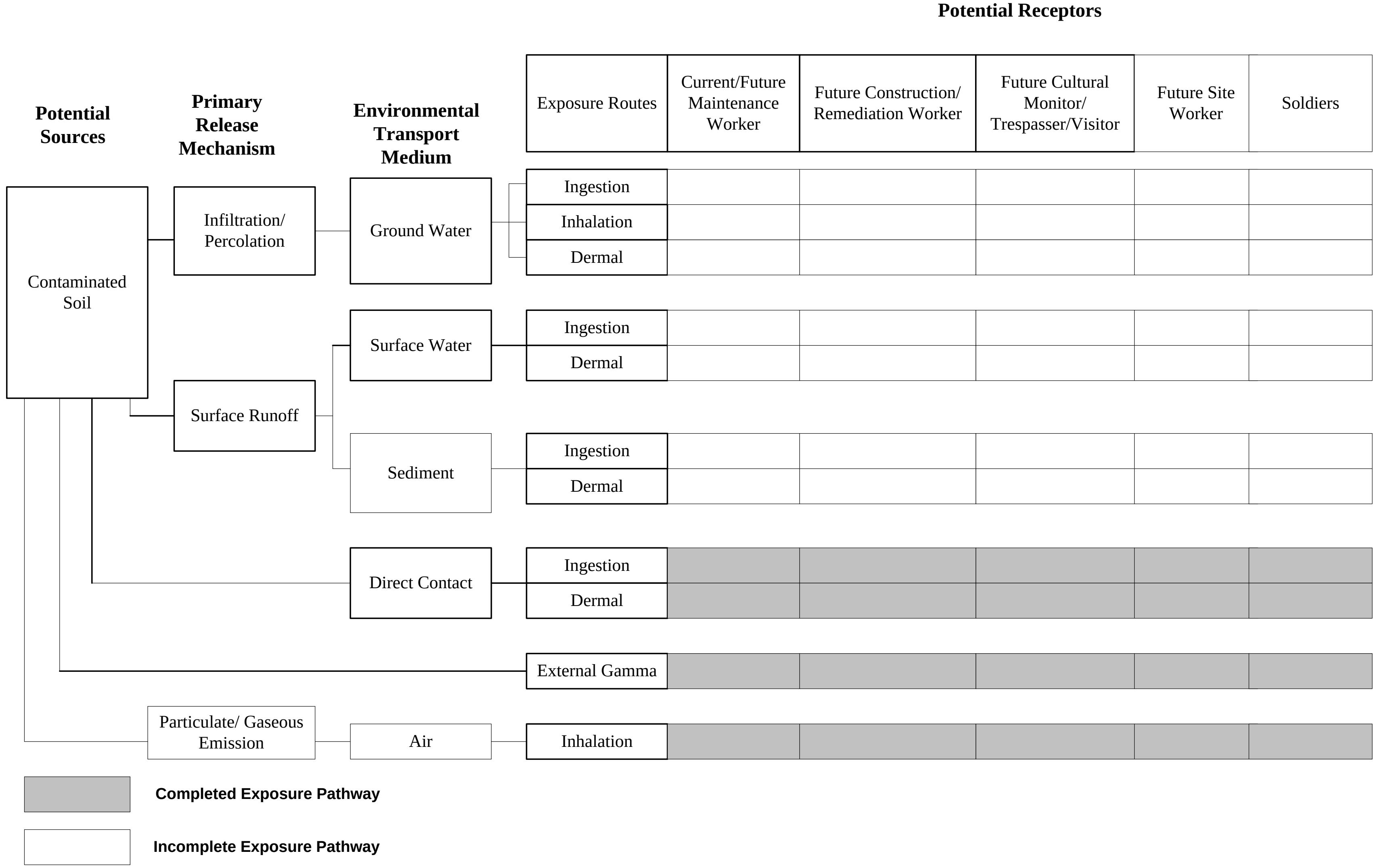
1) The radon pathway is suppressed during the radiological BHHRA: Radium is not a COPC for the Site; therefore, the radon pathway was not evaluated in this BHHRA.

2) External exposure to radionuclides that emit gamma radiation or x-rays was evaluated: This external exposure pathway accounts for radionuclides that may produce a risk without any physical contact.
3) A volatile emission of chemicals from surface soil is not a complete exposure pathway for this BHHRA because DU, the only COPC, is not a volatile compound.

Specific information relative to quantifying exposure for receptors and pathways are presented below. Exposure parameters for pertinent receptors are also summarized on Table 4-1.

Five reasonable maximum exposure (RME) receptor scenarios - range maintenance worker, construction/remediation worker, and adult cultural monitor/trespasser/visitor (including military trainee) were evaluated under future land use scenarios. In addition, the BHHRA was also performed for a site worker. PTA worker scenario was considered with the (very conservative) assumption that PTA 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. The assessment receptor scenarios did not include a member of the public as the public scenario is bounded by the PTA worker scenario. The worker scenario includes time for personnel remaining in contact with the site for extended periods of time as described below. The time and proximity of the worker to the site provides a bounding conservative assessment that would also bound the public exposure.

FIGURE 4-1: CONCEPTUAL SITE MODEL FOR PTA



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.

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, 250 days per year over a 3-year construction activity at the PTA for target modernization. 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 per year (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; and
- Inhalation of airborne contaminated dust from 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 PTA. 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 m^3 of air per day (USEPA, 1989). The receptor is assumed to spend 8 hours per day outdoors at PTA.

Exposure pathways evaluated for the receptor scenario include:

- External gamma radiation from radionuclides in the surface soil;
- Incidental ingestion of surface soil; and
- Inhalation of airborne contaminated dust from surface 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 PTA 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). 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; and
- Inhalation of airborne contaminated dust from surface soil; and

Soldiers: Under this scenario, the soldiers who are involved in various training activities are exposed to the depleted uranium (DU) present at the site. There are two ways a soldier might be exposed to the DU present in surface soil.

(1) Exposure to Volumetric Contamination in Soil: Under this scenario, the soldier is exposed to the volumetric contamination present in the surface soil while walking, crawling, or running on the range for 8 hours per day, 171 days per year, for 25 years. The adult soldier is assumed to ingest 100 milligram (mg) of soil (USEPA, 1989) and inhale 1.4 cubic meters of air

per hour (m^3/hr) or 12,300 m^3 of air per year (m^3/yr) (ANL, 1993). Similar to the other four receptor scenarios, the soldier will be exposed via the same three exposure pathways, as follows:

- External gamma radiation from radionuclides in the surface soil;
- Incidental ingestion of surface soil; and
- Inhalation of airborne contaminated dust from surface soil; and

(2) Exposure to Surface Soil Contamination in a Vehicle: Under this scenario, the same soldier spends 8 hours per day, 83 days per year inside a contaminated vehicle. The adult soldier is assumed to have the same inhalation rate of 1.4 m^3/hr or 12,300 m^3/yr of air (ANL, 1993). The receptor will not ingest soil directly; instead, the receptor will ingest soil secondarily. While driving the vehicle, the soldier disturbs the soil surface and the dust generated from the soil will become airborne. The vehicle provides some protection from gamma rays from surface soil contaminated with gamma emitting radionuclides. However, the exterior of the vehicle maneuvering in radionuclide-contaminated soil is likely to become contaminated. This contamination can then be passed on to the passenger when exiting and entering the vehicles. During this assessment, the floor, dashboard, driver-side doors, and passenger-side doors of the vehicles are assumed to be uniformly contaminated by 10% of the volumetric surface soil DU contamination. Windows are not assumed to be contaminated. The surface area for the dash and doors are assumed to be one-half of the surface area of the floor.

The sources of all four sides of the vehicle are assumed to be present at equal distance and are directly perpendicular to the receptors. The soldier is exposed externally to radiation from residual radioactivity on the surface of the equipment, as well as internally to resuspended and inadvertently ingested contamination. Tables A-1, A-2, and A-3 of Appendix A 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.

TABLE 4-1: EXPOSURE VARIABLES FOR PTA FIRING RANGE AREA RECEPTORS

Receptor	**Exposure Duration**			**Soil Ingestion Rate**	**Inhalation Rate**
	Years	**Days/Yr**	**Hrs/Day**	**(mg/d)**	**(m^3/hr)**
Current/Future Maintenance Worker	6.6	10	8	100	1.4
Future Construction/ Remediation Worker	3	250	8	330	3
Future Adult Cultural Monitor/Trespasser/ Visitor	30	26	8	100	0.83
Future Site Worker	25	250	8	50	0.83
Current/Future Soldier	25	254	8	100	1.4

4.2.4 Methodology for Estimating the Exposure Point Concentration

To calculate a cancer risk or a non-cancer hazard, an estimate must first be made of the chemical concentration in the environmental medium to which an individual may be exposed. Per USEPA guidance, the EPC should be the estimate of the average concentration measured over the area to which an individual would be exposed for the specified duration of exposure for that receptor (USEPA, 2002a). For the development of a BHHRA, the typical process would be to collect the data obtained during the site investigation wherein the nature and extent of contamination had been determined. Statistical methods would then be used to determine an upper estimate of the average concentration (e.g., the 95% upper confidence limit above the mean) to enable the conservative quantification of chemical intake per exposure route for each receptor. This is typically referred to as a means of evaluating the RME scenario, a conservative approach. However, the BHHRA conducted at the PTA Firing Range represents a unique challenge as there are very limited site-specific data are available from which to make a determination of an EPC (or in other words, a source term) of uranium activity in surface soil. Since the appropriate information regarding the number of DU projectiles fired at the range and/or the exact footprint of the area of affected soil cannot be reliably ascertained, the approach described by the St. Louis District of the USACE, in the *Draft Final Range Operations Report No. 9 (RO-9)* (2005) were utilized to derive a site specific EPC (source term) for uranium.

With an approximation of the mass of DU on site, and an understanding of uranium activity, the total activity of uranium can be calculated as follows:

Total Activity, U (pCi) = (DU on site, g) x (specific activity of U, pCi/g)

To complete the derivation of a conservative source term for the Firing Range, it is important to consider the area of affected soil. An important assumption that must be made is with respect to the distribution of DU across the affected area. For this BHHRA, it is assumed that the total uranium activity is uniformly distributed across the affected area of Range 11T. A total of 714 rounds were assumed to have been fired at PTA. Assumption of uniform contamination provides a measure of conservatism as compared to discrete fragments as the exposure to any individual receptor scenario is always in direct contact with the contaminant. Another important assumption regarding the spatial representation of uranium activity in soil is with regard to the depth of affected soil. Due to absence of any site-specific information, a very conservative standard default approach of 2 meters (as presented in RESRAD, 2005) was considered as the recommended thickness of contamination in soil at the PTA Firing Range. Hence, the method recommended for deriving the source term for uranium at the Firing Range is:

$$U, pCi/g = \frac{\text{Total Activity } U, pCi}{\text{Area soil } (m^2) \times \text{depth soil } (m)} \times \frac{1^3\ m^3}{100^3\ cm^3} \times \frac{cm^3}{\text{soil density, } g}$$

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). These ratios were utilized to calculate the source term for each uranium isotope.

However, for the chemical risk evaluation, it is 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)*

4.2.4.1 Determination of the EPC via Volumetric Contamination in Soil: Under this exposure scenario, for each round of SRB, the EPCs for three uranium isotopes of DU in surface soil were determined and reported in the BHHRA report, and these are as follows:

$$U\text{-}234 = 2 \times 10^{-6}\ pCi/g$$
$$U\text{-}235 = 1 \times 10^{-7}\ pCi/g$$
$$U\text{-}238 = 9 \times 10^{-6}\ pCi/g$$

4.2.4.2 Determination of the EPC via Surface Contamination in a Vehicle: Under this exposure scenario, it is assumed that 10% of the volumetric contamination at each of four sides of the vehicle results in 1 millimeter (mm) thickness of surface contamination. Based on that, for each round of SRB, the EPC for surface contamination of DU at each vehicle side were calculated as follows

$$U\text{-}234 = 10\%\ of\ 2 \times 10^{-6}\ pCi/g \times 1.5\ g/cm^3 \times 1\ mm \times (1\ cm/10\ mm) \times (10^4\ cm^2/m^2);$$

where, 1.5 g/cm^3 *is the specific density of soil.*

$$= 3 \times 10^{-4}\ pCi/m^2;$$

$$U\text{-}235 = 10\%\ of\ 1 \times 10^{-7}\ pCi/g \times 1.5\ g/cm^3 \times 1\ mm \times (1\ cm/10\ mm) \times (10^4\ cm^2/m^2);$$
$$= 2 \times 10^{-5}\ pCi/m^2;\ and$$

$$U\text{-}238 = 10\%\ of\ 9 \times 10^{-6}\ pCi/g \times 1.5\ g/cm^3 \times 1\ mm \times (1\ cm/10\ mm) \times (10^4\ cm^2/m^2);$$
$$= 1 \times 10^{-3}\ pCi/m^2.$$

4.2.5 Pathway-Specific Intake Equations and Methodologies for Radionuclides

The human health radiological dose and risk assessments due to volumetric and surface contamination were conducted by utilizing the *RESidual RADioactivity* (RESRAD) computer code, Version 6.3 (ANL, 2005) and RESRAD-BUILD 3.4 (ANL, 2008), respectively. These software codes were 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 and structures.

While RESRAD uses methods consistent with those presented in 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 within a single calculation or "run"; and
- RESRAD provides both carcinogenic risk and radiological dose estimates for comparison to appropriate regulatory limits.

Except for these differences, the RESRAD calculations parallel risk assessment methodologies for non-radiological constituents. The same exposure parameters are utilized, the same exposure pathways are considered, and the same exposure scenarios are evaluated.

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. Additional preliminary input parameter values which may be used for input into RESRAD are found in the Appendix as Table A-2. Importantly, these input parameters are preliminary in nature and may change based on the site-specific information that may become available.

The magnitude of human exposure to chemicals in environmental media is usually described in terms of the average daily intake (DI), which is the amount of chemical in contact with an exchange surface of the body (skin, lungs, and gastrointestinal tract). Average daily chemical intake for the incidental ingestion of soil is calculated by use of the following formula (USEPA, 1989):

$$DI_{Soil\text{-}Ing} = \frac{CS \times IR \times CF \times FI \times EF \times ED}{BW \times AT}$$

where:

$DI_{Soil\text{-}Ing}$ = *average daily chemical intake via soil ingestion (mg/kg-day)*
CS = *chemical concentration in soil (mg/kg)*
IR = *ingestion rate (mg soil/day)*
CF = *conversion factor (10^{-6} kg/mg)*
FI = *fraction ingested from contaminated source (unitless)*
EF = *exposure frequency (days/year)*
ED = *exposure duration (years)*
BW = *body weight (kg)*
AT = *averaging time (period over which exposure is averaged, days)*

Average daily chemical intake by inhalation of soil particles is calculated by use of the following formula (USEPA, 1989):

$$DI_{Inh} = \frac{CA \times IR \times ET \times EF \times ED}{BW \times AT}$$

where:

DI_{Inh} = *average daily chemical intake via inhalation (mg/kg-day)*
CA = *chemical concentration in air (mg/m^3)*
IR = *inhalation rate (m^3/hour)*
ET = *exposure time (hours/day)*
EF = *exposure frequency (days/year)*
ED = *exposure duration (years)*
BW = *body weight (kg)*
AT = *averaging time (period over which exposure is averaged, days)*

The chemical concentration in air (CA) term was calculated as follows:

$$CA = CS \times (1/PEF)$$

where:

PEF = *Particle emission factor (m^3/kg)*

Note: exposure via the inhalation pathway typically also involves the volatile chemical component, in addition to the particle component, in the above equation for the CA term. However, DU is not a volatile compound; therefore volatility is not a concern.

4.3 Toxicity Assessment

The toxic effects of a constituent generally depend not only upon the inherent toxicity of the constituent and the level of exposure (intake), but also on the route of exposure (oral, inhalation, dermal) and the duration of exposure. Thus, a full description of toxic effects of a constituent includes a listing of what adverse health effects the chemical may cause, and how the occurrence of these effects depend upon intake, route, and duration of exposure. 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 exposures.

Of the radionuclides, only uranium is considered as both a carcinogenic risk and non-carcinogenic hazard. To estimate radiological risk, the RESRAD code utilizes Federal Guidance Report (FGR) Number 13 Risk Coefficient Values (USEPA, 2002b). The risk coefficients derived in FGR 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 (for internal pathways) or risk per year per pCi/g (for external pathway).

The cancer slope factor (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, 1989). Slope factors are specific for each chemical and route of exposure. The potential for noncarcinogenic health effects resulting from exposure to chemicals 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, 1989). An RfD is also specific to a chemical and route of exposure.

A CSF for a radionuclide is defined differently than a CSF for a chemical other than a radionuclide, USEPA outlines these differences in *Radiation Exposure and Risk Assessment Manual* (1996), and major differences include the following:

- Radiological risk estimates are based primarily on human data, while chemical risk estimates are based primarily on animal studies; and

- Radiological risk estimates are traditionally based on the central estimate of the mean, however in others the 95th percentile of a population is used as an estimator, while chemical risk estimates are based on 95% upper confidence limit of the mean.

For chemical contaminants, the assessment of toxicity is based on two general effects: carcinogenic and non-carcinogenic. These values are listed and described in various USEPA publications, including the *Integrated Risk Information System* (*IRIS*) (USEPA, accessible on-line), the *Health Effects Assessment Summary Tables* (*HEAST)* (USEPA, 2001) for chemicals having insufficient data for inclusion in *IRIS*, and the Agency for Toxic Substances and Disease Registry (ATSDR, 1999).

In general, toxicity values for uranium are only available for the ingestion and inhalation pathways. Oral RfD values of 3.0×10^{-3} milligram per kilogram-day (mg/kg-d), as specified in IRIS (USEPA, on-line), was used for evaluating the non-carcinogenic effects of exposure to soluble uranium 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 the use of ATSDR chronic minimum risk levels (MRLs) for some chemicals (such as uranium), consistent with their description in OSWER Directive 9285.7-53 (USEPA, 2003) as Tier 3 toxicity values. Therefore, an inhalation RfD of 8.6×10^{-5} mg/kg-day was used for evaluating the non-carcinogenic effects of exposure to soluble uranium by inhalation.

Since uranium has not been found to be carcinogenic by inhalation or oral 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.

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 site contaminants (USEPA, 1989). Risks were calculated using the results of the toxicity assessment and the exposure assessment. In addition, natural background radiation is ubiquitous at levels exceeding typical risk targets and natural variability may preclude the ability to quantify small incremental risks due to contamination (USEPA, 1996).

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 National Contingency Plan (NCP) (USEPA, 1990) of 10^{-6} to 10^{-4} (meaning from 1 in 1,000,000 to 1 in 10,000 persons developing cancer over and above the normal cancer rate for unexposed populations). ILCRs less than 10^{-6}, are considered acceptable risks and ILCRs greater than 10^{-4} are considered unacceptable risks. Risks between 10^{-6} and 10^{-4} fall into the NCP "area of concern". Any decisions to address them further, either through further study or engineered control measures, should account for uncertainty in the risk estimates.

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

$$ILCR = I \times CSF$$

where:

ILCR = *incremental lifetime cancer risk (unit-less probability)*

I = *chronic daily intake from exposure assessment (mg/kg-day)*

CSF = *cancer slope factor* $(mg/kg\text{-}day)^{-1}$

For a given carcinogen, with simultaneous pathways of exposure, the total risk to a receptor is the sum of the ILCRs for each pathway.

In addition to developing cancer from exposure to constituents, an individual may experience noncarcinogenic 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 were evaluated by comparing an exposure level or intake to a RfD. 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, 1989) and is defined as:

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

Where:

HQ = *hazard quotient (unit-less ratio)*

I = *chronic daily intake (mg/kg-day)*

RfD = *reference dose (mg/kg-day)*

HQs for each chemical and pathway were summed to obtain a Hazard Index (HI). An HI greater than unity (1.0) has been defined as the level of concern for any potential adverse noncarcinogenic health effects (USEPA, 1989). This approach is different from the probabilistic approach used to evaluate carcinogens. An HQ of 0.01 does not imply a 1 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. A total ILCR and a total HI for each receptor were estimated by summing pathway-specific values.

5.0 SUMMARY AND CONCLUSION

The human health radiological dose and risk assessments due to volumetric and surface contamination were conducted by utilizing the RESRAD, Version 6.3 (ANL, 2005) and RESRAD-BUILD 3.4 (ANL, 2008), respectively. USEPA's standard RAGS equations were utilized to determine the chemical hazard associated with DU present at the Site. The following sections of the report summarized the results of both radiological and chemical assessments.

5.1 Results of Radiological Dose and Risk Assessments

Single Round of SRB

For volumetric contamination, 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 A, Table A-1, were used as model input values for all receptors evaluated. The exposure variables listed in Appendix A, Table A-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 A, Table A-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.

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 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 5-1 summarizes the results of radiological dose and risk assessments for each receptor scenario.

TABLE 5-1: SUMMARY OF RADIOLOGICAL DOSE AND RISK ESTIMATES (UNIT ROUND OF SRB)

Receptor Scenarios	Maximum Dose (mrem/yr)	Maximum Risk
Current/Future Maintenance Worker	$2. \times 10^{-8}$	7×10^{-14}
Future Construction/ Remediation Worker	$5. \times 10^{-7}$	9×10^{-13}
Future Adult Cultural Monitor/Trespasser/ Visitor	$4. \times 10^{-8}$	8×10^{-13}
Future Site Worker	$3. \times 10^{-7}$	5×10^{-12}
Current/Future Soldier	$4. \times 10^{-7}$	6×10^{-12}
Soldier-Volumetric Contamination	4×10^{-7}	6×10^{-12}
Soldier-Surface Contamination	3×10^{-8}	6×10^{-15}

Site-wide Dose and Risk Assessments

The Lake City Ordnance Plant (Lake City Army Ammunition Plant) manufactured, assembled, loaded, and packed the Cartridge, 20mm Spotting M101 except for the fuse. The first lot was accepted on 23 June 1961. The final lot produced at the plant was accepted on 19 September 1963. Total production accepted by the government of this cartridge was 75,318. They were shipped to a number of military installations. By comparing the Ammunition Data Cards and munitions shipping documents (DD Form 550) recovered from the Cartridge, 20mm Spotting M101 manufacturer, Lake City Ordnance Plant, total rounds verified shipped to Oahu from Lake city Ordnance Plant were 714 rounds on 27 April 1962.

Based on aerial reconnaissance conducted as a part of the scoping survey, there is definitive evidence that the Davy Crockett weapon was used at PTA. Anywhere from 120 to 400 pistons were identified by air (30 to 100 in four locations). Because of the sparse vegetation, the Army is confident that the PTA site was used for practice firing. However, there is no site-specific information available regarding the actual rounds of SRB being fired at the Site. Therefore, as very conservative approach, this BHHRA assumed that all 714 rounds of SRB being fired at the PTA site. Therefore, the results of the radiological dose and risk assessments for single round of SBR were multiplied by 714 to determine the site-wide total dose and risks for each receptor scenario and the results are presented in Table 5-2.

TABLE 5-2: RESULTS OF RADIOLOGICAL DOSE AND RISK ASSESSMENTS (714 ROUNDS SRB)

Receptor Scenarios	Maximum Dose (mrem/yr)	Maximum Risk
Current/Future Maintenance Worker	$1. \times 10^{-5}$	$5. \times 10^{-11}$
Future Construction/ Remediation Worker	$4. \times 10^{-4}$	$6. \times 10^{-10}$
Future Adult Cultural Monitor/Trespasser/ Visitor	$3. \times 10^{-5}$	$6. \times 10^{-10}$
Future Site Worker	$2. \times 10^{-4}$	$3. \times 10^{-9}$
Current/Future Soldier	$3. \times 10^{-4}$	$4. \times 10^{-9}$

The results of site-wide radiological dose and risk assessment showed that the soldier received the maximum risk due to presence of DU at the Site. The maximum risk is 4E-9, which is well below the USEPA acceptable risk range of 10^{-6} to 10^{-4}. Therefore, the results of the risk assessment demonstrate that the presence of DU in soil at the PTA results in radiological risk that falls well below the USEPA limits for what considered safe by the USEPA. Therefore, no significantly increased risks for the human receptors considered in this document exist at PTA. 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 PTA.

5.2 Results of Chemical Risk Assessments for Single Round of SRB

Single Round of SRB

For each receptor present at the Site, an HQ was calculated for each exposure pathway by using the chemical intake and established RfDs for both ingestion and inhalation exposure routes. Results of the ingestion and inhalation, HQ calculations were summed for each potential receptor to derive the HI for that receptor. The chemical risk calculations for the five receptors evaluated in this risk assessment are presented in Appendix C. The HIs calculated for each receptor are summarized in Table 5-3.

TABLE 5-3: SUMMARY OF HAZARD INDEX CALCULATIONS (UNIT ROUND OF SRB)

Receptor	Pathway-Specific Hazard Quotient [1]		Hazard Index
	Ingestion	Inhalation	
Current/Future Maintenance Worker	4×10^{-10}	3 × 10-^{12}	4×10^{-10}
Future Construction/ Remediation Worker	3×10^{-8}	1×10^{-10}	3×10^{-8}
Future Adult Cultural Monitor/Trespasser/ Visitor	1×10^{-9}	4×10^{-12}	1×10^{-9}
Future Site Worker	5×10^{-9}	4×10^{-11}	5×10^{-9}
Current/Future Soldier	9×10^{-9}	7×10^{-11}	9×10^{-9}

[1] Hazard quotients calculated based on non-carcinogenic effects of exposure to uranium, because these are more conservative.

Site-wide Chemical Risk Assessments

The results of the chemical risk assessments for single round of SBR were multiplied by 714 to determine the site-wide total chemical risks for each receptor scenario and the results are presented in Table 5-4.

TABLE 5-4: SUMMARY OF HAZARD INDEX CALCULATIONS (714 ROUNDS OF SRB)

Receptor	Pathway-Specific Hazard Quotient [1]		Hazard Index
	Ingestion	Inhalation	
Current/Future Maintenance Worker	3×10^{-7}	2×10^{-9}	3×10^{-7}
Future Construction/ Remediation Worker	2×10^{-5}	1×10^{-7}	2×10^{-5}
Future Adult Cultural Monitor/Trespasser/ Visitor	7×10^{-7}	3×10^{-9}	7×10^{-7}
Future Site Worker	3×10^{-6}	3×10^{-8}	3×10^{-6}
Current/Future Soldier	7×10^{-6}	5×10^{-8}	7×10^{-6}

[1] Hazard quotients calculated based on non-carcinogenic effects of exposure to uranium, because these are more conservative.

The results of site-wide chemical risk assessment showed that due to higher ingestion rate, the hazard index is the highest for the construction worker. The maximum HI is 2×10^{-5}, which is well below the USEPA acceptable value of 1. Therefore, the results of the risk assessment demonstrate that the presence of DU in soil at the PTA results in chemical risk that falls well below the USEPA limits for what considered safe by the USEPA. Therefore, no significantly increased risks for the human receptors exist at PTA. 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 PTA.

5.3 Uncertainty Analysis

Risk assessment of contaminated sites must not be viewed as yielding single invariant values. Rather, the results of risk assessment are estimates that span a range of possible values, and should be understood only in light of the assumptions and methods used in the evaluation. There is uncertainty associated with every risk assessment. Because of the conservative nature of the risk assessment process, assumptions built into the risk assessment are likely to overestimate, rather than underestimate, potential risks. Occasionally, assumptions can result in underestimating risk. Uncertainty is inherent in the selection of input parameters and in every step of the risk assessment process

As with all evaluations of human health risk, there are uncertainties associated with the PTA risk assessment. First, with respect to the exposure assessment, it is not known what types of future activities may be conducted at PTA that would involve regular exposure to contaminants. Currently, access to the PTA 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.

Derivation of an appropriate estimate of the EPC without actual site data is most likely to be a major source of uncertainty for this BHHRA at PTA. For the most part then, the important missing variable is the site-specific soil source term, also referred to as the exposure point concentration. Derivation of a site-specific soil source term can be accomplished by the methodologies presented in Section 4.2.4, understanding that such methodologies are more into estimating methods and away from having actual site-specific information, as a result, uncertainty surrounding the resulting risk estimate is likely to increase.

In absence of site-specific knowledge of actual rounds being fired at the Site, initially this BHHRA was performed for dose and risk associated with single round of SBR. Later, based on historical knowledge, a very conservative assumption was made by assuming all SRBs were being fired at the PTA site. The total rounds was used to determine the total dose and risks for each receptor present at the Site, hence overestimated the total risk to each receptor scenario.

There is an uncertainty associated with the impact of the potential source term concentration due to natural weathering and subsequent oxidation that may occur at PTA given the typical environmental conditions for that area of Hawaii. Weathering over time can affect the speciation of uranium in the environment. The various uranium species differ in their solubility and toxicity. The compounds of uranium present in the Davy Crockett spotter rounds are in the form of solid metal. Over time and by weathering reactions, the uranium in DU metal can form the uranium oxides; primarily triuranium octaoxide (U_3O_8) and uranium dioxide (UO_2). These two species are the most common forms of uranium oxides. U_3O_8 is the most stable form of uranium and is the form most commonly found in nature. Uranium dioxide (UO_2) is the form in which uranium is most commonly used as a nuclear reactor fuel. At ambient temperatures, UO_2 will gradually convert to U_3O_8.

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 (USAEPI, 1995). Additional research has been conducted since this report was published. Both the International Atomic Energy Agency (IAEA, 2003) and the Battelle Memorial Institute (BMI, 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 USAEPI risk assessment likely overestimate the radioactivity concentration of ^{234}U in DU, resulting in a conservative representation of risk in the radiological analysis, because of its intrinsic higher specific activity.

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. It is generally accepted that these uncertainties err on the side of protection and safety.

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