RECORD OF TECHNICAL CHANGE

Technical Change No. DOE/NV--1475-ROTC 1 Page 1 of 2

Activity Name Soils Risk-Based Corrective Action (RBCA) Evaluation Process Date September 24, 2012

The following technical changes (including justification) are requested by:

Lynn Kidman	Senior Technical Advisor
(Name)	(Title)

Description of Change:

Replace the Residual Radioactive Material Guideline (RRMG) tables in Appendix A, Pre-calculated Exposure Scenario-Specific RRMGs of the Soils Risk-Based Corrective Action Evaluation Process (DOE/NV--1475) with the attached tables.

Justification:

The Soils RBCA Process document issued in April of 2012 lists RRMG values to be used in converting radionuclide contaminant concentrations to radiological dose. Subsequent to the publication of this document, the radionuclides Al-26, Am-243, Np-237, Tc-99, and U-233 were identified as having the potential to have been used as tracers in some nuclear tests. It was decided to develop RRMG values for these radionuclides even though their potential contribution to total dose is likely to be negligible. When the RRMGs for these additional radionuclides were calculated, RRMGs for the original set of radionuclides were also recalculated. Differences between the original set of RRMG values and the values of the recalculated set of RRMGs were identified during the checkprinting (i.e., verification) process before the loading of these values into the analytical services database.

An independent assessment was conducted to determine the source of the discrepancies. This assessment determined that the technical cause was the truncating of numbers for the two Residual Radioactive (RESRAD) model input parameters listed in Table 1. Although all input parameters for the RESRAD calculations were verified in both sets of calculations, the errors in the two input parameter values were not identified.

Table 1, RESRAD Input Parameter Corrections

Parameter	Value Used for Original Set of RRMGs	Value Listed in Soils RBCA Document	Units	Affected Scenarios
Wind Speed	5.8	5.81	m/sec	all
Indoor Time Fraction	0.025	0.0256	none	Remote Work Area only

The assessment confirmed that the recalculated set of RRMGs were the correct values based on the use of the non-truncated input parameter values as listed in the Soils RBCA Process document.

No changes to Federal Facility Agreement and Consent Order (FFACO) documents need to be made as no FFACO investigation reports have used the incorrect RRMG values.

The task time will be (Increased) (Decreased) [✓ (Unchanged)] by approximately 0 days.

9/28/12

Applicable Activity-Specific Document(s):

- Soils Risk-Based Corrective Action Evaluation Process (DOE/NV--1475)

Approved By:	/s/ Tiffany A. Lantow Tiffany Lantow, Activity Lead	Date	9/20/2012
	/s/ Robert F. Boehlecke Robert Boehlecke, EM Operations Manager	Date	9/27/12
	/s/ Jeff J. MacDougall NDEP	Date	9/28/12

Table A.1-1
Industrial Area Exposure Scenario - Internal Dose Only (IA-I)

Radionuclide	$\mathrm{RRMG}_{(IA\text{-}I)}$ (pCi/g)
Ag-108m	1.063E+07
Al-26	7.084E+06
Am-241	9.987E+03
Am-243	9.958E+03
Cm-243	1.331E+04
Cm-244	1.650E+04
Co-60	1.128E+06
Cs-137	2.830E+05
Eu-152	2.541E+06
Eu-154	1.814E+06
Eu-155	1.182E+07
Nb-94	1.404E+07
Np-237	1.798E+04
Pu-238	8.452E+03
Pu-239/240	7.732E+03
Pu-241	3.888E+05
Sr-90	1.215E+05
Tc-99	3.784E+07
Th-232	2.924E+03
U-233	5.371E+04
U-234	5.578E+04
U-235	5.861E+04
U-238	5.840E+04

A soil sample at this Residual Radioactive Material Guideline (RRMG) value would present an internal dose potential of 25 millirem under the Industrial Area exposure scenario.

Table A.1-2
Industrial Area Exposure Scenario - Internal & External Dose (IA-IE)

Radionuclide	RRMG(IA-IE) (pCi/g)
Ag-108m	1.929E+02
Al-26	1.249E+02
Am-241	2.687E+03
Am-243	2.345E+02
Cm-243	3.736E+02
Cm-244	1.626E+04
Co-60	2.047E+01
Cs-137	8.145E+01
Eu-152	4.275E+01
Eu-154	3.990E+01
Eu-155	1.074E+03
Nb-94	2.008E+02
Np-237	2.115E+02
Pu-238	8.380E+03
Pu-239/240	7.645E+03
Pu-241	1.932E+05
Sr-90	9.252E+03
Tc-99	7.612E+06
Th-232	2.234E+01
U-233	3.939E+04
U-234	4.946E+04
U-235	2.897E+02
U-238	1.667E+03

A soil sample at this Residual Radioactive Material Guideline (RRMG) value would present a total effective dose potential of 25 millirem under the Industrial Area exposure scenario.

Table A.1-3
Remote Work Area Exposure Scenario - Internal Dose Only (RWA-I)

Radionuclide	RRMG$_{(RWA-I)}$ (pCi/g)
Ag-108m	6.312E+07
Al-26	4.208E+07
Am-241	5.932E+04
Am-243	5.915E+04
Cm-243	7.908E+04
Cm-244	9.798E+04
Co-60	6.698E+06
Cs-137	1.681E+06
Eu-152	1.510E+07
Eu-154	1.077E+07
Eu-155	7.022E+07
Nb-94	8.342E+07
Np-237	1.068E+05
Pu-238	5.020E+04
Pu-239/240	4.592E+04
Pu-241	2.309E+06
Sr-90	7.220E+05
Tc-99	2.248E+08
Th-232	1.737E+04
U-233	3.190E+05
U-234	3.314E+05
U-235	3.481E+05
U-238	3.361E+05

A soil sample at this Residual Radioactive Material Guideline (RRMG) value would present an internal dose potential of 25 millirem under the Remote Work Area exposure scenario.

Table A.1-4
Remote Work Area Exposure Scenario - Internal & External Dose (RWA-IE)

Radionuclide	$RRMG_{(RWA-IE)}$ (pCi/g)
Ag-108m	1.146E+03
Al-26	7.419E+02
Am-241	1.596E+04
Am-243	1.393E+03
Cm-243	2.219E+03
Cm-244	9.656E+04
Co-60	1.216E+02
Cs-137	4.838E+02
Eu-152	2.539E+02
Eu-154	2.370E+02
Eu-155	6.380E+03
Nb-94	1.193E+03
Np-237	1.256E+03
Pu-238	4.977E+04
Pu-239/240	4.542E+04
Pu-241	1.148E+06
Sr-90	5.496E+04
Tc-99	4.521E+07
Th-232	1.327E+02
U-233	2.340E+05
U-234	2.938E+05
U-235	1.720E+03
U-238	9.904E+03

A soil sample at this Residual Radioactive Material Guideline (RRMG) value would present a total effective dose potential of 25 millirem under the Remote Work Area exposure scenario.

Table A.1-5
Occasional Use Area Exposure Scenario - Internal Dose Only (OUA-I)

Radionuclide	$RRMG_{(OUA-I)}$ (pCi/g)
Ag-108m	1.762E+08
Al-26	1.177E+08
Am-241	1.579E+05
Am-243	1.575E+05
Cm-243	2.108E+05
Cm-244	2.609E+05
Co-60	1.872E+07
Cs-137	4.705E+06
Eu-152	4.203E+07
Eu-154	3.001E+07
Eu-155	1.958E+08
Nb-94	2.323E+08
Np-237	2.849E+05
Pu-238	1.337E+05
Pu-239/240	1.223E+05
Pu-241	6.149E+06
Sr-90	2.019E+06
Tc-99	6.269E+08
Th-232	4.739E+04
U-233	8.687E+05
U-234	9.018E+05
U-235	9.488E+05
U-238	3.361E+05

A soil sample at this Residual Radioactive Material Guideline (RRMG) value would present an internal dose potential of 25 millirem under the Occasional Use Area exposure scenario.

Table A.1-6
Occasional Use Area Exposure Scenario - Internal & External Dose (OUA-IE)

Radionuclide	$RRMG_{(OUA\text{-}IE)}$ (pCi/g)
Ag-108m	3.856E+03
Al-26	2.496E+03
Am-241	5.014E+04
Am-243	4.658E+03
Cm-243	7.412E+03
Cm-244	2.579E+05
Co-60	4.092E+02
Cs-137	1.628E+03
Eu-152	8.544E+02
Eu-154	7.975E+02
Eu-155	2.147E+04
Nb-94	4.012E+03
Np-237	4.214E+03
Pu-238	1.328E+05
Pu-239/240	1.212E+05
Pu-241	3.451E+06
Sr-90	1.821E+05
Tc-99	1.461E+08
Th-232	4.457E+02
U-233	6.713E+05
U-234	8.173E+05
U-235	5.782E+03
U-238	3.310E+04

A soil sample at this Residual Radioactive Material Guideline (RRMG) value would present a total effective dose potential of 25 millirem under the Occasional Use Area exposure scenario.

RECORD OF TECHNICAL CHANGE

Technical Change No.	DOE/NV—1475-ROTC 2	Page	1 of 1
Activity Name	Soils Risk-Based Corrective Action (RBCA) Evaluation Process	Date	April 29, 2013

The following technical changes (including justification) are requested by:

Lynn Kidman	Senior Technical Advisor
(Name)	(Title)

Description of Change:

1. Remove the acronym "RESRAD" and the associated callout description "residual radioactive" from the acronym list in the *Soils Risk-Based Corrective Action Evaluation Process* document (DOE/NV--1475).

2. Replace the Residual Radioactive Material Guideline (RRMG) tables in DOE/NV--1475-ROTC 1 with the attached tables.

Justification:

1. RESRAD is not an acronym. It is the proper name of a computer code.

2. The Soils RBCA ROTC 1, issued on September 24, 2012, lists RRMG values to be used in converting radionuclide contaminant concentrations to radiological dose. Subsequent to the publication of the ROTC, additional reviews identified the need to revise several input parameter values to the RESRAD code that was used to calculate the RRMGs. These changes in input parameter values resulted in the revised list of RRMG values presented in this ROTC.

The task time will be (Increased) (Decreased) (Unchanged) by approximately 0 days.

Applicable Activity-Specific Document(s):

Soils Risk-Based Corrective Action Evaluation Process (DOE/NV--1475)
Soils Risk-Based Corrective Action Evaluation Process (DOE/NV--1475), ROTC 1

Approved By: /s/ Tiffany A. Lantow Date 4/29/2013
Activity Lead

/s/ Robert F. Boehlecke Date 4/30/13
EM Operations Manager

/s/ Jeff MacDougall Date 4/30/13
NDEP

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Table A.1-1
Industrial Area Exposure Scenario - Internal Dose Only (IA-I)

Radionuclide	**$RRMG_{(IA-I)}$ (pCi/g)**
Ag-108m	5.682E+05
Al-26	3.724E+05
Am-241	5.186E+03
Am-243	5.164E+03
Cm-243	7.034E+03
Cm-244	8.809E+03
Co-60	3.807E+05
Cs-137	9.475E+04
Eu-152	8.838E+05
Eu-154	6.277E+05
Eu-155	4.063E+06
Nb-94	7.632E+05
Np-237	9.428E+03
Pu-238	4.523E+03
Pu-239/240	4.143E+03
Pu-241	2.135E+05
Sr-90	3.998E+04
Tc-99	2.032E+06
Th-232	3.909E+03
U-233	2.231E+04
U-234	2.327E+04
U-235	2.414E+04
U-238	2.368E+04

A soil sample at this RRMG value would present an internal dose potential of 25 mrem under the Industrial Area exposure scenario.

Table A.1-2
Industrial Area Exposure Scenario - Internal & External Dose (IA-IE)

Radionuclide	$\mathbf{RRMG_{(IA\text{-}I)}}$ (pCi/g)
Ag-108m	3.000E+01
Al-26	2.000E+01
Am-241	2.111E+03
Am-243	2.230E+02
Cm-243	3.640E+02
Cm-244	8.741E+03
Co-60	2.000E+01
Cs-137	8.100E+01
Eu-152	4.300E+01
Eu-154	4.000E+01
Eu-155	1.073E+03
Nb-94	3.100E+01
Np-237	2.090E+02
Pu-238	4.503E+03
Pu-239/240	4.118E+03
Pu-241	2.001E+05
Sr-90	7.874E+03
Tc-99	8.597E+05
Th-232	6.110E+02
U-233	1.935E+04
U-234	2.208E+04
U-235	2.840E+02
U-238	1.581E+03

A soil sample at this RRMG value would present a TED potential of 25 mrem under the Industrial Area exposure scenario.

Table A.1-3
Remote Work Area Exposure Scenario - Internal Dose Only (RWA-I)

Radionuclide	$\text{RRMG}_{(\text{IA-I})}$ (pCi/g)
Ag-108m	3.375E+06
Al-26	2.212E+06
Am-241	3.080E+04
Am-243	3.068E+04
Cm-243	4.178E+04
Cm-244	5.233E+04
Co-60	2.262E+06
Cs-137	5.628E+05
Eu-152	5.250E+06
Eu-154	3.729E+06
Eu-155	2.414E+07
Nb-94	4.533E+06
Np-237	5.600E+04
Pu-238	2.687E+04
Pu-239/240	2.461E+04
Pu-241	1.268E+06
Sr-90	2.375E+05
Tc-99	1.207E+07
Th-232	2.322E+04
U-233	1.325E+05
U-234	1.382E+05
U-235	1.434E+05
U-238	1.406E+05

A soil sample at this RRMG value would present an internal dose potential of 25 mrem under the Remote Work Area exposure scenario.

Table A.1-4
Remote Work Area Exposure Scenario - Internal & External Dose (RWA-IE)

Radionuclide	**$RRMG_{(IA-I)}$** **(pCi/g)**
Ag-108m	1.800E+02
Al-26	1.160E+02
Am-241	1.254E+04
Am-243	1.322E+03
Cm-243	2.164E+03
Cm-244	5.192E+04
Co-60	1.220E+02
Cs-137	4.840E+02
Eu-152	2.540E+02
Eu-154	2.370E+02
Eu-155	6.374E+03
Nb-94	1.870E+02
Np-237	1.240E+03
Pu-238	2.675E+04
Pu-239/240	2.446E+04
Pu-241	1.189E+06
Sr-90	4.677E+04
Tc-99	5.106E+06
Th-232	3.629E+03
U-233	1.149E+05
U-234	1.312E+05
U-235	1.687E+03
U-238	9.393E+03

A soil sample at this RRMG value would present a TED potential of 25 mrem under the Remote Work Area exposure scenario.

Table A.1-5
Occasional Use Area Exposure Scenario - Internal Dose Only (OUA-I)

Radionuclide	$RRMG_{(IA-I)}$ (pCi/g)
Ag-108m	9.451E+06
Al-26	6.194E+06
Am-241	8.624E+04
Am-243	8.588E+04
Cm-243	1.170E+05
Cm-244	1.465E+05
Co-60	6.333E+06
Cs-137	1.576E+06
Eu-152	1.470E+07
Eu-154	1.044E+07
Eu-155	6.758E+07
Nb-94	1.269E+07
Np-237	1.568E+05
Pu-238	7.522E+04
Pu-239/240	6.890E+04
Pu-241	3.550E+06
Sr-90	6.649E+05
Tc-99	3.379E+07
Th-232	6.500E+04
U-233	3.710E+05
U-234	3.871E+05
U-235	4.014E+05
U-238	3.361E+05

A soil sample at this RRMG value would present an internal dose potential of 25 mrem under the Occasional Use Area exposure scenario.

Table A.1-6
Occasional Use Area Exposure Scenario - Internal & External Dose (OUA-IE)

Radionuclide	$\text{RRMG}_{(\text{IA-I})}$ (pCi/g)
Ag-108m	6.040E+02
Al-26	3.900E+02
Am-241	3.899E+04
Am-243	4.411E+03
Cm-243	7.205E+03
Cm-244	1.455E+05
Co-60	4.090E+02
Cs-137	1.626E+03
Eu-152	8.540E+02
Eu-154	7.970E+02
Eu-155	2.145E+04
Nb-94	6.280E+02
Np-237	4.154E+03
Pu-238	7.494E+04
Pu-239/240	6.856E+04
Pu-241	3.363E+06
Sr-90	1.514E+05
Tc-99	1.583E+07
Th-232	1.184E+04
U-233	3.292E+05
U-234	3.704E+05
U-235	5.663E+03
U-238	3.119E+04

A soil sample at this RRMG value would present a TED potential of 25 mrem under the Occasional Use Area exposure scenario.

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DOE/NV--1475

National Nuclear Security Administration

Soils Risk-Based Corrective Action Evaluation Process

Controlled Copy No.: ___
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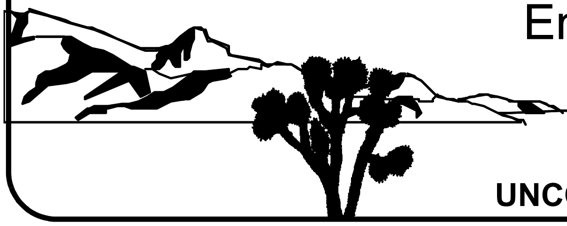
April 2012



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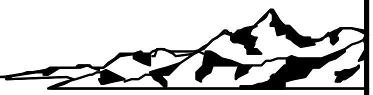

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SOILS RISK-BASED CORRECTIVE ACTION EVALUATION PROCESS

U.S. Department of Energy, National Nuclear Security Administration
Nevada Site Office
Las Vegas, Nevada

Controlled Copy No.: ___

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April 2012

Approved for public release; further dissemination unlimited.

Reviewed and determined to be UNCLASSIFIED.
Derivative Classifier: Joseph P. Johnston/N-I CO
(Name/personal identifier and position title)
Signature: /s/ Joseph P. Johnston
Date: 4/5/2012

SOILS RISK-BASED CORRECTIVE ACTION
EVALUATION PROCESS

Approved by: /s/ Kevin Cabble Date: 4-9-12

Kevin J. Cabble
Federal Sub-Project Director
Soils Sub-Project

Approved by: /s/ Robert F. Boehlecke Date: 4/9/12

Robert F. Boehlecke
Federal Project Director
Environmental Restoration Project

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List of Acronyms and Abbreviations

Ag	Silver
Am	Americium
ANPR	Advance Notice of Proposed Rulemaking
ASTM	ASTM International
CAA	Corrective action alternative
CADD	Corrective action decision document
CAI	Corrective action investigation
CAP	Corrective action plan
CAS	Corrective action site
CAU	Corrective action unit
CFR	*Code of Federal Regulations*
Cm	Curium
cm	Centimeter
cm^2	Square centimeter
cm^3/cm^3	Cubic centimeters per cubic centimeter
Co	Cobalt
COC	Contaminant of concern
COPC	Contaminant of potential concern
CR	Closure report
Cs	Cesium
CSM	Conceptual site model
day/yr	Days per year
DOE	U.S. Department of Energy
DQA	Data quality assessment
DQO	Data quality objective
EPA	U.S. Environmental Protection Agency

List of Acronyms and Abbreviations *(Continued)*

Eu	Europium
FAL	Final action level
FFACO	*Federal Facility Agreement and Consent Order*
g/day	Grams per day
g/g	Grams per gram
g/cm^3	Grams per cubic centimeter
g/m^3	Grams per cubic meter
g/yr	Grams per year
HCA	High contamination area
hr/day	Hours per day
hr/yr	Hours per year
ICRP	International Commission on Radiological Protection
IRIS	Integrated Risk Information System
kg	Kilogram
L/kg	Liters per kilogram
m	Meter
m^2	Square meter
m^3	Cubic meter
m^3/day	Cubic meters per day
m^3/mg	Cubic meters per milligram
m^3/yr	Cubic meters per year
m/sec	Meters per second
m/yr	Meters per year
mg/day	Milligrams per day
mg/kg-day	Milligrams per kilogram day
mg/cm^2	Milligrams per square centimeter

List of Acronyms and Abbreviations *(Continued)*

mg/m^3	Milligrams per cubic meter
mrem	Millirem
mrem/yr	Millirem per year
N/A	Not applicable
NAC	*Nevada Administrative Code*
Nb	Niobium
NDEP	Nevada Division of Environmental Protection
NNSA/NSO	U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office
NNSS	Nevada National Security Site
PAL	Preliminary action level
pCi/g	Picocuries per gram
PRG	Preliminary Remediation Goal
PSM	Potential source material
Pu	Plutonium
RBCA	Risk-based corrective action
RBSL	Risk-based screening level
RCRA	*Resource Conservation and Recovery Act*
RESRAD	Residual Radioactive
RfC	Reference concentration
RfD	Reference dose
RRMG	Residual radioactive material guideline
RSL	Regional Screening Level
SL	Screening level
Sr	Strontium
SSL	Soil Screening Level
SSTL	Site-specific target level

List of Acronyms and Abbreviations *(Continued)*

TED	Total effective dose
Th	Thorium
TLD	Thermoluminescent dosimeter
TPH	Total petroleum hydrocarbons
U	Uranium
UCL	Upper confidence limit
UR	Use restriction
$\mu g/m^3$	Micrograms per cubic meter

1.0 Introduction

The U.S. Department of Energy (DOE), National Nuclear Security Administration/Nevada Site Office (NNSA/NSO) oversees numerous sites on the Nevada National Security Site (NNSS) and other locations in the State of Nevada that have been impacted by activities related to the development and testing of nuclear devices and support activities. NNSA/NSO is responsible for protecting members of the public, including site workers, from harmful exposure to both chemical and radiological contaminants at these sites.

The Nevada Division of Environmental Protection (NDEP) is the primary state agency responsible for protection of human health and the environment with respect to chemical and radiological contamination. In 1996, the DOE, U.S. Department of Defense, and the State of Nevada entered into an agreement known as the *Federal Facility Agreement and Consent Order* (FFACO) (1996, as amended). Appendix VI to the FFACO describes the strategy employed to plan, implement, and complete environmental corrective action activities at NNSS and other locations in the state of Nevada. One of the categories of corrective action units (CAUs) is Soils. This category of CAUs includes sites with surface and shallow subsurface soil contamination resulting from various types of nuclear experiments or testing at the NNSS and Nevada Test and Training Range (including the Tonopah Test Range). Approximately 126 locations that may require some level of investigation and corrective action are included in this category of CAUs.

To evaluate the need for the extent of corrective action at a particular site, NNSA/NSO assesses the potential impacts to receptors by comparing measurements of contaminant levels to risk-based standards (action levels). Preliminary action levels (PALs) are established as part of the data quality objectives (DQOs) process and are presented in the FFACO corrective action planning documents (FFACO plans). Final action levels (FALs) are established as part of the corrective action alternative (CAA) evaluation process and are presented in the FFACO corrective action report documents (FFACO reports).

This document formally defines and clarifies the NDEP-approved process the NNSA/NSO Soils Activity uses to fulfill the requirements of the FFACO and state regulations. This process is used to establish FALs in accordance with the risk-based corrective action (RBCA) process stipulated in

Chapter 445 of the *Nevada Administrative Code* (NAC) as described in the ASTM International (ASTM) Method E1739-95 (NAC, 2008; ASTM, 1995). It is designed to provide a set of consistent standards for chemical and radiological corrective actions.

2.0 Regulatory Basis

The FFACO Part III, Section III.3 (1996, as amended) stipulates conformance with Chapter 445 of the NAC (NAC, 2008). Section NAC 445A.227 lists requirements for sites with soil contamination and stipulates a process to determine the necessary remediation standards (or FALs) based on an evaluation of the risk the site poses to public health and the environment.

Section NAC 445A.22705 states:

1. *Except as otherwise provided in NAC 445A.22715, if an owner or operator is required to take corrective action pursuant to NAC 445A.227, the owner or operator may conduct an evaluation of the site, based on the risk it poses to public health and the environment, to determine the necessary remediation standards or to establish that corrective action is not necessary. Such an evaluation must be conducted using Method E1739-95, adopted by the American Society for Testing and Materials, as it exists on October 3, 1996, or an equivalent method approved by the Division.*

2. *The Division shall determine whether an evaluation complies with the requirements of Method E1739-95, or an equivalent method of testing approved by the Division. The Division may reject, require revisions be made to, or withdraw its concurrence with the evaluation at any time after the completion of the evaluation for the following reasons:*

   (a) The evaluation does not comply with the applicable requirements for conducting the evaluation;

   (b) Conditions at the site have changed; or

   (c) New information or previously unidentified information which would alter the results of the evaluation becomes available and demonstrates that the release may have a detrimental impact on public health or the environment.

Therefore, in compliance with NAC 445A.22705, NNSA/NSO will “conduct an evaluation of the site, based on the risk it poses to public health and the environment, to determine the necessary remediation standards or to establish that corrective action is not necessary.” Based on NAC 445A.2272, PALs are used for site screening purposes. They are not intended for use as remediation standards (as defined in NAC 445A.22675). The process to establish the remediation standards (i.e., FALs) is to conduct an evaluation of the site as specified in NAC 445A.22705. This section requires the use of ASTM Method E1739-95 (ASTM, 1995) or an equivalent method to conduct this RBCA site evaluation.

Risk for chemical contaminants (and the toxic effects of radiological contaminants) is based on well-established cancer slope factors or non-cancer reference doses (RfDs) that relate contaminant concentrations to risk levels. However, available data do not unequivocally document cancer risks from exposure to low levels of radiation (below 20,000 millirem [mrem]) (Mukherjee and Mircheva, 1991). Therefore, rather than attempt to correlate low levels of radiological contamination directly to risk, radiological dose is used as a surrogate for radiological cancer risk. Dose is a measure of the effects of ionizing radiation on the human body. When ionizing radiation interacts with tissue, the average energy imparted by the radiation to the tissue (per unit of mass) is called absorbed dose.

The DOE dose limit for a member of the public is 100-mrem total effective dose (TED) in a year. The term TED, as used in this document, is the sum of ionizing radiation doses to a potential receptor from both external irradiation and from radioactive materials taken into the body. The DOE dose limit applies to all sources of ionizing radiation and exposure pathways that contribute significantly to the total dose excepting dose from radon and its decay products in air; dose received by patients from medical sources of radiation; dose from background radiation; and dose from occupational exposure under a U.S. Nuclear Regulatory Commission or Agreement State license (DOE 458.1, 4.b(1)(a) [DOE, 2011]). The public dose limit applies to members of the public located off DOE sites and on DOE sites outside controlled areas, and to those exposed to residual radioactive material subsequent to any remedial action or clearance of property.

The DOE dose constraint for the release or clearance of land and buildings is a TED of 25 mrem above background in any calendar year (DOE O 458.1, 4.k(2)(a) [DOE, 2011]. The 25-millirem per year (mrem/yr) dose constraint is also commensurate with the radiological criteria for unrestricted use as provided in 10 *Code of Federal Regulations* (CFR), Part 20 (CFR, 2012a), and with NAC 459.316 to 459.3184 (NAC, 2010).

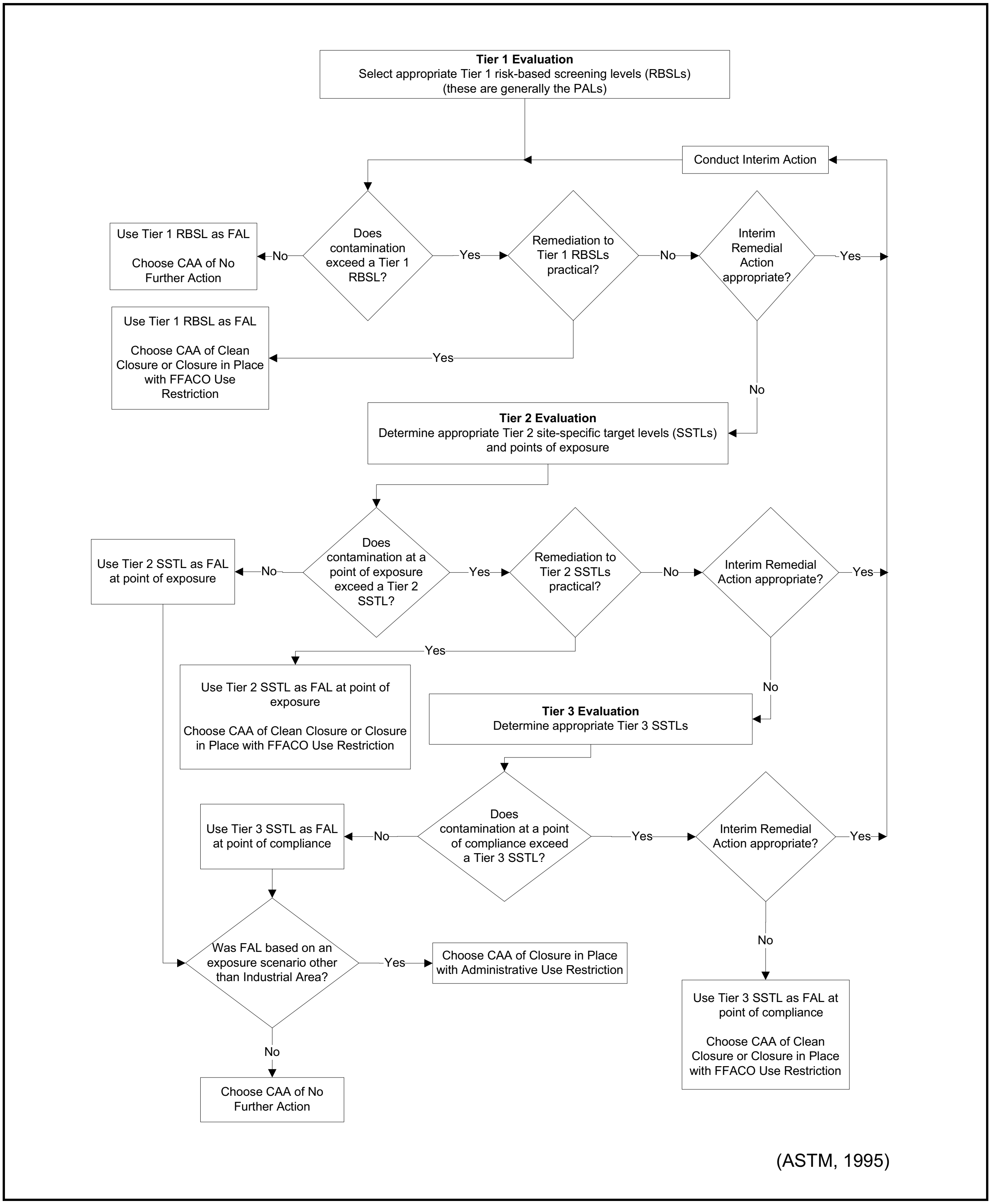
3.0 Process Overview

The RBCA decision process used by the Soils Activity follows ASTM Method E1739-95 (hereafter referred to as the RBCA process) and is summarized in Figure 3-1. This process uses a three-tiered approach in evaluating the DQO decisions. Each tier establishes an action level using increasingly sophisticated (and site-specific) calculations. The action level established for Tier 1 is referred to as a risk-based screening level (RBSL), while action levels calculated for Tier 2 and Tier 3 are referred to as site-specific target levels (SSTL). The FAL for any particular contaminant will be based on a Tier 1 RBSL, a Tier 2 SSTL, or a Tier 3 SSTL. The site-specific implementation of this process will be described in the FFACO plans. Site-specific FALs and the bases for the FALs will be reported in the Corrective Action Decision Document (CADD), Corrective Action Decision Document/Corrective Action Plan (CADD/CAP), Corrective Action Plan (CAP), or Corrective Action Decision Document/Closure Report (CADD/CR) (hereafter referred to as FFACO reports).

The Soils Activity RBCA process implements U.S. Environmental Protection Agency (EPA) DQOs protocols to ensure that the right type, quality, and quantity of data will be available to support the resolution of corrective action decisions. Sites will be investigated and evaluated based on DQOs developed and agreed to by NDEP and NNSA/NSO representatives before the field investigation. This process includes a provision for conducting an interim remedial action if necessary and appropriate. The decision to conduct an interim action may be made at any time during the investigation. NDEP and NNSA/NSO concurrence will be obtained before any interim action is implemented. Evaluation of DQO decisions will be based on conditions at the site following completion of any interim actions. Any interim actions conducted will be reported in the subsequent FFACO report.

The three tiers that may be used for evaluating DQO decisions are as follows:

- **Tier 1.** Tier 1 RBSLs are the generic (non-site-specific) PALs defined in the DQO process and listed in the FFACO plans. These are compared to contamination levels at source areas.
- **Tier 2.** Tier 2 SSTLs are calculated using site-specific inputs and receptor exposure scenarios. These are compared to contamination levels at exposure points.



(ASTM, 1995)

Figure 3-1
RBCA Process Based on ASTM Method E1739-95

- **Tier 3.** Tier 3 SSTLs are calculated using site-specific inputs to more sophisticated chemical fate/transport and probabilistic models. These are compared to contamination levels at points of compliance.

The rationale and justification for using any combination of these tiers will be presented in the risk appendix to the FFACO report.

The FALs for chemical contaminants will also be based on a site-specific evaluation of the time a worker could be exposed to site contamination. The methodologies used for each of three evaluation tiers (including the site-specific worker exposure times used for each tier) are discussed in the following subsections.

Corrective action decisions based on chemical and radiological FALs must consider the combined effect of the significant contaminants present at the release site (from the specific release being evaluated). For chemical contaminants, the risks from individual carcinogenic contaminants will be combined and the risks from individual toxic contaminants will be combined. For radioactive contaminants, the risks from individual radiological contaminants will be combined. These combined effects will be calculated using the multiple contaminant analysis method as described in Section 7.4.

3.1 Tier 1 Evaluation

A Tier 1 evaluation will be conducted to determine whether levels of contamination found at the site may warrant further investigation (or site cleanup), or whether no further investigation (or corrective action) is required. This is accomplished by comparing contaminant concentrations or radiological dose from a source area to Tier 1 RBSLs. Source areas are defined as the locations containing the highest concentrations or activities of contaminants. The Tier 1 RBSLs are defined to be the PALs established during the DQO process and documented in the FFACO plans. All PALs will be based on the Industrial Area exposure scenario (as defined in Section 4.3.1).

3.1.1 Chemical PALs

The PALs for chemical constituents are generally based on the Regional Screening Level (RSL) Industrial Soil Table listed in the *Pacific Southwest, Region 9: Regional Screening Levels (Formerly PRGs), Screening Levels for Chemical Contaminants* webpage (http://www.epa.gov/region9/superfund//prg/index.html) (EPA, 2011d). As stated in the RSL User's Guide (http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/usersguide.htm) (EPA, 2011b):

> *It should be emphasized that SLs are not cleanup standards. PRGs (Preliminary Remediation Goals) is a term used to describe a project team's early and evolving identification of possible remedial goals. Typically, it is necessary for PRGs to be more generic early in the process and to become more refined and site-specific as data collection and assessment progress.*

The RSLs are based on default exposure parameters and factors that represent reasonable maximum exposure conditions for long-term/chronic exposures and are based on the methods outlined in *Risk Assessment Guidance for Superfund: Volume I – Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals)* (EPA, 1991b); *Soil Screening Guidance: User's Guide* (EPA, 1996c); *Soil Screening Guidance: Technical Background Document* (EPA, 1996b); and *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (EPA, 2002c).

For detected chemical contaminants without established RSLs, the protocols used by EPA Region 9 in establishing RSLs (or similar) will be used (and documented in the FFACO report) to establish PALs. When natural background concentrations exceed the RSL (e.g., arsenic on the NNSS), background concentrations of naturally occurring chemical contaminants will be used instead of RSLs. As background concentrations vary with variations in geologic material, the PAL for naturally occurring chemical contaminants is considered to be the average natural concentration plus two standard deviations of the average concentration for sediment samples collected by the Nevada Bureau of Mines and Geology throughout the Nevada Test and Training Range (formerly the Nellis Air Force Range) (NBMG, 1998; Moore, 1999).

For total petroleum hydrocarbon (TPH) contamination, PALs will be established for the individual specific hazardous constituents of TPH (TPH is an inconsistent mixture of many chemical compounds that do not have established EPA Region 9 RSLs). The ASTM procedure (Section 6.4.3, "Use of Total Petroleum Hydrocarbon Measurements") states: "The TPHs should not be used for risk assessment because the general measure of TPH provides insufficient information about the amounts of individual chemical(s) of concern present" (see also Sections X1.5.4 and X1.42 of the ASTM procedure [ASTM, 1995]). The individual hazardous constituents of TPH will depend on the petroleum product that was the source of the contamination. These constituents are defined in Appendix D.

3.1.2 Radiological PALs

The PAL for radioactive contaminants is 25-mrem/yr TED to an industrial worker based upon the Industrial Area exposure scenario (defined in Section 4.3.1). When analytical results from soil samples are used to calculate dose, results are converted to dose using residual radioactive material guideline (RRMG) values for each individual radionuclide contaminant of potential concern (COPC). RRMGs are radionuclide-specific values for radioactivity in surface soils (expressed in units of pCi/g) that would result in a dose of 25 mrem/yr to a receptor without any other sources of radioactivity present. When more than one radionuclide is present, the total potential dose must be evaluated by adding the dose contributions from each radionuclide contaminant (see Section 7.3).

RRMGs are specific to a particular exposure scenario (i.e., exposure time) and pathway (i.e., internal dose or internal and external dose combined). Therefore, dose estimates obtained from the use of RRMGs are valid only for the pathway and exposure scenario used in the calculation of the RRMGs. Sets of RRMGs are calculated for internal dose and for total dose under the three exposure scenarios of Industrial Area, Remote Work Area, and Occasional Use Area (as defined in Section 4.3.1). The RRMG calculations are performed using a current version of the Residual Radioactive (RESRAD) material code (Yu et al., 2001) with the input parameters presented in Section 4.3.1. The RRMGs (used for the calculation of Tier 1 PALs) are the Industrial Area exposure scenarios presented in Appendix A.

3.2 Tier 2 Evaluation

If further evaluation of potential dose or risk is not appropriate, the FAL would be established as the Tier 1 RBSL. This is generally the case when contamination levels do not exceed the Tier 1 RBSL or when further evaluation would not affect the final corrective action decision. Otherwise, a Tier 2 evaluation may be conducted. Rationale and justification for using a Tier 2 evaluation will be presented in the FFACO reports.

The Tier 2 evaluation starts by evaluating site-specific land use and potential receptors to determine appropriate exposure scenarios and determine the most exposed individual. Then Tier 2 SSTLs are calculated using site-specific inputs to standard risk equations (for chemical contaminants), using pre-calculated RRMGs based on the Remote Work Area or Occasional Use Area exposure scenarios, or calculating RRMGs based on site-specific RESRAD input parameters (including site-specific exposure scenarios). The calculation of these SSTLs is described in Section 4.3.1. The Tier 2 SSTLs are then compared to individual sample results from reasonable points of exposure (as opposed to the source areas as is done in Tier 1) or to the 95 percent upper confidence limit (UCL) of the mean concentration or activity of sample results collected from random sample locations representative of the exposure area. Points of exposure or exposure areas are defined as those locations or areas at which an individual or population may come in contact with a contaminant of concern originating from a release site.

The pre-calculated exposure scenario-specific RRMGs (used for the calculation of Tier 2 SSTLs) are presented in Appendix A.

If a Tier 2 evaluation is conducted, the calculations used to derive the SSTLs will be documented in the FFACO report. If further evaluation of potential risk is warranted, a Tier 3 evaluation may be conducted.

3.3 Tier 3 Evaluation

A Tier 3 evaluation may be conducted by calculating Tier 3 SSTLs on the basis of more sophisticated risk analyses using methodologies described in ASTM Method E1739-95, such as Groundwater Modeling System software (Brigham Young University, 1999), that consider site-, pathway-, and receptor-specific parameters. A Tier 3 evaluation is much more complex than Tier 1 and 2 evaluations because it may include additional site characterization, probabilistic evaluations, and sophisticated chemical fate/transport models. The Tier 3 SSTLs are then compared to sample results from the points of compliance. Contaminant concentrations or activities exceeding Tier 3 SSTLs require corrective action. If a Tier 3 evaluation is conducted, the calculations used to derive the SSTLs will be provided as an appendix to the FFACO report.

4.0 Process for Calculating Tier 2 SSTLs

Contaminant Tier 2 SSTLs can be based on carcinogenicity, systemic toxicity, or radiological dose depending upon the type of health hazard posed by a specific constituent. The calculation of Tier 2 SSTLs based on carcinogenic or systemic toxicity risk is described in Section 4.1, and the calculation of Tier 2 SSTLs based on radiological dose is described in Section 4.2.

4.1 Chemical Contaminants

Tier 2 SSTLs based on carcinogenicity or systemic toxicity are calculated using site-specific inputs to standard risk equations such as those listed in the RSL User's Guide website (http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm) (EPA, 2011b). This website contains a calculator (EPA Region 9 RSL Calculator) of risk-based RSLs that set concentration limits using carcinogenic or systemic toxicity values under specific exposure conditions. The calculator uses the latest human health toxicity values (i.e., cancer slope factors or non-cancer RfDs), default exposure assumptions, and physical and chemical properties. The calculator can also be used to assess site-specific risks by changing the default parameters to reflect site-specific risk conditions. Parameters used in the calculation of Tier 2 SSTLs other than those defined in this document will be justified in the FFACO report.

4.1.1 Use of Standard Risk Equations

The standard risk equations can be solved manually, or using the EPA Region 9 RSL Calculator (EPA, 2011b) (which uses standard risk equations) to automate the calculation of SSTLs. Both techniques will produce equivalent risk-based SSTLs when using the same site-specific input parameters. The risk-based SSTLs developed using these methods result in evaluations of residual risks from direct contact with contaminated medium that comply with the *National Oil and Hazardous Substances Pollution Contingency Plan* (EPA, 2011c) requirements for protection of human health.

To use the automated EPA Region 9 RSL Calculator (EPA, 2011b) for outdoor industrial soil, the user makes the following choices from the calculator menu:

- Select Scenario (select “Outdoor Worker”).
- Select Media (select “Soil”).
- Select screening level (SL) type (select “Site Specific” to modify default input parameters).
- Select Chemical Info Type (select “Database hierarchy defaults”).
- Select RfD/RfC Type (select chronic for scenarios of 7 years or more and subchronic for scenarios that are less than 7 years).
- Select Individual Chemicals (select contaminants for which SSTLs are needed).
- Select the “Retrieve” button and a screen will open where default input parameters are displayed for each of the equations used in the calculation of screening levels with the option of changing the parameters to site- or scenario-specific values (see Section 4.1.2 for default input parameters).

For the purposes of calculating SSTLs using the EPA Region 9 RSL Calculator or the standard risk equations, adult workers are assumed to be routinely exposed to contaminated media within an industrial site. Routes of exposure included for soil are as follows:

- Incidental ingestion of soil (or sediment)
- Inhalation of particulates and vapors emitted from soil (or sediment)
- Dermal contact with soil (or sediment)

The EPA Region 9 RSL Calculator will calculate an SL for each route of exposure, and each of the two types of chemical risk (carcinogenicity or toxicity). A combined SL is also calculated using all of the routes of exposure for each type of chemical risk.

4.1.2 Default Chemical Input Parameters

The input parameters used to calculate Tier 2 SSTLs for chemical contaminants are categorized into the following groups:

- Chemical-specific
- Site-specific

- Exposure scenario-specific
- Other non-specific

The chemical-specific input parameters listed in Table 4-1 are used to calculate Tier 2 SSTLs. The human health toxicity values known as cancer slope factors or non-cancer RfDs are used to define the SSTLs. This information is contained in the EPA Region 9 RSL Calculator chemical database for the chemicals listed on the website (EPA, 2011b). The chemical-specific input parameters listed in Table 4-1 are provided by the EPA Region 9 RSL Calculator database. If the chemical is not listed in the EPA Region 9 RSL Calculator database or the risk equations are solved manually, toxicity values will be used from published databases following the toxicity value hierarchy below:

- *Integrated Risk Information System (IRIS)* (EPA, 2011a)

- The Provisional Peer Reviewed Toxicity Values derived by EPA's Superfund Health Risk Technical Support Center for the EPA Superfund program (EPA, 2011e)

- *Agency for Toxic Substances and Disease Registry* (ATSDR, 2012) minimal risk levels

- The California Office of Environmental Health Hazard Assessment's Chronic Reference Exposure Levels from December 18, 2008, and the Cancer Potency Values from July 21, 2009 (OEHHA, 2011)

- The EPA Superfund program's Health Effects Assessment Summary Tables (EPA, 1997)

If the toxicity information is not available from these sources, other sources of toxicity information may be used and documented in the risk assessment section of the FFACO report.

Site-specific input parameters include the following:

- Thickness of contaminated zone

- Precipitation

- Climatic zone

- Function dependent on U_m/U_t (ratio of mean annual wind speed and equivalent threshold value wind speed)

- Mean annual wind speed

Table 4-1
Chemical-Specific Input Parameters

Parameter	Value	Units
Fraction of Contaminant Absorbed Dermally from Soil	Chemical-specific	none
Chronic Oral Slope Factor	Chemical-specific	mg/kg-day
Fraction of Contaminant Absorbed in Gastrointestinal Tract	Chemical-specific	none
Dimensionless Henry Law Constant	Chemical-specific	none
Chronic Inhalation Unit Risk	Chemical-specific	$\mu g/m^3$
Soil-Water Partition Coefficient	Chemical-specific	L/kg
Soil Organic Carbon/Water Partition Coefficient	Chemical-specific	L/kg
Chronic Inhalation RfC	Chemical-specific	mg/m^3
Chronic Oral RfD	Chemical-specific	mg/kg-day

L/kg = Liters per kilogram
mg/kg-day = Milligrams per kilogram day
mg/m^3 = Milligrams per cubic meter
RfC = Reference concentration
$\mu g/m^3$ = Micrograms per cubic meter

- Equivalent threshold value wind speed
- Fraction of vegetative cover
- Organic carbon content of soil
- Water-filled soil porosity
- Dry soil bulk density
- Soil particle density

Exposure scenario-specific input parameters include the following:

- Exposure duration
- Exposure frequency
- Exposure time
- Soil ingestion rate

These parameters have been standardized for the calculation of Tier 2 SSTLs. Site-specific and exposure scenario-specific input parameters are common to the calculation of both chemical and radiological Tier 2 SSTLs. Therefore, the selection of these types of input parameters is discussed in Section 4.3.

Other non-specific input parameters used in the chemical risk-based calculations will use the default values listed in EPA Region 9 RSL Calculator as presented in Table 4-2.

Table 4-2
Non-specific Chemical Input Parameter Values

Parameter	Default Value	Units	Reference
Worker Soil Adherence Factor	0.2	mg/cm^2	SSL supplemental guidance (EPA, 2002c)
Areal Extent of the Site or Contamination	0.5	acres	Lowest available value in calculator
Body Weight	70	kg	SSL supplemental guidance (EPA, 2002c)
Lifetime	70	years	SSL supplemental guidance (EPA, 2002c)
Worker Soil Surface Area - Adult	3,300	cm^2	SSL supplemental guidance (EPA, 2002c)
Exposure Interval	7.89E+08	seconds	Based on the exposure duration of 25 years

cm^2 = Square centimeter
kg = Kilogram
mg/cm^2 = Milligrams per square centimeter
SSL = Soil Screening Level

4.2 Radiological Contaminants

Whereas the Tier 2 SSTLs for chemical contaminants are adjusted for site-specific conditions and compared directly to analytical results, the Tier 2 SSTLs for radiological contamination are adjusted based on an appropriate exposure scenario and compared to radiological dose that must also be adjusted to the appropriate exposure scenario. This radiological dose is calculated as the sum of external dose and internal dose that the most exposed individual could receive during the cumulative annual time this individual is exposed to site contamination.

The external dose from radiological contaminants is generally measured directly through the use of thermoluminescent dosimeter (TLD) devices, which integrate the penetrating radiation dose at the location being evaluated. Because these devices will also integrate the external dose from natural sources of penetrating radiation (i.e., cosmic rays, radon, naturally occurring radionuclides in soil), a natural background level must be measured and subtracted. This is generally done through the placement of additional devices in adjacent areas, with similar characteristics, that are not affected by the release. This dose can be a significant fraction of the SSTL. Background levels and the locations used to establish these levels will be justified in the FFACO report.

The potential internal dose is determined by comparing analytical results from soil samples to RRMGs (Section 3.1). The internal dose associated with any specific radionuclide would be established using the following equation:

$$Internal\ dose\ \left(\frac{mrem}{yr}\right) = \frac{Analytical\ result\left(\frac{pCi}{g}\right)}{Internal\ dose\ RRMG\ \left(\frac{pCi}{g}\right)}\ x\ 25\ \left(\frac{mrem}{yr}\right) \qquad (Eq.\ 1)$$

A set of RRMGs was also established based on TED (i.e., a combination of both internal and external pathways) for use where an external dose measurement from a TLD is not appropriate or available (such as when evaluating dose for subsurface soil). When more than one radionuclide is present, the calculated internal or total dose will be calculated as the sum of the internal or total doses from each radionuclide. Calculating TED using RRMGs is generally not feasible for locations where large amounts of Trinitite are present in the surface soils.

4.2.1 Use of Standard Dose Model

The RESRAD computer code will be used to develop RRMGs representative of TED, using the following exposure pathways:

- Inhalation
- Soil ingestion
- External gamma

This will also be performed for internal dose without the external gamma pathway.

RESRAD (Yu et al., 2001) was developed by the Argonne National Laboratory, under contract to DOE, to provide a tool for evaluating the risk to human health at sites exhibiting contamination with residual radioactive material in surface soil. The RESRAD methodology is cited in DOE Order 458.1 (DOE, 2011) for dose assessment and for the determination of guidelines to be used in the cleanup of contaminated sites. RESRAD is widely used in the United States and abroad, and has been approved by multiple federal and state agencies. RESRAD has been extensively tested, verified, and validated. The most recent version of the code will be used to account for revision updates. The version used will be documented in the FFACO reports.

4.2.2 Default Radiological Input Parameters

The input parameters used to calculate Tier 2 SSTLs for radiological contaminants are categorized into the following groups:

- Radionuclide-specific
- Site-specific
- Exposure scenario-specific
- Other non-specific

Based on the inhalation, soil ingestion, and external gamma pathways used by the Soils Activity (Section 4.2.1), the only radionuclide-specific input parameters used in the RESRAD modeling are the internal and external dose conversion factors. RESRAD uses a library of dose conversion factors to translate a radionuclide contaminant concentration into units of radiation exposure to a receptor. External dose conversion factors used in RESRAD are taken from *Federal Guidance Report No. 12, External Exposure to Radionuclides in Air, Water, and Soil* (EPA, 1993). Internal dose conversion factors that are currently being used by the NNSA/NSO Soils Activity within RESRAD are taken from the International Commission on Radiological Protection (ICRP) report *ICRP Publication 72: Age-Dependent Doses to the Members of the Public from Intake of Radionuclides Part 5, Compilation of Ingestion and Inhalation Coefficients* (ICRP, 1996). The ICRP Publication 72 factors reflect updated dosimetric models that are described in 10 CFR Part 835, "Occupational Radiation Protection" (CFR, 2012b). The internal dose conversion factors for an adult are utilized.

Site-specific input parameters include the area of the contaminated zone, the thickness of contaminated zone, the contaminated zone erosion rate, the average annual wind speed, and precipitation.

Exposure scenario-specific input parameters include the inhalation rate, the soil ingestion rate, the mass loading for inhalation, the indoor dust filtration factor, the shielding factor for external gamma, the indoor time fraction, and the outdoor time fraction. As many of these site- and scenario-specific input parameters are common to the calculation of both chemical and radiological Tier 2 SSTLs, the selection of these input parameters is discussed in Section 4.3.

Other non-specific input parameters used in the RESRAD calculations will use the default values listed in RESRAD manual as presented in Table 4-3. The inhalation rate of 20 cubic meters (m^3) per 8-hour workday is recommended by EPA's Risk Assessment Guidance for Superfund: Volume I – Human Health Evaluation Manual as representing a reasonable upper-bound inhalation rate for the occupational setting (EPA, 1991b).

Table 4-3
Non-specific RESRAD Input Parameter Values

Parameter	Default Value	Units	Reference
Mass Loading for Inhalation	2.0E-04	g/m^3	RESRAD default value takes into account short periods of high mass loading and sustained periods of normal farmyard activities
Inhalation Rate	7,300	m^3/yr	Based upon an EPA recommended average adult inhalation rate of 20 m^3/day (EPA, 1991b)

g/m^3 = Grams per cubic meter
m^3/day = Cubic meters per day
m^3/yr = Cubic meters per year

4.3 Standardized Exposure Scenarios and Input Parameters

Some of the input parameters used in calculating Tier 2 SSTLs are dependent upon site-specific physical conditions or the assumed exposure scenario under which NNSS workers or visitors are exposed to contaminants present at a particular site. To facilitate calculation of Tier 2 SSTLs, standardized input parameters were developed for NNSS-specific conditions and for three generic exposure scenarios. The exposure scenario-specific input parameters are presented in Section 4.3.1. The NNSS-specific default input parameters are presented in Section 4.3.2. The FFACO reports will document the use of the input parameter values specified herein by referencing this document. If parameter values are used that deviate from the default exposure-specific parameter values, the values will be documented and justified in the FFACO report (see Section 9.0).

4.3.1 Exposure-Specific Input Parameters

Three generic exposure scenarios were developed to represent potential exposures to soil contamination at the NNSS based on the type of site, the time workers are present at the site, and the projected future use of the site:

- Industrial Area (IA)
- Remote Work Area (RW)
- Occasional Use Area (OU)

The exposure of workers and visitors to site contaminants is dependent upon activities of the exposed individuals at each contaminated site. Based on the future land use as identified in the *Nevada Test Site Resource Management Plan* (DOE/NV, 1998), each contaminated site will be categorized into one of the three generic exposure scenarios, or a site-specific exposure scenario will be developed as part of the DQO process. NNSA/NSO will select the appropriate scenario for each site during development of the DQOs using the criteria presented for each of the scenarios below. The selected exposure scenarios will be documented in the FFACO plans and FFACO reports.

Industrial Area. Assumes continuous industrial use of a site. This scenario addresses exposure to industrial workers exposed daily to contaminants in soil during an average workday. This scenario assumes that this is the regular assigned work area for the worker who will be on the site for an entire career (250 days per year [day/yr], 8 hours per day [hr/day] for 25 years). The criteria for this exposure scenario are that active powered buildings with toilets are present at the site for the shelter and comfort of the worker. Due to the type of work done at the NNSS and the harsh climate, site workers spend most of their time in air-conditioned indoor facilities. However, for the purposes of calculating risk and dose, it will be conservatively assumed that workers under this scenario will spend one third of their workday outdoors and two thirds of their workday indoors. Of the 2,000 work hours on site, a worker would be exposed to soil contamination for 667 hours per year (hr/yr) and would be in some type of uncontaminated facility for 1,333 hr/yr. Because the RESRAD input for outdoor time fraction is in terms of the fraction of a year spent outdoors, this is calculated as the daily time fraction (1/3) times 2,000 hours spent on site per year (8 hr/day times 250 days) divided by the total number of hours per year (8,760 hours). This equates to a RESRAD outdoor time fraction of 0.0761.

As presented in Equation 2, the indoor soil ingestion rate is 50 milligrams per day (mg/day) and the outdoor soils ingestion rate is 100 mg/day. This results in a total soil ingestion rate of 66.7 mg/day.

$$\frac{\begin{array}{c} indoor\ soil\ ingestion\ rate\ of\ 50\frac{mg}{day} \times\ the\ indoor\ fraction\ of\ \frac{2}{3} \\ +\ outdoor\ soil\ ingestion\ rate\ of\ 100\frac{mg}{day} \times\ the\ outdoor\ fraction\ of\ \frac{1}{3} \end{array}}{=\ the\ total\ daily\ soil\ ingestion\ rate\ of\ 66.7\frac{mg}{day}} \qquad \textit{(Eq. 2)}$$

As the RESRAD input parameter is in terms of grams per year (g/yr), this is calculated as 0.067 grams per day (g/day) (based on the 66.7 mg/day rate from Equation 1) times 365 day/yr for an equivalent soil ingestion rate of 24.3 g/yr of total dust ingestion. RESRAD modifies this amount during code execution to adjust for onsite exposure time.

Remote Work Area. Assumes non-continuous work activities at a site. This scenario addresses worker exposure to contaminants in soil during a portion of an average workday. This scenario assumes that this is an area where the worker regularly visits but is not an assigned work area where the worker spends an entire workday. The criteria for this exposure scenario is that site structures may be present for shelter and comfort of the worker but not sufficient to support full-time work assignments (e.g., power substations or temporary test locations) nor are any such facilities anticipated to be built based on NNSS future land use specifications. A site worker under this scenario is assumed to be on the site for an equivalent of 336 hr/yr (or 42 days) for an entire career (25 years). Because this scenario assumes the presence of sheltered workspace, the indoor/outdoor time fractions and the soil ingestion rates are calculated in the same manner as for the Industrial Area scenario. Of the 336 work hours on site, a worker would be exposed to soil contamination for 112 hr/yr and would be in some type of uncontaminated facility for 224 hr/yr.

The RESRAD input for outdoor time fraction in terms of the fraction of a year spent outdoors for the Remote Work Area scenario is calculated as the daily time fraction (1/3) times 336 hours spent on site per year (8 hr/day times 42 days) divided by the total number of hours per year (8,760 hours). This equates to a RESRAD outdoor time fraction of 0.0128.

As the RESRAD soil ingestion rate is in terms of g/yr, this is calculated as 0.067 g/day (based on the 66.7 mg/day rate from Equation 1) times 365 day/yr for an equivalent soil ingestion rate of 24.3 g/yr of total dust ingestion. RESRAD modifies this amount during code execution to adjust for onsite exposure time.

Occasional Use Area. Assumes occasional work activities at a site. This scenario addresses exposure to workers who are not assigned to the area as a regular worksite but may occasionally use the site. This scenario assumes that this is an area where the worker does not regularly visit but may occasionally use for short-term activities. The criteria for this exposure scenario are that it is a remote area with no active improvements and the future land use designation is for outdoor tests and/or military training exercises. A site worker under this scenario is assumed to be on the site for an equivalent of 80 hr/yr (or 10 days) for 5 years. A worker would be exposed to soil contamination for all 80 work hr/yr on site.

The RESRAD input for outdoor time fraction in terms of the fraction of a year spent outdoors for the Occasional Use Area scenario is calculated as the daily time fraction (1.0) times the number of hours spent on site per year (8 hr/day times 10 days) divided by the total number of hours per year (8,760 hours). This equates to a RESRAD outdoor time fraction of 0.00913.

The Indoor Dust Filtration Factor assumes that the indoor dust level is lower than the outdoor dust level by this factor. The RESRAD default value is 0.4, which is used for the Industrial Area and Remote Work Area exposure scenarios. A value of 1.0 sets the indoor dust level equal to the outdoor dust level. This value will be used for the Occasional Use Area scenario, which assumes that no shelters are present.

The External Gamma Shielding Factor assumes that the indoor gamma radiation level is lower than the outdoor gamma radiation level by this factor due to the shielding of building materials. The RESRAD default value is 0.7, which is used for the Industrial Area and Remote Work Area exposure scenarios and assumes that the gamma radiation level indoors is 30 percent lower than the outdoor gamma radiation level. A value of 1.0 sets the indoor gamma radiation level equal to the outdoor gamma radiation level. This value will be used for the Occasional Use Area scenario, which assumes that no shelters are present.

As the RESRAD soil ingestion rate is in terms of grams per year, this is calculated as 0.1 g/day (based on the 100 mg/day outdoor soil ingestion rate from Equation 1) times 365 day/yr for an equivalent soil ingestion rate of 36.5 g/yr of total dust ingestion. RESRAD modifies this amount during code execution to adjust for onsite exposure time.

The default scenario-specific input parameter values for each of the exposure scenarios are presented in Table 4-4.

Table 4-4
Scenario-Specific Input Parameters

Parameter	Industrial Area	Remote Work Area	Occasional Use Area	Units	Source
Fraction of Entire Year Spent Onsite and Indoors	1.52E-01	2.56E-02	0 (no time spent indoors)	none	(Exposure Frequency x 8 hr/day) / (8,766 hr/yr) x 2/3 of workday except for Occasional Use
Fraction of Entire Year Spent Onsite and Outdoors	7.6E-02	1.28E-02	9.13E-03 (all time spent outdoors)	none	(Exposure Frequency x 8 hr/day) / (8,766 hr/yr) x 1/3 of workday except for Occasional Use
Exposure Duration	25	25	5	years	Scenario-specific
Exposure Frequency	250	42	10	day/yr	Scenario-specific
Chemical Exposure Time	667	112	80	hr/yr	Scenario-specific
Indoor Dust Filtration Factor	0.4	0.4	1	none	RESRAD default
Shielding Factor, External Gamma	0.7	0.7	1	none	RESRAD default
Soil Ingestion Rate	24.3	24.3	36.5	g/yr	SSL supplemental guidance (EPA, 2002c) based on 100 mg/day for outdoor and 50 mg/day for indoor
	66.7	66.7	100	mg/day	

4.3.2 NNSS-Specific Input Parameters

As conditions vary across the NNSS, the following site-specific input parameters used in calculating chemical risk or radiological dose may also vary:

- Mean annual precipitation
- Mean annual wind speed
- Fraction of vegetative cover
- Water-filled soil porosity

However, to simplify and standardize the site-specific input parameters, default NNSS-specific values are listed in Table 4-5. The justifications for these conservative parameter values are also listed in Table 4-5.

Table 4-5
NNSS-Specific Input Parameters
(Page 1 of 2)

Parameter	Value	Units	Justification
Area of contaminated zone	1,000	m^2	Larger areas give higher doses. RRMGs calculated for 1,000 m^2, but applied to 100-m^2 areas provides conservatism.
Thickness of contaminated zone	0.05	m	Research at the NNSS shows that 90% or more of the radioactive contamination is located in the top 5 cm of soil. This will yield a maximum dose estimate for surface deposition sites.
Contaminated Zone Erosion Rate	0.0	m/yr	Greater erosion rates will remove the contaminated material faster, leading to lower dose estimates. Assuming no erosion provides a more conservative dose estimate.
Cover Depth	0.0	m	Assuming no cover over the contamination provides a higher dose estimate.
Mean Annual Precipitation	0.326	m/yr	Higher values are more conservative. This value represents the highest rate measured at NNSS Soils site locations.
Climatic Zone	Las Vegas	none	Nearest location listed on calculator.
Function Dependent on U_m/U_t	0.194	none	Automatically generated by RSL calculator based on climatic zone (EPA, 1996c).
Mean Annual Wind Speed	5.81	m/sec	Higher values are more conservative. This value represents the highest rate measured at NNSS Soils site locations.
Equivalent Threshold Value Wind Speed	11.32	m/sec	This is a standard value used in the SSL supplemental guidance (EPA, 2002c).

Table 4-5
NNSS-Specific Input Parameters
(Page 2 of 2)

Parameter	Value	Units	Justification
Fraction of Vegetative Cover	0	none	Assuming no cover provides a higher dose estimate.
Organic Carbon Content of Soil	0.001	none	Lower values are more conservative. This near zero value is based on an NNSS estimate of low organic content.
Water-Filled Soil Porosity	10	percent	Lower values are more conservative. 95% lower confidence limit of NNSS measurements is 10.2.
Dry Soil Bulk Density (Density of Contaminated Zone)	1.5	g/cm^3	This is a standard value used in the SSL supplemental guidance (EPA, 2002c).
Soil Particle Density	2.65	g/cm^3	This is a standard value used in the SSL supplemental guidance (EPA, 2002c).

cm = Centimeter
g/cm^3 = Grams per cubic centimeter
m = Meter
m^2 = Square meter
m/sec = Meters per second
m/yr = Meters per year

4.4 EPA Region 9 RSL Calculator Input Parameter Sensitivity Analysis

Appendix B presents a sensitivity analysis conducted on EPA Region 9 RSL Calculator input parameters (EPA, 2011b). The standard risk equations used in this calculator include three pathways (dermal, ingestion, and inhalation) and two risk types (carcinogenicity and toxicity). To evaluate the effect of changing input parameter values on resulting RSL values, the six chemicals listed in Table 4-6 were chosen to represent each pathway/risk type combination.

Table 4-6
Chemicals Chosen for Sensitivity Analysis

Risk Type	Pathway	Representative Chemical
Cancer	Dermal	Pentachlorophenol
Cancer	Ingestion	Chromium (VI)
Cancer	Inhalation	Benzene
Toxic	Dermal	Anthracene
Toxic	Ingestion	Antimony
Toxic	Inhalation	Phosgene

Baseline RSLs were calculated using these representative chemicals and the default input parameters listed in Table 4-7. Then an RSL was calculated for each upper and lower input parameter value (listed in Table 4-7) with all other input parameter values at the default level.

Table 4-7
Default, Upper, and Lower Input Parameter Values

Parameter	Code	Default Value	Upper Value	Lower Value	Units	Rationale
Areal Extent of the Site or Contamination	A	0.5 (minimum)	5	N/A	acres	10 times minimum
Worker Soil Adherence Factor	AF	0.2	0.3	0.1	mg/cm^2	+/- 50%
Body Weight	BW	70	105	35	kg	+/- 50%
Exposure Duration	ED	25	37.5	12.5	years	+/- 50%
Exposure Frequency	EF	250	288	212	day/yr	+/- 15%
Exposure Time	ET	2.67	8	N/A	hr/day	Maximum no indoor
Organic Carbon Content of Soil	f_{oc}	0.001	0.1	0	g/g	Estimated
Soil Ingestion Rate	IR	66.7	100	33.3	mg/day	+/- 50%
Lifetime	LT	70	105	35	years	+/- 50%
Dry Soil Bulk Density	ρ_b	1.5	1.65	1.35	g/cm^3	+/- 10%
Soil Particle Density	ρ_s	2.65	N/A	N/A	g/cm^3	Fixed value
Worker Soil Surface Area - Adult	SA	3,300	4,950	1,650	cm^2	+/- 50%
Exposure Interval	T	7.89E+08	1.18E+09	3.94E+08	seconds	+/- 50%
Water-Filled Soil Porosity	θ_v	0.1	0.15	0.05	cm^3/cm^3	+/- 50%
Mean Annual Wind Speed	U_m	5.81	8.72	2.91	m/sec	+/- 50%
Equivalent Threshold Value Wind Speed	U_t	11.32	17	5.65	m/sec	+/- 50%
Fraction of Vegetative Cover	V	0	0.1	N/A	none	Maximum estimated

cm^3/cm^3 = Cubic centimeters per cubic centimeter
g/g = Grams per gram
N/A = Not applicable

This sensitivity analysis determined that the following input parameters are not considered to be sensitive (based on a change in the RSL value of less than 25 percent):

- Areal extent of the site or contamination
- Worker soil surface area (except for dermal pathway)

- Worker soil adherence factor for ingestion or inhalation pathways
- Exposure time for ingestion or dermal pathways
- Organic carbon content of soil (except for reducing parameter for cancer inhalation)
- Lifetime for toxic chemicals
- Dry soil bulk density (except for cancer inhalation)
- Water-filled soil porosity (except for inhalation)
- Mean annual wind speed
- Raising equivalent threshold value wind speed value
- Lowering equivalent threshold value wind speed value (except for cancer inhalation)
- Fraction of vegetative cover

The sensitivity analysis demonstrated that RSL results are sensitive to the following input parameters:

- The exposure time parameters of exposure interval, exposure duration, exposure frequency, exposure time, and lifetime

- The receptor physical parameters of body weight, soil ingestion rate, worker soil surface area, and worker soil adherence factor

The selection of appropriate site-specific input parameters is important to the results of the RSL calculator. The values for the input parameters should be realistic. However, when a range of uncertainty is associated with an input parameter value, a more conservative estimate of the actual value should be used. Therefore, the more sensitive input parameter values should be evaluated by stakeholders before use. This sensitivity analysis allows the stakeholders to focus their attention on the subset of parameters that have a notable impact on the output of the RSL values.

4.5 RESRAD Input Parameter Sensitivity Analysis

Appendix C presents a sensitivity analysis of the input parameters for the RESRAD computer code used to generate the pre-calculated exposure scenario-specific RRMGs. The sensitivity analysis of the input parameters was conducted to identify parameters which have a significant impact on RRMG values.

The Industrial Area exposure scenario was selected for the sensitivity analysis, as this scenario is the most limiting (i.e., provides the larger dose for a given concentration of radionuclides in surface soil). The “External Gamma,” “Inhalation,” and “Soil Ingestion” exposure pathways were activated for the analysis, which is consistent with the established exposure scenario.

Each of the available input parameters was then selected for sensitivity analysis. The base-case value for each of the available input parameters was the current value as established in *Industrial Sites Project Establishment of Final Action Levels* (NNSA/NSO, 2006) for the Industrial Area scenario. The sensitivity analysis range value was selected to multiply and divide the input parameter value by a factor of two. It is important to note that if this multiplication or division takes the value of the input parameter outside an acceptable range of values, RESRAD provides a warning message and defaults the value to the upper or lower limit for the parameter.

When generating the graphical output of each code run, the “Plot Type” selected was “Dose,” and the “Radionuclide” was “Summed.” The “Pathways” was selected as “Individual,” and the exposure pathway was selected. The “Base Case” was unselected under “Sensitivity,” and the input parameters were selected sequentially until all of the available input parameters had been tested.

Under the Industrial Area scenario, with the three accepted exposure pathways, the maximum potential radiation dose to a receptor occurs in the first year of exposure. An input parameter was determined to be sensitive if the difference between the base-case and the upper or lower value was more than 2.5 mrem (which is 10 percent of the annual limit of 25 mrem).

Based upon previous RESRAD code runs, it was known that the ingestion exposure pathway comprised a very small fraction of the potential radiation dose and was insignificant when compared to the external gamma and the inhalation exposure pathways. Because of this, graphical output of the sensitivity analysis for the ingestion pathway was not generated.

The following RESRAD input parameters were identified as being sensitive under either the external gamma and/or the inhalation exposure pathways:

- Area of Contaminated Zone *[AREA]*
- Thickness of Contaminated Zone *[THICK0]*
- Contaminated Zone Erosion Rate *[VCZ]*
- Average Annual Wind Speed *[WIND]*
- Precipitation *[PRECIP]*
- Inhalation Rate *[INHALR]*
- Mass Loading for Inhalation *[MLINH]*
- Shielding Factor, Inhalation *[SHF3]*
- Shielding Factor, External Gamma *[SHF1]*
- Fraction of Time Spent Outdoors (on site) *[FOTD]*

The selection of appropriate site-specific input parameters is important to the results of the RESRAD code. The values for the input parameters should be realistic. However, when a range of uncertainty is associated with an input parameter value, a more conservative estimate of the actual value should be used. Therefore, the more sensitive input parameter values should be evaluated by stakeholders before use. This sensitivity analysis allows the stakeholders to focus their attention on the subset of parameters that have a notable impact on the output of the RESRAD code.

5.0 Process for Calculating Tier 3 SSTLs

If appropriate, a Tier 3 evaluation may be conducted by calculating Tier 3 SSTLs on the basis of more sophisticated risk analyses using methodologies described in ASTM Method E1739-95 that consider site-, pathway-, and receptor-specific parameters (i.e., a site-specific risk assessment) (ASTM, 1995). The site-specific risk assessment is an analysis of the potential adverse health effects (current or future) caused by contaminant releases from a site in the absence of any actions to control or mitigate these releases (i.e., under an assumption of no further action). The site-specific risk assessment contributes to the subsequent development, evaluation, and selection of CAAs. The results of the site-specific risk assessment will document the magnitude of risk at a site, and the primary causes of that risk.

Site-specific risk assessments vary in both detail and the extent to which qualitative and quantitative analyses are used, depending on the complexity and particular circumstances of the site. Therefore, specific methodologies must be developed based on site conditions, contaminants present, potential receptors, and future land use scenarios. The calculation of Tier 3 SSTLs using site-specific risk assessments will be accomplished according to the provisions of *Risk Assessment Guidance for Superfund: Volume III – Part A, Process for Conducting Probabilistic Risk Assessment* (EPA, 2001).

6.0 Selection of Sampling Design

The selection of a judgmental or probabilistic sampling design for evaluating site data must be appropriate to the site being evaluated. The basis and assumptions used to select the sampling design will be discussed and agreed to during the DQO process. The criteria for selecting a judgmental or probabilistic sampling design are listed below.

Judgmental Sampling Design Criteria

- The location(s) of the highest concentrations of contamination within an area can be identified.
- Contamination was released from a known point source location(s) that can be identified.

Probabilistic Sampling Design Criteria

- Contamination was released over a defined area.
- Multiple releases are present within a well-defined area.
- Point source release(s) is/are suspected but location(s) cannot be confidently identified.

The sampling approach for sample plots generally will use a combination of judgmental and probabilistic approaches. The locations of the sample plots, each of which will be 10 by 10 m square, will be selected and evaluated judgmentally from within the study area. The samples collected from within each sample plot will be selected as random locations and evaluated under a probabilistic approach.

6.1 Judgmental Sampling Design

This design will be used when there is sufficient information on the contamination sources and site history to select specific sampling locations. This design is used to confirm the existence of contamination at specific locations and provide information (such as extent of contamination) about specific releases at the site.

The statistic of this sampling design to be compared to the FAL is the individual sample result. Justification for the use of this sampling design will be that samples are collected from locations where there is a high confidence that contaminants of concern (COCs) would be located if they existed anywhere within the site being evaluated. The number and location of samples chosen to meet this criterion will be discussed and agreed to during the DQO process.

6.2 Probabilistic Sampling Design

This design will be used when there is insufficient information on the contamination sources and history to select specific sampling locations. This design is used to establish contaminant concentrations that represent the site as a whole (i.e., a site characteristic contaminant concentration). Justification for the use of this sampling design will be that the areas to be characterized encompass (and are limited to) a distinct contaminant population. The areas chosen for characterization will be discussed and agreed to during the DQO process.

The objective of the probabilistic sampling design is to determine, with a specified degree of confidence, whether the true average contaminant concentrations at the site in question represent an unacceptable risk to human health and the environment (EPA, 2002b). The true average concentration for each contaminant at the site is estimated from the average of sample analytical results. An unacceptable risk to human health and the environment is deemed to be any average site contaminant concentrations exceeding FALs.

Because the average contaminant concentrations from samples are only an estimate of the true (unknown) average contaminant concentrations, it is uncertain how well the sample averages represent the true averages. If a sample average were directly compared to the FAL, any error in estimating the true average could lead to making a decision error. To reduce the probability of making a false negative decision error, a conservative estimate of the true average is used to compare to the FAL. This conservative estimate of the true average contaminant concentration will be calculated as the 95 percent UCL of the average sample contaminant concentration. By definition, there will be a 95 percent probability that the true average concentration is less than the 95 percent UCL of the sample average. The default method for calculating a 95 percent UCL of the average TED for each sample plot will be summing the 95 percent UCL of the TLD element results for external dose and the 95 percent UCL of the sample results for internal dose.

6.2.1 Computation of the UCL

The computation of appropriate UCLs depends upon the data distribution, the number of samples, the variability of the dataset, and the skewness associated with the dataset. The statistical package ProUCL (or similar) will be used to determine the appropriate probability distribution (e.g., normal, lognormal, gamma) and/or a suitable non-parametric distribution-free method and then to compute appropriate UCLs. To ensure that the appropriate UCL computational method is used, the sample data will be tested for goodness-of-fit to all of the parametric and non-parametric UCL computation methods described in the EPA guidance document *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* (EPA, 2002a).

A UCL will be calculated for each contaminant that is detected in any sample at a concentration greater than the PAL. This computation requires that a minimum number of samples be collected from random locations at each site and a basic assumption that

- the data originate from a symmetric, but not necessarily normally distributed, population,
- the estimation of the variability is representative of the population being sampled, and
- the population values are not temporally or spatially correlated.

6.2.2 Sample Size

A minimum number of samples are required to compute a UCL for each site being evaluated using the probabilistic approach. This will verify that a sufficient number of samples are collected to adequately evaluate the site. As the minimum number of samples needed to perform the UCL comparison tests cannot be determined until after investigation results are obtained, the planned number of samples to be collected during a corrective action investigation (CAI) must be estimated. The bases for establishing sample sizes will be discussed and agreed to during the DQO process.

After the data have been generated, the sufficiency of the number of probabilistic samples collected at each location will be evaluated. For TED at sample plots, the minimum number of samples required for each sample plot will be calculated for internal dose (soil samples) and external dose (TLD elements) samples. The minimum sample size will be calculated using the following EPA sample size formula (EPA, 2006a):

$$n \geq \frac{s^2(z_{.95} + z_{.80})^2}{(\mu - C)^2} + \frac{(z_{.95})^2}{2} \qquad \textit{(Eq. 3)}$$

where

s = standard deviation
$z_{.95}$ = z score associated with the false negative rate of 5 percent
$z_{.80}$ = z score associated with the false positive rate of 20 percent
μ = dose level where false positive decision is not acceptable (12.5 mrem/yr)
C = FAL (25 mrem/yr)

The use of this formula requires the input of basic statistical values associated with the sample data. Data from a minimum of three samples are required to calculate these statistical values and as such, the least possible number of samples required to apply the formula is three. Therefore, in instances where the formula results in a value less than three, three is adopted as the minimum number of samples required.

All calculations for the determination of sample size sufficiency will be provided in the FFACO report. If the minimum sample size is not met, one of the following actions may be taken:

- Additional sample(s) may be collected.
- Conservatively assume that the result exceeds the FAL.

If these criteria cannot be met, justifications for use of the result without meeting the criteria will be made in the FFACO report.

7.0 DQO Decisions

DQOs are used to ensure that the right type, quality, and quantity of data will be available to support the resolution of those decisions with an appropriate level of confidence. Data quality assessments (DQAs) are used to evaluate the degree of acceptability and usability of the reported data in the decision-making process. Using both the DQO and DQA processes helps to ensure that DQO decisions are sound and defensible.

7.1 DQO Process

The DQO process used by the Environmental Restoration Project conforms with the *Guidance on Systematic Planning Using the Data Quality Objectives Process* (EPA, 2006b). Soils sites will be investigated based on DQOs developed and agreed to by NDEP and NNSA/NSO representatives before the field investigation. The DQOs will be documented in the FFACO planning document.

The DQO planning process relies on assumptions described in a conceptual site model (CSM). The CSM describes the most probable scenario for current conditions at each site and defines the assumptions that are the basis for identifying the future land use, contaminant sources, release mechanisms, migration pathways, exposure points, and exposure routes. This process defines the potential contaminants and the analytical methods and criteria to be used to be able to identify if these potential contaminants are present with detection capabilities that are less than the FALs. The evaluation of potential contaminants will be based on available historical information about the process that generated the release and the list of potential NNSS contaminants.

The CSM is used to develop appropriate sampling strategies and data collection methods. The CSM integrates information from the physical setting, potential contaminant sources, release information, historical background information, knowledge from similar sites, and physical and chemical properties of the potentially affected media and COPCs.

If contamination is identified during investigation activities that is not consistent with the CSM, the situation will be reviewed, the CSM will be revised, the DQOs will be reassessed, and a recommendation will be made as to how best to proceed. In such cases, NDEP representatives will be notified and given the opportunity to comment on the recommendation.

Contamination of environmental media originating from activities not identified in the CSM of any corrective action site (CAS) will not be considered as part of the CAS unless the CSM and the DQOs are modified to include the release. If not included in the CSM, the contamination will be identified as part of another CAS (either new or existing).

The CSM for atmospheric deposition of radionuclide contamination onto the soil surface (that has not been displaced through excavation or migration) assumes that the contamination is limited to the top 5 cm of soil. Atmospheric releases of radionuclides that have been deposited on the soil surface at the NNSS from aboveground nuclear testing have been found to be concentrated in the upper 5 cm of undisturbed soil (McArthur and Kordas, 1983 and 1985; Gilbert et al., 1977; Tamura, 1977).

Mechanisms responsible for the placement of radionuclide contamination other than atmospheric deposition will also be addressed in the CSM. This will include contamination that was initially deposited atmospherically and then moved by scraping, windrowing, excavation, and similar activities; had been covered by placement of additional soil; was buried in a disposal unit; or has migrated with stormwater flow or infiltrating precipitation. The CSM must also address any other types of releases such as spills, wastes, or activated material.

A corrective action will be determined for any site containing a COC. For a judgmental sampling design, any contaminant result exceeding the FAL will result in that contaminant being designated as a COC. Judgmental samples must be collected in areas most likely to contain a COC. For the probabilistic sampling design, any 95 percent UCL of the average contaminant concentration above the FAL will result in that contaminant being designated as a COC. Probabilistic samples must be collected from unbiased locations that represent contamination within the sampling unit. A COC may also be defined as a contaminant that, in combination with other like contaminants, is determined to jointly pose an unacceptable risk based on a multiple contaminant analysis (NNSA/NSO, 2006).

A corrective action may also be required if a waste present within a CAS contains contaminants that, if released, could cause the surrounding environmental media to contain a COC. Such a waste would be considered potential source material (PSM). To evaluate wastes for the potential to result in the introduction of a COC to the surrounding environmental media, the conservative assumption is made that any physical waste containment will fail at some point and the contaminants will be released to the surrounding media. The following will be used as the criteria for determining whether a waste is PSM:

- A waste, regardless of concentration or configuration, may be assumed to be PSM and handled under a corrective action.
- Based on process knowledge and/or professional judgment, some waste may be assumed to not be PSM if it is clear that it could not result in soil contamination exceeding a FAL.

If assumptions about the waste cannot be made, then the waste material will be sampled, and the results will be compared to FALs based on the following criteria:

- For non-liquid wastes, the concentration of any chemical contaminant in soil (after degradation of the waste and release of contaminants into soil) would be equal to the mass of the contaminant in the waste divided by the mass of the waste. If the resulting soil concentration exceeds the FAL, then the waste would be considered to be PSM.
- For non-liquid wastes, the dose resulting from radioactive contaminants in soil (after degradation of the waste and release of contaminants into soil) would be calculated using the activity of the contaminant in the waste divided by the mass of the waste (for each radioactive contaminant) and calculating the combined resulting dose using the appropriate RRMGs. If the resulting dose exceeds the FAL, then the waste would be considered to be PSM.
- For liquid wastes, the resulting concentration of contaminants in the surrounding soil will be calculated based on the concentration of contaminants in the waste and the liquid holding capacity of the soil. If the resulting soil concentration exceeds the FAL, then the liquid waste would be considered to be PSM.

7.2 DQA Process

The DQA process used by the Soils Activity conforms with the *Data Quality Assessment: Statistical Methods for Practitioners* (EPA, 2006a). The DQA process is the scientific evaluation of the actual investigation results to determine whether the DQO criteria established in the FFACO plan were met and whether DQO decisions can be resolved at the desired level of confidence. The DQA will be documented in the FFACO report.

The DQA will evaluate whether information generated during the investigation supports the CSM assumptions, and whether the data collected met the DQOs and support their intended use in the decision-making process. Confidence in judgmental sampling scheme decisions are established qualitatively through validation of the CSM and verification that the selected plot locations meet the DQO criteria. Confidence in probabilistic sampling scheme decisions are established by validating the CSM, justifying that sampling locations are representative of the plot area, and demonstrating that a sufficient number of samples were collected to justify statistical inferences (e.g., averages and 95 percent UCLs).

The DQA involves five steps that begin with a review of the DQOs and end with an answer to the DQO decisions. The five steps are briefly summarized as follows:

- **Step 1: Review DQOs and Sampling Design.** Review the DQO process to provide context for analyzing the data. State the primary statistical hypotheses; confirm the limits on decision errors for committing false negative (Type I) or false positive (Type II) decision errors; and review any special features, potential problems, or deviations to the sampling design.

- **Step 2: Conduct a Preliminary Data Review.** Perform a preliminary data review by reviewing quality assurance reports and inspecting the data both numerically and graphically, validating and verifying the data to ensure that the measurement systems performed in accordance with the criteria specified, and using the validated dataset to determine whether the quality of the data is satisfactory.

- **Step 3: Select the Test.** Select the test based on the population of interest, population parameter, and hypotheses. Identify the key underlying assumptions that could cause a change in one of the DQO decisions.

- **Step 4: Verify the Assumptions.** Perform tests of assumptions. If data are missing or are censored, determine the impact on DQO decision error.

- **Step 5: Draw Conclusions from the Data.** Perform the calculations required for the test.

7.3 Calculation of Radiological Dose

The TED will be calculated as the sum of the internal and external doses at each location. The internal and external doses are calculated as the sums of the respective types of doses from each radionuclide contaminant. The following subsections describe a default approach for calculating radiological dose. If another method is used, it will be documented in the FFACO report.

7.3.1 Internal Dose

Sample results for individual radionuclides will be used to calculate internal dose using the internal dose RRMGs (Section 3.1.2). The probabilistic sampling scheme will be used to select sample locations and evaluate the analytical results for internal dose at sample plots. For each sample collected within the sample plot, randomly selected subsample locations will be chosen based on a random start, triangular pattern. If sufficient sample material cannot be collected at a specified location (e.g., rock, caliche or buried concrete), the sample will be collected at the nearest location that a surface sample can be obtained. Composite samples will be collected at each sample plot in the following manner:

- At least four composite samples will be collected from each established sample plot.
- Each composite sample will be comprised of nine aliquots taken from randomly selected locations within each plot.
- The entire volume of the composited material collected will be submitted to the laboratory for analysis.

The potential internal dose at each TLD location where soil samples were not collected may be conservatively estimated using the potential external dose from the TLD and the ratio of internal dose to external dose from the sample plot with the maximum internal dose. This can be done under the conservative assumption that the internal dose at any location would constitute the same percentage of the total dose as at the plot where the maximum internal dose was observed. This CAS-specific internal dose to external dose ratio is then multiplied by the external dose measured at each TLD location where soil samples were not collected to estimate the internal dose at these locations.

7.3.2 External Dose

The default method for determining external dose will be collecting *in situ* measurements using a TLD. The TLD measurements will be taken at a height of 1 m (3.3 feet). For sample plots, the TLDs will be located in the approximate center of the plot.

TLD placement and processing will follow the protocols established in the *Nevada Test Site Routine Radiological Environmental Monitoring Plan* (BN, 2003). TLDs will be in place for a targeted total exposure time of 2,000 hours, or the resulting data will be adjusted to be equivalent to an exposure time of 2,000 hours.

TLDs will be obtained from, and measured by, the Environmental Technical Services group at the NNSS. TLDs will be analyzed using automated TLD readers that are calibrated and maintained by the National Security Technologies, LLC, Radiological Control Department in accordance with existing quality control procedures for TLD processing. Certification is maintained through the DOE Laboratory Accreditation Program for dosimetry. The Panasonic UD-814 TLD used to measure external dose contains four individual elements. The readings from each element are compared as part of the routine quality assurance checks during the TLD processing. External dose at each TLD location is determined using the readings from TLD elements 2, 3, and 4. Element 1 is designed to measure dose to the skin and is not relevant to the determination of the external dose.

Determination of external dose using TLDs was determined to be the most accurate method because of the following factors:

1. TLDs will be exposed at the sample plots for an extended period of time (the target time interval will be the 2,000 hours of exposure time used for the Industrial Area exposure scenario). This reduces errors in reading dose-rate meter scale graduations and needle fluctuations that would be magnified when as-read meter values are multiplied from units of “per-hour” to 2,000 hours.
2. The use of a TLD to determine an individual’s external dose is the standard in radiation safety and serves as the “legal dose of record” when other measurements are available. Specifically, 10 CFR Part 835.402 (CFR, 2012a) indicates that personal dosimeters shall be provided to monitor individual exposures and that the monitoring program that uses the dosimeters shall be accredited in accordance with a DOE Laboratory Accreditation Program.

Estimates of external dose will be presented as net values (e.g., a background has been subtracted from the raw result) as the FAL is only applicable to radiation dose in excess of the naturally occurring terrestrial and cosmic radiation (i.e., background) dose (Section 4.2). TLDs will be placed at locations representative of the background conditions present at the release site but that are not impacted by the release.

External dose may also be calculated in combination with internal dose using soil sample results and the total dose RRMGs as described in Section 4.2.

7.3.3 Total Effective Dose

As discussed in Section 6.2, the 95 percent UCL of the TED from each sample location will be used to evaluate dose at probabilistic sampling locations. The 95 percent UCL of the TED for each probabilistic sample location will be established as the sum of the 95 percent UCL of the internal dose and the 95 percent UCL of the external dose. These 95 percent UCL dose estimates will be calculated using the three external dose measurements from the TLD and the RRMG-calculated internal dose estimates from the soil samples.

7.4 Multiple Contaminant Analysis

For all contaminants that exceed an RBSL, DQO decisions based on FALs will be subject to an evaluation of additive risk from multiple contaminants. This will address a potential situation where all contaminants present at a site are below the individual FALs (and, therefore, the DQO decision may otherwise be that no corrective action is required), but the additive effect of multiple contaminants may pose a total risk that requires corrective action.

The multiple contaminant analysis for radiological dose is addressed by summing the individual doses from each radionuclide contaminant in the internal and external dose calculations.

A multiple contaminant analysis for chemical contaminants will be conducted for carcinogenic risk and/or toxicity using all of the contaminants exceeding RBSLs that have either a slope factor or an RfD (i.e., that are either carcinogenic or toxic).

The multiple contaminant analysis will be conducted by summing the ratios of each contaminant concentration exceeding an RBSL to their corresponding Tier 2 or Tier 3 carcinogenic- or toxicity-based SSTL. If the sum of the ratios exceeds 1.0, then the DQO decision will be modified such that a corrective action will be required. If a multiple contaminant analysis is conducted for chemical contaminants, it will be documented in the FFACO report.

7.5 Default Contamination Boundaries

Releases at some Soils sites may not be feasible to investigate. These include the subsurface detonation sites and safety experiment sites with high levels of removable radioactive contamination.

Soils sites with subsurface detonations contain radioactivity at depth (some to hundreds of feet below the surface) due to the prompt injection of radionuclides to subsurface media. Craters are also present at these sites that present additional physical hazards for investigation personnel. Soil erosion gradients are into the bottom of the crater, and less contaminated material has since accumulated in the craters covering the original crater surface. Therefore, the contamination within a crater is physically contained by the crater, is covered by less-contaminated material, and is not amenable to industrial activities that could expose industrial workers to the contamination. Characterization of radioactive contamination within these craters would require personnel entering the craters to position drilling and excavation equipment. This would present significant logistical concerns and safety challenges. It is probable that high levels of residual radioactivity (exceeding FALs) from the nuclear detonations exist beneath these craters that would require corrective action. Therefore, it is more appropriate to assume contamination within craters requires corrective action without an investigation.

Safety experiment sites with high levels of removable radioactive contamination exist at several Soils sites based on the documented presence of readily removable alpha contamination exceeding 10 CFR Part 835 High Contamination Area (HCA) criteria (CFR, 2012b). Although removable contamination located at Soils sites is addressed under the RBCA dose evaluation, this evaluation does not address the potential for removable contamination to be transported to other areas. A discussion on the risks associated with removable radioactive contamination is presented in Section 7.6. This discussion proposes a requirement for corrective action at areas that exceed HCA criteria even though the area may not present a potential radiation dose to a receptor that exceeds the FAL. Therefore, it can be assumed that removable contamination that exceeds HCA criteria requires corrective action.

For subsurface detonation crater sites and safety experiment sites with high levels of removable radioactive contamination, it will be assumed that corrective action is required. These areas will be designated as default contamination boundaries where no investigation will be needed to determine that corrective actions are required. For areas outside default contamination boundaries, information will be generated during a site investigation to resolve DQO decisions.

7.6 Removable Radioactive Contamination

Removable radioactive contamination is present at many Soils sites. Removable contamination at Soils site locations (where it was released to the environment) is addressed for the receptors and exposure scenarios defined herein. The scenarios do not address the potential for removable radioactive contamination to be transported to other areas. Activities at areas where removable contamination is present could result in the translocation of radioactive contamination.

Evaluation of the risk associated with removable contamination that is transported to another location would require additional exposure scenarios based on specific locations and potential receptors where the radioactivity was translocated. As it is difficult to know where this removable contamination might be transported, a conservative assumption is made to require corrective action.

Therefore, it is determined that a corrective action will be required for any area where removable radioactive contamination exceeds the criteria in federal regulations to define an HCA, even though the area may not present a potential radiation dose to a receptor that exceeds the FAL. Currently, entry into areas that exceed HCA criteria is strictly controlled under 10 CFR Part 835 (CFR, 2012b) requirements. Personnel, equipment, and materials exiting these areas must meet stringent release criteria. This methodology brings the areas with significant amounts of removable contamination under FFACO corrective action.

7.7 Corrective Action Boundaries

The initial corrective action boundary area will be calculated using the 95 percent UCL of the TED from each sample location and a corresponding measurement from an appropriate radiation survey. These paired values will be used to establish a correlation for each radiation survey and identify the radiation survey that has the best correlation to TED values. This correlation will be used to establish a radiation survey value corresponding to the 25-mrem/yr FAL (using the appropriate exposure scenario). An isopleth of this value from the radiological survey, including any default contamination boundaries (Section 7.5) will be used as the initial corrective action boundary.

The final corrective action boundary will include other areas identified as exceeding a FAL (e.g., migration in drainages) and areas exceeding removable contamination criteria (Section 7.6).

7.8 Future Land Use

If the Industrial Work Area scenario is not used to calculate a FAL for any site, an administrative use restriction (UR) will be recorded for any area where there is a potential for a future worker to receive a dose exceeding 25 mrem/yr under the Industrial Work Area scenario (assuming some future use of the site that would cause the presence of a full-time industrial worker). Administrative URs (no monitoring, fencing, or signage required) are recorded in the FFACO database; the NNSA/NSO Facility Information Management System; and the NNSA/NSO CAU/CAS files. Any proposed activity within this administrative UR that would potentially cause a worker to exceed the 25-mrem/yr exposure limit would require NDEP approval. For this reason, contamination at all sites will be evaluated against Industrial Area exposure scenario-based PALs and site-specific exposure scenario-based FALs.

These administrative URs will be implemented as best management practices and are not part of FFACO corrective actions. The FFACO corrective actions are based on the assumption that activities on the NNSS will be limited to those that are industrial in nature and that the NNSS will maintain controlled access (i.e., restrict public access and residential use). Should the future land use of the NNSS change such that these assumptions are no longer valid, additional evaluation may be necessary.

7.9 Evaluation Process Overview

A summary of the evaluation levels discussed in Sections 3.0 through 5.0 is presented in Table 7-1. The potential actions to be taken based on exceedance or non-exceedance of the RBSL or SSTL at each evaluation level are presented in Table 7-2.

Table 7-1
Evaluation Levels

Evaluation Level	Tier	Exposure Scenario	Exposure Assumptions	Environmental Dataset	Comments
1	Tier 1 RBSL	Industrial Area	Direct exposure to contaminated soil for entire career. (8 hr/day, 250 day/yr, 25 years)	Evaluate results from each location.	These are the PALs.
2	Tier 2 SSTL	Industrial Area	Direct exposure to contaminated soil for entire career. (8 hr/day, 250 day/yr, 25 years)	Evaluate results from exposure areas.	SSTL is roughly equivalent to the Tier 1 RBSL.
3	Tier 2 SSTL	As appropriate to land use	Exposure based on the appropriate scenario.	Evaluate results from exposure areas.	Use carcinogenic risk of 1 per 100,000.
4	Tier 3 SSTL	N/A	Specific to most exposed individual.	Evaluate risk at points of compliance.	Conduct risk assessment.

Table 7-2
Progression of Evaluations

Evaluation Level	Action Taken for Non-exceedance	Potential Actions Taken for Exceedance
1	Establish FAL at RBSL concentration. No further action required.	• Apply appropriate corrective actions - or • Evaluate at Level 2.
2	Establish FAL at SSTL concentration. No further action required.	• Apply appropriate corrective actions - or • Evaluate at Level 3 if the actual land use is less than the Industrial Area exposure scenario, and record administrative UR for areas exceeding the RBSL - or • Evaluate at Level 4.
3	Establish FAL at SSTL concentration.	• Apply appropriate corrective actions - or • Evaluate at Level 4.
4	Establish FAL at SSTL concentration. No further action required.	• Apply appropriate corrective actions.

8.0 CAA Evaluation Process

The CAA evaluation process describes the general standards and decision factors used to screen the various CAAs, and develops and evaluates a set of selected CAAs that will meet the corrective action objectives. All CAAs on the NNSS are based on the presumption that all areas within the current NNSS boundary will be controlled in perpetuity and restricted from release to the public. As such, only industrial activities are permitted and risks to receptors under residential scenarios will not be considered. Should the control of the NNSS change in the future to include public access or residential use, the selected CAAs may need to be reconsidered.

8.1 Corrective Action Objectives

On May 1, 1996, EPA issued an Advance Notice of Proposed Rulemaking (ANPR) for corrective action for releases from solid waste management units at hazardous waste management facilities (EPA, 1996a). The EPA states that the ANPR should be considered the primary corrective action implementation guidance (Laws and Herman, 1997). The ANPR states that a basic operating principle for remedy selection is that corrective action decisions should be based on risk. It emphasizes that current and reasonably expected future land use should be considered when selecting corrective action remedies and encourages use of innovative site characterization techniques to expedite site investigations.

The ANPR provides the following EPA expectations for corrective action remedies (EPA, 1996a):

- Treatment should be used to address principal threats wherever practicable and cost effective.
- Engineering controls, such as containment, should be used where wastes and contaminated media can be reliably contained, pose relatively low long-term threats, or for which treatment is impracticable.
- A combination of methods (e.g., treatment, engineering, and institutional controls) should be used, as appropriate, to protect human health and the environment.
- Institutional controls should be used primarily to supplement engineering controls as appropriate for short- or long-term management to prevent or limit exposure.

- Innovative technologies should be considered where such technologies offer potential for comparable or superior performance or implementability, less adverse impacts, or lower costs.
- Usable groundwater should be returned to maximum beneficial use wherever practicable.
- Contaminated soils should be remediated as necessary to prevent or limit direct exposure and to prevent the transfer of unacceptable concentrations of contaminants from soils to other media

Implementation of the corrective action will ensure that contaminants remaining at each release site will not pose an unacceptable risk to human health and the environment, and that conditions at each site are in compliance with all applicable laws and regulations.

8.2 Screening Criteria

The screening criteria used to evaluate and select the preferred CAA are identified in the *Guidance on RCRA Corrective Action Decision Documents: The Statement of Bases, Final Decision and Response to Comments* (EPA, 1991a) and the *Final RCRA Corrective Action Plan* (EPA, 1994).

CAAs are evaluated based on four general corrective action standards and five remedy selection decision factors. All CAAs must meet the four general standards to be selected for evaluation using the remedy selection decision factors.

The general corrective action standards are as follows:

- Protection of human health and the environment
- Compliance with media cleanup standards
- Control the source(s) of the release
- Comply with applicable federal, state, and local standards for waste management

The remedy selection decision factors are as follows:

- Short-term reliability and effectiveness
- Reduction of toxicity, mobility, and/or volume
- Long-term reliability and effectiveness
- Feasibility
- Cost

The following considerations specific to operations at the NNSS will also be evaluated:

- Impact to ongoing NNSS mission
- Security of nuclear material
- Control of contamination

8.3 Corrective Action Standards

The following subsections describe the corrective action standards used to evaluate the CAAs.

Protection of Human Health and the Environment

Protection of human health and the environment is a general mandate of the *Resource Conservation and Recovery Act* (RCRA) statute (EPA, 1994). This mandate requires that the corrective action include any necessary protective measures to ensure the requirements are met. These measures may or may not be directly related to media cleanup, source control, or management of wastes.

Compliance with Media Cleanup Standards

CAAs are evaluated for the ability to meet the proposed media cleanup standards. The media cleanup standards are the FALs.

Control the Source(s) of the Release

CAAs are evaluated for the ability to stop further environmental degradation by controlling or eliminating additional releases that may pose a threat to human health and the environment. Unless source control measures are taken, efforts to clean up releases may be ineffective or, at best, will involve a perpetual cleanup. Therefore, each CAA must provide effective source control to ensure the long-term effectiveness and protectiveness of the corrective action.

Comply with Applicable Federal, State, and Local Standards for Waste Management

CAAs are evaluated for the ability to be conducted in accordance with applicable federal and state regulations (e.g., 40 CFR 260 to 282, “Hazardous Waste Management” [CFR, 2011a]; 40 CFR 761 “Polychlorinated Biphenyls,” [CFR, 2011b]; and NAC 444.842 to 444.980, “Facilities for Management of Hazardous Waste” [NAC, 2011]).

8.3.1 Remedy Selection Decision Factors

The following subsections describe the remedy selection decision factors used to evaluate the CAAs.

Short-Term Reliability and Effectiveness

Each CAA must be evaluated with respect to its effects on human health and the environment during implementation of the selected corrective action. The following factors will be addressed for each alternative:

- Protection of the community from potential risks associated with implementation, (e.g., fugitive dusts, transportation of hazardous materials, and explosion)
- Protection of workers during implementation
- Adverse environmental impacts that may result from implementation
- The amount of time until the corrective action objectives are achieved

Reduction of Toxicity, Mobility, and/or Volume

Each CAA must be evaluated for its ability to reduce the toxicity, mobility, and/or volume of the contaminated media. Reduction in toxicity, mobility, and/or volume refers to changes in one or more characteristics of the contaminated media by using corrective measures that decrease the inherent threats associated with that media.

Long-Term Reliability and Effectiveness

Each CAA must be evaluated in terms of risk remaining at the CAU after the CAA has been implemented. The primary focus of this evaluation is on the extent and effectiveness of the control that may be required to manage the risk posed by treatment of residuals and/or untreated wastes.

Feasibility

The feasibility criterion addresses the technical and administrative feasibility of implementing a CAA and the availability of services and materials needed during implementation. Each CAA must be evaluated for the following criteria:

- **Construction and Operation.** The feasibility of implementing a CAA given the existing set of waste and site-specific conditions.

- **Administrative Feasibility.** The administrative activities needed to implement the CAA (e.g., permits, URs, public acceptance, rights of way, offsite approval).

- **Availability of Services and Materials.** The availability of adequate offsite and onsite treatment, storage capacity, disposal services, necessary technical services and materials, and prospective technologies for each CAA.

Cost

Costs for each alternative are estimated for comparison purposes only. The cost estimate for each CAA includes both capital, and operation and maintenance costs, as applicable. The following is a brief description of each component:

- **Capital Costs.** Costs that include direct costs that may consist of materials, labor, construction materials, equipment purchase and rental, excavation and backfilling, sampling and analysis, waste disposal, demobilization, and health and safety measures. Indirect costs are separate and not included in the estimates.

- **Operation and Maintenance.** Separate costs that include labor, training, sampling and analysis, maintenance materials, utilities, and health and safety measures. These costs are not included in the estimates.

8.4 Development of CAAs

The following alternatives have been pre-defined in the FFACO and will be considered for each CAS. Additional alternatives may also be developed for consideration. Final corrective actions determined for any CAS may also involve a combination of these alternatives.

- **Alternative 1.** No Further Action
- **Alternative 2.** Clean Closure
- **Alternative 3.** Closure in Place

8.4.1 Alternative 1 – No Further Action

Under the no further action alternative, no corrective action activities will be implemented. This alternative is a baseline case with which to compare and assess the other CAAs and their ability to meet the corrective action standards.

8.4.2 Alternative 2 – Clean Closure

Alternative 2 includes excavating and disposing of site contamination exceeding FALs. This will generally be followed by a visual inspection and the collection of verification samples to confirm that the corrective action objectives have been met. Contaminated materials removed will be disposed of at an appropriate disposal facility. Excavated areas will be returned to surface conditions compatible with the intended future use of the site.

8.4.3 Alternative 3 – Closure in Place

Alternative 3 includes the implementation of a UR where contamination is present at levels that exceed a final action level. This UR will restrict inadvertent contact with contaminated media by prohibiting any activity that would cause a site worker to exceed a defined risk level.

8.5 Evaluation and Comparison of Alternatives

Each CAA will be evaluated based on the general corrective action standards listed in Section 8.2. Any CAA that does not meet the general corrective action standards will be removed from consideration.

For each remedy selection decision factor, the CAAs are ranked relative to one another. The CAA with the least desirable impact on the remedy selection decision factor will be given a ranking of 1. The CAAs with increasingly desirable impacts on the remedy selection decision factor will receive increasing rank numbers. The CAAs that will have an equal impact on the remedy selection decision factor will receive an equal ranking number.

The five EPA remedy selection decision factors are short-term reliability and effectiveness; reduction of toxicity, mobility, and/or volume; long-term reliability and effectiveness; feasibility; and cost.

- The first remedy selection decision factor—short-term reliability and effectiveness—is a qualitative measure of the impacts on human health and the environment during implementation of the CAA.
- The second remedy selection decision factor—reduction of toxicity, mobility, and/or volume—is a qualitative measure of changes in characteristics of contaminated media that result from implementation of the CAA.

- The third remedy selection decision factor—long-term reliability and effectiveness—is a qualitative evaluation of performance following site closure, and into the future.

- The fourth remedy selection decision factor—feasibility—includes an evaluation of the requirements for construction and operation as well as administrative constraints.

- The fifth remedy selection decision factor—cost—includes assessment of both capital (direct) costs of implementation and costs for operation and maintenance of the corrective action.

Each of the remedy selection decision factors will be scored for each CAA, and the total score for each alternative will be the sum of the scores. However, the highest scoring alternative may not be selected as the most appropriate. The scores from each alternative will be one consideration in selecting the most appropriate CAA. Other considerations are the impact to ongoing NNSS mission, security of nuclear materials, and control of contamination. The most appropriate corrective action may also be a combination of CAAs such as a limited removal of contaminated soil or waste items (i.e., clean closure) with a UR for the remaining contamination (i.e., closure in place).

9.0 Process Documentation

FALs along with the basis for their selection (e.g., PALs, Tier 2 SSTL, or Tier 3 SSTL) will be documented in FFACO reports where they will be compared to laboratory results in the evaluation or verification of corrective actions. If the FALS are established as Tier 2 or Tier 3 SSTLs, any equations or input parameter values used that differ from the standards presented in this document will be provided in the risk assessment appendix of the FFACO report. This appendix will be consistent with the format and content of the example text contained in Section X.5 of ASTM Method E1739-95 (ASTM, 1995).

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Appendix A

Pre-calculated Exposure Scenario-Specific RRMGs

Table A.1-1
Industrial Area Exposure Scenario - Internal Dose Only (IA-I)

Radionuclide	$RRMG_{(IA-I)}$ (pCi/g)
Ag-108m	1.063E+07
Am-241	9.985E+03
Cm-243	1.331E+04
Cm-244	1.649E+04
Co-60	1.128E+06
Cs-137	2.830E+05
Eu-152	2.541E+06
Eu-154	1.814E+06
Eu-155	1.182E+07
Nb-94	1.404E+07
Pu-238	8.450E+03
Pu-239/240	7.730E+03
Pu-241	3.887E+05
Sr-90	1.215E+05
Th-232	2.924E+03
U-234	5.578E+04
U-235	5.860E+04
U-238	5.840E+04

A soil sample at this RRMG value would present an internal dose potential of 25 mrem under the Industrial Area exposure scenario.

Table A.1-2
Industrial Area Exposure Scenario - Internal & External Dose (IA-IE)

Radionuclide	$RRMG_{(IA\text{-}IE)}$ (pCi/g)
Ag-108m	1.929E+02
Am-241	2.687E+03
Cm-243	3.736E+02
Cm-244	1.625E+04
Co-60	2.047E+01
Cs-137	8.145E+01
Eu-152	4.275E+01
Eu-154	3.990E+01
Eu-155	1.074E+03
Nb-94	2.008E+02
Pu-238	8.378E+03
Pu-239/240	7.645E+03
Pu-241	1.932E+05
Sr-90	9.252E+03
Th-232	2.234E+01
U-234	4.946E+04
U-235	2.897E+02
U-238	1.667E+03

A soil sample at this RRMG value would present a TED potential of 25 mrem under the Industrial Area exposure scenario.

Table A.1-3
Remote Work Area Exposure Scenario - Internal Dose Only (RWA-I)

Radionuclide	$RRMG_{(RWA-I)}$ (pCi/g)
Ag-108m	6.411E+07
Am-241	6.010E+04
Cm-243	8.012E+04
Cm-244	9.926E+04
Co-60	6.804E+06
Cs-137	1.708E+06
Eu-152	1.533E+07
Eu-154	1.094E+07
Eu-155	7.132E+07
Nb-94	8.472E+07
Pu-238	5.086E+04
Pu-239/240	4.653E+04
Pu-241	2.340E+06
Sr-90	7.334E+05
Th-232	1.762E+04
U-234	3.361E+05
U-235	3.531E+05
U-238	3.361E+05

A soil sample at this RRMG value would present an internal dose potential of 25 mrem under the Remote Work Area exposure scenario.

Table A.1-4
Remote Work Area Exposure Scenario - Internal & External Dose (RWA-IE)

Radionuclide	$RRMG_{(RWA-IE)}$ (pCi/g)
Ag-108m	1.162E+03
Am-241	1.618E+04
Cm-243	2.250E+03
Cm-244	9.783E+04
Co-60	1.233E+02
Cs-137	4.905E+02
Eu-152	2.574E+02
Eu-154	2.403E+02
Eu-155	6.469E+03
Nb-94	1.209E+03
Pu-238	5.043E+04
Pu-239/240	4.602E+04
Pu-241	1.163E+06
Sr-90	5.573E+04
Th-232	1.345E+02
U-234	2.980E+05
U-235	1.744E+03
U-238	1.004E+04

A soil sample at this RRMG value would present a TED potential of 25 mrem under the Remote Work Area exposure scenario.

Table A.1-5
Occasional Use Area Exposure Scenario - Internal Dose Only (OUA-I)

Radionuclide	$\mathrm{RRMG}_{(\mathrm{OUA\text{-}I})}$ (pCi/g)
Ag-108m	1.762E+08
Am-241	1.579E+05
Cm-243	2.107E+05
Cm-244	2.609E+05
Co-60	1.872E+07
Cs-137	4.705E+06
Eu-152	4.203E+07
Eu-154	3.001E+07
Eu-155	1.958E+08
Nb-94	2.323E+08
Pu-238	1.336E+05
Pu-239/240	1.222E+05
Pu-241	6.148E+06
Sr-90	2.019E+06
Th-232	4.738E+04
U-234	9.017E+05
U-235	9.486E+05
U-238	3.361E+05

A soil sample at this RRMG value would present an internal dose potential of 25 mrem under the Occasional Use Area exposure scenario.

Table A.1-6
Occasional Use Area Exposure Scenario - Internal & External Dose (OUA-IE)

Radionuclide	$\text{RRMG}_{(\text{OUA-IE})}$ (pCi/g)
Ag-108m	3.856E+03
Am-241	5.013E+04
Cm-243	7.412E+03
Cm-244	2.579E+05
Co-60	4.092E+02
Cs-137	1.628E+03
Eu-152	8.544E+02
Eu-154	7.975E+02
Eu-155	2.147E+04
Nb-94	4.012E+03
Pu-238	1.327E+05
Pu-239/240	1.212E+05
Pu-241	3.451E+06
Sr-90	1.821E+05
Th-232	4.457E+02
U-234	8.172E+05
U-235	5.782E+03
U-238	3.310E+04

A soil sample at this RRMG value would present a TED potential of 25 mrem under the Occasional Use Area exposure scenario.

Appendix B

EPA Region 9 RSL Calculator Sensitivity Analysis

B.1.0 EPA Region 9 RSL Calculator Sensitivity Analysis

A sensitivity analysis was conducted on EPA Region 9 RSL Calculator input parameters (EPA, 2001). The standard risk equations used in this calculator include three pathways (dermal, ingestion, and inhalation) and two risk types (carcinogenicity and toxicity). To evaluate the effect of changing input parameter values on resulting RSL values, the six chemicals listed in Table B.1-1 were chosen to represent each pathway/risk type combination. These were chosen based on a potential to be present at the NNSS and high relative ingestion, dermal, or inhalation SL values listed in the generic RSL table for carcinogens and non-carcinogens.

Table B.1-1
Chemicals Chosen for Sensitivity Analysis

Risk Type	Pathway	Representative Chemical
Cancer	Dermal	Pentachlorophenol
Cancer	Ingestion	Chromium (VI)
Cancer	Inhalation	Benzene
Toxic	Dermal	Anthracene
Toxic	Ingestion	Antimony
Toxic	Inhalation	Phosgene

Baseline RSLs were calculated using these representative chemicals and the default input parameters listed in Table B.1-2. Then an RSL was calculated for each upper and lower input parameter value (listed in Table B.1-2) with all other input parameter values at the default level. The upper and lower values used in the sensitivity analysis were initially set at 150 percent and 50 percent of the default value. However, some of the resulting values were not realistic. For the aerial extent (A) parameter, 0.5 acres is the default value as well as the minimum value available in the calculator. The upper value was set at 5 acres (10 times the minimum). For the fraction of vegetative cover (V) parameter, the default value is based on completely bare soil (a fraction of zero). Therefore, a lower value does not make sense. The upper value was set at 0.1 or 10 percent of the soil surface being covered by vegetation. For the exposure time (ET) parameter, a full day (8 hours) was used as an upper value while a lower value was not used (less than 1/3 day does not make sense). For the organic carbon content of soil (f_{oc}) parameter, the default value of 1/10 of one percent was conservatively estimated

Table B.1-2
Default, Upper, and Lower Input Parameter Values

Parameter	Code	Default Value	Upper Value	Lower Value	Units	Rationale
Areal Extent of the Site or Contamination	A	0.5 (minimum)	5	N/A	acres	10 times minimum
Worker Soil Adherence Factor	AF	0.2	0.3	0.1	mg/cm^2	+/- 50%
Body Weight	BW	70	105	35	kg	+/- 50%
Exposure Duration	ED	25	37.5	12.5	years	+/- 50%
Exposure Frequency	EF	250	288	212	day/yr	+/- 15%
Exposure Time	ET	2.67	8	N/A	hr/day	Maximum no indoor
Organic Carbon Content of Soil	f_{oc}	0.001	0.1	0	g/g	Estimated
Soil Ingestion Rate	IR	66.7	100	33.3	mg/day	+/- 50%
Lifetime	LT	70	105	35	years	+/- 50%
Dry Soil Bulk Density	ρ_b	1.5	1.65	1.35	g/cm^3	+/- 10%
Soil Particle Density	ρ_s	2.65	N/A	N/A	g/cm^3	Fixed value
Worker Soil Surface Area - Adult	SA	3,300	4,950	1,650	cm^2	+/- 50%
Exposure Interval	T	7.89E+08	1.18E+09	3.94E+08	seconds	+/- 50%
Water-Filled Soil Porosity	θ_v	0.1	0.15	0.05	cm^3/cm^3	+/- 50%
Mean Annual Wind Speed	U_m	5.81	8.72	2.91	m/sec	+/- 50%
Equivalent Threshold Value Wind Speed	U_t	11.32	17	5.65	m/sec	+/- 50%
Fraction of Vegetative Cover	V	0	0.1	N/A	none	Maximum estimated

based on typical desert soils containing very little organic matter. A value of 10 percent organic matter (100 times the default) was used for the upper value based on the potential for higher altitude soils at the NNSS containing much higher organic matter content. The lower value of zero was estimated as a minimum potential organic matter content. The soil particle density (ρ_s) parameter was not tested as this value is essentially a constant (i.e., not a variable). The exposure interval (T) and exposure duration (ED) parameters were set to be equal time periods but expressed in different units (seconds and years, respectively). The default, upper, and lower parameter value calculations for these two parameters were run together, and the results are jointly presented as the ED RSLs. All of the resulting RSLs are listed in Table B.1-3.

Table B.1-3
RSL Results for Default, Upper, and Lower Input Parameter Values (mg/kg)

Parameter			RSL Result					
Code	Test Value	Default Value	Cancer Dermal	Cancer Ingestion	Cancer Inhalation	Toxic Dermal	Toxic Ingestion	Toxic Inhalation
A high	5	0.5	3.09	7.86	4.91	201,000	613	2.31
AF high	0.3	0.2	2.28	8.08	7.03	157,000	613	3.41
AF low	0.1	0.2	4.79	8.08	7.03	280,000	613	3.41
BW high	105	70	4.63	11.8	7.25	302,000	919	3.41
BW low	35	70	1.54	4.16	6.45	101,000	306	3.41
ED high	37.5	25	2.06	5.39	4.69	201,000	613	3.41
ED low	12.5	25	6.18	16.2	14.1	201,000	613	3.41
EF high	288	250	2.68	7.01	6.1	175,000	532	2.96
EF low	212	250	3.64	9.53	8.29	237,000	723	4.02
ET high	8	2.67	3.09	7.24	2.5	201,000	613	1.14
f_{oc} high	0.1	0.001	3.09	8.08	33.2	201,000	613	4.1
f_{oc} low	0	0.001	3.09	8.08	4.84	201,000	613	3.4
IR high	100	66.7	2.7	5.5	6.73	165,000	409	3.41
IR low	33.3	66.7	3.61	15.3	7.36	257,000	1230	3.41
LT high	105	70	4.63	12.1	10.5	201,000	613	3.41
LT low	35	70	1.54	4.04	3.51	201,000	613	3.41
ρ_b high	1.65	1.5	3.09	8.08	7.6	201,000	613	3.45
ρ_b low	1.35	1.5	3.09	8.08	6.75	201,000	613	3.48
SA high	4,950	3,300	2.28	8.08	7.03	157,000	613	3.41
SA low	1,650	3,300	4.79	8.08	7.03	280,000	613	3.41
θ_v high	0.15	0.1	3.09	8.08	9.34	201,000	613	4.57
θ_v low	0.05	0.1	3.09	8.08	5.41	201,000	613	2.63
U_m high	8.72	5.81	3.09	7.1	7.03	201,000	613	3.41
U_m low	2.91	5.81	3.09	8.51	7.03	201,000	613	3.41
U_t high	17	11.32	3.09	8.43	7.03	201,000	613	3.41
U_t low	5.65	11.32	3.09	5.73	7.03	201,000	613	3.41
V high	0.1	0	3.09	8.13	7.03	201,000	613	3.41
Default	*	N/A	3.09	8.08	7.03	201,000	613	3.41

*This run used default values for all parameters.

To effectively compare the relative sensitivities of RSL results to a change in an input parameter, the percent change in the RSL result (Equation 1) was divided by the percent change of the input parameter value (Equation 2). The percent change in the input and RSL values are listed in Table B.1-4 for each tested parameter. The relative changes in RSL values are listed in Table B.1-5 as the percent RSL value change normalized to the change in the input parameter values.

$$\%\text{ change in RSL} = \frac{(\text{RSL test value} - \text{default RSL value})}{\text{default RSL value}} \qquad \textit{(Equation 1)}$$

$$\%\text{ change in input parameter} = \frac{(\text{test value} - \text{default value})}{\text{default value}} \qquad \textit{(Equation 2)}$$

Based on a determination that a relative parameter change less than 25 percent indicates that the RSL result is not considered sensitive, the potentially sensitive parameter changes are highlighted in Table B.1-5. A relative parameter change could not be calculated for fraction of vegetative cover because the default value for this parameter is zero. However, as seen in Table B.1-4, changing this parameter from zero to 10 percent caused less than 1 percent change in the cancer ingestion RSL and no change in the other tests.

Table B.1-4
Percent Change in Input Parameter and from Default RSLs
(Page 1 of 2)

	Percent Change						
Parameter Name	**Input**	**Cancer Dermal**	**Cancer Ingestion**	**Cancer Inhalation**	**Toxic Dermal**	**Toxic Ingestion**	**Toxic Inhalation**
A high	900%	0%	3%	30%	0%	0%	32%
AF high	50%	26%	0%	0%	22%	0%	0%
AF low	50%	55%	0%	0%	39%	0%	0%
BW high	50%	50%	46%	3%	50%	50%	0%
BW low	50%	50%	49%	8%	50%	50%	0%
ED high	50%	33%	33%	33%	0%	0%	0%
ED low	50%	100%	100%	101%	0%	0%	0%
EF high	15%	13%	13%	13%	13%	13%	13%
EF low	15%	18%	18%	18%	18%	18%	18%
ET high	200%	0%	10%	64%	0%	0%	67%

Table B.1-4
Percent Change in Input Parameter and from Default RSLs
(Page 2 of 2)

	Percent Change						
Parameter Name	**Input**	**Cancer Dermal**	**Cancer Ingestion**	**Cancer Inhalation**	**Toxic Dermal**	**Toxic Ingestion**	**Toxic Inhalation**
f_{oc} high	9,900%	0%	0%	372%	0%	0%	20%
f_{oc} low	100%	0%	0%	31%	0%	0%	0%
IR high	50%	13%	32%	4%	18%	33%	0%
IR low	50%	17%	89%	5%	28%	101%	0%
LT high	50%	50%	50%	49%	0%	0%	0%
LT low	50%	50%	50%	50%	0%	0%	0%
ρ_b high	10%	0%	0%	8%	0%	0%	1%
ρ_b low	10%	0%	0%	4%	0%	0%	2%
SA high	50%	26%	0%	0%	22%	0%	0%
SA low	50%	55%	0%	0%	39%	0%	0%
θ_v high	50%	0%	0%	33%	0%	0%	34%
θ_v low	50%	0%	0%	23%	0%	0%	23%
U_m high	50%	0%	12%	0%	0%	0%	0%
U_m low	50%	0%	5%	0%	0%	0%	0%
U_t high	50%	0%	4%	0%	0%	0%	0%
U_t low	50%	0%	29%	0%	0%	0%	0%
V high	*	0%	1%	0%	0%	0%	0%

*Percent change in input value not defined, as default is zero.

Table B.1-5
Percent Change from Default RSLs Relative to Change in Input Parameter

	Relative Change					
Parameter Name	**Cancer Dermal**	**Cancer Ingestion**	**Cancer Inhalation**	**Toxic Dermal**	**Toxic Ingestion**	**Toxic Inhalation**
A high	0%	0%	3%	0%	0%	4%
AF high	52%	0%	0%	44%	0%	0%
AF low	110%	0%	0%	79%	0%	0%
BW high	100%	92%	6%	100%	100%	0%
BW low	100%	97%	17%	100%	100%	0%
ED high	67%	67%	67%	0%	0%	0%
ED low	200%	201%	201%	0%	0%	0%
EF high	87%	87%	87%	85%	87%	87%
EF low	117%	118%	118%	118%	118%	118%
ET high	0%	5%	32%	0%	0%	33%
f_{oc} high	0%	0%	4%	0%	0%	0%
f_{oc} low	0%	0%	31%	0%	0%	0%
IR high	25%	64%	9%	36%	67%	0%
IR low	34%	178%	9%	56%	201%	0%
LT high	100%	100%	99%	0%	0%	0%
LT low	100%	100%	100%	0%	0%	0%
ρ_b high	0%	0%	81%	0%	0%	12%
ρ_b low	0%	0%	40%	0%	0%	21%
SA high	52%	0%	0%	44%	0%	0%
SA low	110%	0%	0%	79%	0%	0%
θ_v high	0%	0%	66%	0%	0%	68%
θ_v low	0%	0%	46%	0%	0%	46%
U_m high	0%	24%	0%	0%	0%	0%
U_m low	0%	11%	0%	0%	0%	0%
U_t high	0%	9%	0%	0%	0%	0%
U_t low	0%	58%	0%	0%	0%	0%

Shaded cells = Sensitive parameter

The analysis demonstrates that RSL results are sensitive to the following:

- The exposure time parameters of exposure interval (T), exposure duration (ED), exposure frequency (EF), exposure time (ET) (inhalation only), and lifetime (LT) (cancer only)

- The receptor physical parameters of body weight (BW), soil ingestion rate (IR), worker soil surface area (SA) (dermal only), and worker soil adherence factor (AF) (dermal only)

The analysis demonstrates that RSL results are not sensitive to the following:

- Areal extent of the site or contamination (A)
- Worker soil surface area (AF) (except for dermal pathway)
- Worker soil adherence factor (AF) for ingestion or inhalation pathways
- Exposure time (ET) for ingestion or dermal pathways
- Organic carbon content of soil (f_{oc}) (except for reducing parameter for cancer inhalation)
- Lifetime (LT) for toxic chemicals
- Dry soil bulk density (ρ_b) (except for cancer inhalation)
- Water-filled soil porosity (θ_v) (except for inhalation)
- Mean annual wind speed (U_m)
- Raising equivalent threshold value wind speed value (U_t)
- Lowering equivalent threshold value wind speed value (U_t) (except for cancer inhalation)
- Fraction of vegetative cover (V)

B.2.0 References

EPA, see U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. 2011. *Mid-Atlantic Risk Assessment Regional Screening Table - User's Guide*. As accessed at http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/usersguide.htm on 13 December. Prepared by EPA Office of Superfund and Oak Ridge National Laboratory.

Appendix C

RESRAD Sensitivity Analysis

C.1.0 RESRAD Sensitivity Analysis

C.1.1 Introduction

The RESRAD computer code (Yu et al., 2001) provides a tool for evaluating the potential risk to human health for exposure to radioactive contamination in surface soils. The code accepts site-specific input parameters, based upon environmental factors and the exposure scenario, and can translate the information into a listing of RRMGs. The RRMG for each radionuclide COC is the value, in units of picocuries per gram of surface soil that would present a potential dose of 25 mrem/yr to a receptor under the conditions established in the exposure scenario.

The selection of appropriate site-specific input parameters is important to the results of the RESRAD output. The value for the input parameters should be conservative, realistic, and should be evaluated by stakeholders before use.

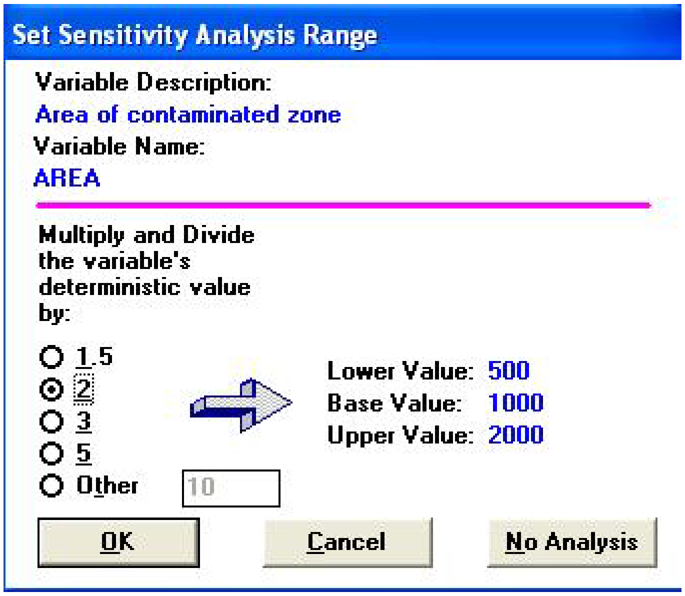
A sensitivity analysis of the input parameters allows the stakeholders to focus their attention on the subset of parameters that have a notable impact on the output of the RESRAD code.

C.1.2 Discussion

To assist users in selecting proper input parameter values, the developers of the RESRAD code performed an extensive literature search to develop default deterministic values for each parameter. The compiled data was published in the *Data Collection Handbook To Support Modeling the Impacts of Radioactive Material in Soil* (Yu et al., 1993). The handbook provides the definition, typical range, default value used in RESRAD, relationship to other parameters, and a site-specific measurement methodology (where appropriate) for each parameter.

In order to understand the uncertainties involved in dose estimates, deterministic and probabilistic sensitivity analysis methods were incorporated into the RESRAD code. The deterministic method studies the influence of one input parameter at a time, while keeping the others at fixed values. For each of the RESRAD data input screens, the user can select a parameter for sensitivity analysis. When a parameter is selected, a sensitivity analysis dialog box allows the user to specify how the parameter will be varied during the analysis (e.g., multiply or divide the default value by a specified amount).

Refer to Figure C.1-1. Up to five input parameters can be selected for deterministic sensitivity analysis in a single run of the code.


Set Sensitivity Analysis Range

Variable Description:
Area of contaminated zone
Variable Name:
AREA

Multiply and Divide the variable's deterministic value by:

○ 1.5
● 2
○ 3
○ 5
○ Other 10

Lower Value: 500
Base Value: 1000
Upper Value: 2000

Figure C.1-1
RESRAD Sensitivity Dialog Box

After execution of the code, RESRAD displays the sensitivity analysis results in graphics that compare the final results calculated from the default parameters and from the perturbed parameters. In this manner, the user gets a clear picture of the degree of change in the results as a parameter is varied. Figure C.1-2 shows an example of a sensitivity graphical display.

C.1.3 Methodology

The Industrial Area exposure scenario was selected for the sensitivity analysis, as this scenario is the most limiting (i.e., provides the larger dose for a given concentration of radionuclides in surface soil). The "External Gamma," "Inhalation," and "Soil Ingestion" exposure pathways were activated for the analysis, which is consistent with the established exposure scenario.

Each of the available input parameters was then selected for sensitivity analysis. The base-case value for each of the available input parameters was the current value as established in the *Industrial Sites Project Establishment of Final Action Levels* (NNSA/NSO, 2006) for the Industrial Area scenario.

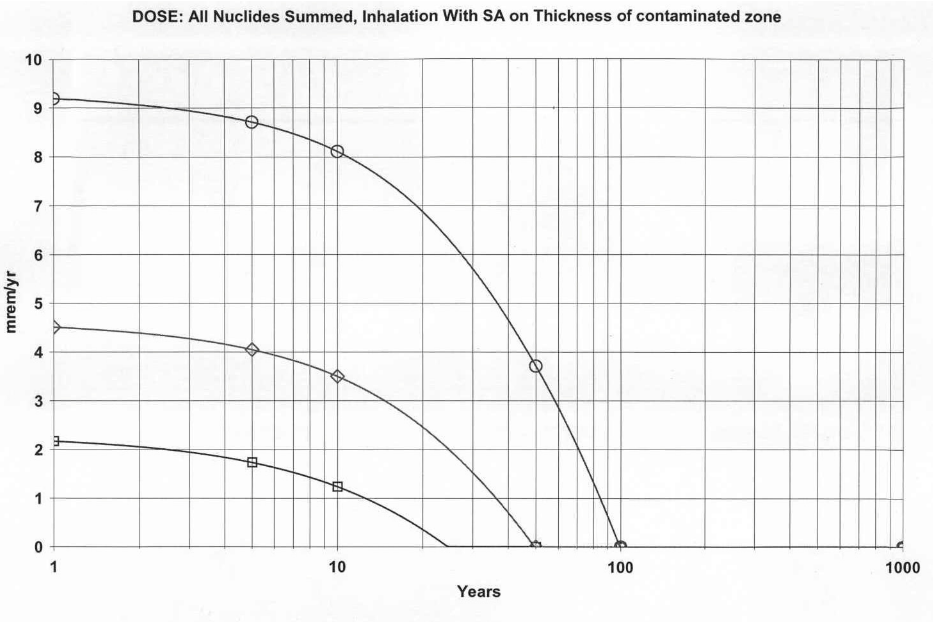


Figure C.1-2
Sensitivity of Inhalation Dose with Changes to the Thickness of the Contaminated Zone

The sensitivity analysis range value was selected to multiply and divide the input parameter value by a factor of two. It is important to note that, if this multiplication or division takes the value of the input parameter outside an acceptable range of values, RESRAD provides a warning message and defaults the value to the upper or lower limit for the parameter.

Up to five input parameters were selected for sensitivity analysis, and the RESRAD code was executed. Upon completion of the run, the results were viewed using the graphical output. The “Plot Type” selected was “Dose,” and the “Radionuclide” was “Summed.” The “Pathways” was selected as “Individual,” and the exposure pathway was selected from the drop-down box. The “Base Case” was unselected under “Sensitivity,” and each of the five input parameters was selected sequentially in the drop-down box. Each graphical output was printed. Additional input parameters were selected, in groups of five or less, and the code again executed until all of the available input parameters had been tested.

Under the Industrial Area scenario, with the three accepted exposure pathways, the maximum potential radiation dose to a receptor occurs in the first year of exposure. The graphical output was examined at year 1, and the range of doses (i.e., base-case or “mid” value, upper value, and lower value) were estimated from the y-axis. An input parameter was determined to be sensitive if the difference between the base-case and the upper or lower value was more than 2.5 mrem (which is 10 percent of the annual limit of 25 mrem).

Based upon previous RESRAD code runs, it was known that the ingestion exposure pathway comprised a very small fraction of the potential radiation dose and was insignificant when compared to the external gamma and the inhalation exposure pathways. Because of this, graphical output for the ingestion pathway was not generated or inspected.

C.1.4 Results and Conclusions

The following RESRAD input parameters were identified as being sensitive for the Industrial Area exposure scenario under either the external gamma and/or the inhalation exposure pathways:

- Area of Contaminated Zone *[AREA]*
- Thickness of Contaminated Zone *[THICK0]*
- Contaminated Zone Erosion Rate *[VCZ]*
- Average Annual Wind Speed *[WIND]*
- Precipitation *[PRECIP]*
- Inhalation Rate *[INHALR]*
- Mass Loading for Inhalation *[MLINH]*
- Shielding Factor, Inhalation *[SHF3]*
- Shielding Factor, External Gamma *[SHF1]*
- Fraction of Time Spent Outdoors (on site) *[FOTD]*

C.2.0 References

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Appendix D

Evaluating Petroleum Hydrocarbon Contaminated Soil

(15 Pages)

Evaluating Petroleum Hydrocarbon-Contaminated Soil – 11557

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ABSTRACT

At many remediation sites contaminated by petroleum products, concentrations of total petroleum hydrocarbons (TPH) or concentrations of subsets of TPH are used to evaluate the need for corrective actions. Regardless of the type of petroleum product that is present in the soil, the petroleum products start out as an inconsistent mixture of many chemical compounds and then change with time as the individual constituents degrade at different rates to form other compounds. As such, it is not possible to accurately determine the inventory of related potentially hazardous chemical contaminants or their concentrations based only on knowing the type of product or the TPH concentrations. This issue is related to the lack of reliable toxicity information based only on types of petroleum products or fractions of TPH. Thus, it is not possible to reliably assign toxicity information (or risk-based action levels) to petroleum-contaminated soils. However, toxicity information is available for the individual potentially hazardous chemical compounds that may be present in petroleum products. If the concentrations of these potentially hazardous chemical compounds are known, the risk to receptors can be evaluated using conventional risk assessment methodologies. The potentially hazardous chemical compounds that may be present in petroleum products have been identified through numerous analyses of petroleum products. These analyses show significant variation in the chemical composition of petroleum products and identify the range of chemicals and concentrations that may be present in the products. An assessment was performed to (1) identify the chemical constituents in these products that have been identified as hazardous constituents by EPA, (2) determine whether there is a potential for these hazardous constituents to exceed EPA screening levels in soil, and (3) determine analytical methods available to detect these constituents at concentrations below their respective screening levels. At the Nevada National Security Site (NNSS) (formerly the Nevada Test Site), many remediation sites have been closed using a TPH criterion of 100 milligrams per kilogram (mg/kg). These sites were either cleaned up to this criterion or closed in place with use restrictions. The risk-based strategy described in this paper led to the removal of TPH-based use restrictions at 59 sites and the elimination or reduction of the need for corrective actions at many other sites. This represents significant savings in remediation and maintenance/monitoring costs.

INTRODUCTION

Due to the pervasive use of petroleum-based products (e.g., gasoline, diesel, fuel oil, and lubricating oil), inadvertent spills and releases of these products to soil is widespread. Although no federal regulations are in place for petroleum-contaminated soils, nearly all states have cleanup standards that are in some way linked to a general measurement of petroleum contamination in soil called total petroleum hydrocarbons (TPH) [1]. The presence of TPH in soil test results may require corrective action to remove or reduce the risk posed by petroleum contamination to receptors. The TPH soil cleanup standards range from 100 to 20,000 milligrams per kilogram (mg/kg) [2].

The definition of TPH depends on the analytical method used because the TPH measurement is the total concentration of the hydrocarbons extracted and measured by a particular method [3]. Many analytical techniques are available to measure TPH concentrations in the environment, and each may vary in the way hydrocarbons are extracted, cleaned up, and detected. Thus, they each measure slightly different subsets of the petroleum-derived hydrocarbons present in a sample. Variations in reporting TPH include the following:

- Total recoverable petroleum hydrocarbons (TRPH)
- Total petroleum hydrocarbons–diesel-range organics (TPH-DRO)
- Total petroleum hydrocarbons–gasoline-range organics (TPH-GRO)
- Total petroleum hydrocarbons–oil-range organics (TPH-ORO)
- Volatile petroleum hydrocarbons (VPH)
- Extractable petroleum hydrocarbons (EPH)

The term "gasoline" or "diesel" in the above analytical reporting does not necessarily imply that gasoline or diesel is present but simply reflects different categories of TPH based on carbon ranges.

The term TPH may include a broad family of compounds that would require a large undertaking to assess the risk from all the individual chemical constituents. As it is not practical to measure each one of these potential contaminants, several simplifying approaches have been developed and implemented. The major approaches to deal with petroleum product contamination include the following:

- The Massachusetts Department of Environmental Protection (MADEP) approach [4]
- The Total Petroleum Hydrocarbons Criteria Working Group (TPHCWG) approach [3]
- The Agency for Toxic Substances and Disease Registry (ATSDR) approach [5]
- The California State Water Resources Control Board approach [6]
- The American Society for Testing and Materials (ASTM) approach [7]

All of these approaches reduce the comprehensive list of potential petroleum contaminant constituents to a manageable size. These approaches (except for the ASTM approach) accomplish this purpose through some combination of TPH fractionization and indicator compounds. The TPH fractionization is a categorization of the petroleum constituents into a small number of groups (fractions) that have similar properties (based on similarity of chemical composition or physical properties such as mobility). The use of indicator compounds is a conservative simplification based on using a compound that has established risk information to represent the entire contaminant mixture.

The MADEP approach to characterize and evaluate risks posed by petroleum-contaminated sites was developed based on the following observations and conclusions:

- Petroleum products are composed mainly of aliphatic/alicyclic and aromatic hydrocarbon compounds.
- Aromatic hydrocarbons appear to be more toxic than aliphatic compounds.
- The toxicity of aliphatic compounds appears to be related to their carbon numbers/molecular weights.

This approach breaks down TPH into collective aliphatic and aromatic fractions. To support and implement this approach, MADEP developed VPH and EPH analytical methods that differentiate and quantify collective concentrations of aliphatic and aromatic hydrocarbons in soil and water. Specifically, under this approach, the non-cancer toxicity of petroleum-contaminated media is established by (1) determining the collective concentrations of specified ranges of aliphatic and aromatic hydrocarbons, and (2) assigning a toxicity value (e.g., Reference Dose) to each range. Toxicity values are determined based on a review and/or extrapolation of available toxicological data on hydrocarbon mixtures and specific hydrocarbon compounds. Cancer effects are evaluated separately by the identification and quantification of specific hydrocarbon compounds that are designated carcinogens, such as benzene and certain polycyclic aromatic hydrocarbons (PAHs) [4].

The TPHCWG approach was developed to address the large disparity among cleanup requirements used by states at sites contaminated with hydrocarbon materials such as fuels, lubricating oils, and crude oils. These requirements usually focus on TPH with numerical standards ranging from tens to tens of thousands of milligrams of TPH per kilogram of soil. Recognizing that these standards are not based on a scientific assessment of human health risk, TPHCWG members set out to develop scientifically defensible information for establishing soil cleanup levels that are protective of human health at petroleum-contaminated sites. The TPHCWG approach is a combined indicator and grouping or fraction approach. The carcinogenic risk is evaluated using indicator compounds, and the non-carcinogenic risk using fractions. The fractions of TPH are defined based on the potential mobility of the hydrocarbons [3].

The ATSDR approach is generally consistent with the TPHCWG approach, but ATSDR has developed its own set of TPH fraction representatives, many of which overlap those of the TPHCWG [5]. The California Leaking Underground Fuel Tank (LUFT) Program also assesses risk using a modified version of the MADEP fractionated approach as well as screening levels for individual constituents [6]. The ASTM approach relies on the direct analysis of petroleum constituents to evaluate risk to receptors [7].

PROBLEMS WITH THE ASSESSMENT OF TPH RISK

The ASTM approach states that TPH should not be used for risk assessment because the general measure of TPH provides insufficient information about the amounts of individual chemical(s) of concern present [7]. The amount of TPH found in a sample may provide a general indicator of petroleum contamination at that site, but does not directly provide useful information about the risk it may pose to a receptor. The TPHCWG states:

> TPH concentration data cannot be used to quantitatively estimate human health risk. The same concentration of TPH may represent very different compositions and very different risks to human health and the environment. For example, two sites may have TPH measurements of 500 ppm [parts per million] but constituents at one site may include carcinogenic compounds while these compounds may be absent at the other site. The risk at a specific site will change with time as contaminants evaporate, dissolve, biodegrade, and become sequestered. A valid correlation between TPH and risk would have to be site- and time-specific, related to a single spill, and, even then, the correlation might not be the same around the periphery of a plume where the rate of compositional change accelerates [3].

The difficulty of assigning risk to petroleum contamination that starts out as an inconsistent mixture of many chemical constituents is compounded by the fact that the constituents change with time as the individual constituents degrade at different rates to form other compounds. As such, it is not possible to accurately determine the inventory of related potentially hazardous chemical contaminants or their concentrations based only on knowing the type of product or the TPH concentrations. Therefore, the risk associated with fractions of TPH will be specific to the type of petroleum product released and the amount of "weathering" that has taken place.

The TPH fractionization approaches do not take into account the impacts of weathering. Weathering changes the composition of petroleum hydrocarbon soil contamination due to biodegradation, chemical reactions in the soil, the preferential loss of soluble constituents in percolating water, and volatilization of high vapor pressure constituents in the air. The rate of weathering is controlled by site-specific parameters such as temperature, precipitation, infiltration, soil density, depth of contamination, soil chemical composition, and biota present. If the contamination is on the soil surface, photodegradation also can be a significant weathering factor. Another complication in assigning risk to weathered petroleum contamination in soil is that very few data were identified that characterized the composition of weathered petroleum fuel mixtures [3].

NEVADA NATIONAL SECURITY SITE APPROACH

The Industrial Sites and Soils Projects within the Environmental Restoration Project at the Nevada National Security Site (NNSS) implement a risk-based corrective action (RBCA) process as defined in the *Industrial Sites Project Establishment of Final Action Levels* [8]. This process conforms with *Nevada Administrative Code* (NAC) Section 445A.227 [9], which lists the requirements for sites with soil contamination. For the evaluation of corrective actions, NAC Section 445A.22705 [10] requires the use of ASTM Method E1739 [7]. Based on Sections X1.5.4 and X1.42 of Method E1739 [7], potentially hazardous constituents in TPH are individually compared to their corresponding action levels to determine the need for corrective action. This approach eliminates assumptions about contaminants that are present in the various TPH fractions, assumptions about the risk associated with the TPH fractions, and any assumptions about the amount of weathering (or lack thereof) by directly measuring contaminants that are present in the soil. The difficulty of this approach is in the ability to measure all of the individual chemical contaminants contained in petroleum products that may have been released to the soil. As it is not practical to measure each one of these potential contaminants, a potential contaminant list was developed for each of the following four petroleum products: (A) diesel, (B) gasoline, (C) motor oil, and (D) fuel oil.

DETERMINATION OF THE POTENTIAL CONTAMINANT LIST

The potential contaminant list for each of the four petroleum products was developed from comprehensive lists of constituents in petroleum products that were compiled by the TPHCWG. The TPHCWG contacted government and private sector laboratories involved in petroleum hydrocarbon mixture analysis and searched the published technical literature. Individuals at the U.S. Environmental Protection Agency (EPA), U.S. Air Force, U.S. Navy, U.S. Department of Energy, and the oil industry research centers were contacted, and a comprehensive search of the technical literature was performed to identify all available composition data for the most common petroleum-based fuels, crude oil, and lubricating oils [3].

From these comprehensive lists of constituents, the potential contaminant lists were developed to include the constituents that met the following criteria:

1. They were listed as being of environmental concern by EPA in Appendix IX to Title 40 of the *Code of Federal Regulations* (CFR) Part 264 [11] (Note: Appendix IX to 40 CFR 264 comprises those compounds listed in Appendix VIII to 40 CFR 261 [12] for which it is feasible to analyze in groundwater samples, plus 17 chemicals that are routinely monitored for in the Superfund program).
2. They were listed on the EPA Regions 3, 6, and 9 Screening Levels for Chemical Contaminants list [13].
3. The concentration of the constituent in the petroleum product was sufficient to exceed the EPA Regions 3, 6, and 9 Screening Level when released to the soil.

The constituents of gasoline, diesel, fuel oil, and motor oil are listed in Table I. Table I also identifies those petroleum product constituents that were identified as being potentially hazardous constituents based on being listed in either Appendix IX to 40 CFR 264 [11] or the EPA regional screening level table [13]. Also presented is a conservative estimate of the concentration of each constituent within each of the petroleum products.

Table I. Constituents of Selected Petroleum Products.

Compound	Product (mg/kg)	40 CFR 264 Appendix IX?	EPA Region 9 Screening Levels?
A. Diesel Fuel No. 2			
1,2-Dimethylcarbazole	8.37[a]	No	No
1,3,5-Trimethylbenzene	3,115[a]	No	Yes
1,3-Dimethylcarbazole	5.21[a]	No	No
1,3-Dimethylnaphthalene	11,536[a]	No	No
1,4-Dimethylcarbazole	17.2[a]	No	No
1,4-Dimethylnaphthalene	2,108[a]	No	No
1,5-Dimethylnaphthalene	3,407[a]	No	No
1,6-Dimethyldibenzothiophene	105[a]	No	No
1-Methyl-4-isopropylbenzene	260[b]	No	No
1-Methyl-7-isopropylphenanthrene	16.0[a]	No	No
1-Methylcarbazole	21.7[a]	No	No
1-Methylnaphthalene	6,542[a]	No	Yes
1-Methylphenanthrene	105[a]	No	No
1-Methylpyrene	6.05[a]	No	No
2,6-Dimethyldibenzothiophene and 2-Ethyldibenzothiophene	273[a]	No	No
2-Aminoanthracene	5.62[a]	No	No
2-Aminophenanthrene	3.45[a]	No	No
2-Azapyrene	1.92[a]	No	No
2-Ethyldibenzothiophene	275[a]	No	No
2-Methylanthracene	95.2[a]	No	No
2-Methylcarbazole	7.09[a]	No	No
2-Methyldodecane	3,608[a]	No	No
2-Methylnaphthalene	11,981[a]	Yes	Yes
2-Methylphenanthrene	1,707[a]	No	No
2-Methylpyrene	5.35[a]	No	No
2-Methyltetradecane	5,608[a]	No	No
2-Phenylindole	5.04[a]	No	No
3-Aminophenanthrene	2.68[a]	No	No
3-Methylcarbazole	5.61[a]	No	No
3-Methylphenanthrene	67.5[a]	No	No
3-Methyltridecane	2,326[a]	No	No
3-Methylundecane	2,218[a]	No	No
4- & 9-Methylphenanthrene	141[a]	No	No
4-Aminophenanthrene	5.21[a]	No	No
4-Methylcarbazole	10.8[a]	No	No
6-Phenylquinoline	9.38[a]	No	No
9-Cyanoanthracene	9.07[a]	No	No
9-Cyanophenanthrene	9.47[a]	No	No
9-Phenylcarbazole	5.32[a]	No	No
Anthracene	93.5[a]	Yes	Yes
Arsenic	0.071[c]	Yes	Yes
Benz(a)anthracene	2.32[a]	Yes	Yes
Benzene	843[a]	Yes	Yes
Benzo(a)fluorene	5.68[a]	No	No
Benzo(a)pyrene	5.54[a]	Yes	Yes
Benzo(b+k)fluoranthene	0.759[a]	Yes	Yes
Benzo(e)pyrene	0.851[a]	No	No
Benzo(g,h,i)fluoranthene	1.80[a]	No	No

Compound	Product (mg/kg)	40 CFR 264 Appendix IX?	EPA Region 9 Screening Levels?
Benzo(g,h,i)perylene	0.227[a]	Yes	No
Benzo[def]carbazole	4.33[a]	No	No
Biphenyl	1,200[b]	No	Yes
Cadmium	0.490[c]	Yes	Yes
Chromium	1.70[c]	Yes	Yes
Chrysene	0.450[c]	Yes	Yes
Chrysene and Triphenylene	2.34[a]	No	No
Cyclopenta(cd)pyrene	1.48[a]	No	No
Dibenzothiophene	170[a]	No	No
Ethylbenzene	1,272[a]	Yes	Yes
Ethylhexyl nitrate	2,000[c]	No	No
Fluoranthene	95.4[a]	Yes	Yes
Fluorene	1,073[a]	Yes	Yes
Indeno(1,2,3-cd)pyrene	0.381[a]	Yes	Yes
Iron	37.0[c]	No	Yes
m+p-Xylenes	3,916[a]	No	No
Manganese	3.20[c]	No	Yes
Molybdenum	0.140[c]	No	Yes
Naphthalene	3,169[a]	Yes	Yes
n-Butylbenzene	460[b]	No	No
n-Decane	10,224[a]	No	No
n-Docosane	4,630[a]	No	No
n-Dodecane	20,819[a]	No	No
n-Eicosane	7,889[a]	No	No
n-Heneicosane	6,310[a]	No	No
n-Heptadecane	25,378[a]	No	No
n-Hexadecane	26,378[a]	No	No
n-Nonadecane	11,910[a]	No	No
n-Nonane	4,482[a]	No	Yes
n-Octadecane	18,277[a]	No	No
n-Octane	1,300[b]	No	No
n-Pentadecane	28,864[a]	No	No
n-Propylbenzene	542[a]	No	Yes
n-Tetracosane	3,500[c]	No	No
n-Tetradecane	23,091[a]	No	No
n-Tridecane	24,158[a]	No	No
n-Undecane	18,039[a]	No	No
o-Xylene	792[a]	No	Yes
Phenanthrene	1,236[a]	Yes	No
Phytane	5,654[a]	No	No
Picene	0.370[a]	No	No
Pristane	7,175[a]	No	No
Pyrene	73.3[a]	Yes	Yes
Toluene	4,021[a]	Yes	Yes
Triphenylene	3.30[c]	No	No
Zinc	3.10[c]	Yes	Yes
B. GASOLINE			
1,2,4-Trimethylbenzene	30,967[a]	No	Yes
1,3,5-Trimethylbenzene	10,113[a]	No	Yes
1,3-Butadiene	38.3[a]	No	Yes
1-Methyl-2-ethylbenzene	7,338[a]	No	No
1-Methyl-3-ethylbenzene	18,595[a]	No	No

Compound	Product (mg/kg)	40 CFR 264 Appendix IX?	EPA Region 9 Screening Levels?
1-Methyl-4-ethylbenzene	8,268[a]	No	No
1-Methylnaphthalene	724[a]	No	Yes
2,2,4-Trimethylpentane	24,878[a]	No	No
2,2-Dimethylbutane	5,064[a]	No	No
2,3,3-Trimethylpentane	6,853[a]	No	No
2,3,4-Trimethylpentane	10,057[a]	No	No
2,3-Dimethylbutane	10,327[a]	No	No
2,3-Dimethylhexane	4,032[a]	No	No
2,4-Dimethylhexane	4,544[a]	No	No
2,4-Dimethylpentane	8,583[a]	No	No
2-Methyl-1-butene	5,564[a]	No	No
2-Methyl-2-butene	11,327[a]	No	No
2-Methylhexane	30,967[a]	No	No
2-Methylnaphthalene	1,864[a]	Yes	Yes
2-Methylpentane	40,250[a]	No	No
3-Methylheptane	7,738[a]	No	No
3-Methylhexane	17,551[a]	No	No
3-Methylpentane	25,804[a]	No	No
Benzene	19,610[a]	Yes	Yes
cis-2-Butene	3,201[a]	No	No
cis-2-Pentene	4,019[a]	No	No
Cyclohexane	4,038[a]	No	Yes
Cyclopentane	4,864[a]	No	No
Ethylbenzene	17,551[a]	Yes	Yes
Isobutane	17,610[a]	No	No
Isopentane	81,530[a]	No	No
Methylcyclohexane	5,993[a]	No	No
Methylcyclopentane	18,595[a]	No	No
Methyl-tert-butylether	3,449[a]	No	Yes
m-Xylene	47,488[a]	No	Yes
Naphthalene	2,585[a]	Yes	Yes
n-Butane	48,637[a]	No	No
n-Heptane	11,357[a]	No	No
n-Hexane	24,789[a]	No	Yes
n-Pentane	40,280[a]	No	Yes
o-Xylene	25,833[a]	No	Yes
p-Xylene	19,610[a]	No	Yes
Toluene	83,679[a]	Yes	Yes
trans-2-Butene	3,718[a]	No	No
trans-2-Pentene	7,423[a]	No	No
C. Motor Oil			
1,1,1-Trichloroethane	2,800[b]	Yes	Yes
1,3,5-Trimethylnaphthalene	37.0[b]	No	No
1,5-Dimethylnaphthalene	56.0[b]	No	No
1-Methylnaphthalene	57.0[b]	No	Yes
1-Methylpyrene	1.30[c]	No	No
2-Ethylnaphthalene	58.0[b]	No	No
4-Methylpyrene	1.90[c]	No	No
4-Phenyltoluene	6.00[b]	No	No
Anthracene	46.7[a]	Yes	Yes
Arsenic	17.0[b]	Yes	Yes
Barium	210[b]	Yes	Yes

Compound	Product (mg/kg)	40 CFR 264 Appendix IX?	EPA Region 9 Screening Levels?
Benz(a)anthracene	69.6[a]	Yes	Yes
Benzene	960[b]	Yes	Yes
Benzo(a)fluorene	2.70[b]	No	No
Benzo(a)pyrene	18.0[a]	Yes	Yes
Benzo(b)fluoranthene	0.430[b]	Yes	Yes
Benzo(b)fluorene	1.60[c]	No	No
Benzo(b)naptho (2,1-d) thiophene	3.96[a]	No	No
Benzo(c)fluorene	0.500[c]	No	No
Benzo(c)phenanthrene	0.140[c]	No	No
Benzo(e)pyrene	19.4[a]	No	No
Benzo(g,h,i)perylene	31.1[a]	Yes	No
Benzo(k)fluoranthene	2.06[a]	Yes	Yes
Benzonaphthothiophene	0.390[c]	No	No
Biphenyl	83.0[b]	No	Yes
Cadmium	3.10[b]	Yes	Yes
Chromium	28.0[b]	Yes	Yes
Chrysene	82.1[a]	Yes	Yes
Chrysene and Triphenylene	26.4[a]	No	No
Coronene	3.06[a]	No	No
Cyclopenta(cd)pyrene	0.890[c]	No	No
Dibenz(a,c)anthracene	0.080[c]	No	No
Dibenzothiophene	0.900[c]	No	No
Dichlorodifluoromethane	370[c]	Yes	Yes
Ethylbenz(a)anthracene	0.740[c]	No	No
Fluoranthene	43.9[a]	Yes	Yes
Fluorene	95.5[a]	Yes	Yes
Indeno(1,2,3-cd)pyrene	40.6[a]	Yes	Yes
Lead	2,600[b]	Yes	Yes
Methylbenzo(mno)fluoranthene	0.340[c]	No	No
Naphthalene	1,001[a]	Yes	Yes
n-Dodecane	140[c]	No	No
n-Eicosane	2,200[b]	No	No
n-Heptadecane	530[b]	No	No
n-Hexadecane	280[b]	No	No
n-Nonadecane	820[b]	No	No
n-Octadecane	640[b]	No	No
Nonylcyclohexane	22.0[b]	No	No
n-Pentadecane	140[b]	No	No
n-Tetradecane	150[b]	No	No
n-Tridecane	230[b]	No	No
Octylcyclohexane	11.0[b]	No	No
Other Benzonaphthothiophenes	1.40[c]	No	No
Perylene	3.87[a]	No	No
Phenanthrene	151[a]	Yes	No
Phenanthro(4,4a,4b,5-bcd)thiophene	0.410[c]	No	No
Phenylnaphthalene	1.00[c]	No	No
Phytane	370[b]	No	No
Pristane	280[b]	No	No
Pyrene	107[a]	Yes	Yes
Terphenyl	0.140[c]	No	No
Tetrachloroethylene (PCE)	1,400[b]	Yes	Yes
Tetralin	24.0[b]	No	No

Compound	Product (mg/kg)	40 CFR 264 Appendix IX?	EPA Region 9 Screening Levels?
Toluene	2,200[b]	Yes	Yes
trans-Decalin	10.0[c]	No	No
Trichloroethylene (TCE)	1,400[b]	Yes	Yes
Trichlorotrifluoroethane	63,000[c]	No	No
Triphenylene	2.50[c]	No	No
Triphenylene(4,4a,4b,5-bcd)thiophene	0.120[c]	No	No
Zinc	980[b]	Yes	Yes
D. FUEL OIL NO. 6			
1-Methylphenanthrene	43.0[c]	No	No
2-Methylphenanthrene	830[c]	No	No
Anthracene	50.0[c]	Yes	Yes
Benz(a)anthracene	1,966[a]	Yes	Yes
Benzo(a)pyrene	44.0[c]	Yes	Yes
Benzo(b+k)fluoranthene	440[c]	No	No
Benzo(e)pyrene	10.0[c]	No	No
Chrysene	1,929[a]	Yes	Yes
Fluoranthene	240[c]	Yes	Yes
Indeno(1,2,3-cd)pyrene	100[c]	Yes	Yes
Naphthalene	124[a]	Yes	Yes
n-Decane	150[b]	No	No
n-Docosane	1,573[a]	No	No
n-Dodecane	340[b]	No	No
n-Dotriacontane	510[b]	No	No
n-Eicosane	1,573[a]	No	No
n-Heneicosane	1,573[a]	No	No
n-Hentricontane	662[a]	No	No
n-Heptacosane	1,166[a]	No	No
n-Heptadecane	1,792[a]	No	No
n-Heptatriacontane	99.0[b]	No	No
n-Hexacosane	1,199[a]	No	No
n-Hexadecane	1,709[a]	No	No
n-Hexatriacontane	110[b]	No	No
Nickel	89.0[c]	Yes	Yes
n-Nonacosane	968[a]	No	No
n-Nonadecane	1,725[a]	No	No
n-Nonane	59.0[b]	No	Yes
n-Nonatriacontane	76.0[b]	No	No
n-Octacosane	1,048[a]	No	No
n-Octadecane	1,588[a]	No	No
n-Octatriacontane	87.0[b]	No	No
n-Pentacosane	1,292[a]	No	No
n-Pentadecane	1,489[a]	No	No
n-Pentatriacontane	150[b]	No	No
n-Tetracontane	55.0[b]	No	No
n-Tetracosane	1,503[a]	No	No
n-Tetradecane	1,372[a]	No	No
n-Tetratriacontane	300[b]	No	No
n-Triacontane	867[a]	No	No
n-Tricosane	1,516[a]	No	No
n-Tridecane	885[a]	No	No
n-Tritriacontane	360[b]	No	No
n-Undecane	250[b]	No	No

Compound	Product (mg/kg)	40 CFR 264 Appendix IX?	EPA Region 9 Screening Levels?
Perylene	22.0[c]	No	No
Phenanthrene	439[a]	Yes	No
Phytane	710[b]	No	No
Pristane	620[b]	No	No
Pyrene	23.0[c]	Yes	Yes
Triphenylene	31.0[c]	No	No
Vanadium	73.0[c]	Yes	Yes

[a]Based on the 95% upper confidence limit (UCL) of measurements
[b]Based on the maximum measurement
[c]Based on the average measurement

As demonstrated by the TPHCWG's Composition of Petroleum Mixtures tables, the petroleum products are variable mixtures of large numbers of components with significant variations within different samples of the same product type. As such, these tables listed the number of samples from which compositional data were derived as well as the statistics of the datasets (e.g., average, minimum, maximum, and variability) for each of the petroleum products and their individual constituents. The concentration of each constituent for each of the petroleum products listed in Table I was conservatively estimated based on the following hierarchy:

- The 95th upper confidence limit (UCL) of the average concentration for those constituents with available statistical information
- The maximum concentration if statistical information was not available
- The average concentration if a maximum was not listed

All of the petroleum product constituents of diesel, gasoline, motor oil, and fuel oil that are listed in either Appendix IX to 40 CFR 264 [11] or the EPA regional screening level table [13] are defined as the constituents of potential environmental concern and listed in Table II.

POTENTIAL CONTAMINANTS OF CONCERN AT SOIL RELEASE SITES

The constituents of potential environmental concern in the petroleum products that are present in sufficient concentrations to result in a soil concentration exceeding the EPA screening levels are identified and shown in boldface in Table II. The potential concentration of each constituent in soil (i.e., soil contaminant) was calculated based on the concentration of the constituent in the petroleum product and the concentration of the petroleum product in soil using the following equation:

$$C_{cs} = C_{ps} \times C_{cp}, \qquad \text{(Eq. 1)}$$

where C_{cs} is the resulting potential concentration of the constituent in soil at saturation (milligrams of constituent per kilogram of soil), C_{ps} is the saturated concentration of the petroleum product in soil (kilograms of petroleum product per kilogram of soil), and C_{cp} is the concentration of the constituent in the petroleum product (milligrams of constituent per kilogram of petroleum product).

Table II. Constituents of Potential Environmental Concern.

Compound	Action Level (mg/kg)	Sat. Soil (mg/kg)	Compound	Action Level (mg/kg)	Sat. Soil (mg/kg)
A. Diesel Fuel No. 2					
1,3,5-Trimethylbenzene	10,200	576	Fluoranthene	22,000	17.7
1-Methylnaphthalene	**98.7**	**1,210**	Fluorene	22,000	199
2-Methylnaphthalene	4,090	2,220	Indeno(1,2,3-cd)pyrene	2.11	0.0705
Anthracene	165,000	17.3	Iron	715,000	6.85
Arsenic	1.59	0.0131	Manganese	22,700	0.592

Compound	Action Level (mg/kg)	Sat. Soil (mg/kg)	Compound	Action Level (mg/kg)	Sat. Soil (mg/kg)
Benz(a)anthracene	2.11	0.429	Molybdenum	5,110	0.0259
Benzene	**5.37**	**156**	**Naphthalene**	**18**	**586**
Benzo(a)pyrene	**0.211**	**1.03**	**n-Nonane**	**234**	**829**
Benzo(b)fluoranthene	2.11	0.14	n-Propylbenzene	21,500	100
Benzo(g,h,i)perylene	16,500	0.042	o-Xylene	19,300	147
Biphenyl	51,100	222	Phenanthrene	165,000	229
Cadmium	798	0.0907	Pyrene	16,500	13.6
Chromium	45.5	0.315	Toluene	45,200	744
Chrysene	211	0.0833	Zinc	307,000	0.574
Ethylbenzene	**26.8**	**235**			
B. Gasoline					
1,2,4-Trimethylbenzene	**261**	**5,060**	**Methyl-tert-butylether**	**215**	**563**
1,3,5-Trimethylbenzene	10,200	1,650	m-Xylene	16,600	7,750
1,3-Butadiene	**0.262**	**6.25**	**Naphthalene**	**18**	**422**
1-Methylnaphthalene	**98.7**	**118**	**n-Hexane**	**2,620**	**4,050**
2-Methylnaphthalene	4,090	304	**n-Pentane**	**3,670**	**6,580**
Benzene	**5.37**	**3,200**	o-Xylene	19,300	4,220
Cyclohexane	29,500	659	p-Xylene	16,900	3,200
Ethylbenzene	**26.8**	**2,870**	Toluene	45,200	13,700
C. Motor Oil					
1,1,1-Trichloroethane	38,100	549	Chrysene	211	16.1
1-Methylnaphthalene	98.7	11.2	Dichlorodifluoromethane	781	72.5
Anthracene	165,000	9.15	Fluoranthene	22,000	8.6
Arsenic	**1.59**	**3.33**	Fluorene	22,000	18.7
Barium	191,000	41.1	**Indeno(1,2,3-cd)pyrene**	**2.11**	**7.95**
Benz(a)anthracene	**2.11**	**13.6**	Lead	800	509
Benzene	**5.37**	**188**	**Naphthalene**	**18**	**196**
Benzo(a)pyrene	**0.211**	**3.53**	Phenanthrene	165,000	29.6
Benzo(b)fluoranthene	2.11	0.0842	Pyrene	16,500	21
Benzo(g,h,i)perylene	16,500	6.09	**Tetrachloroethylene (PCE)**	**2.64**	**274**
Benzo(k)fluoranthene	21.1	0.404	Toluene	45,200	431
Biphenyl	51,100	16.3	**Trichloroethylene (TCE)**	**14.2**	**274**
Cadmium	798	0.607	Zinc	307,000	192
Chromium	45.5	5.49			
D. Fuel Oil No. 6					
Anthracene	165,000	9.25	**Naphthalene**	**18**	**22.9**
Benz(a)anthracene	**2.11**	**364**	Nickel	19,700	16.5
Benzo(a)pyrene	**0.211**	**8.14**	n-Nonane	234	10.9
Chrysene	**211**	**357**	Phenanthrene	165,000	81.2
Fluoranthene	22,000	44.4	Pyrene	16,500	4.26
Indeno(1,2,3-cd)pyrene	**2.11**	**18.5**	Vanadium	71.5	13.5

The concentrations of each constituent in each of the petroleum products are listed in Table I. The concentration of the petroleum product in soil will depend on physical properties of the soil (i.e., soil texture and porosity), the petroleum product (e.g., viscosity, density, surface tension), and the amount of saturation. However, to identify potential petroleum contaminants in soil, the potential concentration of the petroleum product in soil was conservatively estimated based on a saturation of the available soil pore space by the petroleum product.

$$C_{ps} = \theta_{mo},$$

$$\theta_{mo} = \theta_{vo} \times \rho_o/\rho_b, \qquad \text{(Eq. 2)}$$

where θ_{mo} is the mass petroleum product concentration in soil (kilograms of petroleum product per kilogram of soil), θ_{vo} is the residual petroleum product volume fraction (cubic meters of petroleum product per cubic meter of soil), ρ_o is the density of the petroleum product (kilograms of petroleum product per cubic meter), and ρ_b is the bulk density of soil (kilograms of soil per cubic meter).

Typical soil physical properties and the potential soil content of petroleum products at saturation are listed in Table III. The volumetric fraction of soil occupied by petroleum product was calculated based on the total amount of soil pore space available to be occupied by a petroleum product infiltrating into the soil and the fraction of the available pore space that is filled by the petroleum product [14].

$$\theta_{vo} = p_a \times s_r, \qquad \text{(Eq. 3)}$$

where p_a is the available porosity of soil (cubic centimeters of available pore space per cubic centimeter of soil), and s_r is the volumetric fraction of available pore space occupied by petroleum product (cubic meters of petroleum product per cubic meter of pore space). For the purposes of this paper, it was assumed that 100% of available pore space was filled with petroleum product (i.e., $s_r = 1$).

The available soil pore space was estimated as the soil pore space not occupied by air, water, or organic material. The amount of total pore space was calculated based on typical estimates of soil bulk density. When more than one fluid exists in a porous media, the fluids compete for pore space [17]. Therefore, higher soil water contents would retain less of the spilled liquid hydrocarbons. The amount of pore space occupied by soil water was conservatively estimated at the permanent wilting point. The permanent wilting point is defined as the volumetric water content at which plants can no longer extract water from the soil (and thus permanently wilt and die). The volumetric water content of soil was converted from reported typical mass water contents at the permanent wilting point using soil bulk density and the density of water. Fractions of soil pore space occupied by organic matter and other biota were conservatively ignored (i.e., a larger fraction of soil pore space is then available to contain the petroleum product). This parameter was calculated using the following equation:

$$p_a = 1 - \left(\rho_b/\rho_p\right) - \theta_v,$$

$$\theta_v = \theta_{mwp} \times \rho_b/\rho_w, \qquad \text{(Eq. 4)}$$

where p_a is the available porosity of soil (cubic meters of available pore space per cubic meter of soil), ρ_p is the particle density of soil (kilograms of solids per cubic meter), θ_{mwp} is the mass water content of soil at the permanent wilting point (kilograms of water per kilogram of soil), and ρ_w is the bulk density of water (kilograms of water per cubic meter).

The calculation of the potential concentrations in the soil of each constituent for each petroleum product as reported in Table III was conservatively based on saturation of the available pore space by the petroleum product. This may be a reasonable assumption if the spill is fresh and the soil is saturated by the product. For sites contaminated from historical releases, saturation is not a reasonable assumption. Petroleum products in the vadose zone tend to infiltrate through the soil in a period of days or weeks, which leads to the conclusion that nonaqueous phase liquid (NAPL) present in a vadose-zone soil months or years after a spill event is by definition immobile residual [18]. For these types of release sites, the saturation values listed in Table III should be adjusted using reported residual saturation values. Residual saturation values represent the amount of petroleum product retained in the soil after the soil was initially saturated with the product and allowed to drain. Residual saturation is expressed as the ratio of the soil void space occupied by the petroleum product to the total pore space (volume of product divided by the total soil pore volume) [17]. It can also be influenced by the amount of pore space occupied by soil water that is not displaced by the petroleum product. Residual saturation values are generally higher for fine-grained soils, for dry soils, and for more viscous fluids.

Table III. Typical Soil Physical Properties and Potential Soil Content of Petroleum Products

Texture	Average Soil Bulk Density[a]	Total Porosity[b] (%)	Mass Water Content Wilting Point[c] (%)	Volumetric Water Content[d] (%)	Residual Available Porosity[e] (%)	Gasoline (% mass in soil)g	Diesel Fuel No. 2 (% mass in soil)[f]	Fuel Oil No. 6 (% mass in soil)[i]	Motor Oil (% mass in soil)[h]
Sand	1.71	35.5	1	1.4	34.1	15.0	17.0	17.0	17.9
Loamy Sand	1.66	37.4	2	2.5	34.9	15.8	17.9	17.9	18.9
Sandy Loam	1.53	42.3	5	6.9	35.4	17.3	19.7	19.7	20.8
Silt	1.45	45.3	8	10.9	34.4	17.8	20.2	20.2	21.4
Silt Loam	1.41	46.8	10	13.8	33.0	17.5	19.9	19.9	21.0
Loam	1.42	46.4	11	15.1	31.4	16.6	18.8	18.8	19.9
Sandy Clay Loam	1.4	47.2	14	20.0	27.1	14.5	16.5	16.5	17.5
Silty Clay Loam	1.27	52.1	17	21.1	31.0	18.3	20.7	20.7	22.0
Clay Loam	1.31	50.6	17	22.8	27.8	15.9	18.0	18.0	19.1
Sandy Clay	1.32	50.2	20	26.9	23.3	13.2	15.0	15.0	15.9
Silty Clay	1.22	54.0	20	24.9	29.1	17.9	20.3	20.3	21.4
Clay	1.21	54.3	23	28.3	26.0	16.1	18.3	18.3	19.4

[a] Calculated using the Soil Bulk Density Calculator (U.S. Texture Triangle) available on the Pedosphere.com website [15].
[b] Calculated using bulk density and a particle density of 2.65 grams per cubic centimeter (g/cm^3).
[c] Source: Campbell [16].
[d] Calculated from mass water content and bulk density.
[e] Total porosity minus volumetric water content.
[f] Calculated using available porosity volume, bulk density, and density of fuel oils (0.85 g/cm^3) [5].
[g] Calculated using available porosity volume, bulk density, and density of gasoline (0.75 g/cm^3) [5].
[h] Calculated using available porosity volume, bulk density, and density of mineral oil (0.9 g/cm^3) [5].
[i] Calculated using available porosity volume, bulk density, and density of fuel oils (0.85 g/cm^3) [5].

Based on these results, the potential contaminants of concern for each of the petroleum products are listed in Table IV for soil that is saturated with the petroleum product. This table also lists the EPA analytical method that can be used to detect soil concentrations of each of these potential contaminants [19]. Except for n-nonane, n-pentane, and arsenic, these potential contaminants can be evaluated using only EPA methods 8260 and 8270. For historical releases, n-nonane and n-pentane can be eliminated from consideration based on their volatility, solubility, and rapid biodegradation [20]. Arsenic can be removed from consideration if background concentrations in soil are greater than the 1.59 mg/kg screening level (as is the case at NNSS, where background concentrations of arsenic are approximately 23 mg/kg).

Table IV. Petroleum Soil Contaminants of Potential Concern.

Compound	Analytical Method[a]	Diesel Fuel No. 2	Gasoline	Motor Oil	Fuel Oil No.6
1,2,4-Trimethylbenzene	8260		x		
1,3-Butadiene	8260		x		
1-Methylnaphthalene	8270	x	x		
Arsenic	6010			x	
Benz(a)anthracene	8270			x	x
Benzene	8260	x	x	x	
Benzo(a)pyrene	8270	x		x	x
Chrysene	8270				x
Ethylbenzene	8260	x	x		
Indeno(1,2,3-cd)pyrene	8270			x	x
Methyl-tert-butylether	8260		x		
Naphthalene	8270	x	x	x	x
n-Hexane	8260		x		
n-Nonane	EPA TO-15	x			
n-Pentane	ASTM 5134		x		
Tetrachloroethylene (PCE)	8260			x	
Trichloroethylene (TCE)	8260			x	

[a] See the EPA publication SW-846 [19].

Although these data were generated from the analysis of fresh products, identifying the constituents that have the potential to exceed EPA screening levels based on these concentrations is conservative because the overall environmental hazard posed by weathered petroleum mixtures is considered less than that posed by fresh mixtures [3]. This is due to the depletion of the more water soluble, more volatile, and more easily biodegradable compounds.

APPLICATION TO HISTORICAL AND CURRENT RELEASES

At the NNSS, many remediation sites were closed using a TPH criterion of 100 mg/kg. These sites were either cleaned up to this criterion or closed in place with use restrictions. The risk-based strategy described in this paper led to the removal of use restrictions at 59 sites and the elimination or reduction of the need for corrective actions at many other sites. This represents significant savings in remediation and future maintenance/monitoring costs.

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Appendix E

Nevada Division of Environmental Protection Comments

(1 Page)

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NEVADA DIVISION OF ENVIRONMENTAL PROTECTION
protecting the future for generations

STATE OF NEVADA
Department of Conservation & Natural Resources
DIVISION OF ENVIRONMENTAL PROTECTION

Brian Sandoval, Governor
Leo M. Drozdoff, P.E., Director
Colleen Cripps, Ph.D., Administrator

March 08, 2012

Robert F. Boehlecke
Federal Project Director
Environmental Restoration Project
National Nuclear Security Administration
Nevada Site Office
P. O. Box 98518
Las Vegas, NV 89193-8518

RE: Review of the Draft Soils Project Risk-Based Corrective Action Evaluation Process, Revision 0, February 2012
Federal Facility Agreement and Consent Order

Dear Mr. Boehlecke,

The Nevada Division of Environmental Protection, Bureau of Federal Facilities (NDEP) staff has received and reviewed the draft Soils Project Risk-Based Corrective Action Evaluation Process. NDEP's review of this document did not indicate any deficiencies.

If you have any questions regarding this matter contact me at (702) 486-2850 ext. 233.

Sincerely,

/s/ Jeff MacDougall

Jeff MacDougall, Ph.D., CPM
Supervisor
Bureau of Federal Facilities

JJM/JW/KC/SP

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