DETERMINING CLEANUP GOALS AT RADIOLOGICALLY-CONTAMINATED SITES

RSAL Annual Review Task 5

April 2002

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Introduction

The purpose of this report is to examine the context in which cleanup levels have been developed at various radioactively contaminated sites The report documents cleanup levels from various sites and case studies from 12 selected sites to demonstrate variations in the decision-making framework and basis

Various terms are used, sometimes interchangeably, to describe numbers that guide remedial actions at radioactively contaminated sites Terms used in the case studies in this report include "action levels," "ALARA goal levels," "allowable residual soil concentrations," "cleanup levels," "cleanup standards," "derived concentration guideline levels," "guideline concentrations," "remedial goal options," "remedial goals," "remediation levels," "risk-based concentrations," "soil cleanup concentrations," and "soil cleanup criteria " Cleanup levels from site to site, or even at a single site, cannot be compared without knowing their purpose, how they were derived, and how they will be applied

An "action level" in the Superfund program refers to the existence of a contaminant concentration in the environment high enough to warrant action or trigger a response under SARA and NCP Responses triggered may include actions such as removal, treatment, containment, stabilization, or institutionally controlling exposure The term can be used similarly in other regulatory programs (EPA, 2002) An action level is referred to as an "investigation level" in Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (EPA, et al , 2000) MARSSIM's "derived concentration guideline levels" are examples of specific investigation levels derived by converting dose or risk from a release criterion into concentration or activity levels that are directly measurable

"Preliminary remediation goals" (PRGs) are the initial remedial guidelines usually developed early in the RI phase to provide risk-reduction targets PRGs based on ARARs are generally considered protective for single pathways or contaminants Risk-based PRGs are developed when multiple pathways or contaminants are present Numerical PRGs for radionuclides are typically based on the upper-bound carcinogenic risk of one in a million (10^{-6}) Until the final remedy is selected and documented in a ROD or other decision document, PRGs constitute initial guidelines, not final cleanup goals [40 CFR 300 430 (e)(2)(i)]

"Remediation goals" (RGs) are media-specific cleanup goals for a selected remedial action CERCLA requires the development of " methods and criteria for determining the appropriate extent of removal, remedy, and other measures " for responding to releases of hazardous pollutants and contaminants [CERCLA Section 105(a)(3)] To meet this requirement, a process defined in the revised NCP evaluates potential remedial alternatives once it has been determined that remediation is warranted The development of remedial action objectives is directly tied to this alternative evaluation Numerical RGs, which are part of the remedial action objectives, can be based on existing standards that are ARARs or on risk calculations [40 CFR 300 430(e)] These two criteria are the "threshold criteria" for evaluating both remedial alternatives and remedial action objectives Final RGs, along with the final remedy, are selected and documented in a ROD

Because risk-based PRGs do not necessarily represent realistic exposure and risk, those numbers may not be appropriate cleanup levels PRGs can be proportionally adjusted upward to become RGs using a level higher in the acceptable carcinogenic risk range to account for the conservatism inherent in the PRGs Other factors related to technical limitations (e g , detection or quantification limits) can also be applied In addition, the "balancing criteria" and the "modifying criteria" for analyzing remedial alternatives, such as cost, state and community acceptance, should also be considered [40 CFR 300 430(e)(2)(i)(A)] In some cases, RGs may be adjusted downward to account for multiple radionuclides or co-occurring nonradionuclide chemicals Final RGs are documented in the decision summary section of the ROD as radionuclide-specific "remediation levels" [40 CFR 300 430(f)(5)] or qualitative definition of the risk-reduction cleanup objective to be achieved for the nonnumerical RGs [40CFR 300 430 (Subpart E)]

Cleanup Level Development Process

Differences between cleanup levels from site to site are due to variations in one or more of the elements in the cleanup level development process This process begins with determining which regulatory authority applies Other elements in the process that may vary among sites include the selection among risk assessment approaches, exposure scenarios, computer codes/models, and input parameters

Regulatory Authority

In developing soil remediation levels, it is necessary to understand the regulatory framework that drives the remedial action Radioactively contaminated soils are covered under several separate and distinct statutory authorities Selecting one or more appropriate statutory authorities and associated regulations is fundamental to the development of soil cleanup levels Table 1 lists major radiological standards in effect in the United States

The Conference of Radiation Control Program Directors (CRCPD, 1998) has complained that radioactively contaminated sites "are not being cleaned up in a timely manner because there is no uniform cleanup standard applicable to the radioactive materials [T]he U S has a mixed bag of inconstant annual dose limit fractions (4 mrem/year for water, 10 mrem/year for air, 15 mrem/year for high level waste [proposed], 25/75/25 mrem/year for fuel cycle) Uniformity is not apparent in this melange "

Table 1. Major U.S. Radiation Standards

Standard	Agency[a]	Numerical limits[b]
General public (10 CFR 20)	NRC	100 millirem/year
Uranium mill tailings (40 CFR 192, 10 CFR 40, App A)	EPA	Ra-226/228 5 pCi/g (surface) 15 pCi/g (subsurface) Rn-222 20 pCi/m^2-sec
High-level waste operations (10 CFR 60)	NRC	100 millirem/year
Low-level waste (10 CFR 61)	NRC	25/75/25 millirem/year
Drinking water (40 CFR 141 15–16)	EPA	Radium 5 pCi/L Gross alpha 15 pCi/ L (excludes Ra and U) Beta/photon 4 mrem/year[c] Uranium 30 µg/L
Uranium fuel cycle (40 CFR 190)	EPA	25/75/25 mrem/year
Air emissions (National Emission Standards for Hazardous Air Pollutants) (40 CFR 61, H)	EPA	10 mrem/year to nearest off-site receptor
Superfund (CERCLA) cleanup (40 CFR 300)	EPA	1:10,000 to 1:1,000,000 (10^{-4}–10^{-6}) excess lifetime risk of getting cancer
Decommissioning (10 CFR 20)	NRC	25/100/500 mrem/year
Occupational standards (29 CFR 1910, 10 CFR 20, 10 CFR 835)	OSHA, NRC, DOE	5,000 mrem/year

[a] NRC = Nuclear Regulatory Commission
EPA = Environmental Protection Agency
OSHA = Occupational Safety and Health Administration
DOE = Department of Energy
[b] A picocurie (pCi) is one trillionth of a curie, a unit of radioactivity
A millirem (mrem) is one-thousandth of a rem, a unit of dose
[c] Radioactivity from manmade radionuclides in community drinking water systems

Selecting Among Risk Assessment Approaches

The methodology used to evaluate health effects due to radiation at contaminated sites depends on the regulatory authority The two methods for calculating adverse health effects associated with radiation exposure are

- Dose assessment—where a dose is calculated by multiplying a dose conversion factor (expressed in terms of unit dose/unit intake) for a given radionuclide by the total intake/exposure to that radionuclide (i e , ingestion, inhalation or external exposure) The calculated dose can also be multiplied by a probability coefficient to arrive at a risk value
- Risk assessment (cancer slope factor approach)—where risk is calculated directly by assigning a unit of risk for every unit of exposure (i e , probability of adverse effect/pCi), and multiplying by the total exposure

Exposure Scenarios

Generally, cleanup based on a residential scenario (suburban resident, rural resident, resident farmer or rancher) will allow unrestricted use of a site Choosing a less conservative scenario invokes institutional controls and inherent long-term stewardship issues The considerable difference in half-lives among various radionuclides is an important consideration in deciding whether long-term controls are feasible and therefore may affect exposure scenario selection Table 2 shows the various scenarios selected for risk assessment at selected case study sites

Table 2. Selection of Exposure Scenarios at Case Study Sites

Site	Scenario								
	Resident	**Rancher**	**Farmer**	**Park/Open Space User**	**Commercial/ Industrial**	**Fish & Wildlife Service**	**Ecotourist**	**Homesteader**	**Subsurface**
Brookhaven	✓				✓				
Enewetak	✓		✓						✓
Fernald			✓	✓					
Ft Dix	✓				✓				
Hanford	✓								
Johnston Atoll	✓					✓	✓	✓	
Linde Site					✓				
Nevada	✓	✓	✓		✓				
Oak Ridge					✓				
Savannah River					✓				
Rocky Flats	✓			✓	✓	✓			
Weldon Spring	✓		✓	✓		✓			

Selecting Computer Models

Mathematical models are used to approximate human and ecological exposure at a site The basic equations used to assess health effects due to radiological exposure are relatively straightforward and can be computed with a hand calculator or a spreadsheet These equations generally sum the exposure from the ingestion, inhalation, and external irradiation pathways, each of which has an intake or source term, an exposure period, and either a dose conversion factor or a cancer slope factor Modifying factors can be added, which adjust exposure periods and account for fate and transport of radionuclides in the environment These factors may add considerably to the number of interacting terms and therefore to the complexity of the calculations

Selecting Input Parameters

Many of the key parameters used in calculating cleanup levels are bounded within certain ranges once an exposure scenario is established For example, typical exposure periods and breathing and ingestion rates for various scenarios have been determined for use in risk or dose calculations (EPA, 1989) In some cases, especially for sensitive parameters, distributions may be available and used in place of discrete values Using distributions enables the entire range of possible values to be considered for a parameter and helps to account for the uncertainty and variability inherent in parameter selection (EPA, 2001) Relatively few input parameters used in computer codes or risk equations have significant influence on the resultant cleanup level These include inhalation rate, dose conversion factors, soil ingestion rate, mass loading for inhalation, and others Table 3 compares the various input parameters used in calculating risk at some of the sites that are examined in this report

Table 3. Comparison of Key Residential RESRAD Input Parameters

Parameter	Units	Hanford Site (WDOH, 1997)	Johnston Atoll (Uncapher et al, 2000)	Clean Slate Sites, Nevada (DOE, 1997)	Rocky Flats Cleanup Agreement (DOE, 1996b)	Rocky Flats Oversight Panel (RAC, 2000)	Rocky Flats Revised Soil Action Levels (draft) (EPA et al, 2001)
Dose limit [or risk range]	mrem/yr	15	[10^{-4}–10^{-6}]	100	15	15	25 [10^{-4} – 10^{-6}]
RESRAD version		5 7	5 82	5 61	5 61	5 82	6 0
Exposure pathways							
External gamma		Active	Active	Active	Active	Active	Active
Inhalation		Active	Active	Active	Active	Active	Active
Plant ingestion		Active	Active	Active	Active	Active	Active
Meat ingestion		Active	Suppressed	Active	Suppressed	Active	Suppressed
Milk ingestion		Active	Suppressed	Active	Suppressed	Active	Suppressed
Aquatic foods		Active	Suppressed	Suppressed	Suppressed	Suppressed	Suppressed
Drinking water		Active	Suppressed	Active	Suppressed	Active	Suppressed
Soil ingestion		Active	Active	Active	Active	Active	Active
Radon		Suppressed	Active	Active	Suppressed	Suppressed	Suppressed
Plutonium form		Soluble	Insoluble	Soluble	Insoluble	Insoluble	Insoluble
Distribution coefficients (Kd)	cm^3/g						
Americium		200	10,000	1900	76	2300*	1800
Plutonium		200	230,000	550	218	218*	2300
Uranium		2	50	35	50	218*	2 3
Area-contaminated zone	m^2	10,000	98,000	248,000	40,000	*	1,400,000
Thickness-contaminated zone	m	4 6	0 61	0 05	0 15	0 2	0 15
Inhalation rate	m^3/year	7,300	8,400	6,820	7,000	10,800	8,400*
Mass loading (inhalation)	g/m^3	0 0001	0 0002	0 000015	0 000026	0 007*	0 000058*
Exposure duration	year	30	10	30	30	70	30
Inhalation shielding factor		0 4	1	1	1	1	0 7
External gamma shielding factor		0 8	0 5	0 7	0 8	0 7	0 4
Indoor time fraction		0 6	0 25	0 58	1	0 6	0 82*
Outdoor time fraction		0 2	0 75	0 0155	0	0 4	0 14*
Wind speed	m/s	--	9	--	--	4	4 2
Fruits, vegetables, grain ingestion	kg/year	110	1	120 5	40 1	190	85*

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Parameter	Units	Hanford Site (WDOH, 1997)	Johnston Atoll (Uncapher et al, 2000)	Clean Slate Sites, Nevada (DOE, 1997)	Rocky Flats Cleanup Agreement (DOE, 1996b)	Rocky Flats Oversight Panel (RAC, 2000)	Rocky Flats Revised Soil Action Levels (draft) (EPA et al, 2001)
Leafy vegetable ingestion	kg/year	2 7	1	10	--	64	6 4*
Soil ingestion	g/year	36 5	73	37 4	70	75	36 5
Drinking water intake	L/year	510		444 6	--	730	--
Drinking water fraction from groundwater		1	--	1	--	1	--
Depth – soil mixing layer	m	0 15	--	0 15	0 15	0 03	0 15
GI absorption factor (f_1)							
Am-241			1E-3			5E-4	
Pu-239			1E-3			5E-4	
U-238 + D			5E-2			2E-2	
Ingestion slope factor	risk/pCi						
Am-241			3 28E-10				
Pu-239			3 16E-10				
U-238 + D			6 20E-11				
Inhalation slope factor	risk/pCi						
Am-241			3 85E-8				
Pu-239			2 78E-8				
U-238 + D			1 24E-8				
External exposure	risk/year per pCi/g						
Am-241			4 59E-9				
Pu-239			1 26E-11				
U-238 + D			5 25E-8				
Dose conversion factors	mrem/pCi						
Inhalation							
Am-241				4 40E-1	4 44E-1	1 55E-1	
Pu-239				4 29E-1	3 08E-1	5 9E-2	
U-234				1 32E-1	1 32E-1	3 5E-2	
U-235 + D				1 23E-1	1 23E-1	3 1E-2	
U-238 + D				1 18E-1	1 18E-1	3 0E-2	
Ingestion							
Am-241				3 64E-3	3 64E-3	7 4E-4	
Pu-239				3 54E-3	5 18E-5	9 3E-4	
U-234				2 83E-4	2 83E-4	1 8E-4	

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Parameter	Units	Hanford Site (WDOH, 1997)	Johnston Atoll (Uncapher et al, 2000)	Clean Slate Sites, Nevada (DOE, 1997)	Rocky Flats Cleanup Agreement (DOE, 1996b)	Rocky Flats Oversight Panel (RAC, 2000)	Rocky Flats Revised Soil Action Levels (draft) (EPA et al, 2001)
U-235 + D				2 67E-4	2 67E-1	1 7E-4	
U-238 + D				2 69E-4	2 69E-4	1 7E-4	

* Derived probabilistically using distributions of data

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Case Studies

Case studies from 12 radiologically-contaminated sites present a background of each site including the site history and nature of contamination These case studies then discuss the unique manner in which each site developed cleanup levels – the regulatory basis, models and inputs used, and what factors may have been applied to derive a final cleanup number If actual cleanup has taken place at the site, the status of those activities is reported Contact information is listed for most sites, including persons who are knowledgeable about the site and websites, if available The sites reported are

1 Brookhaven National Laboratory, NY
2 Enewetak Atoll, Marshall Islands
3 Fernald Environmental Management Project, OH
4 Ft Dix, NJ
5 Hanford Site, WA
6 Johnston Atoll
7 Linde Site, NY
8 Maralinga, Australia
9 Nevada Test Site and Associated Ranges, NV
10 Oak Ridge Reservation, TN
11 Savannah River Site, SC
12 Weldon Spring Site, MO

Cleanup levels have been identified for several other sites besides those in this report Without the background and context for these values, however, they will not be included here Most cleanups of nuclear weapons accident sites will also not be discussed in this report At least 11 nuclear bombs from the Cold War era, including five in the United States, have still not been recovered Accident sites where contamination was spread and cleanup occurred include Palomares, Spain (1966) and Thule, Greenland (1968) For the most part, activity levels reported at these sites are post-remediation measurements rather than cleanup levels determined prior to remediation As such, these levels are not appropriate for comparison in this report

Brookhaven National Laboratory, New York

Brookhaven National Laboratory (BNL) consists of 5,320 acres and is about 60 miles east of New York City BNL, formerly Camp Upton, was administered by the U S Army during World Wars I and II and has been operated by DOE and its predecessors since 1947 This facility processed, treated, and stored radioactive and hazardous waste The BNL site was placed on New York State's Department of Environmental Conservation (NYDEC) list of inactive hazardous waste sites in 1980 and on the NPL in 1989 Remediation at this site is being done under CERCLA, 40 CFR Part 300 Soils in several areas were contaminated with radionuclides from past waste handling operations, spills, or inadvertent use of contaminated soils for landscaping Most of the radioactively contaminated soils are at the former Hazardous Waste Management Facility

The radionuclide soil cleanup level is based on a total dose limit of 15 mrem/year above background considering 50 years of institutional controls for the selected land use This dose limit was based on EPA's draft proposed cleanup rule and is contained in a decision document finalized in October 1999 Residual radiological contamination following remediation will also be within the CERCLA risk range Specific cleanup levels for individual radionuclides (Table 4) were determined for both residential and industrial land use scenarios, using the RESRAD computer code Cesium cleanup levels within the former Hazardous Waste Management Facility assumes industrial land use with 50 years of institutional controls and residential land use with 100 years of institutional controls Outside the facility, cleanup levels for cesium are based on residential land use with 50 years of institutional controls The cleanup level for strontium-90 is based on impacts to groundwater and is protective of residential and industrial use as well DOE Order 5400 5 is the basis for the cleanup level chosen for radium-226 NYDEC's guidance of 10 mrem/year above background is an ALARA goal to be considered during remedial design

Table 4 Brookhaven National Lab Site Cleanup Levels (pCi/g)

Radionuclide	Residential Land Use	Industrial Land Use
Cesium-137	23	67
Strontium-90	15	15
Radium-226	5	5

Operable Unit I includes soils at the site contaminated with radionuclides Over 2,500 cubic yards of landscaping soils with low levels of radionuclides have been excavated and shipped to a disposal facility in Utah Soil cleanup at Operable Unit I is expected to be completed by 2005 Other areas of radioactively contaminated soils include the Hazardous Waste Management Facility, the Waste Concentration Facility, the Reclamation Facility sump, and tanks at Building 811 Post-remedial sampling will ensure that the dose from all residual radionuclides will not exceed 15 mrem/year (considering 50 years of institutional control for the specified land use)

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Enewetak Atoll

Enewetak Atoll is a ring of 40 islands surrounding a lagoon about 20 miles in diameter The total area of the islands is about 1800 acres Before World War II, Enewetak was used as a military base by the Japanese It was attacked and taken by the United States in February 1944 After the war, AEC required a site for nuclear weapons tests Enewetak Atoll was selected, and in

December 1947 its 136 inhabitants were transported to Ujelang, a nearby atoll Between 1948 and 1957, forty-three different nuclear devices were detonated on Enewetak, including the largest device tested by the United States These tests left much of the atoll contaminated with short-lived fission products as well as longer lasting isotopes of plutonium (Pu) In 1971, the U S government made the decision to return the atoll to the Trust Territory of the Pacific Islands, and planning for the cleanup was started

The remediation of Enewetak represents the first time that the United States attempted to set cleanup standards for Pu Many different agencies were involved From the published sources it is not clear how the first standards were derived It appears that 400 pCi/g was chosen by AEC in 1974 as the maximum exposure and that 1/10 of that level, 40 pCi/g, was considered safe It was then decided to remove all soil over 400 pCi/g and leave soil below 40 pCi/g Soil with Pu between 40 pCi/g and 400 pCi/g would be considered on a case-by-case basis In September 1974, a draft environmental impact statement (EIS) was published that recommended the 40–400 pCi/g standards and rejected cleanup of fission products due their short half-life and the extreme disruption of islands that removing them would cause One interesting concept discussed in the EIS was that once a cleanup action was initiated, the Pu concentrations should be reduced to the lowest possible levels, a concept similar to ALARA During the comment period on the draft EIS, numerous objections were brought up both about the standards and the placement of the waste, nevertheless, the final EIS was nearly identical to the draft

Although demolition of the buildings and cleanup of the debris were started, controversy over the soil cleanup continued In August 1977 an independent committee chaired by Dr W Blair (the Blair Committee) was formed to recommend a course of action EPA had recently released its draft guidance on Pu cleanup, which contained a 15 pCi/g cleanup recommendation This value was rejected as being not applicable to Enewetak Also planning and budgeting were already too advanced to allow the project to be delayed by more studies The Blair Committee generally endorsed the standards in the EIS, meanwhile the short-lived ERDA, successor to the AEC, objected that the new EPA Pu soil standard should apply The project was again put on hold until a decision could be made In the meantime the DOE replaced ERDA In January 1978, the Blair committee was again asked to recommend cleanup levels and made the following recommendations

- Residential islands should be cleaned up if the average concentration exceeded 40 pCi/g
- Agriculture islands should be given second priority and should be cleaned up if the average is greater than 80 pCi/g
- Third priority should be given to the other islands, and they should be cleaned up if the average is greater than 160 pCi/g

The committee reaffirmed that once the cleanup began, it should continue until a level of at least 40 pCi/g was achieved The committee recognized that because of the fixed cleanup budget, this standard could result in some islands not being cleaned up and that they may have to be quarantined This recommendation essentially formed the basis for the soil cleanup

During 1977 and 1978 a total of 253 thousand cubic yards of debris were removed, including nearly 6000 cubic yards of contaminated debris The soil cleanup went much better than planned, and in the end only one island, Runit, was quarantined due the disposal cell being on the island, even though the surface soil was cleaned up All the other islands were cleaned to at least the 160 pCi/g standard, and most did not exceed 40 pCi/g (Defense Nuclear Agency, 1981)

According to the Defense Threat Reduction Agency, no U S agency currently has jurisdiction for any further remediation, per the request of the inhabitants of the island

Fernald Environmental Management Project, Ohio

The Fernald Environmental Management Project (Fernald) is a 1500-acre DOE facility about 17 miles northwest of Cincinnati, near the village of Fernald, Ohio Fernald operated from 1952 to 1989 as the Feed Materials Production Center, a large-scale production facility extracting uranium from ores and ore concentrates to yield high-purity metal products in support of U S defense programs During this period, over 500 million pounds of slightly enriched and depleted uranium metal products were shipped to other DOE sites across the country Smaller amounts of thorium were also produced Production stopped in 1989, and the site was added to the NPL In 1991 the site was officially closed and renamed to reflect its new cleanup mission

Topography in the area consists of gently rolling uplands with steep hillsides along a major stream Surface drainage at Fernald is from east to west and south into Paddy's Run, with the exception of the northeast corner, which drains east toward the Great Miami River Groundwater is contained in two geologic units glacial overburden ranging in thickness 0–50 feet, and sand and gravel of the Great Miami Aquifer Groundwater in the glacial overburden is considered perched, since it is contained within silty sand lenses within a low-permeability, clay-rich soil The underlying Great Miami Aquifer is the principal drinking water supply for the region and is regulated as a sole-source aquifer under the Safe Drinking Water Act

Six waste pits used during past operations contain approximately 475,000 tons of waste, including uranium, thorium and other radioactive and chemical contaminants The pits range in size from a football field to a baseball diamond, and vary in depth 13–30 feet Two of the pits have a water cover, one has a synthetic cap, and the others have a soil cover The waste pits are either in close proximity to, or in contact with, the Great Miami Aquifer and are contributing to contamination of the groundwater

There are four concrete silos at Fernald that were constructed to store radioactive materials Two of them, referred to as the K-65 silos, contain high radium-bearing residues, one contains lower-level dried uranium residues, and one has never been used To reinforce the K-65 silos, a soil berm was added in the 1960s and enlarged in the early 1980s In 1991, bentonite clay was injected into the tops of the two K-65 silos to cap the high radium residues and reduce radon emissions from the silos

Large volumes of contaminated soil exist on site as a result of dumping, spilling and fugitive emissions during site operations Disposal areas include the Southern Waste Units, Solid Waste Landfill, and Lime Sludge Ponds Soil underlying the current production area is contaminated as a result of leaks and spills

EPA and DOE have a federal facility agreement covering CERCLA remediation and National Emissions Standards for Hazardous Air Pollutants (NESHAP) activities The state of Ohio and DOE have a consent order covering hazardous waste, surface water, and natural resource restoration

Cleanup levels for the entire site have been established through CERCLA RODs for the five operable units that encompass the site Soil cleanup levels are risk based using EPA risk assessment guidance and land uses consisting of an on-site undeveloped park and an off-site resident farmer Groundwater cleanup levels are based upon EPA drinking water maximum contaminant levels (MCLs), proposed MCLs, or risk-based numbers Table 5 lists cleanup values presented in the Operable Unit 5 ROD (DOE, 1996c), which addresses the large majority of the site Cleanup values differ in other portions of the site based upon proximity to groundwater and contaminant type, but are generally similar

Table 5. Fernald Site Final Remediation Levels (FRLs)

Contaminant	On-Property FRL[a] (pCi/g)	Off-Property FRL[b] (pCi/g)
Cesium-137 + 1D	$1\ 4 \times 10^{0}$	$8\ 2 \times 10^{-1}$
Neptunium + 1D	$3\ 2 \times 10^{0}$	$4\ 9 \times 10^{-1}$
Lead-210	$3\ 8 \times 10^{1}$	$2\ 2 \times 10^{0}$
Plutonium-238	$7\ 8 \times 10^{1}$	$9\ 3 \times 10^{0}$
Plutonium-239/240	$7\ 7 \times 10^{1}$	$9\ 0 \times 10^{0}$
Radium-226 + 8D	$1\ 7 \times 10^{0}$	$1\ 5 \times 10^{0}$
Radium-228 + 1D	$1\ 8 \times 10^{0}$	$1\ 4 \times 10^{0}$
Strontium-90	$1\ 4 \times 10^{1}$	$6\ 1 \times 10^{-1}$
Technetium-99	$3\ 0 \times 10^{1}$	$1\ 0 \times 10^{0}$
Thorium-228 + 7D	$1\ 7 \times 10^{0}$	$1\ 5 \times 10^{0}$
Thorium-230	$2\ 8 \times 10^{2}$	$8\ 0 \times 10^{1}$
Thorium-232 + 10D	$1\ 5 \times 10^{0}$	$1\ 4 \times 10^{0}$
Uranium, total (K_l=325 L/kg) (ppm)	$8\ 2 \times 10^{1}$	$5\ 0 \times 10^{1}$
Uranium, total (K_l=15 L/kg) (ppm)	$2\ 0 \times 10^{1}$	NA

[a] Undeveloped park user scenario at 10^{-6} excess cancer risk
[b] Resident farmer scenario at $10^{\ 5}$ excess cancer risk

- Waste Pits Remedial Action Project (waste storage area, including six waste pits, clear well and burn pit)—The waste pit contents is being excavated, thermally dried, and shipped by rail to a permitted commercial disposal facility Significant effort has been put into upgrading on- and off- site rail systems
- On-Site Disposal Facility (OSDF)—Contaminated soil and debris are being excavated and disposed of in the on-site engineered disposal cell Any waste that exceeds the waste

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acceptance criteria will be disposed of off site No off-site waste will be allowed in the disposal cell The first waste placement occurred in December 1997 The OSDF is designed to hold 2 5 million yards of waste

- Facilities Closure and Demolition Project (former production area, including all buildings, equipment, inventoried hazardous material and scrap metal piles)—All on-site buildings will be decontaminated and dismantled Debris within the waste acceptance criteria will go in the on-site disposal facility, with higher-level materials going off site Significant progress has been made in the safe shutdown of nuclear materials by decontamination and dismantling of production facilities A number of innovative technologies have been deployed during the decontamination and decommissioning activities, including oxy-gasoline torch, insulation removal, decontamination equipment, and scanning equipment
- Silos Project (Silos 1–4, including the K-65 silos, their contents and associated piping and soils)—Due to the 1996 failure in the Vitrification Pilot Plant, an "explanation of significant difference" was completed for Silo 3 and a ROD amendment will be completed for Silos 1 and 2
- Soils Characterization and Excavation Project (formerly Operating Units [OU] 2 and 5)—Contaminated soils are excavated, and those meeting the waste acceptance criteria are disposed of in the on-site disposal facility Excavation of the first contaminated soils area was completed in 1997 Technologies being used include a number of field-deployed analytical devices for quick assessment of radionuclide concentrations
- Aquifer Restoration and Waste Water Project (formerly OU5)—The Great Miami Aquifer will be remediated by a combination of treatment, extraction, and injection of the groundwater The Advanced Waste Water Treatment Facility was completed in 1994 with additional capacity added in 1998 The South Plume extraction system removal action began pumping in August 1993 The South Field extraction and injection system became operational in the summer of 1998

The future land use will include natural resource restoration on the majority of the site Natural resource restoration is part of on-going negotiations to settle the state of Ohio's natural resource damages claim against DOE Restoration will include development of wetlands, forests, and prairie areas Low-impact public access will be allowed The On-Site Disposal Facility will remain and be managed/monitored

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Fort Dix, New Jersey

In June 1960, a large fire in an antiaircraft bunker melted the warhead of a Boeing Michigan Aeronautical Research Center (BOMARC) missile, releasing plutonium to the environment Water used to fight the fire spread the plutonium over the land surface and into the subsurface Some equipment was eventually removed and the area of contamination covered with layers of concrete Many of the details regarding this accident and subsequent response remain classified

On August 7, 2000, the New Jersey Commission on Radiation Standards promulgated Soil Remediation Standards for Radioactive Materials (N J A C 7 28-12), intended to apply as an ARAR at radioactively contaminated CERCLA sites Minimum remediation standards are based on a 15-mrem TEDE limit This annual dose limit includes the groundwater pathway and equates to 1 standard deviation of the background levels in the state This dose limit was translated to soil concentration limits using an all-pathways approach These soil remediation standards are increments above background Average background concentrations of the radionuclides at a site are determined using MARSSIM methodologies or other approved methods The sum of fractions rule applies to sites with multiple radionuclides

DCGLs have been calculated using a spreadsheet for several individual radionuclides (U-234, U-235, U-238, Ra-226, Ac-227, and Th-232) These dose-based DCGLs have been derived for unrestricted use (residential), limited restricted use (institutional controls required), and restricted use (institutional controls and engineering controls required) using parameters from EPA's Exposure Factors Handbook (EPA, 1997b) and NRC's NUREG 5512 (NRC, 1992) Table 6 shows the values for 1 foot of contaminated soil

Table 6. Fort Dix Soil Remediation Standards for Radionuclides, in pCi/g

Radionuclide	Unrestricted Use[a]	Limited Restricted Use[b]	Restricted Use[c] (1-foot cover)
Ac-227	3	5	17
Ra-226	3	5	7
Th-232	2	3	15
U-234	62	69	81
U-235	29	37	62
U-238	54	64	82

[a] Residential use
[b] Institutional controls required
[c] Commercial use, institutional and engineering controls required, cover must be maintained

Sites may petition for alternative remediation standards in lieu of the DCGL tables using RESRAD or the spreadsheet RaSoRS These alternate soil cleanup standards must

- not exceed 15-mrem/year TEDE,
- not exceed 3 pCi/L of radon in indoor air, and
- not exceed New Jersey Groundwater Quality Standards

Table 7 shows the input values for alternative remediation standards and how they differ for the unrestricted and restricted land use

Table 7. Standard Input Values for Certain Parameters for Calculating Alternative Soil Standards for Radionuclides at Fort Dix

Parameter	Unrestricted Use	Limited or Restricted Use
Indoor onsite breathing rate (m^3/h)	0 63	1 4
Outdoor onsite breathing rate (m^3/h)	1 40	1 4
Soil ingestion rate (g/year)	70	12 5
Homegrown crop ingestion rate (g/year)	17,136	0
Drinking water consumption rate (L/year)	700	700
Shielding factor through building or slab	0 20	0 20
Shielding factor through wall	0 80	0 80
Shielding factor outside	1	1
Fraction of time spent indoors on site	0 70	0 18
Fraction of time spent outdoors on site	0 05	0 05
Soil-to-vegetation transfer factors (pCi/g wet plant to pCi/g dry soil)		
Thorium	1×10^{-3}	1×10^{3}
Radium	4×10^{-2}	4×10^{2}
Lead	1×10^{-2}	1×10^{2}
Polonium	1×10^{-3}	1×10^{3}
Uranium	$2\ 5 \times 10^{-3}$	$2\ 5 \times 10^{-3}$
Actinium	$2\ 5 \times 10^{-3}$	$2\ 5 \times 10^{-3}$
Protactinium	1×10^{-2}	1×10^{-2}
Bismuth	1×10^{-1}	1×10^{-1}

The U S Air Force, which is responsible for the cleanup at Ft Dix, derived a cleanup level of 8 pCi/g of plutonium for a ROD, which was signed in 1992 This activity level was originally designed to represent a 4-mrem annual dose Even though this value has not been reduced to account for other radionculides such as americium in-growth, it is acceptable to the New Jersey Department of Environmental Protection since it is considerably lower than an unrestricted cleanup level based on the state's current dose criterion of 15 mrem/year (approximately 25 pCi/g of Pu) The ROD requires the removal and off-site disposition of concrete and soils that exceed the 8 pCi/g cleanup level

The New Jersey Soil Remediation Standards include a section pertaining to changes in land use These requirements state that a "subsequent proposed use of a property that is different from the intended use (other than unrestricted use remedial actions) described in the original remediation proposal shall require a prior review and prior approval by the Department [of Environmental Protection] " The department and affected cities must be informed of the following

- the new land use compared to the original use,
- additional remedial actions, or engineering or institutional controls to be implemented,
- a dose assessment analysis, and
- new characterization data, such as soil concentrations

Remediation of the BOMARC missile site at Ft Dix is anticipated for 2002 The U S Air Force will begin by rebuilding a rail line entirely on federal property, a task expected to be completed by the end of March Based on characterization data, the Air Force expects to remove approximately 8,000–10,000 cubic yards of soil Excavation will begin in April and is scheduled for completion in October 2002

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Hanford Site, Washington

The DOE Hanford Site occupies 586 square miles in the southeastern portion of Washington state The site is adjacent to the Columbia River in a semiarid region and constitutes one of the prime remaining examples of shrub-steppe habitat The site is divided into four different sites listed on the NPL, the 100 Area (nine former production reactors), 200 Area (fuel reprocessing and waste management), 300 Area (fuel fabrication), and 1100 Area (support and outlying areas)

Hanford, a government-owned, contractor-operated facility, is part of the nationwide nuclear weapons complex Previous operations at the site consisted of fabrication of uranium fuel for irradiation in production reactors (300 Area), irradiation of fuel in eight single-pass and one closed-loop nuclear reactors (100 Area), and recovery of plutonium and uranium from irradiated fuel (200 Area) Each of the primary environmental issues has an estimated cost of $500–5,000 million

- interim stabilization of the production reactors (100 Area),
- cleanup of burial grounds and liquid waste disposal sites adjacent to the reactors (100 Area),
- retrieval and repackaging of spent nuclear fuel (100 Area),
- disposition of the "canyon"-type reprocessing buildings (200 Area),
- closure of 177 waste tanks, including vitrification of the tank wastes (200 Area),
- environmental restoration of waste treatment, storage, and disposal areas in the former fuel reprocessing (200 Area), and
- environmental restoration of the former fuel fabrication area, including retrieval and treatment of remotely-handled transuranic (TRU) waste from two burial grounds (300 Area)

DOE, EPA, and the Washington Department of Ecology signed a comprehensive cleanup and compliance agreement, the Tri-Party Agreement (TPA) on May 15, 1989 The TPA prescribes numerous milestones for interim remedial actions (IRAs), including IRA RODs The RODs typically present chemical-specific remediation levels based on the most restrictive number from different pathways, e g , (1) protection from direct exposure, (2) contaminant-specific concentration in soil, protective of groundwater, and (3) contaminant-specific concentration in soil, protective of the Columbia River

Washington's Model Toxics Control Act (MTCA), Washington Administrative Code 173-340 (WDOE, 1996), is an ARAR under CERCLA Typically, the critical pathway is contaminant-specific concentration in soil, protective of the Columbia River, and is based on (1) a provision in MTCA establishing the relationship that concentrations in soil shall be "equal to less than one hundred times the groundwater cleanup level" and (2) an assumed dilution factor from groundwater into the Columbia River

MTCA tabulates soil cleanup standards and groundwater cleanup levels under method A (tabulated/routine), and cleanup levels can be calculated using the Cleanup Levels and Risk Calculation (CLARC) risk assessment model for method B (standard/industrial) and method C (conditional application) MTCA requires cleanup to 10^{-5} excess risk for all carcinogens (10^{-6} per contaminant) Proposed revisions to MTCA include methods for assessing impact to terrestrial ecology

The MTCA risk assessment model is not appropriate for calculating risk due to direct exposure to radionuclides, and the state of Washington has not issued a policy statement regarding the use of MTCA for regulating radionuclides The Washington Department of Health administers radiation protection standards as an "agreement state" with NRC, but current usage of those regulations is limited to radionuclides in air The IRA RODs at Hanford generally default to a remediation level of 15 mrem for soil and 4 mrem for groundwater The RESRAD code is used to calculate dose

The Hanford Site Risk Assessment Methodology (HSRAM), published in May 1995, ensures the use of consistent exposure scenarios, exposure parameters, and computer models for IRA risk assessments However, it is only guidance, and it needs to be updated because it was based on then-current EPA Risk Assessment Guidance for Superfund The methodology is typically

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applied on an action-specific (IRA-specific) basis and is used to compute remediation levels for particular contaminants of concern The Native American lifestyle is an important risk scenario for Hanford because of the expectation that, after remediation, Native Americans will resume hunting, fishing, and cultural practices at usual and accustomed places The HSRAM is weak in its treatment of ecological risk assessment Typically, ecological risk assessment has been addressed on either a qualitative basis for particular actions or has been focused on a specific contaminant of concern and specific receptor Again, the proposed revisions to MTCA include additional tools for ecological risk assessment

Remediation in the 100 Area provides an example of how cleanup levels have been developed at Hanford The *Remedial Design Report/Remedial Action Work Plan for the 100 Area* (DOE, 1998) presents remedial action goals (RAGs) for radionuclide contaminants in soil at the 100-Area liquid-waste disposal sites These RAGs are intended to support a cleanup that achieves both the remedial action objective (RAO) for direct exposure and the RAO for protection of groundwater and the Columbia River

A primary goal of the ROD (EPA, 1995), signed in September 1995, is to achieve cleanup levels that would not restrict future land use in the 100 Area Unrestricted use is represented by a rural residential scenario, and RAGs are based on a 15-mrem annual dose as calculated by the RESRAD code This dose limit had EPA's draft proposed cleanup rule as its basis The direct exposure pathways considered in estimating dose from radionuclides in soil are inhalation, soil ingestion, ingestion of homegrown crops, meat, fish, drinking water, and milk, and external gamma exposure The resident is assumed to live in a house with a basement 3 7 m (12 feet) below grade and to spend 25% of the time in the basement Doses are calculated separately for fill soil 0–4 6 m (0–15 feet) below grade and for residual contaminants at the bottom of the basement excavation For most of the radionuclide contaminants of concern in the 100 Area, external gamma exposure is the dominant modeled pathway (inhalation and ingestion contribute little to the total dose) Ingestion pathways dominate for strontium-90, however

The single radionuclide values in Table 8 are "intended for use in estimating contamination volumes, screening field sampling and analytical data, and guiding remediation They are not intended to represent final cleanup concentrations to be achieved by remedial action at a particular site" (DOE, 1998) The most limiting among the RAGs calculated for protection from direct exposure, protection of groundwater, or protection of the Columbia River, is selected as a "look-up" value Since most sites will have multiple radionuclides driving cleanup, the dose limit would result in individual radionuclide concentrations that are lower than these values Generic input parameters have been assumed for the purpose of developing the look-up values in this table, many of the important parameters used are listed in Table 3 These parameters are essentially the same developed in guidance by the Washington Department of Health (WDOH, 1997) Final cleanup levels for specific site closeout verification will be determined using site-specific parameters Deed restrictions are required to prohibit excavation in areas where concentrations below the 4 6-m (15-foot) level exceed the direct-exposure RAGs

Table 8. Remedial Action Goals for the 100 Area at the Hanford Site (DOE, 1998)

Radionuclide	Remedial Action Goal for Direct Exposure[a] (pCi/g)	Soil Concentration Protective of Groundwater/ Columbia River[b] (pCi/g)	Remedial Action Goals—Look-Up Values (pCi/g)	
			Shallow Zone[c] <4.6 m (15 feet)	Deep Zone[d] >4.6 m (15 feet)
Americium-241	31 1	1,577,000	31 1	1,577,000
Cesium-137	6 2	[e]	6 2	NA
Cobalt-60	1 4	[e]	1 4	NA
Europium-152	3 3	[e]	3 3	NA
Europium-154	3 0	[e]	3 0	NA
Europium-155	125	[e]	125	NA
Nickel-63	4,026	[e]	4,026	NA
Plutonium-238	37 2	1,123	37 2	1,123
Plutonium-239/240	33 9	718,600	33 9	718,600
Strontium-90	4 5	[e]	4 5	NA
Technetium-99	15	15[f]	15[f]	15[f]
Thorium-232	1 3	[e]	1 3	NA
Tritium (H-3)	510	35 5	510	35 5
Uranium-233/234	1 1	1 1[g]	1 1[g]	1 1[g]
Uranium-235	1 0	1 0[f]	1 0[f]	1 0[f]
Uranium-238	1 1	1 1[g]	1 1[g]	1 1[g]

[a] 15-mrem dose to a rural resident
[b] Soil concentration that either corresponds to a 4-mrem annual dose or achieves the groundwater/river protection RAGs per RESRAD calculations
[c] In the shallow zone, cleanup must achieve the direct exposure RAO and the groundwater/Columbia River RAO, therefore, the lowest value associated with those RAOs is the applicable look-up value
[d] In the deep zone, cleanup must achieve the groundwater/Columbia River RAO, therefore, the lowest value associated with that RAO is the applicable look-up value
[e] RESRAD predicts the radionuclide will not reach groundwater within a 1,000-year timeframe
[f] The RAG is below the practical quantitation limit (PQL), the value presented is the PQL
[g] The RAG is below background, the value presented is background

Remedial actions are scheduled over multiple decades ending in 2050

- Interim stabilization of the production reactors (100 Area) is required by 2018, but negotiations in progress (as of December 2001) projected completion by 2012 The reactors will be allowed to "decay in place" for 70 years to allow short-lived radionuclides to decay to inconsequential concentrations DOE plans to make final disposition of the reactors after that
- Cleanup of burial grounds and liquid waste disposal sites adjacent to the reactors (100 Area) is 30% complete and will finish by 2012
- Retrieval and repackaging of spent nuclear fuel (100 Area) is in progress and will finish by 2006 Waste residuals fuel packed in canisters will be stored in the 200 Area pending construction of the national high-level waste repository

- Options for disposition of the "canyon"-type reprocessing buildings (200 Area) are being evaluated and may dovetail with soil remediation schedules One option is use of the canyons for waste disposal
- Closure of 177 waste tanks, including vitrification of the tank wastes (200 Area) is on a multiple-decade schedule DOE has an enforceable milestone to construct and operate a waste treatment plant (vitrification plant)
- RI/FS for environmental restoration of waste treatment, storage and disposal areas in the former fuel reprocessing (200) area will be completed by 2008 Schedules for remedial actions are being negotiated (as of December 2001)
- Environmental restoration of the former fuel fabrication area, including retrieval and treatment of remotely handled TRU waste from two burial grounds (300 Area) will be completed by 2018

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Johnston Atoll

Johnston Atoll is located between Hawaii and the Marshall Islands Oahu, 720 nautical miles northwest of the atoll, is the closest inhabited island The atoll originated as a volcanic island but is now composed exclusively of coral There were no indigenous people on the islands, and until World War II the islands were only occasionally inhabited Since 1941, the atoll has been used as a military reservation The atoll is composed of two islands, Johnston Island and Sand Island Johnston Island was originally about 46 acres, but after several periods of dredging, the area at the time of the nuclear tests was 185 acres Since the tests, the island has been further enlarged to 625 acres The atoll has been determined to have no further defense mission and remains an unincorporated territory of the United States Operational control is currently held by the Defense Threat Reduction Agency (DTRA) of the Department of Defense After cleanup, the island will be declared a wildlife refuge under the administration of the U S Fish and Wildlife Service

The contamination on Johnston Atoll was caused by three separate accidents involving THOR rockets during high-altitude tests of nuclear devices during the summer and fall of 1962 None of the accidents resulted in an accidental detonation of a nuclear device One rocket exploded on the

If the pathways that produced the risks are examined, the ingestion pathway, especially soil ingestion, dominates, as shown in Exhibit 14.

Table 10. Contribution of exposure pathways to calculated risk at Johnson Atoll

Pathway	Fish and Wildlife Worker	Resident	Ecotourist	Homesteader
Inhalation	4.9%	9.3%	1.8%	3.7%
Soil ingestion	86.9%	82.2%	16.1%	34.9%
Plant ingestion	0%	0.7%	0%	56.6%
External exposure	8.2%	7.7%	82.1%	4.6%

Following release of its *Johnston Atoll Radiological Survey*, DTRA proposed a cleanup standard of 40 pCi/g, which is an estimated 2.1×10^{-5} risk to a hypothetical resident.

In September 2000, EPA Region 9 responded to DTRA's proposed cleanup standard and risk assessment (EPA, 2000), concluding that "the Johnston Atoll radiological risk assessment conforms with the standard and uniform methods for the evaluation of site-specific risk" and that the exposure parameters used are reasonable and appropriate. Any of the values calculated for the three risk levels are consistent with EPA's policies. In determining an RME, EPA rejected the homesteader scenario as overly conservative because of the 70-year exposure duration, the remote location, and the lack of potable water and productive soils. The ecotourist was considered insufficiently conservative, since the Fish and Wildlife Service planned to remain on the atoll. The other two scenarios are nearly identical, and EPA selected the resident to represent the RME for an individual.

EPA recommended a cleanup level of 13.5 pCi/g, the historically used value, which equates to a 7.1×10^{-6} risk to a resident. EPA considers this value ALARA, since DTRA had previously achieved this level, and believes this lower level will help to account for the presence of other contaminants, such as dioxins, polychlorinated biphenyls, and lead.

The island has undergone several previous cleanup attempts. In 1962, the debris from the destroyed rockets and some surface coral were loaded into landing craft and disposed of at sea. The less-contaminated soil was dumped into the lagoon. No formal cleanup standard was used to determine the extent of the cleanup. Two years later the lagoon was dredged, and most of the contaminated soil was incorporated into the island. At the end of November 2000, the U.S. Army announced that all of the 400,000 chemical weapons that had been stockpiled on Johnston Atoll had been destroyed. The disposal facility used for the project will be shut down and the islands turned over to the Fish and Wildlife Service.

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Linde Site, New York

The Linde Site is located in the town of Tonawanda, New York, near Buffalo From 1942 to 1946 (or 1948 according to some records), this site was used for separation of uranium ores from Colorado and the Congo under the Manhattan Engineering District Ores were processed in three phases uranium separation from the ore, conversion of U_3O_8 to uranium dioxide, and conversion of UO_2 to UF_4 The principal contaminants of concern resulted from the first processing phase, residues from the other phases were recycled Disposal of processing wastes from the Linde property also contaminated three other sites in Tonawanda Radioactive contamination occurs in processing buildings, surface and subsurface soils, and sediments in sumps and storm and sanitary sewers Also, approximately 55 million gallons of waste effluent containing dissolved uranium dioxide was injected into the subsurface through seven wells during a three-year period The RI (BNI, 1993) concluded that subsurface radioactive contamination probably occurs as minor amounts of immobile uranyl sulfates and carbonates precipitate in the underlying shale

The Army Corps of Engineers became the lead regulatory agency for the Linde site in 1998, when Congress handed the Formerly Utilized Sites Remedial Action Program (FUSRAP) to the Corps DOE had previously handled the cleanup effort and had issued a proposed plan in 1993, calling for a cleanup level of 60 pCi/g for total uranium In accordance with the NCP requirement that selected remedies comply with ARARs, the Corps reviewed UMTRCA for applicability Standards in UMTRCA (40 CFR Part 192) are not considered applicable since the regulation applies only to specific sites designated in the act The Corps, however, determined that UMTRCA is relevant and appropriate to the Linde Site cleanup since the processing activities and radionuclides in the resulting wastes are similar to those at uranium mill sites In a new proposed plan (USACE, 1999) issued in March 1999 and in a ROD (USACE, 2000) signed in June 2000, the Corps calculated new cleanup levels based on UMTRCA

Subpart A of 40 CFR 192 establishes groundwater standards including maximum radionuclide concentrations

- combined Ra-226 and Ra-228 5 pCi/L,
- combined U-234 and U-238 30 pCi/L, and
- gross alpha particle activity (excluding radon and uranium) 15 pCi/L

A review by the Corps of previous groundwater sampling results shows that these standards are not exceeded Based on these results and information that showed that groundwater at the site is not potable, the Corps concluded that groundwater at the Linde Site does not need to be remedied

Subpart B of 40 CFR 192 addresses cleanup of soil and buildings and sets standards for residual concentrations of Ra-226 in soil Radium concentrations cannot exceed background by more than 5 pCi/g in the upper 15 cm of soil or 15 pCi/g in any 15-cm layer below the upper layer, averaged over an area of 100 m^2

Subpart D of 40 CFR 192 requires that releases of Rn-222 and Rn-220 into the atmosphere cannot exceed an average rate of 20 pCi/m^2-sec The proposed plan concludes that implementation of the proposed remedy will result in releases that are below this limit

In addition to UMTRCA requirements, the Corps also developed cleanup levels for various risks and doses (USACE, 1999) This cleanup guideline for total uranium applies to areas of the Linde site where soils are predominantly contaminated with uranium and very little radium and thorium A risk assessment conducted by the Corps considered the radiological risk as well as the chemical toxicity of uranium That assessment used the RESRAD computer code (Version 5 782) and considered the most likely future land use to be the site's current industrial/commercial use A cleanup level of 600 pCi/g for uranium was calculated based on limiting potential radiological risks to 10^{-5} This 600 pCi/g cleanup level for uranium, together with the UMTRCA criteria, form the cleanup requirements for the Linde Site The calculated values shown in Table 11 used the input parameters given in Table 12

Table 11. RESRAD-Calculated Estimates for the Commercial/Industrial Exposure Scenario to Meet Acceptable Dose and Risk Limits at the Linde Site

Radionuclide	Residual Concentration (pCi/g)					
	10 mrem/year		25 mrem/year		10^{-4} risk	
	6-inch cover	No cover	6-inch cover	No cover	6-inch cover	No cover
Ra-226	37	5 7	92	14	25	6 1
Th-230	107	16	267	41	71	11
Th-232	23	3 9	58	9 8	16	2 8
Total U[a]	1,888	629	4,720	1,572	7,400	6,200

[a] Total uranium includes U-238, U-235, and U-234 at natural concentration ratios (1 0/0 05/1 0, respectively)

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Table 12. Future Industrial/Commercial Worker Parameters—Linde Site

RESRAD Parameter	Value
Area of impacted zone	2,000 m^2
Thickness of impacted zone	3 m
Cover depth	0–0 15 m
Inhalation rate	8,400 m^3/year
Mass loading for inhalation	0 0001 g/m^3
Exposure duration	25 years
Shielding factor, inhalation	0 4
Shielding factor, external gamma	0 7
Fraction of time indoors	0 2
Fraction of time outdoors	0 03
Soil ingestion rate	18 25 g/year
Drinking water intake	0 L/year

In response to public comments, the Corps redefined how cleanup levels were derived Subsequent to the cleanup levels calculated for the radiological assessment, a new amendment to 10 CFR 40, Appendix A, Criterion 6(6) was promulgated, which addressed areas contaminated with radionuclides in addition to radium This criterion states that post-remedial radioactive contamination, considering all radionuclides including radium, cannot result in a TEDE to the average member of the critical group exceeding the benchmark dose after cleanup to the 40 CFR Part 192 standards for soils contaminated with radium only The benchmark dose for surface cleanup was derived by dividing the 10 mrem/year (with no cover) by the 5 7 pCi/g of Ra-226 associated with that dose, and then multiplying the result by 5 pCi/g of Ra-226, resulting in a benchmark dose of 8 8 mrem/year for surface cleanups The 10-mrem values for Th-230 and total uranium were used to calculate allowable concentrations for those radionuclides The same methodology was used to derive a benchmark dose for subsurface cleanup levels as well These calculated benchmark dose values are shown in Table 13

Table 13 Allowable Residual Concentration Limit for Indicated Benchmark Dose—Linde Site, in pCi/g

Radionuclide	Surface Soil 8.8 mrem/year	Subsurface Soil 4.1 mrem/year
Ra-226	5 0	15
Th-230	14	44
U-total	554	3,021

This new method of deriving cleanup levels resulted in a more stringent cleanup for total uranium than was required in the proposed plan Radionuclide concentrations remaining in soils averaged over 100 m^2 must be below these levels If more than one residual radionuclide is present in a 100-m^2 area, the sum-of-the-ratios methodology will be applied The ROD also commits that no concentration (hotspots) of total uranium greater than 600 pCi/g above background will remain in site soils

The ROD for the Linde site was signed in March 2000 by the Corps' Deputy Commanding General for Civil Works EPA Region 2 and the New York Department of Environmental

Conservation and Department of Health, however, have refused to support the cleanup levels designated in the ROD The agencies disagree with these levels for several reasons

- Since the site will not be government owned, only a residential-based assessment will protect against future changes in ownership
- The current industrial/commercial use is not sufficiently protective of future uses
- The cleanup level calculations exclude a groundwater pathway
- The ALARA concept was not incorporated
- The calculations are not consistent with NRC guidance
- The calculations do not consider state guidance in Technical and Administrative Guidance Memorandum #4003, which limits exposure of maximally exposed individuals to 10 mrem/year

The Corps expects that its remedial actions will lower the average activity levels due to residual contamination to about 60 pCi/g for uranium and 5 pCi/g for radium The state would accept this level of cleanup, which is the level originally presented in the 1993 proposed plan The state plans to require a radioactive materials license for any future landowner if the residual radiation is greater than 0 05% by weight EPA's position is that the cleanup level should be below 100 pCi/g, a level "consistent with cleanup levels at other CERCLA radiation sites "

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Maralinga, Australia

Between 1955 and 1963, the United Kingdom conducted a series of nuclear weapons tests at Maralinga, including seven nuclear explosions called "major trials" The sites of these major trials no longer present any significant health risk, because all the radioactivity released in these explosions was either dispersed throughout the world or has sufficiently decayed since

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(ARPNSA, 2000) Plutonium contamination was spread locally as a fine dust, as small submillimeter-size particles, and as surface contamination on larger fragments by several hundred "minor trials" These consisted of radioactive materials exploded with conventional explosives, similar to the "safety shots" conducted at the Tonapah Test Range in Nevada

The selected remedy involves removing 10 millimeters of soil from the areas of worst contamination and restricting access to 120 km^2 of land The contaminated soil and debris is buried in trenches on-site under at least 5 meters of fill Unknown amounts of contaminated debris in 21 pits will be vitrified in-situ Cleanup criteria were set by using "conservative principals" and by estimating doses for "realistic scenarios" (ARPNSA, 2000) These include Aborigines living just outside the controlled areas and hunting inside them The highest activity allowed outside of controlled areas is 20 - 35 kBq/m^2 (about 540 – 950 pCi/m^2) of Pu-239 depending on the particular site, which is calculated to produce a 5 mSv (500 mrem) annual dose

Because it is relatively easy to detect in the field, Am-241 is used to indicate concentrations of Pu-239 Ratios of Pu-239/Am-241 vary from site to site and even from test to test at a single site Therefore, Pu-239/Am-241 ratios have been determined for every cleanup area Actual soil removals are delineated by activity levels for Am-241 that are specific for that particular area based on these ratios

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Nevada Test Site and Associated Test Ranges, Nevada

The Nevada Test Site (NTS) is a DOE, National Nuclear Security Administration Nevada Operations Office (NNSA/NV) installation occupying approximately 1,505 square miles in southeastern Nye County, Nevada. The site is situated about 65 miles northwest of Las Vegas, home to 1.2 million residents and annual visitor counts now exceeding 30 million. NTS is larger than the state of Rhode Island, and site features include deserts, playas, and mountainous terrain. NTS was established in 1951 as the nation's proving ground for testing and development of nuclear weapons. Between 1951 and 1992, the federal government conducted just over 900 nuclear tests at the site. One hundred of these tests were conducted above ground. NTS is surrounded by thousands of additional acres withdrawn from the public domain for use as a protected wildlife refuge and for military gunnery ranges, creating an unpopulated land area comprising some 5,470 square miles.

NNSA/NV also conducted numerous safety experiments at NTS and on the Nellis Air Force Range (NAFR) complex. These experiments were conducted at five NAFR locations—Double Tracks, Clean Slates 1, 2, and 3, and Project 57—to determine the behavior of nuclear weapons in conventional explosive accident scenarios during handling, storage, and transportation operations and to determine the biological uptake of plutonium by various species of animals and plants. These experiments did not produce nuclear explosions, however, they did create significant surface contamination. The depth of contamination at these soil sites varies and NNSA/NV has estimated that about 2,885 acres is contaminated with plutonium at levels in excess of 40 pCi/g.

In May 1996, the Nevada Division of Environmental Protection (NDEP) and the NNSA/NV signed a federal facilities agreement and consent order that, in part, authorized NDEP to oversee NNSA/NV's remediation of radiologically contaminated surface soil sites in the state. "Clean Slate" sites will be the focus of this remediation effort, Operation Roller Coaster. Operation Roller Coaster was a series of tests conducted to determine the effects of plutonium dispersion. Concentrations of these radioactive materials at the Clean Slate sites range from background to more than 12,800 pCi/g. The sites are located on the Tonopah Test Range, approximately 130 miles northwest of Las Vegas and 40 miles southeast of Tonopah, Nevada, in the high desert region of south central Nevada at an elevation of 5,380 feet.

Proposed interim cleanup actions by DOE at the Clean Slate 1, 2, and 3, Double Tracks, and Project 57 sites were based on a 200-mrem cleanup level established in *Radiological Dose Assessment for Residual Radioactive Material in Soil at the Clean Slate Sites 1, 2, and 3, Tonapah Test Range* (DOE, 1997). This assessment reviewed several dose analyses previously performed in the area of NTS. Each of these analyses used different exposure scenarios and parameter values. Although these analyses varied in their assumptions, the general conclusion reached by the dose assessment was that an average activity level of 200 pCi/g would ensure that the public dose limit of 100 mrem/year in DOE Order 5400.5 would be met. The RESRAD computer code evaluated four human exposure scenarios by means of an environmental pathway analysis performed by a forward calculation of the RESRAD computer code for the following receptors: rancher, farmer, rural resident, and industrial worker.

The two agricultural scenarios were considered implausible by DOE but were included for completeness The maximum committed effective dose equivalent (CEDE) calculated in the dose assessment, 47 mrem/year to a rancher, is less than half the basic dose limit in DOE Order 5400 5 The rural residential and industrial worker scenarios were included because they were established as part of EPA's draft proposed cleanup regulations (EPA, 1996) This proposed regulation was not considered applicable to DOE operations, but the scenarios were included for comparison Calculated CEDE values for both these scenarios were less than the 15-mrem/year dose limit in the draft proposed EPA regulations For the purpose of calculating "guideline concentrations," the Pu-239/240 Am-241 ratio was assumed be 14 1, and the depth of contamination was assumed to be 5 cm These guideline concentrations were never accepted by NDEP as cleanup levels Tables 14 and 15 show the calculated dose and key parameters used for different receptors at the site

Table 14 DOE-Calculated Dose to Hypothetical Individuals Exposed to 200 pCi/g at the Clean Slate Sites, in mrem/year

Scenario	Clean Slate 1	Clean Slate 2	Clean Slate 3
Rancher	47	47	46
Rancher child	23	23	22
Farmer	12	12	12
Rural resident	13	13	13
Industrial worker	4 5	4 4	4 4

Table 15 Key Parameter Values Used for Exposure Scenarios in the Clean Slate Sites Dose Assessment

Parameter	Rural Resident	Rancher	Farmer	Industrial Worker	Child
Exposure frequency (day/year)	341	341	341	250	330
Inhalation (m^3/d)	20	22	22	12 6	12 3
Soil ingestion (mg/d)	120	131	129	50	24
Exposure time indoors (h/d)	14 9	9	9	8	18 4
Exposure time outdoors(h/d)	0 4	15	15	2	5 6
Shielding factor—indoor inhalation	0 4	1	1	0 4	0 4
Drinking water ingestion (L/d)	1 4	1 86	1 86	0 875	0 32
Leafy vegetable ingestion (g/d)	29 5	29 5	29 5	0	18 5
Plant ingestion (g/d)	354	354	353	0	397
Milk ingestion (L/d)	0 61	0 61	0 61	0	1 18
Meat/egg ingestion (g/d)	274	274	274	0	153

NNSA/NV proposed interim remediation requirements for the Clean Slate 1, 2, and 3, Double Tracks, and Project 57 sites were

- average soil concentrations over any 100-m^2 area must not exceed 200 pCi/g,
- plutonium hotspot concentrations averaged over an area of 25 m^2 or less must not exceed the guideline concentration by a factor of (100/hotspot area in meters)$^{0.5}$ [DOE Order 5400 5, Chapter IV, Section 4 a (1)], and
- reasonable efforts must be made to remove any source of radionuclides that exceeds 30 times the guideline levels, regardless of the average concentrations

This interim action, however, did not achieve this guideline concentration level NNSA/NV did some ground-zero remediation and used the KIWI system, which consists of a Chevrolet Suburban with six 2 × 4 × 16-inch sodium iodide detectors mounted in a frame at the rear of the vehicle, to verify that cleanup levels were reached NNSA/NV then decided to have a segmented gate technology demonstration conducted at Clean Slate I to see whether soil reduction could be achieved A comparison of data collected during the segmented gate technology demonstration and revalidated KIWI data showed that the residual soil values were as much as 75% higher than originally reported NNSA/NV determined that the KIWI system did not provide accurate data (initially shown to be low by up to 75%), and NNSA/NV has not conducted any further termination under the NRC based on total dose received by all sources on site

Presently, there are no established regulations for amounts of plutonium that can be left in the soil at DOE-managed sites that are undergoing remediation However, there are NRC regulations and guidelines for commercial license termination that may be applicable, which are based on total dose received by all sources on site Therefore, an integrated evaluation of all potentially appropriate and/or applicable release criteria, utilizing professional judgment, must still be conducted

Ongoing negotiations between NDEP, the Department of Defense, and NNSA/NV indicate that these soil contamination areas should be remediated to a dose receptor limit of 25 mrem/year

NDEP has concerns that the RESRAD model may not provide an adequate or appropriate evaluation based on current utilization of the land NDEP accepts that the residential rancher/farmer scenario is the most conservative approach allowed in the RESRAD model The RESRAD model does not provide for a risk evaluation of the area as an active military installation under the current possible use scenarios While potential exposure risks associated with this type of activity may or may not be as significant as a rancher/farmer, NDEP contends that the current and anticipated future land-use scenario must be evaluated

NNSA/NV and the Air Force are currently working together to determine present land-use scenarios to define appropriate exposure concerns It should be noted that the Air Force would be required to address any residual radioactive soil contamination remaining at these sites based in accordance with the withdrawal legislation, which requires the land to be returned acceptable for unrestricted use This requirement may compel the Air Force to permanently withdraw the land and provide institutional control as well as constrain future mission activity in these areas Should mission activities require use of the land, the Air Force will be responsible for future remediation of these areas prior to use

NDEP has disputed some aspects of the most recent RESRAD calculations NNSA/NV has made, including the use of ICRP-68/72 DCFs NNSA/NV has also used model assumptions and default parameters, not current field data While historic information may be appropriate, NDEP asserts that verification of current conditions at the sites must occur No validation or confirmation of the characterization and remediation activities has been conducted other than a surface radiation survey, averaging residual contamination for activity level verification As reported above, comparison of data collected during a segmented gate technology demonstration and revalidated KIWI data showed that the residual soil values were as much as 75% higher than originally reported Upon the initial review of documentation, it appears to NDEP that historic sampling may not be sufficient to distinguish the variability in the distribution of contaminated particles over the site Additional sampling may be required to fill these data gaps and adequately characterize the site As part of the characterization and remediation of all radiologically contaminated soil sites, NDEP will require NNSA/NV to provide current validation of particulate size, particle distribution, depth profiling, and chemical form, as well as verification that contaminants are not a concern outside of the fenced zone The Air Force has proposed to do its own sampling event within federal fiscal year 2002 to validate NNSA/NV historic data and to obtain current site conditions

The Air Force is also currently conducting its own evaluation of what future land-use scenarios would be credible for Air Force activities and what action level will need to be established for these uses NDEP maintains that, if the scenario allows greater contamination to be left in place for proposed Air Force use, action levels and the cost for unrestricted use (resident rancher farmer) must still be evaluated, as this is a congressional requirement contained in the withdrawal legislation

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Oak Ridge Reservation—Melton Valley Watershed, Tennessee

The Melton Valley area of the Oak Ridge Reservation encompasses 1062 acres and contains numerous radioactive and hazardous waste units These units include low-level waste (LLW) trenches and pits, active waste storage areas, construction landfills, underground and above-grade tanks, impoundments, deep well injection (hydrofracture), buried pipelines, and contaminated buildings From 1943 to 1986, the valley was used for radioactive waste disposal, and as the southern regional burial ground from 1955 to 1963, received waste from across the complex Since 1986, the area has been used for active waste management A brief description of these units is provided below

- LLW—Areas of Melton Valley were used as early as 1943 for the shallow land burial of LLW Early procedures used unlined trenches and auger holes for waste disposal When filled, these areas were covered with soil or, in some cases, concrete Burial in the unlined trenches and auger holes was discontinued in 1986
- Active waste—A portion of the valley is being used for storage of active waste management materials, including TRU waste, LLW, and spent nuclear fuel The materials are stored in concrete silos, above-grade storage units, buildings, tents, and above-grade tanks
- Landfills—There are several construction debris landfills in Melton Valley These areas received bulk material and equipment that was not considered LLW
- Tanks—All tanks in Melton Valley are constructed of steel The newer tanks have cathodic protection to prevent corrosion and have secondary containment Older tanks are single-walled steel tanks These tanks received concentrated liquid LLW for underground storage Several of the tanks have already been remediated, and a few are scheduled for early action under the Bethel Valley ROD
- Impoundments—Several impoundments are located in Melton Valley, used to store wastewater and for direct storage of liquid LLW Most are unlined
- Deep Well Injection—The Hydrofracture facility pumped over 1 5 million curies of radioactive material (primarily cesium-137 and strontium-90) into hydraulically fractured

rock 800–1000 feet deep Monitoring wells that were installed during operation are scheduled to be plugged to prevent upward migration of highly contaminated liquids

Contaminants of concern cover the entire radionuclide spectrum From a soils cleanup perspective, cesium-137 and cobalt-60 are regarded as the most significant radionuclides because of the high energy of gamma radiation that these radionuclides emit

The Melton Valley ROD incorporates a concept of aggregating risk over an entire exposure unit DOE proposed, and the state of Tennessee and EPA have agreed, to identify exposure units and corresponding risk assumptions within the boundary of Melton Valley over which the receptor is assumed to roam

For the industrial areas of Melton Valley, two important assumptions are made in the industrial worker exposure scenario with regard to time The first calculation is based on the industrial worker's risk aggregated over the exposure unit for an entire working year (2000 hours per year) The second calculation is based upon the receptor being exposed to a particular location or hotspot (200 hours per year) The remediation level (soil cleanup level) is determined by the more protective of the two calculations

Soil concentration limits were calculated in three ways

- risk-based limits derived using the RAGS PRG equations (10^{-4} incremental lifetime cancer risk [ILCR]),
- RESRAD-derived risk-based limits (10^{-4} ILCR), and
- RESRAD-derived dose-based limits (25-mrem/year)

Values were derived using the RAGS PRG equations for an industrial worker scenario with a target risk goal of 10^{-4} ILCR The only deviation from the standard RAGS equations and default parameters was the addition of a "decay factor" to account for radioactive decay and in-growth of daughter radionuclides over the 25-year exposure duration This decay factor was incorporated into the calculations with the concurrence of EPA Region 4 and the Tennessee Department of Environment and Conservation

$$RL_{industrial} = 10^{-4} / ((SF_{oral})(12\ 5) + (SF_{ext})(0\ 183) + (SF_{inhal})(0\ 00379))\ (25)\ (DF),$$

where

$RL_{industrial}$	=	remediation level for soil under the industrial land use scenario,
SF_{oral}	=	oral slope factor,
SF_{ext}	=	external radiation slope factor,
SF_{inhal}	=	inhalation slope factor,
DF	=	radioactive decay factor (calculated as 25-year integrated average, using the midpoint (arithmetic average) activity for each 5-year time interval)

The RESRAD-derived concentration limits were originally developed using RESRAD Version 5 82, but Version 6 0 produces equivalent results Key RESRAD input parameter assumptions were selected to mimic RAGS-PRG calculations for the same industrial worker scenario for each of the pertinent exposure pathways (direct external radiation, particulate inhalation, incidental soil ingestion)

- *External exposure pathway*

  Indoor occupancy factor = 0
  Outdoor occupancy factor = 0
  Area of contaminated zone = 125 m^2 (yields area factor = 0 8, same as RAGS (1-Se))
  (product of occupancy factor and external area factor and depth factor of 1 yields 0 184, corresponding to 0 183 in RAGS-PRG)

- *Inhalation exposure pathway*

  Inhalation rate = 21,900 m^3/year (equivalent to RAGS 20 m^3 per 8-h workday for 8760 h/year)
  Dust loading = 7 5 x 10^{-6} g/m^3
  (product of inhalation rate, mass loading, occupancy factor, and inhalation area factor yields an annual inhaled mass of 0 004 g/year, corresponding to 0 0038 g/year in RAGS-PRG)

- *Soil ingestion pathway*

  Soil ingestion rate = 435 g/yr (when adjusted by occupancy factor (0 23) and ingestion area factor, yields 12 5 g/year soil ingested, equivalent to RAGS)

Other parameter values were set at RESRAD default values, since they do not significantly impact dose and risk estimates for the industrial scenario Table 16 presents the values for various individual radionuclides

The final remediation level for each radionuclide was selected as the most limiting (lowest) soil concentration limit from the RAGS calculation or the two RESRAD-derived concentration limits The risk-based limits were selected for most radionuclides and, with the exception of Sr-90 + D, risk-based limits derived using the RAGS-PRG equations and RESRAD were essentially equivalent (for Sr-90 + D, the RESRAD-derived concentration was lower due to the use of a different slope factor for external radiation) Thus, all values selected were derived to achieve both the target risk of 10^{-4} and the dose limit of 25 mrem/year For Melton Valley, the radionuclides Cs-137 and Co-60 are expected to be limiting in virtually all cases

Where multiple radionuclides are encountered, the sum of fractions will be applied to develop appropriate cleanup numbers for each contaminant In addition, any source, regardless of depth, which regulators determine is causing a significant impact to groundwater or surface water will be remediated This approach provides for risk-based decisions on soil cleanup that can be adapted to a variety of sites with differing land uses and contaminants Consideration must be given to the fact that under this approach, cleanup numbers for a particular radionuclide may vary from one exposure unit to the next, but aggregate risk levels will be the same or similar

Table 16. Oak Ridge—Melton Valley Remediation Levels (Industrial Worker)

Radionculide	RAGS-PRGs 10^{-4} Risk[a] (pCi/g)	RESRAD-Derived		Selected Cleanup Level (pCi/g)	Basis of Selection
		10^{-4} Risk[a] (pCi/g)	25-mrem/year dose (EDE) (pCi/g)		
Cesium-137	13 7	13 7	39 8	14	Risk
Cobalt-60	7 39	7 56	8 37	7 4	Risk
Curium-244	2260	2280	951	950	Dose
Europium-154	10 6	10 6	17 6	11	Risk
Lead-210	453	475	271	270	Dose
Radium-226	Alternative concentration			5	*
Radium-228	Alternative concentration			5	*
Strontium-90	7580	1230	3400	1200	Risk
Thorium-228	Alternative concentration			5	*
Thorium-232	Alternative concentration			5	*
Uranium-233	5050	5370	5510	5100	Risk
Uranium-234	6540	7100	6020	6000	Dose
Uranium-235	81 4	82 4	167	81	Risk
Uranium-238	311	331	852	310	Risk

[a] Incremental lifetime cancer risk

Issues associated with implementation of field remediation of soils using this approach will require more work between the state, EPA, and DOE Work plans will have to contain information on the field techniques that will be used to verify that cleanup has been achieved without imposing significant delays in the remedial actions Subsequent CERCLA documents at Oak Ridge are adopting variations of this approach for remediation of radioactively contaminated soils

The Melton Valley ROD, signed on September 21, 2000, requires approximately $164 million of remediation over the next decade The remediation of Melton Valley includes a complex mix of protective caps, hydraulic isolation, decontamination and decommissioning, and soils removal

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Savannah River Site, South Carolina—Seepage Basins Operable Unit

The Savannah River Site (SRS) is one of several government-owned, contractor-operated sites in DOE's nuclear defense complex Construction of SRS began in February 1951, and the first facility, the heavy water plant, began operating in August 1952 The first production reactor started operating in December 1953 SRS was constructed to produce basic materials used in nuclear weapons, primarily tritium and plutonium-239 Five reactors were built to produce these materials by irradiating target materials with neutrons Support facilities, including two chemical separations facilities, a heavy-water production plant, a nuclear fuel and target fabrication facility, and waste management facilities, were also built SRS produced about 36 metric tons of plutonium from 1953 to 1988 All five reactors are now shut down due to declining defense requirements However, until fresh supplies of tritium are available, recycling and reloading of tritium will continue

The SRS is located in south central South Carolina and occupies an area of approximately 310 square miles in Aiken, Barnwell, and Allendale counties A marked property line establishes the site's boundary to the north, south, and east The Savannah River forms the site's western boundary for approximately 35 miles along the South Carolina/Georgia border

Four unlined basins comprise the SRL [Savannah River Laboratory] Seepage Basins, located in the northwestern portion of SRS near the Savannah River Technology Center in the Administration and Management Area The seepage basins received low-level radioactive wastewater 1954–1982 Basins 1 and 2 began operation in 1954, Basins 3 and 4 were added in 1958 and 1960, respectively The basins are rectangular in shape and are connected by a series of sequential overflow channels designed to receive wastewater by overflow from Basin 1 to Basin 4 Wastewater entered the western end of Basin 1 via the 10-inch-diameter vitrified clay process sewer line Wastewater seldom reached Basin 4 because evaporation and infiltration in Basins 1 through 3 were high enough to maintain the level of wastewater in the basins below the overflow channel to Basin 4 Wastewater discharged to the basins included uranium, plutonium, cesium, strontium, thorium, radium, cobalt, americium, curium, ruthenium, alpha (unidentified), beta-gamma (unidentified), and tritium, tritium was the most abundant radionuclide discharged to the basins Nitrate, sodium, chlorine, calcium, and nickel were the primary inorganic constituents discharged to the basins Process knowledge suggests that no significant quantities of chlorinated organic compounds were discharged to the seepage basins Subsequent to the termination of operations in 1982, weeds, grasses, brush, and trees became established in the basins This vegetation underwent a volume reduction process by chipping and was bagged and staged within the basins pending disposition consistent with the basin soils This early action achieved the removal objective of limiting the spread of contamination due to foliage drop and wind dispersion

The conceptual site model for the SRL Seepage Basins OU identified several pathways for potential exposure to constituents released from the unit Mechanisms identified for constituents to reach receptors were ingestion of contaminated media, inhalation of airborne dust and/or volatile emissions, biotic uptake, dermal contact with contaminated media, and external radiation dose Four exposure pathways were identified in the conceptual site model airborne (volatiles and dust), biota (biotic uptake), surface soil (direct contact with excavated subsurface soil), and groundwater (leaching) Soil, surface water and sediment, and groundwater sample results were used to evaluate potential exposures and risks for each of these

On December 21, 1989, SRS was included on NPL This inclusion created a need to integrate the established RCRA Facility Investigation (RFI) program with the CERCLA requirements to provide for a focused environmental program In accordance with Section 120 of CERCLA, 42 USC Section 9620, DOE negotiated a federal facility agreement with EPA and the South Carolina Department of Health and Environmental Control (SCDHEC) to coordinate remedial activities at SRS as one comprehensive strategy which fulfills these dual regulatory requirements DOE functions as the lead agency for remedial activities at SRS, with concurrence EPA Region 4 and SCDHEC

The SRL Seepage Basins OU was identified as a solid waste management unit requiring investigation in the Natural Resources Defense Council consent agreement This decree required SRS to submit various documents, including a closure plan for the units A closure plan proposing the installation of a RCRA cap was written and submitted in 1993, using procedural requirements applicable to RCRA closure plans Revision 0 of the closure plan received a notice of deficiencies/warning from SCDHEC and was revised and reissued Revision 1 received considerable comment from public stakeholders After consideration of comments, SCDHEC determined that a more comprehensive evaluation of the unit and closure alternatives was warranted DOE and SCDHEC decided that the SRL Seepage Basins OU should be evaluated under the RCRA/CERCLA process, which considers remedial alternatives against the nine CERCLA criteria to select a remedy protective of human health and the environment

As the investigation/assessment process for the SRL Seepage Basins OU, a baseline risk assessment was performed using data generated during the investigation phase This evaluation identified the contaminants of concern (COCs) and the presence of principal threat source material (PTSM) and therefore provided the basis for remedial action PTSM is defined as source material that is highly toxic and/or mobile at levels that pose a risk to human health greater than 1×10^{-3} (industrial worker scenario) should exposure occur

RAOs are established to identify the cleanup objectives for a given waste unit The RAO for the SRL Seepage Basins is to ensure the protection of human health and the environment This objective will be achieved by eliminating surficial soil exposure and potential leachability to groundwater and removing or treating all PTSM Remedial goal options (RGOs) are developed to achieve the RAOs RGOs are concentration goals for individual chemicals in specific media and land use combinations They are designed to provide conservative, long-term targets for the selection and analysis of remedial alternatives Human health RGOs estimate protective remedial levels for COCs based on risk to human receptors In a similar manner, ecological RGOs are based on risks to ecological receptors Contaminant migration RGOs are based on risk from contaminants in soil leaching to groundwater above an MCL Final remedial levels for the COCs, which will be selected by risk managers, are to be protective of human health and ecological receptors and comply with federal and South Carolina ARARs

Excess lifetime cancer risk was calculated for unit-related radionuclides using EPA exposure factors and slope factors from HEAST Total media risk (TMR, e g , total carcinogenic risk for surface soil) was determined by summing the individual constituent risks within the particular media This TMR value was then used to determine the need for remedial action Since human health and PTSM COCs were identified at the SRL Seepage Basins and the TMR for surface soils was 2×10^{-1} for the industrial scenario, RGOs were then back-calculated for the respective risk levels (10^{-6}, 10^{-5}, 10^{-4} and 10^{-3} industrial for PTSM), shown in Table 17 Based on risk-management decisions, remedial goals were then determined from the RGOs

Table 17. Soil Remediation Goals for the SRL Seepage Basin, in pCi/g

Contaminant of Concern (Radionuclide)	Remedial Goals for Human Health Criteria[a]	Remedial Goals for PSTM Criteria[b]
Actinium-228	0 07	70
Americium-241	8 08	8,080
Cesium-137	0 11	110
Cobalt-60	0 02	20
Curium-243/244	1 6	1,600
Lead-212	0 7	700
Neptunium-239	0 9	900
Plutonium-238	10 857	10,857
Plutonium-239/240	10 130	10,130
Radium-228	0 067	67
Strontium-90	57 130	57,130
Thorium-228	0 035	35
Thorium-230	85 38	85,380
Thorium-232	98 0	98,000
Uranium-233/234	71 0	71,000
Uranium-235	0 83	830
Uranium-238	3 1	3,100

[a] Industrial worker, 10^{-6} excess lifetime cancer risk
[b] Industrial worker, 10^{-3} excess lifetime cancer risk

The preferred remedial response/technology was removal of soil with off-SRS disposal and backfilling the basins with an earthen cover Details are as follows

- Estimated cost $3,550,000
- Estimated construction time to complete 18 months
- Excavation, removal, and disposal of all PTSM (soil above 1×10^{-3} industrial risk) at a licensed off-SRS facility Approximately 3207 m^3 of soil would be removed
- Earthen cover placed over open basins and graded to provide a structural fill barrier (minimum of 9 feet, measured from waste remaining in basin to ground surface) The cover would eliminate risk due to residual contamination left in place greater than 1×10^{-6} but less than PTSM levels
- Institutional controls would remain in place and preclude residential development and disturbance of the cover

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Weldon Spring Site, Missouri—Chemical Plant Area

From 1941 to 1945, as part of the World War II defense effort, the U S Army produced explosives at the Weldon Spring Ordnance Works, a 17,000-acre facility in St Charles County, Missouri, northwest of St Louis After the war, the government transferred ownership of some of this land to the state of Missouri and the University of Missouri, with the Army retaining most of the remainder for use as a training area

In 1955, the Army transferred 205 acres to AEC for construction of the Weldon Spring Uranium Feed Materials Plant From 1957 to 1966, the feed materials plant processed uranium ore concentrates and a small amount of thorium Wastes generated during these operations were stored in four open-air lagoons called the "raffinate pits " From 1963 to 1969, AEC disposed of uranium residues and a small amount of thorium residue in the Weldon Spring Quarry Material placed in the quarry during this time includes uranium- and radium-contaminated building rubble and soils from the demolition of a uranium ore processing facility in St Louis Other radioactive materials in the quarry included drummed wastes, uncontained wastes, and contaminated pieces of manufacturing equipment

The feed materials plant was shut down in 1966, and in 1967 AEC returned the facility to the Army for use as a defoliant production plant to be known as the Weldon Spring Chemical Plant In 1968, the Army started removing equipment and decontaminating several buildings However, the defoliant project was canceled in 1969 before any process equipment was installed The Army retained responsibility for the land and facilities of the chemical plant, but the raffinate pits were transferred back to AEC By direction of the Office of Management and Budget, DOE was to assume responsibility for custody and control of the site, and in 1985 custody was transferred from the Army to DOE In 1985, DOE proposed designating control and decontamination of the chemical plant, raffinate pits, and quarry as a major project to be called the Weldon Spring Site Remedial Action Project (WSSRAP) The quarry was placed on NPL in July 1987, the chemical plant and raffinate pits were added in March 1989

Cleanup at the Weldon Spring Site is being conducted in accordance with both CERCLA and the National Environmental Policy Act (NEPA) In addition, other standards and guidelines are considered ARAR Nonspecific radiological dose standards, such as the 100-mrem/year CEDE limit to the general public in DOE Order 5400 5, are considered applicable National Emission Standards for Hazardous Air Pollutants (NESHAPs) restrict airborne emissions to an effective dose equivalent of 10 mrem/year Missouri radiation regulations limit the maximum whole-body dose to an individual in uncontrolled areas to 2 mrem/h, 100 mrem in any 7 consecutive days, and 500 mrem/year The greatest dose at the site is associated with radium-226 because this radionuclide and its decay products account for most of the total dose at the site from both external gamma irradiation and inhalation of radon

Although the EPA-promulgated standards in the UMTRCA do not apply to the site, they are considered relevant and appropriate since the material at the site is similar to mill tailings DOE guidelines include the EPA standards for radium and establish similar standards for the thorium isotopes for soil in areas of unrestricted access These radionuclides are not to exceed background concentrations by more than 5 pCi/g in the upper 15 cm (6 inches) of soil or 15 pCi/g in each 15-cm layer beneath the surface, averaged over an area of 100 m^2 Since the background concentration of these radionuclides in the vicinity of the site is 1 2 pCi/g, the surface and subsurface standards for radium and thorium are 6 3 pCi/g and 16 2 pCi/g, respectively

No federal or state ARARs were identified for uranium in soil Results of a site-specific risk assessment were used in conjunction with a preliminary ALARA analysis to develop a site-specific cleanup criterion Soil cleanup criteria (or risk-based remediation goals) were developed, assuming failure of institutional controls in the future A recreational visitor, wildlife area ranger in an on-site station, resident, and resident farmer are considered potential future land users Health-based criteria were developed for a resident and farmer since these uses represent maximum exposures and constitute a comprehensive application of the ALARA process Table 18 shows the surface and subsurface cleanup levels developed at the site

Table 18 Weldon Springs Site Cleanup Levels, in pCi/g

Radionuclide	Surface[a]		Subsurface[b]	
	Criteria	ALARA goals	Criteria	ALARA goals
Radium-226[c d]	6 2	5 0	16 2	5 0
Radium-228[c d]	6 2	5 0	16 2	5 0
Thorium-230[c d]	6 2	5 0	16 2	5 0
Thorium-232[c d]	6 2	5 0	16 2	5 0
Uranium-238	120	30 0	120	30 0

[a] Surface soil values apply to contamination within the upper 15 cm (6 inches) of soil

[b] Subsurface soil values apply to contamination in each 15-cm (6-inch) layer of soil more than 15 cm below the surface

[c] If both Th-230 and Ra-226 or both Th-232 and Ra-228 are present and not in secular equilibrium, the cleanup criterion applies for the radionuclide with the higher concentration

[d] At locations where both Ra-226 and Ra-228 are present, the cleanup criteria for both surface and subsurface soil applies to the sum of the concentrations of these two radionuclides

A ROD for the management of the quarry bulk wastes was established in 1990 DOE developed this ROD in consultation with and with the concurrence of the EPA Region 7 and the state of Missouri

These cleanup standards trigger remedial actions and guide confirmation sampling decisions following remediation Confirmation samples are collected from the upper 6 inches of soil, and these surface soil samples are considered representative of the subsurface as well Areas that are potentially contaminated or have been remediated are divided into confirmation units These units are 2,000 m^2, a size approximately the same as the exposure units used in the risk assessment for a future residential lot The mean of the samples across each confirmation unit is compared to the ALARA goals The mean is used since average exposure is the guiding principle for the risk assessment and because there should be little spread in the data after remediation A second decision rule evaluates "hotspots " The average radiological contaminant concentration in each 100-m^2 area will be compared to the cleanup criteria according to the formula

$$\text{maximum concentration} = \text{cleanup criteria} \times (100/A)^{1/2},$$

where, A is the area of the hotspot in square meters In addition, a minimum hot spot size (25 m^2), uncertainty parameters, and minimum sample sizes are all established

The resulting remedy includes an on-site disposal cell The mission of the project is to eliminate potential hazards to the public and environment and to make surplus real property available for other uses to the extent possible The scope of work includes dismantling 44 chemical plant buildings and structures and disposing of both radiologically and chemically contaminated structural materials and soils It also includes disposing of as much material as possible from the raffinate pits, quarry, and nearby properties (including water, sludge, abandoned waste materials, and structural materials) Capping of the on-site disposal cell was completed during 2001

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Conclusions

Differences in cleanup levels from site to site are due to variations in one or more of the elements in the cleanup level development process These elements include regulatory authority, future land use assumptions, site conceptual models, computer models or risk equations, selected input parameters, site-specific physical parameters, and modifying factors, such as the ALARA concept Variations in the elements of this process have led each site to establish different cleanup levels (see Tables 19,20, and 21) The differences in cleanup levels can be understood only by understanding the context in which the decisions in each cleanup level development process were made The following conclusions have been drawn from the case study observations

- Because of differing bases and differing assumptions, cleanup numbers used at one site should not be used to justify similar cleanup numbers at other sites
- Land use assumptions have major consequences for cleanup levels, cleanup costs, and long-term stewardship
- The decision to leave waste in place that will reduce the land use and create a stewardship obligation for many generations, given the long half-lives of some of the radionuclides, must be carefully analyzed
- Variation in health assessment approaches (risk and dose) leads to variation in assessed site risk
- Consistency within a given risk assessment approach is a worthwhile and achievable goal for agencies charged with conducting risk assessments of radioactively contaminated sites
- Models and input parameters make a difference in assessed risks, and they need to be carefully examined for assumptions made Sensitive input parameters must be carefully chosen and justified, using distributions of data where appropriate and available
- The risk assessment and risk management processes should be distinct and separate During the risk management process, modifying factors such as feasibility, cost, stakeholder values, stewardship considerations and the ALARA concept are applied to calculated soil concentrations to produce final cleanup levels
- Additional guidance for converting calculated concentrations to actual cleanup levels at the sites is needed by risk managers
- The selection and application of cleanup goals have a direct impact on selection and use of remedial technologies Consistency in decision making for developing cleanup goals will

enhance selection and deployment of appropriate environmental remediation and characterization technologies

The determination of cleanup levels can involve complex and emotional issues (actual cost, social costs, net benefit to stakeholders, land values, environmental detriment, etc) At each site, special circumstances exist and each cleanup action should be evaluated on its own merits

Table 19. Derived Soil Concentrations for Plutonium-239

Site	Exposure Scenario	Soil Concen-trations (pCi/g)	Date	Comments (Regulatory Standards, Dose Assumptions, and Models Used)
Enewetak	Residential Agricultural Food-gathering Subsurface	40 80 160 400	1973	DOD-DNA/DOE[a]
Erwin, TN	Suburban resident	140	2001	NRC, 25 mrem/year (100 mrem/year if institutional controls are lost), used RESRAD, groundwater ingestion not included, (Nuclear Fuel Services facility)
Fernald	Park user (on site) Resident farmer (off site)	77 9	1995	DOE/EPA/OEPA, 10^{-6} risk (on site), 10^{-5} risk (off site)
Ft. Dix		8	1992	USAF, BOMARC missile accident, 4 mrem/year
Hanford Reservation	Rural resident Commercial/Industrial	34 245	1995	WDOH, 15 mrem/year, used RESRAD Version 5.7
Johnston Atoll	 Fish & wildlife researcher Resident EcoTourist Homesteader	13.5 2.1–210 1.9–190 38–3800 0.32–0.32	1988 2000	Derived as soil screening level, established as ALARA cleanup level by EPA Reg. 9, equivalent to 7.1×10^{-6} residential risk DOD-DTRA, 10^{-6}–10^{-4} risk range, used RESRAD Version 5.82
Lawrence Livermore	Resident	2.5		EPA Region 9 PRG
Mound Facility	Recreational Industrial/construction	75 55		Pu-238 in canal sediments, 25 pCi/g if reasonably achievable (ALARA level)
Rocky Flats • Cleanup Agreement	 Office worker Open space Resident	 1088 1429 252	 1996	 DOE/EPA Reg. 8/CDPHE, 15 mrem/year, used RESRAD Version 5.61
• Oversight Panel	Resident rancher Industrial worker	41 626	2000	Developed by RAC, 15 mrem/year, used RESRAD Version 5.82, 90% of probability distribution
• PRGs	Resident Office worker Open space	2.5 10 17.5	1995 2000	DOE/EPA/CDPHE, 10^{-6} risk, used HEAST (1994) slope factors for residential PRGs in 1995, used Federal Guidance Report 13 slope factors for open space and office worker PRGs in 2000
Tonapah Test Range	Resident rancher	200	2000	DOE, initial cleanup level used at Double Tracks and Clean Slate Sites

[a] CDPHE – Colorado Department of Public Health and Environment, DOD – U.S. Department of Defense, DOE – U.S. Department of Energy, EPA – U.S. Environmental Protection Agency, DNA – Defense Nuclear Agency, DTRA – Defense Threat Reduction Agency, OEPA – Ohio Environmental Protection Agency, RAC – Risk Assessment Corporation, USAF – U.S. Air Force, WDOH – Washington Department of Health

Table 20. Derived Soil Concentrations for Uranium

Site	Exposure Scenario	Soil Concentrations (pCi/g)	Date	Comments (Regulatory Standards, Dose Assumptions, and Models Used)
Fernald	Park user (on site)		1995	EPA/DOE/OEPA[a], 10^{-6} risk, dependent on leachability (K_1)
	Total U (K_1=325 L/kg)	82 ppm		
	Total U (K_1=15 L/kg)	20 ppm		
	Resident farmer (off site)			
	Total U (K_1=325 L/kg)	50 ppm		
New Jersey	Unrestricted use		2000	New Jersey Commission of Radiation Protection, represents 15-mrem/year TEDE in a 1-foot thickness of soil at the surface with no cover, spreadsheet calculations
	U-234	62		
	U-235	29		
	U-238	54		
	Limited restricted use			
	U-234	69		
	U-235	37		
	U-238	64		
	Restricted use			
	U-234	81		
	U-235	62		
	U-238	82		
Hanford	Rural resident		1997	WDOH, 15 mrem/year, used RESRAD Version 5.61
	U-234	160		
	U-235	26		
	U-238	85		
	Commercial/industrial			
	U-234	1200		
	U-235	100		
	U-238	420		
Linde Site	Industrial/commercial (total uranium)	600	2000	USACE, 10^{5} risk, 8.8 mrem/yr for surface cleanups and 4.1 mrem/yr for subsurface cleanups, FUSRAP site
	Subsurface (total uranium)	3,021		
Oak Ridge – Melton Valley	Industrial worker		2000	DOE, 10^{4} risk, except for U-235 (25-mrem/year dose), used RESRAD
	U- 233	5100		
	U-234	6000		
	U-235	81		
	U-238	310		

Site	Exposure Scenario	Soil Concen-trations (pCi/g)	Date	Comments (Regulatory Standards, Dose Assumptions, and Models Used)
Rocky Flats	Industrial Use		1996	DOE/EPA Reg VIII/CDPHE,
• Cleanup	U-234	1627		15 mrem/year, used RESRAD Version
agreement	U-235	113		5 61
	U-238	506		
	Open Space			
	U-234	1738		
	U-235	135		
	U-238	586		
	Resident			
	U-234	307		
	U-235	24		
	U-238	103		
• Oversight	Resident rancher, w/ GW		2000	Developed by Risk Assessment Corp ,
panel	U-234	21		15 mrem/year, used RESRAD Version
	U-235	22		5 82, 90% of probability distribution
	U-238	23		
	Resident rancher w/o GW			
	U-234	494		
	U-235	28		
	U-238	134		
• PRGs	Resident		1995	DOE/EPA Reg 8/CDPHE, 10^{-6} risk, used
	U-233 + D	44 7		HEAST (1994) slope factors for residential
	U-234	17 5		PRGs in 1995, used Federal Guidance
	U-235 + D	0 2		Report 13 slope factors for office worker
	U-238 + D	0 7		and open space PRGs in 2000
	Office worker		2000	
	U-233 + D	68		
	U-234	69		
	U-235 + D	0 8		
	U-238 + D	3 8		
	Open space			
	U-233 + D	122		
	U-234	123		
	U-235 + D	4 2		
	U-238 + D	17 8		

[a] CDPHE – Colorado Department of Public Health and Environment, EPA – U S Environmental Protection Agency, DOE – U S Department of Energy, OEPA – Ohio Environmental Protection Agency, USASCE – U S Army Corps of Engineers, WDOH – Washington Department of Health

Table 21. Comparison of Residential Pathway Dose Contributions from RESRAD-Calculated Cleanup Levels for Plutonium.

Pathway	Rocky Flats Cleanup Agreement (1996)	Hanford Site (WDOH, 1997)	Clean Slate Sites, Nevada (1997)	Rocky Flats Oversight Panel[a] (2000)	Johnston Atoll (2000)	Rocky Flats Revised Soil Action Levels (draft) (2001)
Inhalation	93%	30%	30%	65%	5%	7%
Soil ingestion	6%	23%	31%	20%	87%	73%
Water ingestion	0%	0%	0%	0%	0%	0%
Plant ingestion	1%	45%	29%	15%	0%	20%
Other	0%	1%	10%	0%	8%	0%

[a] Estimates at 35-pCi/g level

References Cited

ARPANSA (Australian Radiation and Nuclear Safety Agency) 2000 *The Maralinga Rehabilitation Project 1996-1999* Website accessed October 10, 2000 http //www health gov au/arpansa/er mrp htm

BNI (Bechtel National Incorporated) 1993 *Remedial Investigation for the Tonawanda Site* DOE/OR21949-300 Oak Ridge, Tenn

CRCPD (Conference of Radiation Control Program Directors) 1998 *Position statement regarding cleanup standards*

Defense Nuclear Agency 1981 *The Radiological Cleanup of Enewetak Atoll* Washington, D C

DOE (U S Department of Energy) 1996a *Rocky Flats Cleanup Agreement* Rocky Flats Environmental Technology Site, Golden, Colo July 19

DOE 1996b *Action Levels for Radionuclides in Soils for the Rocky Flats Cleanup Agreement* Final October 31

DOE 1996c *Record of Decision for Remedial Actions at Operable Unit 5* Fernald Area Office January

DOE 1997 *Radiological Dose Assessment for Residual Radioactive Material in Soil at the Clean Slate Sites 1, 2, and 3, Tonopah Test Range* DOE/NV-482, UC-700 Las Vegas June

DOE 1998 *Remedial Design Report/Remedial Action Workplan for the 100 Area, Rev 1* Richland, Wash May

EPA (U S Environmental Protection Agency) 1977 *Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment* Federal Register, Vol 42

EPA 1989 *Risk Assessment Guidance for Superfund Volume 1 – Human Health Evaluation Manual (Part A, Interim Final)* Publication EPA/540/1-89002, PB90-155581 Office of Emergency and Remedial Response December

EPA 1995 *Interim Action Record of Decision for the 100-BC-1, 100-DR-1, 100-HR-1, Operable Units, Hanford Site, Benton County, Washington* Region 10, Seattle September

EPA 1996 *Radiation Site Cleanup Regulation* 40 CFR Part 196 Staff Draft February 16

EPA 1997a *Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination* OSWER Memorandum No 9200 4-18 Office of Emergency and Remedial Response, and Office of Radiation and Indoor Air August

EPA 1997b *Exposure Factors Handbook (Update)* EPA/600/P-95/002Fc Office of Research and Development, Washington, D C August

EPA 1997c *Radionuclide Carcinogenicity Slope Factors* from Health Effects Assessment Summary Tables (HEAST) Office of Radiation and Indoor Air

EPA 2000 *EPA's Recommended Soil Cleanup Standard for Plutonium Contamination at Johnston Atoll* Correspondence from U S EPA Region IX to Defense Threat Reduction Agency September

EPA, et al (EPA, U S Nuclear Regulatory Commission, U S Department of Energy, and U S Department of Defense) 2000 *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (revised)* NUREG-1575, EPA/402-R-97-016 Washington, D C August

EPA 2001 *Risk Assessment Guidance for Superfund, Vol 3, Part A Process for Conducting Probabilistic Risk Assessment* Draft Office of Emergency and Remedial Response, Washington, D C , OSWER 92845 7-45

EPA, et al (EPA, Colorado Department of Public Health & Environment, U S Department of Energy) 2001 *Draft Task 3 Report Calculation of Surface Radionuclide Soil Action Levels for Plutonium and Americium* October

EPA 2002 *Glossary of Risk Assessment Related Terms* Website accessed April 2002, http //www epa gov/OCEPAterms/intro htm

NRC (U S Nuclear Regulatory Commission) 1992 *Residual Radioactive Contamination from Decommissioning* NUREG/CR-5512 Volumes 1-3 October

RAC (Risk Assessment Corporation) 1999 *Task 1 Cleanup Levels at Other Sites Rocky Flats Citizens Advisory Board, Rocky Flats Soil Action Level Oversight Panel* RAC Report No 3-RFCAB-RFSAL-1999 (Draft) Neeses, South Carolina February

Uncapher, W L, D Hunter, K Higley, L Rahal, and J A Mercer 2000 *Johnston Atoll Radiological Survey* DSWA01-98-C-0179 Defense Threat Reduction Agency, Alexandria, Va Geo-Centers , Inc, Albuquerque, N M January

USACE (U S Army Corps of Engineers) 1999 *Proposed Plan for the Linde Site, Tonowanda, New York* March

USACE 2000 *Record of Decision for the Linde Site, Tonowanda, New York* March

WDOE (Washington [State] Department of Ecology) 1996 *Model Toxics Control Act Cleanup Levels and Risk Calculations (CLARC II) Update* Publication #94-145 Olympia, Wash

WDOH (Washington [State] Department of Health) 1997 *Hanford Guidance for Radiological Cleanup* WDOH/320-015 Olympia, Wash November