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Radiological Dose Assessment for Residual Radioactive Material in Soil at the Clean Slate Sites 1, 2, and 3, Tonopah Test Range

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DOE Nevada Operations Office
Las Vegas, Nevada

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RADIOLOGICAL DOSE ASSESSMENT FOR RESIDUAL RADIOACTIVE MATERIAL IN SOIL AT THE CLEAN SLATE SITES 1, 2, AND 3, TONOPAH TEST RANGE

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List of Acronyms and Abbreviations

ALARA	As low as reasonably achievable
Am	Americium
CEDE	Committed effective dose equivalent
cm	Centimeter(s)
day/yr	Day(s) per year
DOE	U.S. Department of Energy
DU	Depleted Uranium
EPA	U.S. Environmental Protection Agency
FUSRAP	Formerly Utilized Sites Remedial Action Program
ft	Foot (feet)
g	Gram(s)
g/day	Gram(s) per day
g/m^3	Gram(s) per cubic meter
g/yr	Gram(s) per year
Ge	Germanium
GPS	Global positioning system
GZ	Ground zero
h/day	Hour(s) per day
ICRP	International Commission on Radiological Protection
keV	Kiloelectronvolt
kg	Kilogram(s)
km	Kilometer(s)
L	Liter(s)
L/day	Liter(s) per day
L/yr	Liter(s) per year
LLNL	Lawrence Livermore National Laboratory
m	Meter(s)
m/yr	Meter(s) per year
m^2	Square meter(s)
m^2/s	Square meter(s) per second
m^3/yr	Cubic meter(s) per year
mi	Mile(s)

List of Acronyms and Abbreviations *(Continued)*

mg/day	Milligram(s) per day
mrem	Millirem
mrem/yr	Millirem(s) per year
NaI	Sodium Iodide
NCRP	National Council on Radiation Protection and Measurements
NRC	Nuclear Regulatory Commission
NTS	Nevada Test Site
pCi	PicoCurie(s)
pCi/g	PicoCurie(s) per gram
Pa	Protactinium
Pu	Plutonium
RESRAD	Residual Radioactivity (computer code)
RSL	Remote Sensing Laboratory
SFMP	Surplus Facilities Management Program
SNL	Sandia National Laboratories
TTR	Tonopah Test Range
U	Uranium

Summary

A radiological dose assessment has been performed for Clean Slate Sites 1, 2, and 3 at the Tonopah Test Range, approximately 390 kilometers (240 miles) northwest of Las Vegas, Nevada. The assessment demonstrated that the calculated dose to hypothetical individuals who may reside or work on the Clean Slate sites, subsequent to remediation, does not exceed the limits established by the U.S. Department of Energy for protection of members of the public and the environment. The sites became contaminated as a result of Project Roller Coaster experiments conducted in 1963 in support of the U.S. Atomic Energy Commission (Shreve, 1964). Remediation of Clean Slate Sites 1, 2, and 3 is being performed to ensure that the 50-year committed effective dose equivalent to a hypothetical individual who lives or works on a Clean Slate site should not exceed 100 millirems per year. The DOE residual radioactive material guideline (RESRAD) computer code was used to assess the dose. RESRAD implements the methodology described in the DOE manual for establishing residual radioactive material guidelines (Yu et al., 1993a).

In May and June of 1963, experiments were conducted at Clean Slate Sites 1, 2, and 3 to study the effectiveness of earth-covered structures for reducing the dispersion of nuclear weapons material as a result of nonnuclear explosions. The experiments required the detonation of various simulated weapons using conventional chemical explosives (Shreve, 1964). The residual radioactive contamination in the surface soil consists of weapons grade plutonium, depleted uranium, and their radioactive decay products.

The concentration of residual radioactive material in the surficial soil at the Clean Slate sites ranges from background to greater than 12,800 picoCuries per gram. For this dose assessment, it was conservatively assumed that all areas of the Clean Slate sites with plutonium-239/240 concentration in soil exceeding 200 picoCuries per gram would be remediated to a concentration of 200 picoCuries per gram.

Four exposure scenarios were applied in the dose assessment of the Clean Slate sites. These scenarios vary with regard to future land use at the sites, sources of food consumed, and the amount of time individuals would spend on site. The exposure scenarios included two agricultural scenarios (a ranch and a farm), a rural residence, and light commercial industry. In addition to the adult receptors who are assumed to participate in these four exposure scenarios,

the radiological dose assessments include a child dose receptor. The child is assumed to participate in the agricultural and rural residential exposure scenarios. This radiological dose assessment demonstrates that the assumed remedial activity results in calculated doses to hypothetical individuals that comply with the DOE primary dose limit of 100 millirems per year. The calculated annual dose to a maximally exposed individual, after the assumed remediation, is 47 millirems per year to a rancher living on a Clean Slate site. The maximum annual dose calculated for the hypothetical rural resident, farmer, and industrial worker is 12, 23, and 4.5 millirems per year, respectively. The calculated dose for all hypothetical individuals was less than the 100 millirems per year limit established in DOE Order 5400.5 (DOE, 1993).

1.0 Introduction

Residual plutonium (Pu) and depleted uranium (DU) exist in surficial soils at the Nevada Test Site (NTS) and the Tonopah Test Range (TTR) as the result of special experiments involving the detonation of plutonium and depleted uranium-bearing devices using chemical explosives. The experiments were conducted to achieve the following objectives:

- Study the behavior of Pu as it was being explosively compressed.
- Ensure that the accidental detonation of the chemical explosive in a production weapon would not result in criticality.
- Evaluate the ability of personnel to manage large-scale Pu dispersal accidents.
- Develop criteria for transportation and storage of nuclear weapons.

Experiments performed to evaluate cleanup, weapons handling, and storage issues consisted of Operation Roller Coaster. Operation Roller Coaster included four experiments: Double Tracks, and Clean Slates 1, 2, and 3. Collectively, these four nuclear device experiments are referred to as "safety shots."

The sites where these safety shot tests were conducted are contaminated with Pu and trace quantities of DU. At the present time, these sites do not pose a health threat to either workers or the general public because they are under active institutional control. All sites are located in areas of restricted access, and inadvertent human intrusion is deterred by the use of fences and warnings. The Clean Slate sites are situated in the central portion of the TTR, north of the NTS, on the northwest portion of the Nellis Air Force Range which is approximately 390 kilometers (km) (240 miles [mi]) northwest of Las Vegas, Nevada. The nearest TTR boundary is 16.2 km (10.1 mi) to the north, where it is bordered by sparsely populated public land administrated by the U.S. Bureau of Land Management and the U.S. Forest Service. The nearest community is Goldfield, Nevada, which is approximately 42 km (26 mi) west of the TTR boundary (Figure 1-1). However, because the half-lives of Pu and DU isotopes are very long, greater than 10,000 years, residual contamination could pose a long-term health hazard if it were not remediated. Members of the public could acquire the land upon its transfer into the public domain or following a loss of institutional control. The U.S. Department of Energy (DOE) is committed to remediating the safety shot sites so that radiation exposures to members of the

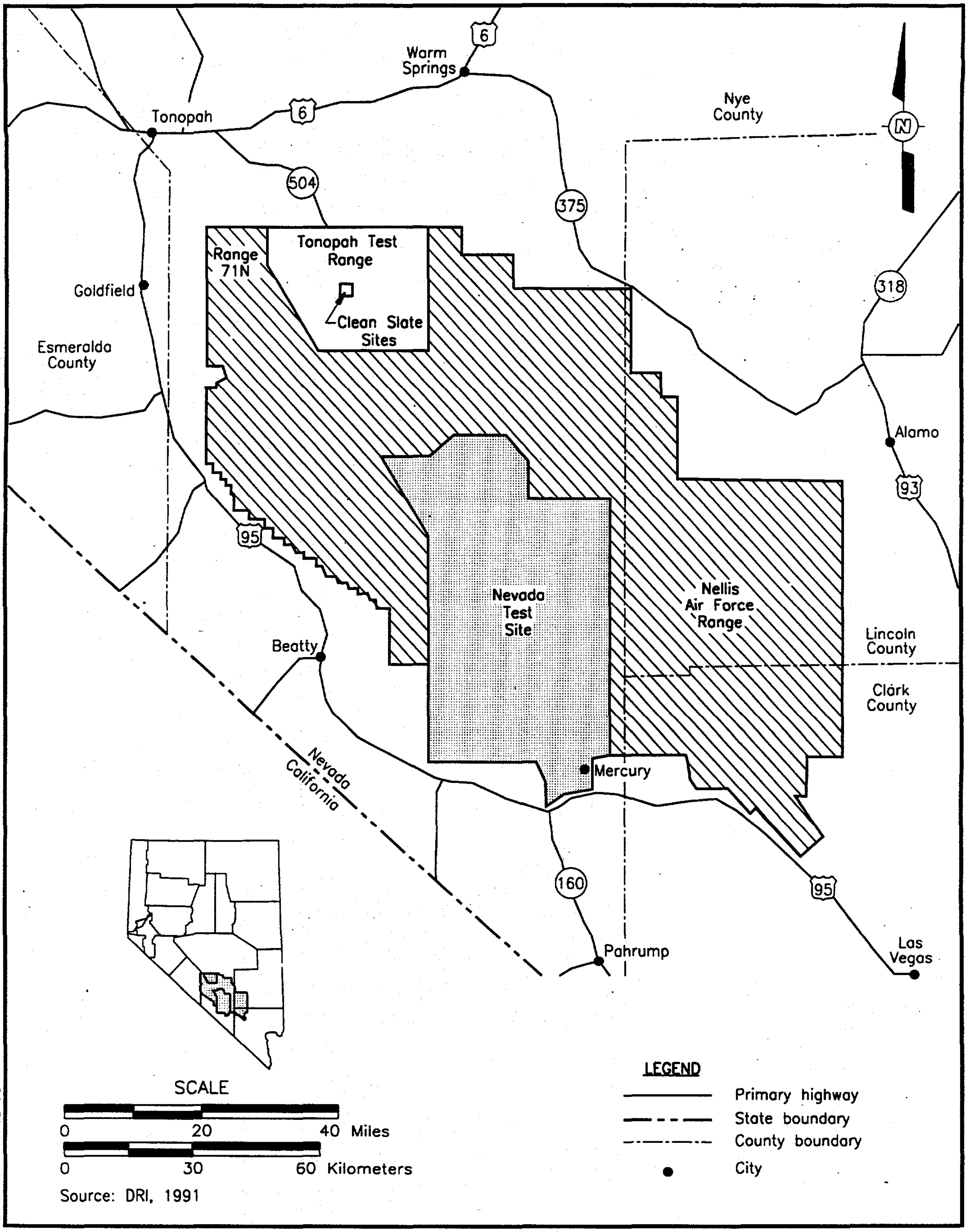


Figure 1-1
General Site Location Map

public, both now and in the future, will be maintained within the established limits and be below the limits, as low as reasonably achievable (ALARA).

Remedial actions of the safety shot sites will ensure that the residual concentration of the Pu and DU in the soil implement the guidelines established in DOE Order 5400.5, *Radiation Protection of the Public and the Environment* (DOE, 1993). A guideline is defined as a radionuclide concentration that, given appropriate use scenarios and site parameters, will reasonably ensure that dose limits to the average individual in the critical population will not be exceeded. The DOE has established generic cleanup guidelines for radium and thorium in soil (DOE, 1993); however, cleanup guidelines for other radionuclides must be derived on a site-specific basis.

The guideline is based upon a radiation dose criterion of 100 millirem in a year (mrem/yr). The radiation dose is defined as the effective dose equivalent from external radiation plus the committed effective dose equivalent from internal radiation (DOE, 1993). The 100 mrem/yr dose criterion is the DOE primary standard dose rate to ensure protection to members of the public. This criterion includes the dose contribution for all significant pathways and sources combined, excluding background. This dose rate complies with the recommendation for controlling dose to members of the public by the International Commission on Radiological Protection (ICRP, 1991).

The methodology used in this dose assessment to calculate the dose to hypothetical individuals is that prescribed in DOE Order 5400.5 (DOE, 1993). According to Chapter IV of the Order, the procedures for deriving specific property guidelines for allowable levels of residual radioactive material from basic dose limits is contained in DOE/CH/8901, *A Manual for Implementing Residual Radioactive Material Guidelines: A Supplement to the U.S. Department of Energy Guidelines for Residual Radioactive Material at FUSRAP [Formerly Utilized Sites Remedial Action Program] and SFMP [Surplus Facilities Management Program] Sites* (Gilbert et al., 1989). DOE/CH/8901 is a manual for implementing DOE procedures and contains guidance on establishing cleanup concentrations for radionuclides in soil using the Residual Radioactivity (RESRAD) microcomputer code (Gilbert et al., 1989). The version of RESRAD used in this dose assessment is 5.61 (Yu et al., 1993a). Details on the RESRAD code and the calculation methodology are discussed in Section 4.0 of this report.

1.1 Derivations of Plutonium and Uranium Cleanup Standards in Soil

The 100 mrem/yr primary public dose standard established in DOE Order 5400.5 is a risk-based standard (DOE, 1993). Maximum concentration limits for community drinking water are another example of risk-based standards. A risk-based standard does not correspond to an absolute number, for example, a specific concentration of plutonium or depleted uranium in soil. For a risk-based standard, a radiological dose assessment must be performed to determine the association between the concentration of the contaminant in the soil and the risk it may present. The radiological dose assessments process estimates the dose to hypothetical future individuals by applying mathematical models designed to quantify the transport of radionuclides through the environment and their subsequent intake by man. Subsequently, radiological monitoring must be performed at the safety-shot sites, and the resulting measurements statistically must be analyzed and compared to a soil concentration of plutonium that corresponds to 100 mrem/yr. No single value can be calculated relating concentration of plutonium in soil to dose because of different assumptions regarding the land use, variations in the level of conservatism chosen for exposure scenarios, inconsistencies in parameter values used in the risk models, and different lifestyles assumed for the hypothetical dose receptors.

All risk-based standards have uncertainty, and the uncertainty will exist for any cleanup standard adopted. It exists because the annual dose of 100 mrem is derived using inherently uncertain conceptual and mathematical models that relate exposure and risk to concentrations of radioactive material in the soil. The parameters used in the models are usually assigned values on the basis of limited information about their true values and about how these true values change over space and time. Typically, each parameter value used in a radiological risk assessment is chosen from the conservative, pessimistic, and upper-bound extremes from a range of possible values. This methodology is known as the traditional point estimate approach to risk assessment.

Several studies using the traditional point estimate approach have been published that evaluate the dose to individuals as a function of plutonium concentration in soil on the Nevada Test Site (DOE/NV, 1995; Layton, 1993; ICRP, 1991; Rutz et al., 1994; Anspaugh and Daniels, 1995; EG&G Idaho, 1986; Tan et al., 1995). Most of these studies calculated plutonium guideline concentrations assuming members of the general public were residing on the remediated site, full-time, and raising all of their food on site. Other studies have used different assumptions with respect to how the land would be used (e.g., a family is living on site and raising a portion of their own food; individuals are intermittently on site prospecting for minerals; or individuals are using the site for recreation purposes such as hunting). In addition, different parameter values in the risk assessment were assumed (e.g., breathing rates, hours an individual remained outdoors, and mass loading of the contaminated soil in the air). Comparisons between the different studies cannot be made unless all of the underlying assumptions and parameters are known and understood.

One study provides a strong argument against cleanup of safety shot soils with plutonium concentrations less than 400 picoCuries per gram (pCi/g) at the NTS and related sites based upon a cost-benefit analysis (DOE/NV, 1995). The study implied that the expenditure of vast economic resources would be necessary to achieve a very small reduction in the expected incidence of cancer fatalities to future populations that might potentially live on contaminated areas.

The Layton study (1993), using a resident farmer scenario on a safety-shot site, estimated that a plutonium soil concentration of approximately 200 pCi/g would result in a dose of 20 mrem/yr. Assuming the linear non-threshold model for relating dose to risk and the risk-factors in an ICRP Publication, 20 mrem/yr is equivalent to a lifetime cancer risk on the order of 4×10^{-4} (ICRP, 1991).

However, in a different study (which assumed more conservative exposure scenarios), a Pu soil concentration of about 270 pCi/g was reported to give a dose rate of 100 mrem/yr (Rutz et al., 1994).

A very conservative pathway analysis relating radionuclide concentration in soil to worker dose was prepared by Lawrence Livermore National Laboratory (LLNL). This study demonstrated that a concentration of 270 pCi/g of Pu would result in a committed, effective dose equivalent of 100 mrem/yr to a worker spending 2,000 hours per year at the site (Anspaugh and Daniels, 1995).

A study performed on the release of land at the Idaho National Engineering Laboratory, a high altitude, semi-arid site not significantly different from the NTS, resulted in a release criterion of 300 pCi/g for Pu-239/240, assuming a dose limit of 100 mrem/yr, a resident farming scenario, and all food raised on site (EG&G Idaho, 1986).

A risk assessment for the safety-shot sites that assumed a resident rancher scenario and extremely conservative exposure parameter values calculated that the dose to a rancher on Clean Slates 1, 2, and 3 would vary from 618 to 8,180 mrem/yr prior to remediation, and the average soil concentration would have to be reduced to 270 pCi/g to ensure the dose would not exceed 100 mrem/yr (Tan et al., 1995).

The referenced dose analyses varied in the assumptions they used in deriving the dose due to the Pu contamination in the soil. However, there appears to be a general consensus that release of a safety-shot site with a Pu soil concentration of 200 pCi/g will not result in a member of the public receiving a dose exceeding 100 mrem/yr.

None of the referenced dose analyses applied the methodology described in DOE/CH/8901 (Gilbert et al., 1989) as prescribed in DOE Order 5400.5 (DOE, 1993). This radiological dose assessment is consistent with the methodology and guidance prescribed and uses the most recent source term data acquired during Clean Slate sites characterization studies. In addition, this dose assessment uses TTR- and NTS-specific data, when available, instead of national averages referenced in the RESRAD code and by federal regulatory agencies (Yu et al., 1993a,b).

The concentration of plutonium in soil at the Clean Slate sites varies from <10 pCi/g to >12,800 pCi/g (Wille, 1996). For the purpose of calculating the dose to hypothetical individuals, this dose assessment has assumed a least-cost strategy for achieving compliance with the primary dose limit. The environmental restoration action assumed, for calculational purposes, that all soil with a Pu-239/240 concentration exceeding 200 pCi/g is remediated to 200 pCi/g. The dose to hypothetical dose receptors is calculated both prior and subsequent to remediation of the Clean Slate sites. Then the calculated doses are compared to the primary dose limit of 100 mrem/yr.

This assessment also presents the methodology used in calculating the dose to a hypothetical member of the public both prior and subsequent to remediation of the Clean Slate sites. Emphasis was placed on obtaining site-specific data for use in calculating dose from the residual soil contamination. When site-specific data were not available, data from the open scientific literature, default values from the RESRAD code, and suggested values from federal and state regulatory agencies were used in calculating dose. The topics addressed in this dose assessment include:

- Dose criteria used to establish the guideline
- Calculation methodology used in determining the guideline concentrations

- Clean Slates 1, 2, and 3 site description and history
- Radiological source terms at Clean Slates 1,2, and 3
- Description of the exposure pathways analyzed by the RESRAD code
- Exposure scenarios investigated and analyzed for Clean Slates 1, 2, and 3
- Analytical results

The analytical results include all of the site-specific and default data used in calculating the guideline concentrations.

2.0 Cleanup Guideline Criteria

The primary dose limits for members of the public from all Department of Energy activities, including remedial actions, are established in Chapters II and IV of DOE Order 5400.5 (DOE, 1993). The primary dose limit is expressed as a committed effective dose equivalent, a term developed by the ICRP for their risk-based system, which requires the risk-weighted summation of doses to various tissues and organs of the body. The exposure of members of the public to radiation sources as a consequence of all routine DOE activities must not cause, in a year, an effective dose equivalent greater than 100 mrem. This is defined by the DOE as their basic dose limit for protection to members of the public, and it is the dose limit used in establishing guideline concentrations. The basic dose limit is an annual limit for members of the public who are assumed to participate in worst-case exposure scenarios. Assessment of a lifetime dose to an individual and the collective dose to a population is not required.

Chapter IV of DOE Order 5400.5 (DOE, 1993) presents radiological protection requirements and guidelines for cleanup of residual radionuclides in soil. The basic dose limit for doses resulting from exposures to residual radionuclides in soil is a prescribed standard from which limits for quantities that can be monitored and controlled are derived. It is also specified in terms of the effective dose equivalent. The basic dose limit is used for deriving guidelines for residual concentrations of radionuclides in soil. A guideline is a concentration of a radionuclide in soil that is acceptable for property use without restrictions due to residual radioactive material. DOE Order 5400.5, Chapter IV, states, "Residual concentrations of radioactive material in soil are defined as those in excess of background concentrations averaged over an area of 100 square meters (m^2)" (DOE, 1993). Guidelines for thorium and radium in soil have also been established in DOE Order 5400.5 (DOE, 1993). Guidelines for residual concentrations for other radionuclides in soil have to be derived from the basic dose limit by means of an environmental pathway analysis using specific property data where available. Procedures for these derivations are given in DOE/CH-8901 and are implemented in the RESRAD computer code (Gilbert et al., 1989; Yu et al., 1993a).

Remediation of the safety-shot sites requires that the following hot spot criteria in DOE Order 5400.5 and DOE/CH/8901 be satisfied. These criteria are:

- Guidelines for residual concentrations of radionuclides, other than radium or thorium, shall be derived from the basic dose limits.
- Environmental pathway analysis shall be used in applying the basic dose limits.
- Specific property data shall be used where available.
- Residual concentrations of radioactive material in soil are defined as those in excess of background concentrations averaged over an area of 100 m^2.
- The procedures in DOE/CH-8901 shall be used in deriving the guideline.
- The hot spot criteria in DOE Order Chapter IV, section 4a.(1) and Chapter 3, section 3.3.2 of DOE/CH/8901 shall apply (DOE, 1993; Gilbert et al., 1989).

The hot spot criterion in DOE Order 5400.5 states that if the average concentration in any soil surface or below-surface area less than or equal to 25 m^2 exceeds the guideline by a factor of $(100/A)^{0.5}$, (where A is the area [in square meters] of the region in which concentrations are elevated), limits for "hot-spots" shall be developed and applied (DOE, 1993).

Procedures for calculating these hot-spot limits, which depend on the extent of the elevated local concentrations, are given in DOE/CH-8901 (Gilbert et al., 1989). In addition, DOE Order 5400.5 states that a reasonable effort will be made to remove any radioactive source that exceeds the appropriate limit by a factor of thirty (DOE, 1993). Therefore, successful remediation of the safety-shot sites will require the following:

- The average soil concentration for plutonium in any 100 m^2 area must not exceed 200 pCi/g.
- The plutonium concentration in any hot-spot must not exceed the guidance in DOE Order 5400.5, Chapter IV, Section 4.a. (1).
- Reasonable efforts shall be made to remove any source of radionuclides that exceeds 30 times the appropriate limit for soil, regardless of the average concentration in the soil (DOE, 1993).

The latter two criteria will ensure that an area of elevated concentration does not result in an unacceptable increase in the potential risk to members of the public, even though the average concentration is less than the cleanup standard.

DOE/CH-8901, *A Manual for Implementing Residual Radioactive Material Guidelines,* was prescribed in Chapter IV of DOE Order 5400.5 for deriving guideline concentrations for residual radioactive material in soil (Gilbert et al., 1989; DOE, 1993). This document is a user's manual for the microcomputer code RESRAD. RESRAD incorporates the methodology for calculating residual radioactive guidelines first developed for DOE's FUSRAP and SFMP. RESRAD was developed to calculate radiation dose to on-site residents from Residual Radioactive material and determine soil guidelines according to the limits specified in DOE Order 5400.5.

3.0 History and Site Description of Clean Slates 1, 2, and 3

Since 1957, the TTR has been used by the United States government as a test site for weapons ballistics, rocket and gun firings, chemical explosives, and nuclear ordinance. In May and June of 1963, experiments were conducted at three locations, Clean Slates 1, 2, and 3, as part of Operation Roller Coaster. The primary function of this project was to study the dispersion of plutonium from nonnuclear explosions of plutonium weapons. The experiments required the detonation of various simulated weapons from a variety of near-surface structures. Surface air sampling, deposition sampling, and some animal exposure studies were completed to study the distribution of plutonium from these detonations (Shreve, 1964).

Radiological measurements taken during and immediately after the experiments indicated that surface contamination was of sufficient activity to construct perimeter fences to isolate the most highly contaminated areas (Shreve, 1964). Since the completion of Operation Roller Coaster, the Clean Slates sites have been monitored to evaluate the potential migration of radiological contamination from surface winds and/or surface water infiltration. The TTR is presently in use by the government for conventional nonnuclear weapons testing-related activities; however, the Clean Slates sites have remained inactive within the perimeter-fenced areas.

In the years following the completion of Operation Roller Coaster, numerous studies and monitoring programs have been completed to monitor the environmental conditions at Clean Slates 1, 2, and 3. These programs, which dealt with monitoring of site radiological conditions, were conducted using land and aerial surveys (Burnett, 1964; Gilbert et al., 1975 and 1977; and Jobst, 1977).

Routine environmental surveillance activities are conducted by Sandia National Laboratories (SNL) as part of their operation requirements for the TTR facility. SNL has been operating this facility for the government since 1957. TTR activities are reported in annual Environmental Monitoring Reports which are currently being submitted to the DOE (SNL, 1987-1992). Monitoring activities include collection and analysis of air and groundwater samples and, during selected years, analysis of soil samples. The results of these monitoring activities indicate no significant changes in environmental conditions at Clean Slates 1, 2, and 3 (Essington, 1977).

In August 1993, an aerial survey was completed for Clean Slates 1, 2, and 3 for IT Corporation by EG&G's Remote Sensing Laboratory (RSL) (Proctor and Hendrix, 1994). The primary objective of this survey was to locate depleted uranium (U-238) at three locations originating from the Clean Slates 1, 2, and 3 experiments. The results of this survey showed that no significant concentration of depleted uranium could be detected; however, the survey indicated substantial americium-241 (Am-241) in the vicinity of the Clean Slates sites. This Am-241 material is a decay product of Pu-241, a component in the original simulated weapons (Proctor and Hendrix, 1994).

The results of the extensive radiological monitoring demonstrate the following:

- Radioactive materials were dispersed from ground zero (GZ) by the force of the detonation and carried downwind from the sites in the debris cloud.

- Surficial distribution of the radionuclides is not uniform. Radioanalyses of soil samples have demonstrated that soil samples taken only a few meters apart can differ in plutonium concentration by up to four orders of magnitude.

- The majority of highly contaminated material was found relatively close to the GZ.

- Some sorting of radioactive particles took place in the debris cloud due to atmospheric turbulent diffusion.

- Uranium and plutonium particles became attached to soil particles by melting of the soils and formed a silicate glass.

- *In situ* monitoring of the Clean Slate sites demonstrated a mean Pu-239:Am-241 activity ratio of 12.7:1, with a range of 9.4 to 32.2 (RSL, 1996). Based upon these measurements, the radiological source term is assumed to have a Pu-239/240:Am-241 ratio of 14:1 in this dose assessment.

- There has been no significant migration of radioactive materials by wind and/or surface water infiltration.

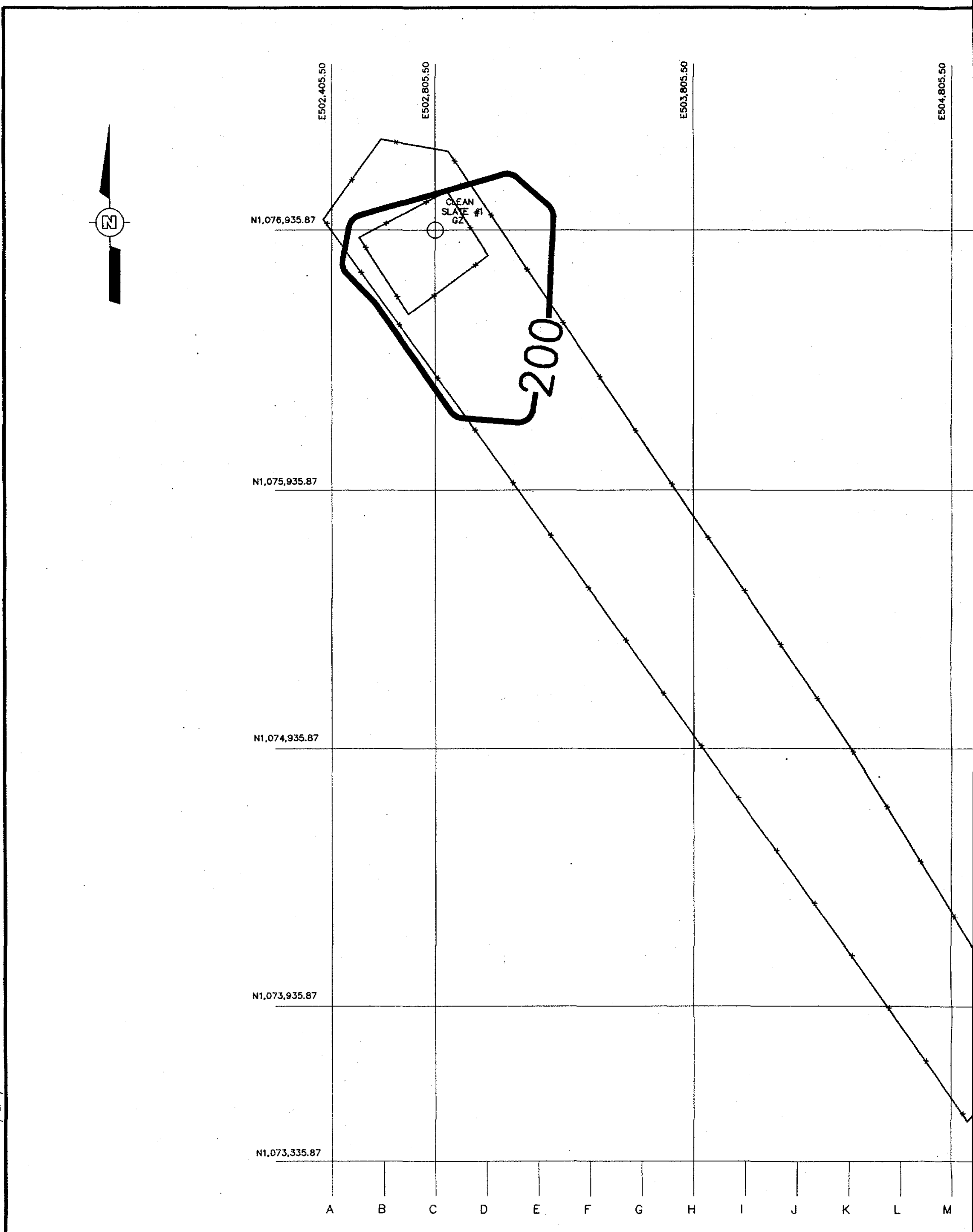
- Vertical contamination within the near-surface soils is limited to the top 3 to 8 centimeters (cm) with an average depth of about 5 cm of soil in areas outside the GZ exclusion fences (RSL, 1996). Outside the GZ, *in situ* measurements demonstrated that the depth of contamination between plants was <1 cm; while around the plants, the depth profile was usually 2 to 3 cm. In this analysis, a depth profile of 5 cm was assumed.

- Vertical contamination in the GZ area is located in mounded and/or burial areas. The depth of contamination is estimated to be within the top 1.5 meters (m) (5 feet [ft]) of soil at Clean Slate Sites 1 and 2, and 3.0 m (10 ft) at Clean Slate Site 3.

- Lateral contamination is confined within the perimeter exclusion fences with some minor areas outside the fences east of Clean Slate Site 1 and southwest of Clean Slate Site 2.

- Groundwater is not present within 55 meters (180 ft) of the ground surface at each location and has not been impacted by the radionuclides originating from the Clean Slates experiments.

- See Figures 3-1, 3-2, and 3-3 for maps of each Clean Slate Site.



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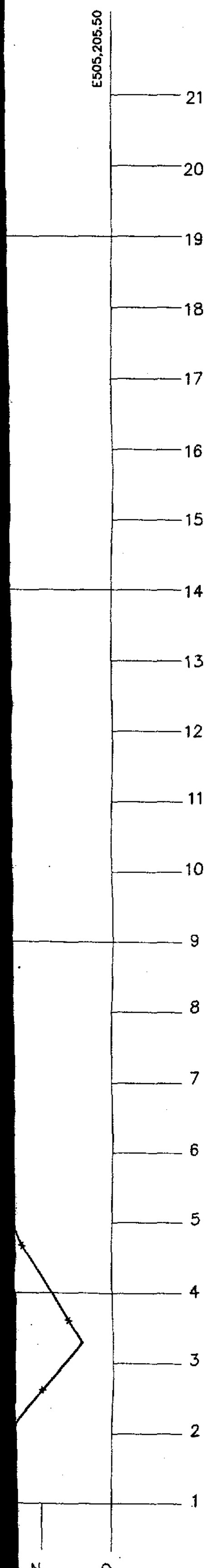


LEGEND

—×——×—	Perimeter fence
o GZ	Ground zero (GZ) location
—— 200 ——	200–pCi/g contour based on 1993 aerial survey by EG&G

NOTES

REECo, 1973a

200—pCi/g contour based on Proctor and Hendrix, 1994.

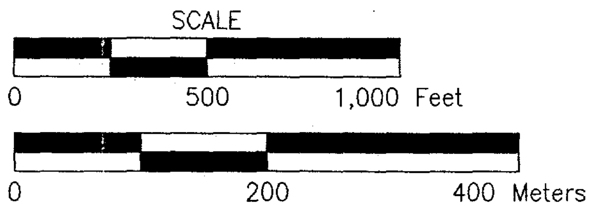
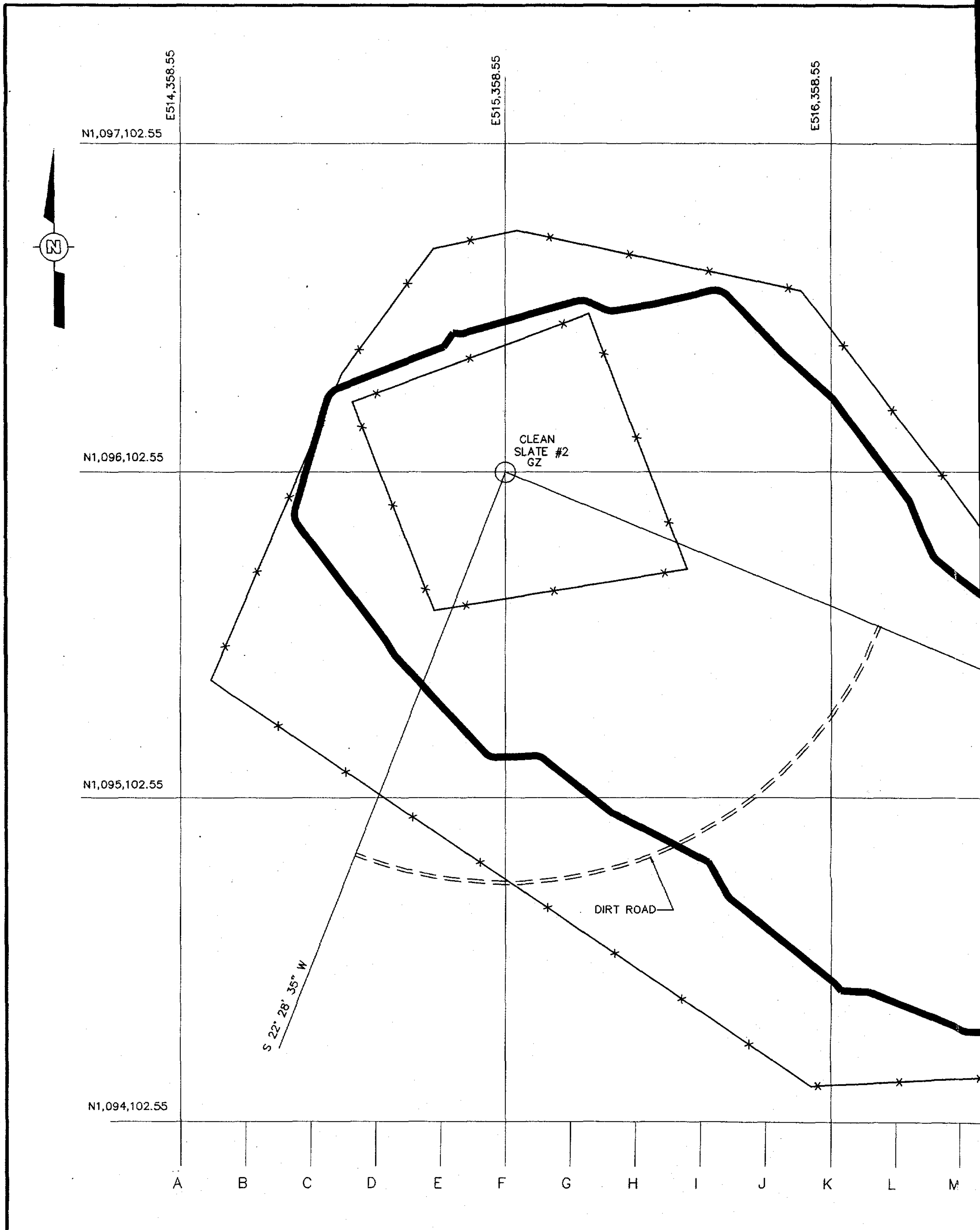


FIGURE 3-1

CLEAN SLATE #1 SITE PLAN



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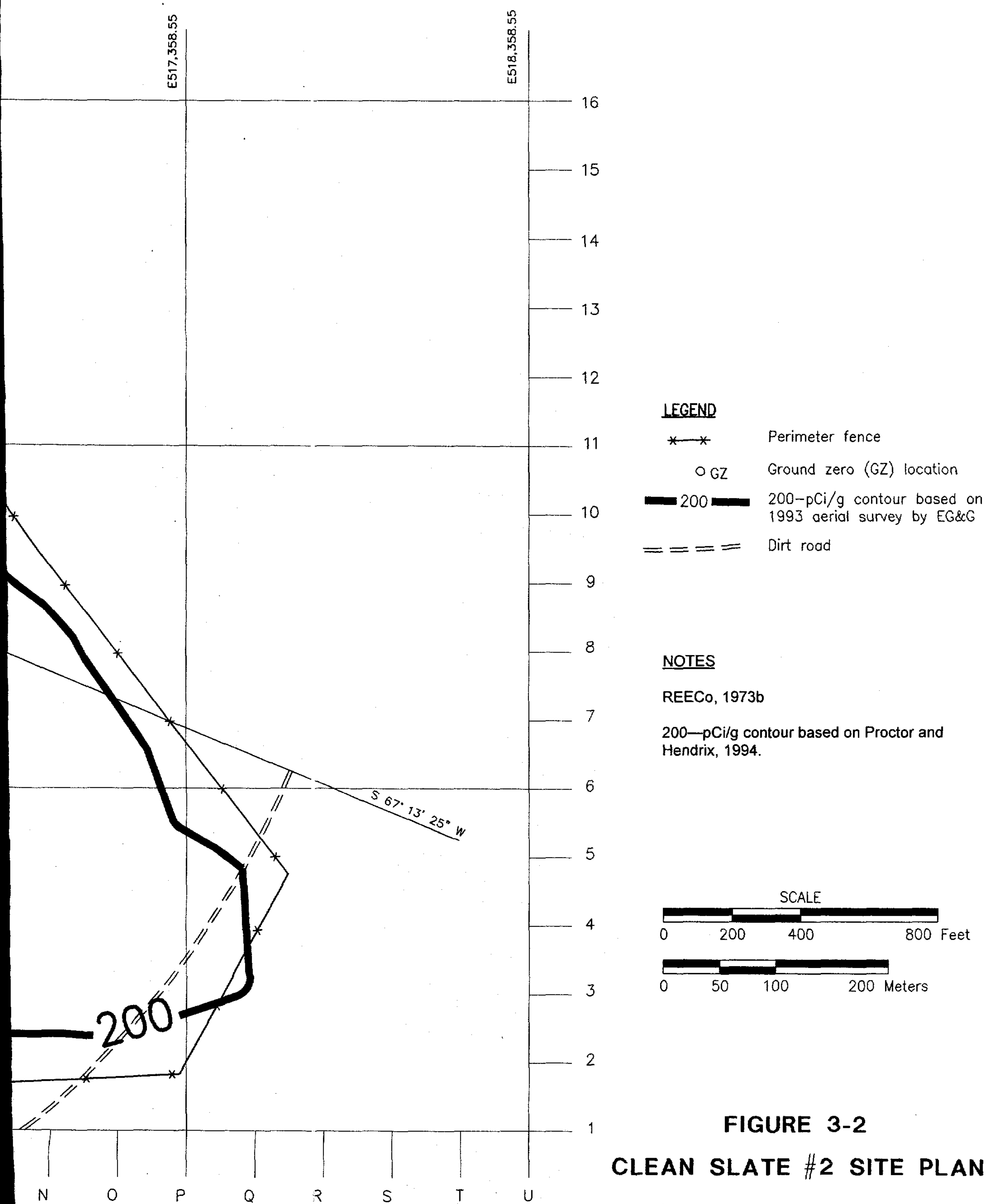


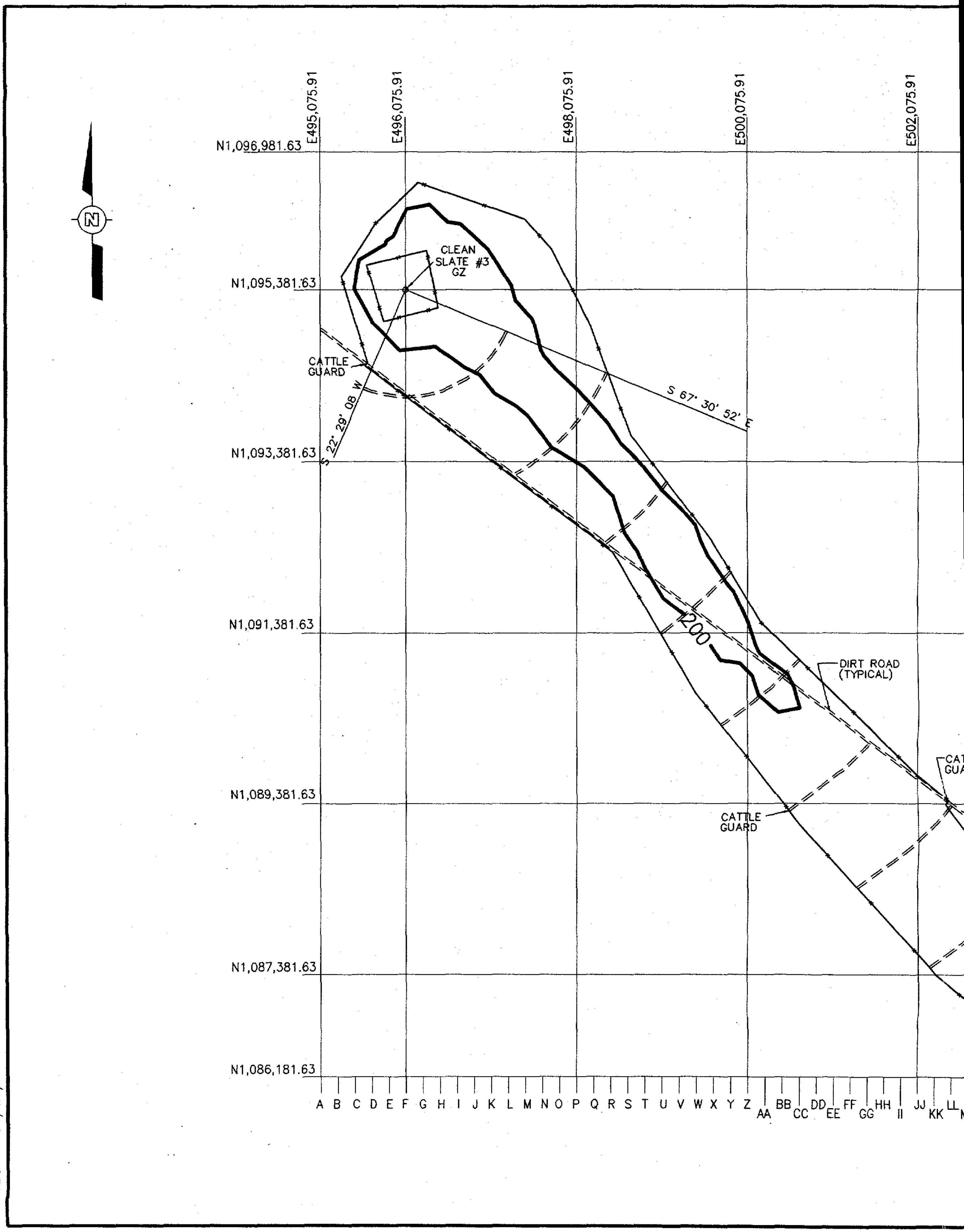
NOTES

REECo, 1973b

200—pCi/g contour based on Proctor and Hendrix, 1994.

FIGURE 3-2

CLEAN SLATE #2 SITE PLAN



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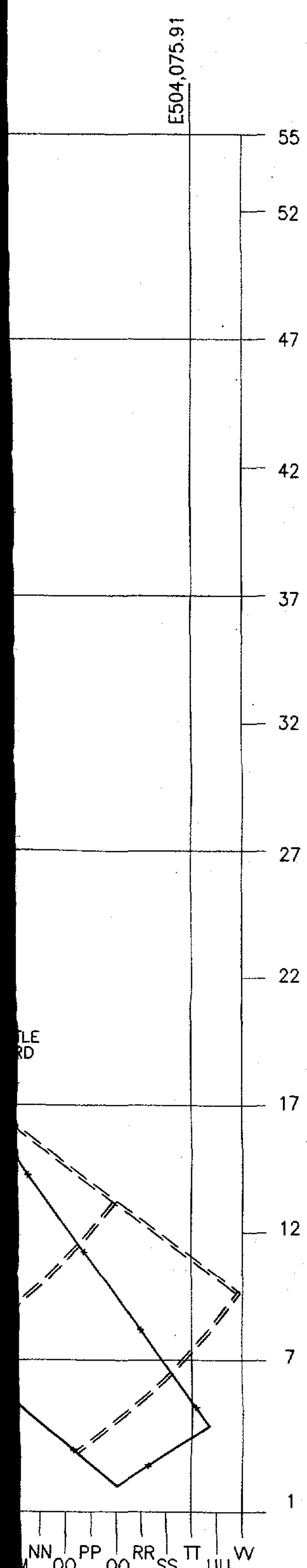

LEGEND

Perimeter fence

GZ Ground zero (GZ) location

200 200-pCi/g contour based on 1993 aerial survey by EG&G

Dirt road

NOTES

REECo, 1973c

200—pCi/g contour based on Proctor and Hendrix, 1994.

SCALE

0 1,500 3,000 Feet

0 400 800 Meters

FIGURE 3-3
CLEAN SLATE #3 SITE PLAN

4.0 Calculational Methodology

As prescribed in DOE Order 5400.5, the RESRAD code was used to calculate the dose to hypothetical dose receptors on the Clean Slate sites (DOE, 1993). Although RESRAD was produced for FUSRAP, SFMP, and the residential scenario, the procedure for determining dose and soil guidelines is general, and the use of the code is being encouraged for all DOE sites and various land-use scenarios.

The doses calculated by RESRAD are based upon a pathway analysis known as the concentration factor method (U.S. Nuclear Regulatory Commission [NRC] 1977; ICRP, 1979-1982; Till and Meyer, 1983; and National Council on Radiation Protection and Measurements [NCRP], 1985). With this method, the relation between radionuclide concentration in the soil and the dose to a hypothetical dose receptor is expressed as a sum of the products of pathway factors. Pathway factors correspond to pathway segments, connecting compartments in models of the environment between which radionuclides can be transported or radiation can be transmitted.

Most pathway factors are assumed to be steady-state ratios of concentrations in adjoining compartments. Some are factors for conversion from a radionuclide concentration to an external radiation dose rate; others are use and occupancy factors that affect exposure. Each term in the sum corresponds to a pathway of connected segments. A pathway product or pathway factor may be added, deleted, or replaced by the code user without affecting the other pathways or pathway factors. This structuring facilitates the use of alternative models for different conditions or transport processes and the incorporation of additional pathways. In this way, RESRAD input values can be modified or tailored to model a given situation by merely adding or replacing factors or terms in the pathway sum.

RESRAD calculates the dose to a hypothetical receptor by considering four types of analysis. These four analyses include:

- Source analysis
- Scenario analysis
- Environmental transport analysis
- Exposure/dose analysis.

Source analysis addresses the problem of deriving the source terms that determine the rate at which residual radioactivity is released into the environment. This rate is determined by the geometry of the contaminated zone, the concentration of the radionuclides, and the removal rate by erosion and leaching. Section 5.0 of this report discusses, in detail, the radiological source terms, the area of contamination, the depth distribution of the contamination, and the distribution coefficients assumed for each radionuclide.

Environmental transport analysis addresses the problems of identifying environmental pathways by which radionuclides can migrate from the source to a human exposure location and determining the migration rate along these pathways. Section 6.0 of this report discusses the environmental pathways assumed in this analysis.

Scenario analysis addresses how the patterns of human activity control the rate of radionuclide releases into the environment and the severity and duration of human exposure at a given location. Though RESRAD was designed for the resident-exposure scenario, it can be modified to represent many other types. For this analysis, four human exposure scenarios are evaluated: two agricultural worker scenarios (a rancher and a farmer), a rural resident, and an industrial worker. Section 7.0 of this report discusses these four exposure scenarios in more detail.

Exposure/dose analysis addresses the derivation of dose due to exposure to external radiation and the intake of radionuclides through ingestion and inhalation. The RESRAD code models environmental transport only. RESRAD uses dose conversion factors for inhalation, ingestion, and external radiation to determine dose; it does not model transport of radionuclides within the body.

5.0 Radiological Source Term

Calculating the dose to a member of the public from residual contamination in soil requires definition of a radiological source term. The radiological source term definition must include the concentration of each radionuclide contaminant in the soil, the area of the contaminated land, and the depth of the contamination. The radiological source term is the region within which radionuclides are present in above-background concentrations and is the common source term and starting point for all exposure pathway analysis. The area and depth of the contamination in the radiological source term is not smooth and uniform. For calculational purposes, an idealized radiological source term is assumed. The derivation of guideline concentrations is based upon an idealized contaminated region of cylindrical shape within which radionuclides are assumed to be uniformly distributed.

The only documented release of contamination at the Clean Slate sites was the weapons grade plutonium and depleted uranium dispersed during the Operation Roller Coaster experiments (Shreve, 1964). Not all of the initial radiological source term is now associated with the surface soil on the Clean Slate sites. Much of the Pu and DU fused with experimental structures (e.g., concrete pad and steel) at GZ. A significant fraction (approximately 40 percent) of the initial source term was vaporized, released to the atmosphere, and distributed onto the soil in the vicinity of TTR at very low concentrations, not distinguishable above fallout and natural background concentrations. Only about 60 percent of the initial radiological source term remained on the Clean Slate sites, and only a fraction of that is in the surface soil.

The data acquired and the methodology used in defining the radiological source term is summarized in the following text (Wille, 1996).

- *In situ* gamma spectroscopy data is gathered from plutonium-contaminated fragments found at each Clean Slate site. The 59.5-kiloelectron volt (keV) gamma emission from Am-241 and the 129-, 375-, and 414-keV gammas emissions from Pu-239 are used to determine the activity ratio in soil between the Am-241 and the Pu-239.

- *In situ* gamma spectroscopy was used to assess the depth of the contamination at the Clean Slate sites. The depth of the contamination is used to define the vertical dimension of the radiological source term.

- The Clean Slate sites were surveyed using a vehicle-mounted, gamma spectroscopy system that monitors the 59.5-keV photons emitted from Am-241. Analysis of the survey data is used to determine the Am-241 concentration and the area of the radiological source term,

- The initial mass of DU and Pu used in the Clean Slate experiments was documented. It is assumed that the mass ratios have remained constant for the DU and Pu contamination in the soil.

- The activity ratios of the radionuclides in standard DU and weapons plutonium Pu are assumed in calculating the radiological source term.

The *in situ* survey data from the Clean Slate sites, combined with the the assumptions regarding DU and Pu mass and activity ratios provide sufficient information for calculating the radiological source term. A detailed discussion on the *in situ* measurements of Pu and DU and the calculational methodology used to define the radiological source term is presented in Sections 5.1 through 5.4.

5.1 Pu:Am Concentration Ratios in Soil

Depleted uranium and weapons grade plutonium consist of a mixture of radionuclides. DU is composed of U-234, U-235, and U-238. Pu consists of Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, and Am-241. The presence of these radionuclides is difficult to detect directly in the environment unless the concentration is significantly above background. The radionuclides in DU and Pu are all alpha emitters, except in the case of Pu-241 which emits a low-energy beta. The alpha and weak beta particles emitted by DU and Pu are absorbed in just a few millimeters of soil. However, these radionuclides also produce gamma photons of different energies and intensities. Some of these gammas may be detectable when the radionuclide is at sufficiently high concentration in the soil.

A team from the Remote Sensing Laboratory conducted a series of *in situ* radiological measurements at the three Clean Slate sites during the period of April 22 through May 24, 1996 (RSL, 1996). The primary purpose of the survey was to characterize the distribution of weapons grade plutonium by measuring the gamma emissions from Am-241.

Am-241 is a decay product of the Pu-241 found in weapons grade plutonium. Am-241 undergoes alpha decay and emits (along with 16 electrons) 25 alpha particles, an x-ray photon, and 140 gamma photons, and a 59.5-keV gamma during approximately 35.9 percent of its disintegrations (Kocher, 1981). All of the measurements performed by RSL rely on detecting this 59.5-keV gamma emitted by Am-241. The concentration of the plutonium isotopes are inferred through a combination of Am-241 field measurements and theoritical considerations. Because the concentration of the Pu in soil at certain locations on the Clean Slate sites is large enough, *in situ* detectors are capable of measuring the gamma rays from both the plutonium and the Am-241. Thus, the plutonium-to-americium concentration ratio in the field can be measured directly.

The *in situ* measurements used a collimated germanium (Ge) detector mounted on a tripod one meter above ground level. Several measurements were made on the mounds near GZ at each Clean Slate site. Analysis of soil samples in the past had indicated these mounds had the highest concentration of Pu in soil at the Clean Slate sites. In addition, a measurement was made of the Pu-contaminated fragments collected at each site (RSL, 1996).

Data were collected on the measurements made of Clean Slate soil and Pu-contaminated fragments. Measurements were made of the 59.5-keV gamma emitted by the Am-241 and of the 129-, 375-, and 414-keV gammas emitted from Pu-239. The data from the Pu-contaminated fragments were considered to be most representative of the Am-241:Pu-239 activity ratio. Measurements taken of Pu-contaminated fragments were conducted outside of the exclusion fence where there is significantly less interference from the soil contamination. The collimator used with the Ge detector is not designed to completely shield higher energy gammas. Thus, the soil measurements are biased. A greater fraction of the higher energy photons emitted from the radionuclides in the nearby soil was penetrating the collimator and being detected than the lower energy gammas. Because of interference from the higher energy photons, the measurements taken of the soil are considered to have greater statistical uncertainty than the measurements taken of the fragments. Therefore, the data from fragments are used to calculate the Pu-239/240:Am-241 activity ratio.

The measurements taken of the fragments yield an Pu-239:Am-241 concentration ratio of 12.7. In weapons grade plutonium, the activity of Pu-240 is approximately 9.5 percent of the Pu-239 (McKinley, 1996). Therefore, the Pu-239/240:Am-241 ratio would be 13.9. For the purpose of calculating guideline concentrations, the Pu-239/240:Am-241 ratio is assumed to be 14:1.

5.2 Depth Profile of the Radiological Source Term

The definition of the radiological source term requires measurement of the depth of the contamination. A simple depth profiling technique was used to assess the depth of contamination at the Clean Slate sites. A collimated Ge tripod system, set up over the desired location, detected the number of Am-241 gammas which reached the detector in a 5-minute counting period (RSL, 1996). After each measurement, a layer of soil across the detector's field of view was carefully removed and another measurement was made. This operation was repeated until the number of detected Am-241 gammas fell either below 10 percent of the surface value or below the minimum detectable activity for this detector geometry and counting period (RSL, 1996).

At Clean Slate 1, most of the depth profiles demonstrated that there was no detectable activity after the first layer of soil (usually 2 to 3 cm) was removed. At Clean Slate 2, most of the depth profiles were taken along the southern and eastern segments of the inner fence and exhibited activity to a depth of 5 to 8 cm. Depth profiles farthest from GZ (about 300 m) only had activity in the top 2 to 3 cm. At Clean Slate 3, nearly all of the depth profiles were taken 150 to 250 m east of GZ and indicated Am-241 contamination to a depth of 7 to 8 cm. The four profiles taken inside the inner fence showed shallower deposits (about 3-4 cm). For the purpose of calculating guideline concentrations the depth of the contamination is assumed to be 5 cm.

5.3 Radiological Survey of the Clean Slate Sites

A radiological survey of the Clean Slate sites was performed by the RSL using ground-based *in situ* gamma spectroscopy. RSL used six 5 × 10 × 40-centimeter sodium iodide (NaI) detectors mounted on the rear of a Chevrolet four-wheel drive vehicle. This is essentially the same gamma spectroscopy system RSL has been using for years in its helicopter for monitoring radiological contamination and has been named the Kiwi system. The NaI detectors are shielded on the back and sides with a sheet of cadmium, while the end-mounted photomultiplier tubes and the vehicle itself provided shielding to the front of the detectors. The shielding produces a well-defined footprint for making assessments of the Am-241 concentration in a given volume of soil. As the vehicle moves, gamma ray spectra are recorded each second to provide complete coverage of the area. The field of view of the detector system is approximately 3 m (10 ft) across and 1.2 m (4 ft) long. The vehicle used a global positioning system (GPS) which has a positioning uncertainty of less than 1 m (RSL, 1996). The data are plotted based on collecting the individual second-by-second measurements into a nominal 10-m (33ft) grid and averaging the data over this interval. The intervals, known as cells, are 10-m on the side with an area of 100 m^2 (1,089 ft^2).

The Am-241 counts at each grid location are converted into a Pu-239/240 concentration in the soil by assuming a 14:1 activity ratio between the Pu-239/240 and the Am-241. The minimum detectable concentration for Pu-239/240 using this system is on the order of 25 pCi/g. Due to nonhomogeneity of the radiological source term, the concentration of Pu-239/240 in each cell is identified as being within a specific range. The lowest concentration cell range is 25 to 50 pCi/g; the highest concentration range is 1,600 to 3,200 pCi/g. In calculating the average concentration for a Clean Slate site, the concentration was assumed to be the average for each respective cell. For example, the average concentration for the 400 to 800 pCi/g cell was assumed to be 600 pCi/g (Wille, 1996).

The radiological survey area exceeds the area inside the outer fence at the three Clean Slate sites. At Clean Slate Sites 1 and 3, the area is only slightly larger than the areas inside the outer fence. At Clean Slate Site 2, the area is significantly larger than the area inside the outer fence because the contaminant plume between background and 200 pCi/g extends several kilometers south of the outer fence. It has been assumed the surveyed area would better represent what actually exists at the Clean Slate Site 2 rather than only considering the area inside the outer fence.

The Kiwi system was used to assess the depleted uranium concentration in the soil at the Clean Slate sites. During the Clean Slate experiments, there was much more DU dispersed at each site than Pu. However, due to the very low specific activity of DU and the extremely low gamma emission yield from most of the six decay products, the detection of depleted uranium is very difficult. The Kiwi data were analyzed for the 1,001-keV gamma from Protactinium (Pa)-234m. This technique has worked well at some other survey locations. At the Clean Slate sites, there were insufficient counts to identify the Pa-234m peak, even after the data were collected into the 10-m grids.

5.4 Calculating the Area Average Concentrations

Reduction of the Kiwi survey data gives the concentration of Pu-239/240 and Am-241 in the soil. The concentration of the remaining plutonium isotopes and the DU have to be calculated. The approximate mass ratios of depleted uranium to plutonium used for each test are provided as follows (Shreve, 1964):

- Clean Slate 1 47.2:1 depleted uranium to total plutonium
- Clean Slate 2 100.4:1 depleted uranium to total plutonium
- Clean Slate 3 99.7:1 depleted uranium to total plutonium

Decay products from the uranium isotopes have been produced since the simulated weapon was manufactured. Based upon the initial DU composition, the RESRAD code automatically calculates the concentration of the uranium radionuclides and their decay products in the soil and other environmental pathway media as well as the resultant dose contribution from each isotope. The initial composition of the DU assumed is that recommended in the *Health Physics Manual of Good Practices for Uranium Facilities* (Rich, 1988) and is listed in Table 5-1.

Table 5-1
Mass Fractions and Specific Activities for Depleted Uranium Isotopes

Isotope	**Mass Fraction** (g/100 g DU)[a]	**Specific Activity** (pCi/g)
U-238	99.75	335,696
U-235	0.25	2,162,400
U-234	0.0005	6,229,431,600

[a]Grams per 100 grams of DU

The radionuclides composing weapons-grade plutonium have shorter half-lives than the radionuclides in DU. Because of the shorter half-lives, the isotopic composition changes significantly in a relatively short period of time. Defining the radiological source term requires that the radioactivity of each isotope be calculated at a specific point in time. The actual date on which the weapons-grade plutonium was manufactured is classified. For this assessment, it is assumed that the weapons-grade plutonium was newly manufactured in 1963. A typical composition of weapons-grade plutonium is listed in Tables 5-2 (McKinley, 1996).

The source term was calculated by applying the mass ratios of the DU and Pu in the simulated weapons, the mass and activity fractions of the DU and Pu isotopes, and the measured activity ratio of Pu-239 to that of Am-241. *In situ* gamma spectroscopy analysis of Clean Slate soil determined that the mean Pu-239:Am-241 activity ratio was 12.7 and the activity ratio of Pu-239/240:Am-241 is assumed to be 14:1 (ITLV, 1996). A brief description of how the radiological source term was calculated is described in the following text:

- The pCi of each uranium isotope per gram of DU was calculated using the data in Table 5-1.
- The plutonium isotopic activity fraction per unit activity of Pu-239/240 was calculated assuming standard weapons plutonium composition and the specific activity of each isotope (see Table 5-3).

Table 5-2
Mass Fractions and Specific Activities for Weapons-Grade Plutonium Isotopes

Isotope	Mass Fraction (g/100 g PU)	Abundance (pCi/100 pCi/Pu)[a]
Pu-238	2.96E-05	7.68E-01
Pu-239	9.73E-01	9.13E+01
Pu-240	2.52E-02	8 69E+00
Pu-241	2.90E-04	4.52E+01
Pu-242	3.10E-05	1.86E-04
Am-241	1.43E-03	7.14E+00

[a]pCi/100 pCi Pu-239/240

Table 5-3
Activity Fractions for the Radiological Source Terms at Clean Slate Sites 1, 2, and 3

Isotope	Clean Slate 1 Activity Fraction (pCi/ Pu-239/240 pCi)[a]	Clean Slate 2 Activity Fraction (pCi/Pu-239/240 pCi)	Clean Slate 3 Activity Fraction (pCi/Pu-239/240 pCi)
U-234	2.23E-5	4.72E-5	4.69E-5
U-235	3.86E-6	8.20E-6	8.14E-6
U-238	2.39E-4	5.09E-4	5.05E-4
Pu-238	7.67E-3	7.68E-3	7.67E-3
Pu-239	9.13E-1	9.13E-1	9.13E-1
Pu-240	8.69E-2	8.69E-2	8.69E-2
Pu-241	4.53E-1	4.52E-1	4.52E-1
Pu-242	1.86E-6	1.85E-6	1.86E-6
Am-241	7.45E-2	7.45E-2	7.44E-2

[a] pCi/100 pCi Pu-239/240

- The isotopic activity per gram of source material was calculated from the known mass of DU and Pu for each Clean Slate device.

- The activity fraction of each uranium, plutonium, and americium isotope to Pu-239/240 was calculated for each Clean Slate.

- The concentration in soil of each DU and Pu isotope could then be calculated by multiplying its activity fraction by the concentration of Pu-239/240 in the soil.

The mathematical details of the calculations used to define the radiological source term are found in Attachment 1.

The Am-241 concentration measured by RSL was converted to Pu-239/240 concentration to determine the Pu-239/240 concentration in pCi/g of soil in each cell at the Clean Slate sites (Wille, 1996). The weighted average Pu-239/240 activity concentration in soil was calculated by summing the number of cell in each Pu-239/240 concentration range, multiplying by 100 m^2 per cell, and dividing by the total area surveyed.

At each Clean Slate site, a significant portion of the surveyed area has Pu-239/240 concentrations in the two lowest concentration ranges, 25 to 50 pCi/g and 50 to 100 pCi/g. The lower concentration ranges are not used to calculate the average Pu-239/240 concentration at each Clean Slate site because the statistical confidence in the data at the lower concentrations is barely significant. Therefore, the weighted-average Pu-239/240 concentration was calculated using only the data from cells with Pu-239/240 concentrations greater than 100 pCi/g. The Pu-239/240 concentration in soil, subsequent to remediation, was calculated by assuming all areas with a Pu-239/240 concentration equal to or exceeding 200 pCi/g will be remediated to 200 pCi/g (Wille, 1996). The area assumed to be at 200 pCi/g for Pu-239/240, subsequent to remediation, was derived using conservative assumptions. The methodology used in smoothing the calculated isoconcentration lines included areas whose Pu-239/240 concentration in soil was lower than the specific contoured region (Wille, 1996). A weighted-average area concentration for Pu-239/240 was then calculated for each site (Wille, 1996). The results of weighted-average area concentration analysis are listed in Table 5-4.

Table 5-4
Clean Slate Sites Weighted-Average Pu-239/240 Soil Concentrations and Area of Contamination

	Clean Slate 1	Clean Slate 2	Clean Slate 3
Pu-239/240 Soil Concentration Before Remediation (pCi/g)	3.57E+2	4.58E+2	3.91E+2
Pu-239/240 Soil Concentration After Remediation (pCi/g)	1.77E+2	1.76E+2	1.74E+2
Area of Contamination (m^2)	3.11E+5	2.72E+6	2.88E+6

The calculated isotopic activity ratios, picoCuries (pCi) of isotope per pCi of Pu-239/240, was multiplied by the Pu-239/240 concentration listed in Table 5-4 to define that isotope's concentration in soil. The radiological source terms calculated for Clean Slate 1, 2, and 3 are listed in Tables 5-5, 5-6, and 5-7, respectively. These are the radiological source terms assumed in the dose assessment.

The concentrations listed in Tables 5-5 through 5-7 are used as input to the RESRAD code as the radiological source terms. Examination of the radiological source term demonstrates that the activity concentration of the plutonium isotopes is significantly greater than the uranium isotopes. This is because the activity of a radionuclide is directly proportional to the inverse of its half-life, the time it takes for half of its radioactivity to decay. The shorter the half-life, the more radioactivity per unit mass. The uranium isotopes that compose DU have half-lives that are two to eight orders of magnitude greater than the half-lives of the weapon-grade plutonium isotopes.

Given equal masses of DU and Pu, the radioactivity of the uranium isotopes are three to four orders of magnitude less than the activity of the weapons-grade plutonium isotopes. For example, even if the Pu mass was only 0.01 percent of the DU mass, the radioactivity from the Pu will contribute 97.8 percent of the total radioactivity while the DU mass will contribute only 2.2 percent of the total radioactivity. The concentration of the DU isotopes in the soil prior to cleanup are already lower than the normal background concentration (NCRP, 1976).

Table 5-5
Clean Slate 1 Radiological Source Terms (pCi/g soil)

Isotope	Prior to Cleanup	Subsequent to Cleanup
U-238	8.53E-2	4.23E-2
U-235	1.38E-3	6.83E-4
U-234	796E-3	3.95E-3
Pu-238	2.74E+0	1.36E+0
Pu-239	3.26E+2	1.62E+2
Pu-240	3.10E+1	1.54E+1
Pu-241	1.62E+2	8.02E+1
Pu-242	6.64E-4	3.29E-4
Am-241	2.66E+1	1.32E+1

Table 5-6
Clean Slate 2 Radiological Source Terms (pCi/g soil)

Isotope	Prior to Cleanup	Subsequent to Cleanup
U-238	2.33E-1	8.96E-2
U-235	3.76E-3	1.44E-3
U-234	2.16E-2	8.31E-3
Pu-238	3.52E+0	1.35E+0
Pu-239	4.18E+2	1.61E+2
Pu-240	3.98E+1	1.53E+1
Pu-241	2.07E+2	7.96E+1
Pu-242	8.47E-4	3.26E-4
Am-241	3.41E+1	1.31E+1

Table 5-7
Clean Slate 3 Radiological Source Terms (pCi/g soil)

Isotope	Prior to Cleanup	Subsequent to Cleanup
U-238	1.97E-1	8.79E-2
U-235	3.18E-3	1.42E-3
U-234	1.83E-2	8.16E-3
Pu-238	3.00E+0	1.33E+0
Pu-239	3.57E+2	1.59E+2
Pu-240	3.40E+1	1.51E+1
Pu-241	1.77E+2	7.86E+1
Pu-242	7.27E-4	3.24E-4
Am-241	2.91E+1	1.29E+1

6.0 Exposure Pathways

This section discusses the exposure pathways evaluated in this dose assessment. An exposure pathway is a route of intake to an individual from the radioactivity associated with the DU- and Pu-contaminated soil. For example, ingestion of vegetables, fruits, and grains grown on contaminated soil would be an exposure pathway. The dose to the hypothetical individual is calculated by summing up the dose from each exposure pathway. The calculations are performed using RESRAD (Yu et al., 1993a).

The exposure pathways used in calculating the dose to the hypothetical individual on a Clean Slate site include:

- External gamma irradiation
- Inhalation of resuspended soil
- Ingestion of plants grown on contaminated soil and irrigated with contaminated water
- Ingestion of meat and milk from cattle and cows raised on contaminated soil, feed-contaminated fodder, and contaminated drinking water
- Ingestion of contaminated soil
- Inhalation of radon and radon daughter products

Gamma radiation from radionuclides distributed throughout the contaminated zone is the dominant external radiation pathway and the only external radiation pathway taken into account in calculating dose by the RESRAD code. RESRAD calculates the external radiation dose using correction factors to adjust the dose rate from an idealized infinite plane to a finite shape, self-shielding of the photons in the soil, and less-than-continuous occupancy. No cover of uncontaminated soil is assumed to shield the DU and Pu contaminated soil. The RESRAD default shielding factor of 0.7 was assumed for the shielding provided to individuals while indoors.

Soil can be resuspended into the air due to wind and mechanical action. The RESRAD code requires as input the annual average mass of resuspended contaminated soil in the air grams per cubic meter (g/m^3). The method used for calculating the amount of contaminated soil in the air is mass loading, which specifies the annual average value of the airborne dust concentration on the basis of empirical data. Measurements at TTR have demonstrated the following (Shinn et al., 1986 and 1994):

- The annual average mass loading of dust particles in the air at Clean Slate 3 is very low, 1.36×10^{-5} g/m^3 (Shinn, 1994). This mass loading is within the range reported for rural areas, 0.9 to 7.9×10^{-5} g/m^3 (Gilbert et al., 1983).

- During the summer when both the wind and the mass loading is at a maximum, measurements taken at Area 5 demonstrate that the particle size distribution is at a maximum, and only 3 to 10 percent of the dust particles are respirable (Shinn et al., 1986).

- Radioactive material in soil is associated with the smallest soil particles. As the mass loading increases, so does the particle size distribution. There is an increase in the mass and number of particles in the air during the summer, but the total amount of radioactive material associated with respirable size particles decreases in the summer (Shinn, et al., 1986). A soil index is used to adjust the calculated mass balance to account for this phenomena (Tamura, 1975).

- It is usually assumed that the concentration of dust in the air within buildings is always less than the concentration of dust in the air outside (Yu et al., 1993b). This is not the case; measurements by LLNL have demonstrated that the respirable dust concentration in air is as great or greater inside than outside (Clayton et al., 1993). In this assessment, no shielding for inhalation was assumed to be provided by housing or buildings for the rancher, farmer, or rural resident. For the industrial worker, the RESRAD default value of 0.4 was applied. This is because the air-handling systems of commercial buildings exert pressure indoors; hence, there is no significant infiltration of outdoor air (and associated airborne particles). The mass loading indoors for the industrial worker is assumed to be 0.4 of the mass loading outdoors. This shielding factor is the RESRAD default value and is recommended by the EPA (Yu et al., 1993a; EPA, 1986).

Three food pathway categories are considered in this dose assessment: plant foods, meat, and milk. The food plant pathway category is divided into four subcategories corresponding to:

- Root uptake from crops grown on contaminated soil
- Foliar uptake from contaminated dust depositing on the foliage
- Root uptake from contaminated irrigation water
- Foliar uptake from contaminated irrigation water

The water ingestion pathway includes both groundwater and surface water. All irrigation, household, and drinking water are taken from a well assumed to be located at the downgradient edge of the contaminated zone. This location will ensure that the water from the well will receive the maximum amount of contamination from the soil.

Soil and dust derived from soil are accidentally ingested by individuals, both while outdoors and indoors. According to guidance by the U.S. Environmental Protection Agency (EPA, 1990), soil ingestion should be considered separately for adults and children for residential scenarios. The input value for the soil ingestion rate, in grams per year (g/yr), depends strongly on the assumed scenario. The soil intake rates assumed in calculating guideline concentrations are based upon the pilot study by Calabrese et al., (1990). This study has been adopted by the EPA and the AIHC (EPA, 1991; AIHC, 1994). The methodology used in applying the Calabrese et al. (1990) study is as follows:

- While on site, an individual engaged in agricultural activities (i.e., plowing or rototilling) will be assumed to be ingesting soil at a rate of 0.48 grams per day (g/day).
- While working on site in an industrial position, an individual is assumed to be ingesting soil at a rate of 50 milligrams per day (mg/day).
- Other on site residents are assumed to be to be ingesting soil at a rate of 100 mg/day while engaging in garden or other outdoor activities; otherwise their soil ingesting rate is 50 mg/day.
- When not on site, individuals are not ingesting contaminated soil.

Individuals are assumed to inhale radon gas and radon decay products produced from radioactive decay of the DU and Pu radionuclides. It takes thousands of years for the radon gas to build up significant concentration from the parent radionuclides. As the parent radionuclide concentration is low, dose from radon gas is expected to be negligible.

Greater detail on the exposure pathways and how the exposure pathway data is used by the RESRAD code to calculate dose can be found in *Methodology for Calculating Guideline Concentrations for Safety Shot Sites* (Adams, 1996).

7.0 Exposure Scenarios

Four exposure scenarios were considered for the Clean Slate sites. The exposure scenarios included a rural resident, two agricultural scenarios (ranching and farming), and an industrial worker participating in light commercial industry. In addition, a child dose receptor was added to the residential and agricultural exposure scenarios. In all scenarios, the assumption is that, at some time within 10,000 years, the sites will be released for use without radiological restrictions following remediation. The remaining parts of Section 7.0 provide the description of each exposure scenario.

7.1 The Rural Resident Exposure Scenario

The rural resident scenario is based on EPA's standardized residential scenario and exposure pathways used in their proposed soil cleanup rule for radiological contaminated soil (EPA, 1993). Under the residential exposure scenario, a total of eight exposure pathways are evaluated:

- External radiation exposure from photon-emitting radionuclides in soil
- Inhalation of resuspended soil and dust containing radionuclides
- Inhalation of radon gas
- Incidental ingestion of soil and dust containing radionuclides
- Ingestion of contaminated drinking water
- Ingestion of contaminated home-grown produce (fruits, vegetables, and grains)
- Ingestion of meat containing radionuclides taken up by cows raised on site
- Ingestion of milk containing radionuclides taken up by cows raised on site

The hypothetical rural resident resides is assumed to work primarily off site and engage only in light gardening and recreational activities on site. Furthermore, it is assumed that 50 percent of the locally grown produce, meat, and milk that the rural resident consumes is grown on site and is contaminated. The hypothetical resident receives external radiation exposure, both while indoors and outside. He breathes air that is contaminated with resuspended contaminated soil, radon gas, and radon decay products. All of the water used for drinking, cooking, and irrigation comes from a well located on site. In addition, the hypothetical resident is assumed to ingest contaminated soil.

The rural resident is assumed to raise food in a garden irrigated with water from a well located at the downgradient edge of the decontaminated area. This location will ensure that the water from the well receives the maximum amount of contamination from the site. All drinking and cooking water is obtained from this well. The resident drinks 1.4 liters (L) of well water per day (L/day) and 472 liters per year (L/yr) (AIHC, 1994). The hypothetical resident raises half of his fruits, leafy and nonleafy vegetables, and grains in a garden located on contaminated soil. In addition, he is assumed to obtain half of the meat and milk he consumes each year from beef cattle and cows raised on site. The consumption rate of all food items by the rural resident is based upon a 10-county lifestyle survey relevant to a rural area and town of less than 25,000 residents in the arid and semi-arid western United States (Whicker et al., 1990).

The inhalation rate for the hypothetical resident is for a reasonable worst-case for individuals performing indoor activities (Yu et al., 1993b). This case is defined for an individual spending 8 hours per day (h/day) sleeping and, during the remaining day, spending 25 percent of his time at a resting activity level, 60 percent at a light activity level, 10 percent at a moderate activity level, and 5 percent at a heavy activity level (Yu et al., 1993b). The breathing rates for these activities are derived from Table 7 of Layton (1993). The annual inhalation rate assumed in this dose assessment is 6,740 cubic meters per year (m^3/yr). However, the RESRAD code adjusts the annual inhalation rate by multiplying the user input value by the occupancy factor, the fraction of the time the resident is on site. The occupancy factor for the resident is 341/365 days per year (day/yr) or 0.934. The calculated annual inhalation rate is then adjusted (6740/0.9342) up to 7,215 m^3/yr. The concentration of resuspended soil in the air is based upon the activities assumed for the hypothetical resident and site-specific measurements performed at the TTR and the NTS. The exposure scenario parameters for the rural resident are listed in Table 7-1. Attachment 1 to Appendix A includes all of the calculations for the user-defined parameter values that were input to the RESRAD code.

7.2 Agricultural Exposure Scenarios: Ranching and Farming

Land use that involves agriculture is assumed to center around a farm or ranch house that is located on contaminated soil. An important human factor determining the magnitude of human exposures in this type of scenario is the amount of time spent outdoors on site on the contaminated land. This is defined as the occupancy factor in RESRAD. In calculating guideline concentrations, the area comprising the agricultural operations is assumed to be limited to the contaminated area.

Table 7-1
Parameter Values for the Rural Resident Exposure Scenario

Parameter (Units)	Numerical Value
Exposure Frequency (days/yr)	341
Inhalation Rate (m^3/day)	20
Soil Ingestion Rate (mg/day)	120
Exposure Time Indoors (h/day)	14.9
Exposure Time Outdoors (h/day)	0.4
Shielding Factor for Inhalation	0.4
Drinking Water Ingestion Rate (L/day)	1.4
Leafy Vegetable Ingestion Rate (g/day)	29.5
Non-Leafy Vegetable Ingestion Rate (g/day)	154
Fruit Ingestion Rate (g/day)	122
Grain Ingestion Rate (g/day)	78
Milk Ingestion Rate (L/day)	0.61
Beef and Poultry Ingestion Rate (g/day)	274

If large commercial ranching or farming operations were assumed, a significant portion of the workers' time would not be spent on the contaminated land. In addition, large operations would result in crops and livestock being raised on uncontaminated soil. Calculating the guideline concentration assuming large agricultural operations would be nonconservative, resulting in a reduced and biased dose as a function of the concentration of the radiological source term in the soil. In this regard, limiting agricultural activities to the contaminated area would involve the hypothetical dose receptor being required to spend a significant amount of time on the contaminated land.

The safety shot sites are large enough to support a self-sustaining herd of beef or dairy cows or raise the fruits, vegetables, and grains to feed a family. Calculation of the guideline concentrations for the agricultural scenarios assumes small family ranches or farms exist on the safety shot site. Lifestyle data for the agricultural scenarios is based upon the articles in a special issue of the Health Physics Journal, *Evaluation of Environmental Radiation Exposures from Nuclear Testing in Nevada* (Gesell and Voilleque, 1990).

Two agricultural exposure scenarios were assumed, a resident rancher and a resident farmer. The guideline concentrations are calculated separately for each of these two exposure scenarios because the activities used in each are significantly different. For example, due to the low annual precipitation rate, a farmer would have to irrigate the land. The irrigation water leaches the radiological source term from the surface, diluting the concentration of the radiological source term by distributing it through a deeper layer of the soil, and thereby reducing the dose received by the farmer.

The farmer is assumed to plow, disk, and till the soil. These activities will mix the radionuclides on the surface soil with the uncontaminated soil below the surface, diluting the concentration of the radiological source term, thereby reducing the dose to the farmer. At the same time, the activities involved in farming, such as plowing, disking, and tilling, will increase the mass loading of radiological contaminated soil into the air, increase the radionuclide intake to the farmer via the inhalation pathway, and thereby increase the dose to the farmer. The rancher is assumed to pasture his herds and not perform activities that would dilute the concentration of the radiological source term, such as plowing, disking, and tilling. A detailed description of the activities associated with each of the agricultural exposure scenarios follows.

Rancher Scenario

The hypothetical rancher scenario is plausible, but very unlikely. At the safety-shot sites, the precipitation rates are low; the production of palatable herbs, grasses, and other forage for cattle is very low; and there is a minimum of infrastructure available to support even a subsistence rancher. Selection of the ranching exposure scenario and exposure pathways will result in conservative (i.e., stringent) dose estimates for a future hypothetical dose receptor. However, in order to ensure a full set of exposure scenarios are evaluated, the rancher exposure scenario is used in calculating guideline concentrations.

Under the rancher exposure scenario, a total of seven exposure pathways are evaluated:

- External radiation exposure from photon-emitting radionuclides in soil
- Inhalation of resuspended soil and dust containing radionuclides
- Inhalation of radon gas
- Incidental ingestion of soil and dust containing radionuclides
- Ingestion of contaminated drinking water
- Ingestion of meat containing radionuclides taken up by cows raised on site
- Ingestion of milk containing radionuclides taken up by cows raised on site

The parameter values used in the rancher scenario are those listed in Table 7-2 and are derived, to the extent possible, from surveys taken on the lifestyles of families living in rural areas and small communities in a 10-county area around the NTS (Henderson and Smale, 1990; Whicker et al., 1990). Appendix A shows how each of the user-calculated parameter values were derived.

Table 7-2
Parameter Values for the Rancher Exposure Scenario

Parameter (Units)	Numerical Value
Exposure Frequency (days/yr)	341
Inhalation Rate (m^3/day)	8010
Soil Ingestion Rate (mg/day)	131
Exposure Time Indoors On-Site (h/day)	9
Exposure Time Outdoors On-Site (h/day)	15
Shielding Factor for Inhalation	1
Drinking Water Ingestion Rate (L/day)	1.86
Leafy Vegetable Ingestion Rate (g/day)	29.5[a]
Non-leafy Vegetable, Fruit, and Grain Ingestion Rate (g/day)	354[a]
Milk Ingestion Rate (L/day)	0.61
Beef and Poultry Ingestion Rate (g/day)	274

[a]Obtained from a farm with soil contamination equivalent to his ranch

The rancher is assumed to raise beef cattle and dairy cows, full time, on the contaminated safety-shot site and to reside on the site 24 hours per day for 341 days per year (Adams, 1996). The rancher spends 15 hours per day outside on site and 9 hours per day indoors.

While on site, the rancher is breathing air assumed to have an average mass loading greater than the baseline mass loading for the site. The baseline mass loading is the mass loading measured at the site or in the vicinity of the site prior to human habitation. Equation 5 of Adams (1996) was used to adjust the mass loading upward using the specific activities associated with ranching. The assumptions used in adjusting the mass loading are as follows:

- During 50 days per year, the rancher's activities increase the mass loading by a factor of two.
- The rancher's activities do not increase the mass loading significantly during the rest of the year.

The adjusted mass loading is 1.56E-5 g/m^3. This value is about 15 percent greater than the mass loading measured during the spring, summer, and fall at Clean Slate 3 (Shinn, 1994). It is within the reported range of mass loadings for rural locations, 0.9 to 7.9E-5 g/m^3 (Gilbert et al., 1983).

The assumed inhalation rate of the rancher is based upon that for a typical outdoor activity (Yu et al., 1993b). He is assumed to sleep seven hours per day. During his waking hours, he is assumed to spend 28 percent of the time at both resting and light activity level, 37 percent at a moderate activity level, and 7 percent at a heavy activity level, which results in an annual inhalation rate of 8,010 m^3/yr (Yu et al., 1993a; Layton, 1993). The RESRAD code adjusts the inhalation rate input of the code user by multiplying it by the occupancy factor (the fraction of the time the rancher is on site). The occupancy factor for the rancher is 341 days per year divided by 365 days per year = 0.934. Therefore, to compensate for the downward adjustment made internally by the RESRAD code, the calculated breathing rate is adjusted upward by a factor of (1/0.9342). The input to the RESRAD code for the rancher's annual inhalation rate is $(8{,}010/0.934) = 8.58 \times 10^3 =$ m^3/yr.

While outdoors, the rancher is exposed to an external radiation rate that is 3.33 times that of indoors. Water is obtained from a well located at the downgradient edge of the contaminated site. This location of the well ensures that the water from the well receives the maximum amount of contamination from the soil. All drinking and household water is obtained from this well. The rancher is assumed to drink 1.4 L of tap water per day, 477 L per year (AIHC, 1994).

The rancher is assumed to raise half of his own meat, milk, and their by-products from cattle and cows raised on the contaminated site. In addition, he obtains half of his annual food consumption of fruits, vegetables, and grains from a farm whose soil contamination is equivalent to his ranch. The consumption rate of all food items is based upon a 10-county, lifestyle survey relevant to rural areas and towns of less than 25,000 residents in the vicinity of the NTS (Whicker et al., 1990).

All livestock is raised on site, and their only source of drinking water is the on-site well. The beef cattle and dairy cows are assumed to ingest 50 kilograms (kg) of fodder per day. The beef cattle are assumed to ingest 50 L of water per day, while the dairy cattle ingest 160 L of water per day (NRC, 1977; Great Lakes Basin Commission, 1975). In addition, both the cattle and cows are assumed to ingest 0.5 kg of contaminated soil per day (Rope and Adams, 1983).

The radon inhalation dose to the rancher is maximized by assuming the residential building foundation depth is set on the soil surface and the effective radon diffusion coefficient is 3×10^{-7} square meters per second (m^2/s) (Yu et al., 1993a).

Farmer Scenario

The hypothetical farmer is a plausible, but very unlikely, scenario. As stated previously, the precipitation and the soil productivity at the safety shot sites are very low; irrigation and fertilization will be required to raise crops. Because the depth to groundwater varies from 80 to several hundred meters on the safety shot sites, the cost of groundwater wells may make agricultural prohibitive. In addition, there is negligible infrastructure available to support farming. However, in order to evaluate a full set of exposure scenarios, the farming scenario is included. The selection of the farming scenario will result in conservative dose estimates for future hypothetical residents on the safety shot sites.

Farming activities in southern Nevada were assumed to be indicative of future farming on the safety shot sites and will include alfalfa farms and orchards. These agricultural uses are more likely to result in outdoor exposure to airborne contaminants adjacent to a farmhouse as the irrigated land is assumed to be in the direct vicinity of the farmer's residence. Thus, in this exposure scenario, an individual would spend a considerable amount of time outdoors farming, with the remainder of time indoors in barns, outbuildings, or the farmhouse, all of which are assumed to be on contaminated soil.

The parameter values used for the resident scenario are those listed in Table 7-3 and are derived, to the extent possible, from surveys taken of residents living in rural and small communities in a 10-county area in the vicinity of the NTS (Henderson and Smale, 1990; Whicker et al., 1990).

Table 7-3
Parameter Values Used in the Farming Exposure Scenario

Parameter (Units)	Values
Exposure Frequency (day/yr)	341
Inhalation Rate (m^3/day)	8010
Soil Ingestion Rate (mg/day)	129
Exposure Time Indoors (h/day)	9
Exposure Time Outdoors (h/day)	15
Shielding Factor for Inhalation	1
Drinking Water Ingestion Rate (L/day)	1.86
Leafy Vegetable Ingestion Rate (g/day)	29.5
Non-leafy Vegetables, Fruit, and Grain Ingestion Rate (g/day)	353
Milk Ingestion Rate (L/day)	0.61[a]
Beef and Poultry Ingestion Rate (g/day)	274[a]

[a]Obtained from a ranch with soil contamination equivalent to his farm

Under the farming scenario, a total of seven exposure pathways are evaluated:

- External radiation exposure from photon-emitting radionuclides in soil
- Inhalation of resuspended soil and dust containing radionuclides
- Inhalation of radon gas
- Incidental ingestion of soil and dust containing radionuclides
- Ingestion of contaminated drinking water
- Ingestion of contaminated home-grown produce (fruits, vegetables, and grains)

While on site, the farmer is breathing air assumed to have an average mass loading greater than the average annual mass loading for the site. Equation 5 of Adams (1996) was be used to adjust the baseline mass loading upward, assuming specific activities associated with farming. The activities include the following tasks:

- The farmer spends 24 hours per year in very intense farming activities such as plowing that result in a 150-fold increase in the mass loading (Leddicotte et al., 1978).

- For 50 days per year, the farmer is engaged in intense activities such as cultivating that increase the mass loading by a factor of two.

- For the remainder of the year, the farmer is involved in less intense activities that do not increase the mass loading.

The adjusted mass loading for the farmer is 2.16E-5 m^3/yr. This is approximately 59 percent greater than the baseline mass loading and within the range reported for rural areas, 0.9 to 7.9E-5 m^3/yr (Gilbert et al., 1983). The details on the calculation of the mass loading are in Attachment 1 of Appendix A.

The annual inhalation rate assumed for the farmer is the same as for the rancher, 8,010 m^3/yr. The annual inhalation rate is adjusted for input to RESRAD by dividing it by the occupancy factor, 0.9342. While outdoors, the farmer is exposed to an external radiation rate that is 3.33 times of that indoors.

The farmer is assumed to obtain all of his household and irrigation water from a well located at the downgradient edge of the contaminated site. This location of the well ensures that the water from the well receives the maximum amount of contamination from the soil. All drinking and household water is obtained from this well. The farmer is assumed to drink 1.4 L of tap water per day, 477 L per year (AIHC, 1994).

The farmer is assumed to raise half of all the vegetables, fruits, and grains consumed during the year. The consumption rate is based upon a 10-county, lifestyle survey relevant to rural areas and towns of less than 25,000 residents in the vicinity of the NTS (Whicker et al., 1990).

The radon inhalation dose to the farmer is maximized by assuming the residential building foundation depth is set on the soil surface and the effective radon diffusion coefficient is 3×10^{-7} m/s (Yu et al., 1993a).

In the agricultural exposure scenarios, a sharp distinction was made between the activities of the rancher and the farmer. In reality, this may not always be the case. For example, the rancher may raise food crops for his own consumption. The farmer may raise poultry, rabbits, beef cattle, or dairy cows as a source of meat and milk. To ensure that the dose calculated for the rancher and farmer is conservative and bounding, the following assumptions were made:

- The rancher obtains half of his annual food consumption of fruits, grains, and vegetables from a farm whose soil has the same concentration and type of radiological contamination as his ranch.

- The farmer obtains half of his annual food consumption of meat, milk, and their by-products from a ranch whose soil has the same concentration and type of radiological contamination as his farm.

7.3 Industrial Worker

The parameter values assumed for the industrial exposure scenario and used to calculate guideline concentrations are identical to those defined by the EPA for Superfund cleanups and in the proposed rule for cleanup of radiologically contaminated soil (EPA, 1993; 1994). The exceptions are the breathing rates and inadvertent soil ingestion rates, they were obtained from the open scientific literature. In calculating guideline concentrations, the breathing rates are from Layton (1993) and the soil ingestion rates are from EPA (1991).

This scenario addresses long-term exposures and risks to commercial or industrial workers exposed daily to residual levels of radionuclides in soil during an average 8-hour workday on site, both indoors and outdoors. This scenario does not consider exposures to site remediation workers or construction workers, nor does it address risks to workers from contaminated structures or building materials.

Under the industrial exposure scenario, a total of five pathways are evaluated:

- External radiation exposure from photon-emitting radionuclides in soil
- Inhalation of resuspended soil and dust-containing radionuclides
- Inhalation of radon
- Incidental ingestion of soil containing radionuclides
- Ingestion of drinking water containing radionuclides transported from soil to groundwater

The dose to the industrial workers will generally be less than those for residents of rural areas because worker exposures are limited to working hours and do not include contributions from ingestion of home-grown produce. As a result, doses for workers are expected to be consistently lower than those for individuals assuming residential or agricultural exposure scenarios. The parameter values assumed for the industrial worker exposure scenario are listed in Table 7-4.

Table 7-4
Parameter Values for the Industrial Worker Exposure Scenario

Parameter (Units)	Numerical Value
Exposure Frequency (day/yr)	250
Inhalation Rate (m^3/day)	12.6
Soil Ingestion Rate (mg/day)	50
Exposure Time Indoors (h/day)	8
Exposure Time Outdoors (h/day)	2
Inhalation Shielding Factor	0.4
Food Ingestion Rate (g/day)	0
Drinking Water Ingestion Rate (L/day)	0.875

The inhalation rate is calculated using the following activity mixture; 60 percent of their time is spent performing light work, 30 percent of their time is spent performing moderate work, and 10 percent of their time is spent performing very heavy work. The breathing rates assumed are from Layton (1993).

A drinking water ingestion rate was not identified by the EPA in their industrial worker exposure scenario. In calculating guideline concentrations, it is assumed that the industrial worker ingests 62.5 percent (10 h/day at work out of 16 h/day they are awake) of his daily ingestion rate of 1.4 L/day while at work (Roseberry and Burmaster, 1992).

7.4 Child Dose Receptor

The child dose receptor is evaluated to determine the difference, if any, between the dose received by a child in comparison to an adult. It will be used as a subset of the agricultural and resident scenarios. The child dose receptor is not pertinent to the industrial worker exposure scenario.

The child dose receptor describes the living patterns, breathing rates, and diet for children up to age eleven. The parameter values that describe the child dose receptor are listed in Table 7-5. To the extent possible, the parameter values assumed are derived from lifestyle surveys taken in rural areas and small communities in the vicinity of the NTS (Henderson and Smale, 1990).

Table 7-5
Parameter Values for the Child Dose Receptor

Parameter (Units)	Numerical Value
Exposure Frequency (day/yr)	330
Inhalation Rate (m^3/day)	12.3
Soil Ingestion Rate (mg/day)	24
Exposure Time Indoors (h/day)	18.4
Exposure Time Outdoors (h/day)	5.6
Shielding Factor for Indoor Inhalation	0.4
Drinking Water Ingestion Rate (L/day)	0.32
Leafy Vegetable Ingestion Rate (g/day)	18.5
Non-Leafy Vegetable, Fruit, and Grain Ingestion Rate (g/day)	397
Milk Ingestion Rate (L/day)	1.18
Meat and Egg Ingestion Rate (g/day)	153

The exposure frequency, exposure time indoors, and exposure time outdoors for elementary school children (ages 5 to 11 years old) were derived from Figure 2 of Henderson and Smale (1990). For children ages 3 and 4, data was obtained from the EPA Exposure Factors Handout and the AIHC Exposure Factors Sourcebook (EPA, 1989; AIHC, 1994). Very young children, less than three years old, were assumed to spend one-half as much time off-site and outdoors on-site as children six to eleven years old, based upon the site-specific data of Henderson and Smale (1990).

The soil ingestion rate assumed for children is based upon the quantifiable soil ingestion rates obtained in the studies of Calabrese and Stanek (1991). The median soil ingestion value for children was reported as 16 mg/day with a 97.5 percentile of 24 mg/day. The 24 mg/day value was assumed for the child exposure scenario.

The inhalation rate assumed for the child dose receptor is a weighted average value derived from the daily inhalation rates for children of less than one to eleven years of age, listed in Table 5 of Layton (1993).

The drinking water ingestion rate assumed for the child dose receptor is a weighted average taken from Table 5.9, "Average and Range of Daily Intake of Tap Water and Beverages Other Than Milk for Various Age Groups," Report No. 76 of the National Council on Radiation Protection and Measurements (NCRP, 1985).

The ingestion rate of fruits, leafy, and non-leafy vegetables, grains, meat and poultry, and milk assumed for the child dose receptor is derived from Table 5-3, "Best Estimates of Average Daily Intake of Various Foods by Age" in NCRP Report No. 76 (NCRP, 1985).

The mass loading, indoor shielding factor for inhalation, dilution length for airborne dust, and the indoor shielding factor for external radiation for the child dose receptor is assumed to be the same as for adults.

Other assumptions used in the dose assessment for the rural residential, agricultural, and industrial worker exposure scenario include the following:

- The concentration of contaminated dust in the air indoors is assumed to be the same as that outdoors except for the Industrial Worker. For the industrial worker, the concentration of contaminated dust in the air indoors is assumed to be 40 percent of the contaminated dust in the air outdoors (EPA, 1993, 1994). Dust is assumed to be filtered by the heating, cooling, or ventilation systems in the worker's building.

- No cover is assumed to be placed over the decontaminated soil after remedial action is completed.

- The surface soil, unsaturated zone, and saturated zone soil is assumed to be a sandy alluvium. This medium has an effective and total porosity of 0.3 (Freeze et al., 1979), an assumed hydraulic conductivity of 100 meters per year (m/yr) (Yu et al., 1993b), a depth to groundwater of 55 m (Thomas et al., 1986) and a water table drop rate of 1E-4 (DOE, 1994a).

- Climatography data was obtained from the 1993 Site Environmental Report for the Tonopah Test Range (Culp and Howard, 1995). This document contains temperature, precipitation, and wind velocity data for TTR. The climatography data is input directly in RESRAD and is also used in calculating other parameter values such as the evapotranspiration coefficient.

- Data on the food consumption rate and lifestyle habits of the hypothetical resident were adapted from articles in the November 1990 Special Issue of the *Health Physics Journal*, "Evaluation of Environmental Radiation Exposures from Nuclear Testing in Nevada" (Gesell and Voilleque, 1990).

- No mixing of the soil was assumed due to ranching activities or for the industrial worker site. Soil mixing for the farmer and rural resident is assumed to result in a mixing depth of 0.15 m, resulting in an effective source term reduction of three. This mixing depth is the RESRAD default factor.

- The leach rates of the DU, Pu, and their decay products from the soil by precipitation and irrigation water were calculated by RESRAD by inputting the distribution coefficients listed for sandy soil as indicated in Table 32.1 of the *RESRAD Data Collection Handbook* (Yu et al., 1993b).

- The mass loading in the air for the resident and industrial worker and the erosion rate due to resuspension were calculated using the TTR and NTS data reported in Shinn et al. (1986 and 1994). The activity mix for the rancher used in calculating mass loading was from Leddicotte et al. (1978) and EG&G Idaho (1986). All mass loadings were adjusted in accordance with the methodology of Tamura (1975) using the data of Shinn (1986 and 1994).

- Soil ingestion rates for adults are based upon the guidance of the *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil* (Yu et al., 1993b).

- Annual ingestion rate of tap water was obtained from the *American Industrial Health Council Exposure Factors Sourcebook* (AIHC, 1994).

- The activity mix for each of the exposure scenarios are from Yu et al. (1993b) while the breathing rate for each activity are from Layton (1993).

All RESRAD input parameters are listed in the tables that are located at the end of this dose assessment. Appendix A, Attachment 1 of this document includes the details on how the user-defined parameter values were calculated.

8.0 Analytical Results

A radiological dose assessment has been performed for residual radioactive material in the soil at Clean Slates Sites 1, 2, and 3. The committed effective dose equivalent (CEDE) was calculated for individuals participating in four hypothetical exposure scenarios:

- Two agricultural scenarios, a resident farmer and a resident rancher
- A rural resident
- An industrial worker

The dose assessment demonstrates that, subsequent to the proposed remediation, the maximum CEDE to a hypothetical individual on the Clean Slate sites will be less than the primary dose limit of 100 mrem/yr promulgated in DOE Order 5400.5 (DOE, 1993). A summary of the calculated doses is listed in Table 8-1.

Table 8-1
Dose to Hypothetical Individuals Subsequent to Remediation of the Clean Slate Sites (mrem/yr)

Scenario	Clean Slate 1	Clean Slate 2	Clean Slate 3
Rancher	47	47	46
Farmer	23	23	22
Rural Resident	12	12	12
Child (Ranch)	13	13	13
Industrial Worker	4.5	4.4	4.4

The agricultural scenarios are considered plausible, but very unlikely; they were included for purposes of completeness. The maximum CEDE calculated in the dose assessment is to the rancher, 47 mrem/yr. This dose is less than half the basic dose limit. The maximum CEDE to the farmer is even less, 23 mrem/yr.

The rural resident and industrial worker scenarios were included because they have been established by the EPA for demonstrating compliance with a proposed regulation for cleanup of land contaminated with residual radioactive materials (EPA, 1993; EPA, 1994). Though the proposed EPA regulation would not have purview over current DOE operations, the EPA's exposure scenarios were included for comparison purposes. The EPA's proposed radiation protection criteria for the rural resident and industrial worker is 15 mrem/yr. The maximum calculated dose to the rural resident and industrial worker, subsequent to remediation, is 13 mrem/yr and 4.5 mrem/yr, respectively. This dose assessment demonstrates that subsequent to remediation, the dose to a rural resident and industrial worker will be less than the radiation protection criteria proposed by the EPA.

A child dose receptor has been included in the dose assessment. The dose to the hypothetical child was calculated for the rural resident, rancher, and farmer exposure scenarios. The parameters used to describe the child's ingestion and inhalation rates are from (NCRP, 1985; Layton, 1983). The child's dose in all exposure scenarios was always less than an adult's. This is due to the child's lower rates of ingestion and inhalation. However, the child's dose contains a great deal of uncertainty. The dose conversion factors, used to calculate dose from a given intake of radioactive material, are for adults. Dose conversion factors for children were recently published for 20 radionuclides associated with nuclear fallout; e.g., various radioisotopes of iodine, cesium, technetium, strontium, zirconium, and neptunium, but not plutonium (Kirchner et al., 1996). None of the radionuclides evaluated had the same characteristics as Pu (bone-seeking, long-lived, alpha emitters). Information required to calculate Pu and DU dose conversion factors for children include:

- The differing retention times of radionuclides in organs and tissues between children and adults
- The linear dimensions of organs, tissues, and inter-organ distances that vary with age and body mass
- Variation of the metabolic retention functions with age
- Fractional deposition and clearance of particulates in the respiratory system as a function of age

Assuming that the retention times and functions, linear dimensions, and fractional depositions and clearance of Pu and DU do not vary significantly with age, the age-specific dose factors for children are estimated to exceed the adult dose conversion factors by multiplicative factors ranging up to ten for infants to three for teenagers (Adams, 1981; Cristy, 1984, and Kirchner, 1996). Therefore, an age-weighted dose conversion factor for the child would increase the dose by a factor of three to four. The maximum calculated CEDE to the child would then increase to a range of 39 to 52 mrem/yr. This dose is less than the primary dose limit of 100 mrem/yr.

The CEDE was calculated using the RESRAD computer code Version 5.61 (Yu et al., 1993a). The time frame considered in this radiological dose assessment was 0 to 10,000 years. Radioactive decay and ingrowth were considered in deriving the doses. The calculated doses are presented in the tables in Appendix A, Attachment 1. The parameter values used in the RESRAD code for the dose assessment as well as the methodology and mathematic equations used in calculating the user-defined parameter values input into the RESRAD code are also found in Attachment 1.

Prior to the assumed remediation activities, the calculated maximum annual dose to a hypothetical individual at the Clean Slate sites would be 120 mrem/yr to a rancher on Clean Slate Site 2. Subsequent to remediation activities, the calculated maximum dose rate to the Clean Slate Site 1 rancher would be 47 mrem/year. The calculated dose for individuals participating in the other exposure scenarios is significantly lower. For four exposure scenarios, the maximum dose occurs in year zero, the first years subsequent to remediation.

The primary exposure pathways contributing to dose for each of the exposure scenarios are:

- For the rancher, soil ingestion contributes 59 percent, inhalation 21 percent, and plant ingestion 10 percent.
- For the farmer, soil ingestion contributes 48 percent, plant ingestion 25 percent, and inhalation 24 percent.
- For the rural resident, plant ingestion contributes 42 percent and soil ingestion contributes 41 percent
- For the industrial worker, soil ingestion contributes 80 percent and inhalation contributes 17 percent.

The exposure pathways that contribute most significantly to dose for all exposure scenarios are soil ingestion, plant ingestion, and inhalation. The dose contribution from all uranium isotopes is essentially zero. For example, the dose contribution from all uranium isotopes is < 0.01 mrem/yr for the rancher during the first year following remediation. The dose from radon is zero, less than 1E-7 mrem/year to the maximum-exposed individual during the year of maximum-radon dose, 50 years subsequent to remediation.

The radionuclide that contributes most significantly to dose at the Clean Slate sites is Pu-239. Approximately 81 to 83 percent of the dose for each exposure scenario is due to Pu-239. This is illustrated by comparing Figures 8-1 and 8-2. Figure 8-1 shows dose to the hypothetical rancher assumed to be living on Clean Slate Site1 as a function of time. Dose contributions from all isotopes and all exposure pathways are included. Figure 8-2 shows the dose from Pu-239 to the same hypothetical rancher on Clean Slate Site 1 from all exposure pathways. The two sets of curves are nearly identical, demonstrating the significant dose contribution from Pu-239. Figures 8-1 and 8-2 also illustrate the significant contribution of soil ingestion and inhalation to the total dose. In addition, both curves show that the total dose is reduced slowly with time.

Figure 8-3 demonstrates that the dose to the farmer is reduced by a factor of about two every 50 years. The dose to the hypothetical farmer and resident at the Clean Slate sites is reduced by a factor of approximately two every 50 years due to leaching of the radionuclides from the surface by irrigation water. The downward transport of the radionuclides with the irrigation water reduces the radioactive source term available for resuspension into the air. The reduction of the radiological source term at the surface reduces the concentration of the dust available for resuspension, thereby reducing the inhalation and soil ingestion dose.

Figure 8-4 illustrates the effects of varying the irrigation rate by ± 50 percent on the inhalation dose for the hypothetical farmer on Clean Slate Site 1. The effect of the irrigation rate on the inhalation dose becomes significant in ten years and is at a maximum in 100 years. Decreasing the irrigation rate 50 percent, from 1.53 m/yr to 1.02 m/yr for 100 years, will result in an increase in the annual inhalation dose by slightly more than 50 percent, from 4.8 mrem/yr to about 7.3 mrem/yr. Increasing the irrigation rate 50 percent, from 1.53 m/yr to 2.3 m/yr for 100 years, will result in a decrease in the inhalation dose by about 50 percent, from 4.8 mrem/yr to about 3.1 mrem/yr.

The ranching scenario assumed that cattle are pastured and the land is not irrigated. The surface concentration of the Pu and DU is not reduced by the leaching effect of irrigation water. The rancher's dose remains relatively constant with time. A slight reduction in the ranchers's dose occurs due to the slow erosion of the source term at the surface by wind erosion. It takes about 250 years for the rancher's dose to be reduced by a factor of two.

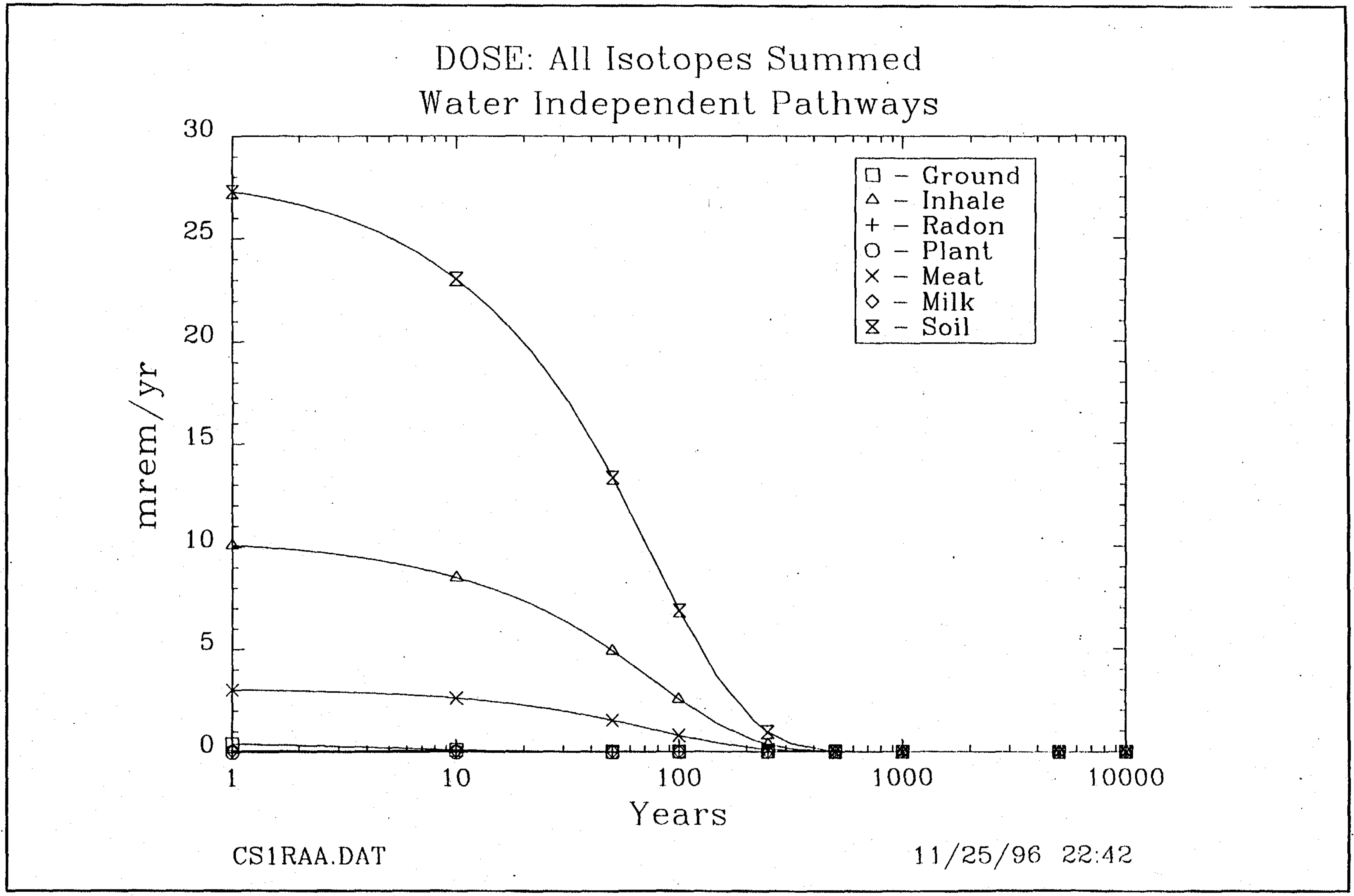

Figure 8-1
Dose to the Hypothetical Rancher Residing on the Clean Slate Sites as a Function of Time: Dose from Seven Exposure Pathways

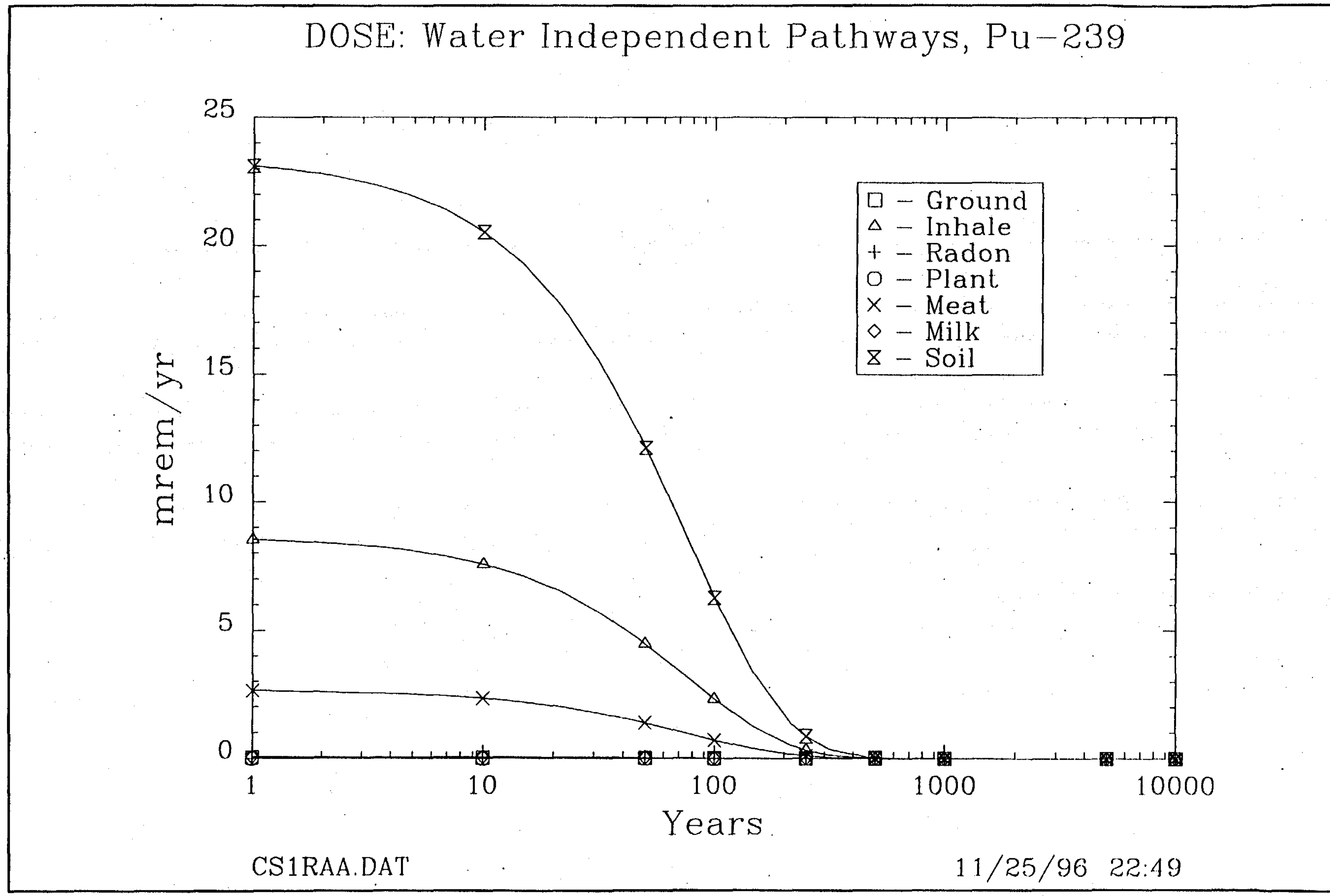

Figure 8-2
Dose from Pu-239 to the Hypothetical Rancher Residing on the Clean Slate Sites as a Function of Time: Dose from Seven Exposure Pathways

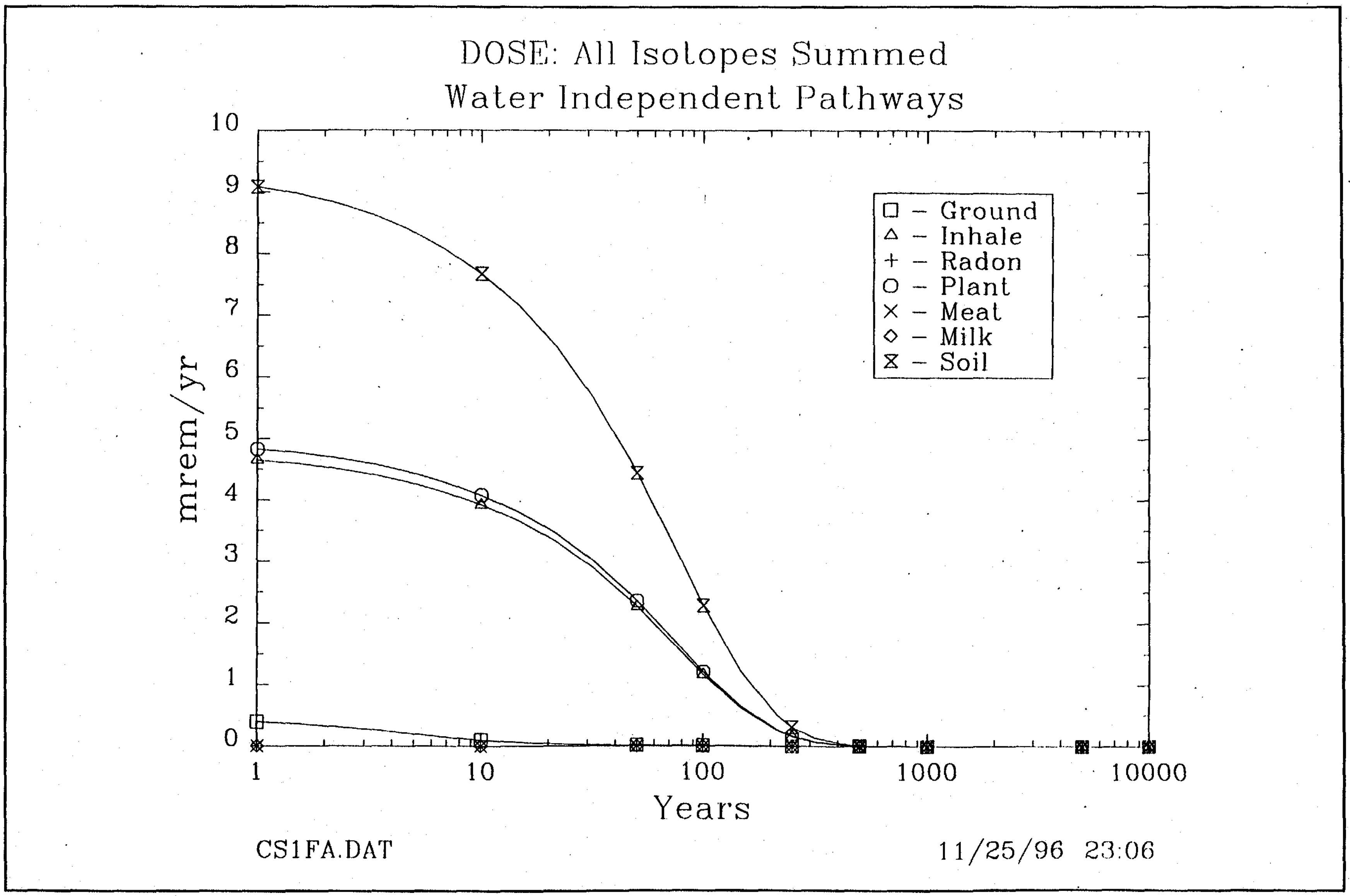

Figure 8-3
Dose to the Farmer from Pu-239
as a Function of Time and Variability in the Rate of Irrigation (RI ± 50 Percent)

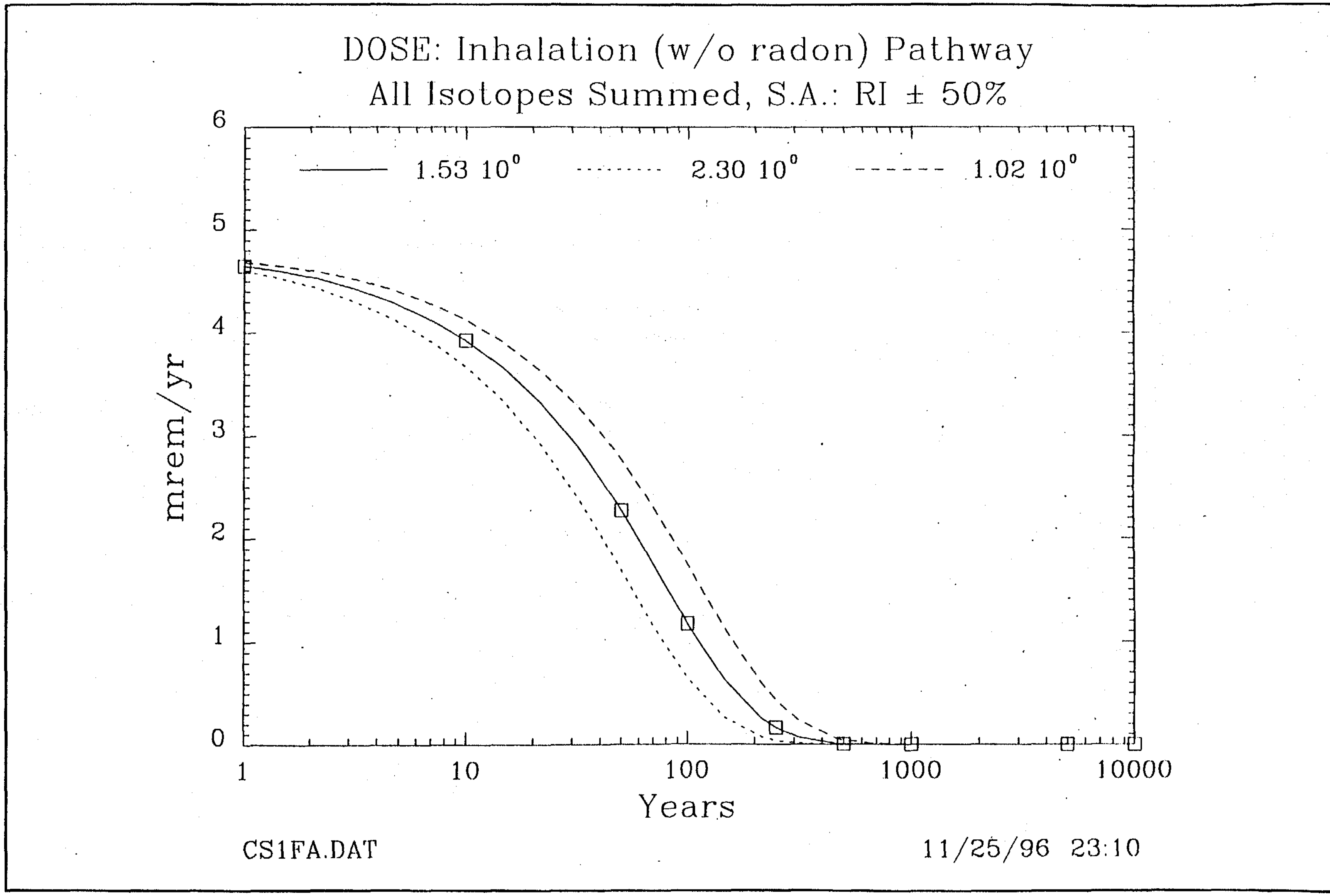

Figure 8-4
Dose to the Farmer Residing on the Clean Slates Sites from all Isotopes as a Function of Time and Variability in the Irrigation Rate (Irrigation ± 50 Percent)

Uncertainty in the derivation of dose from soil concentrations arises from the distribution of possible input parameter values as well as the uncertainty in the conceptual model used to represent the Clean Slate sites. For the exposure scenarios considered, the soil ingestion, particulate inhalation, and plant ingestion exposure pathways are the most significant contributors to dose. Therefore, uncertainties in parameters affecting these pathways (e.g., mass loading of resuspended soil into the air, inhalation rate of the hypothetical dose receptor, and the mixing depth of the radiological source term with clean soil due to agricultural activities) have the greatest impact on the model predictions. Parameters related to other exposure pathways have relatively little impact.

The RESRAD code was used to perform sensitivity analyses on the soil ingestion and inhalation dose by varying the mixing depth and mass loading. The results of the sensitivity analyses are demonstrated in Figures 8-5 and 8-6.

As illustrated in Figure 8-5, increasing the mass loading by 50 percent increases the inhalation dose by 50 percent. Reducing the mass loading by 50 percent reduces the inhalation dose by 50 percent. This linear relationship is expected; the inhalation dose is a linear function of the mass loading. The inhalation intake is calculated by multiplying the breathing rate times the mass loading. The inhalation dose is calculated by multiplying the intake by the dose conversion factor.

Increasing the mixing depth 50 percent, from 0.15 m to 0.23 m, decreases the soil ingestion dose to the farmer by about 30 percent. Decreasing the mixing depth by 50 percent, from 0.15 m to 0.1 m, increased the dose by 30 percent. This is illustrated in Figure 8-6. What may not be obvious is the influence of the mixing depth of the radionuclides in the soil on the inhalation dose. An increase of the mixing depth from 0.05 m (the thickness of the contaminated layer of soil) to 0.2 m reduces the inhalation dose from 47 mrem/yr to about 14 mrem/yr. Decreasing the mixing depth to less than the thickness of the contamination zone has no further effect on the inhalation dose. The effects of varying the mixing depth on the inhalation dose is illustrated in Figure 8-7.

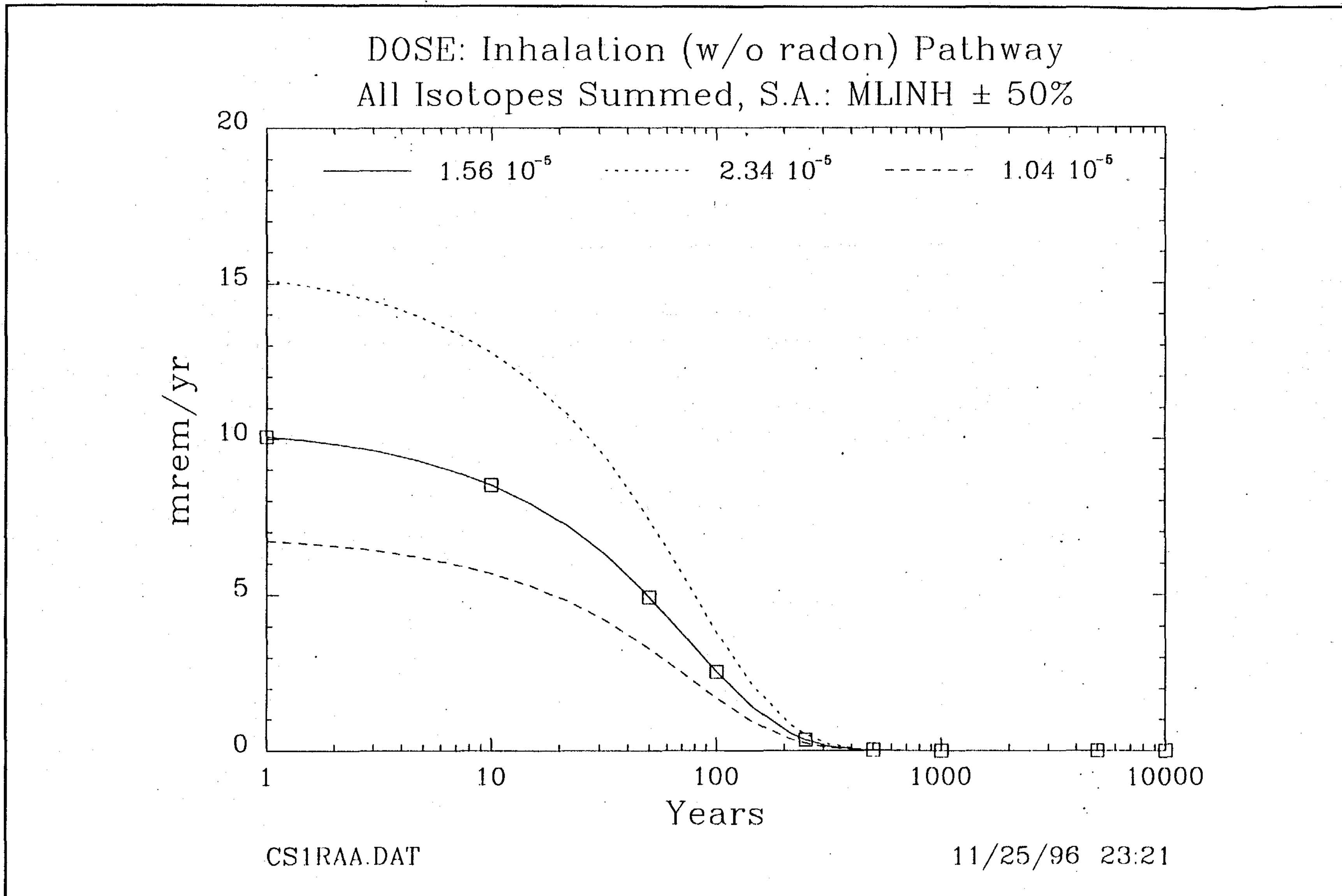

Figure 8-5
Inhalation Dose to the Rancher from all Isotopes as a Function of Time and Variability in the Mass Loading (MLINH ± 50 Percent)

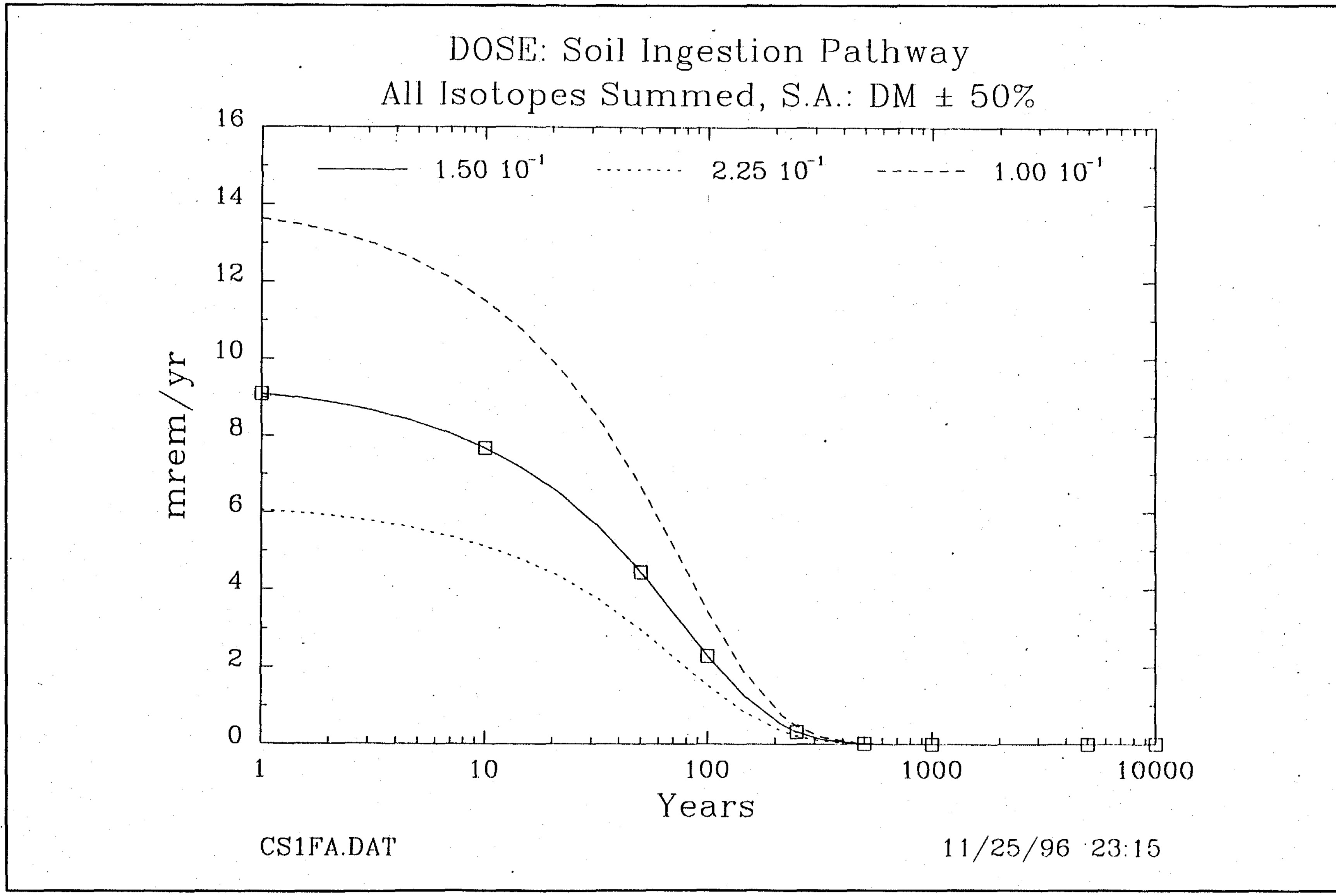

Figure 8-6
Inhalation Dose to the Farmer from all Isotopes
as a Function of Time and Variability in the Mixing Depth (DM ± 50 Percent)

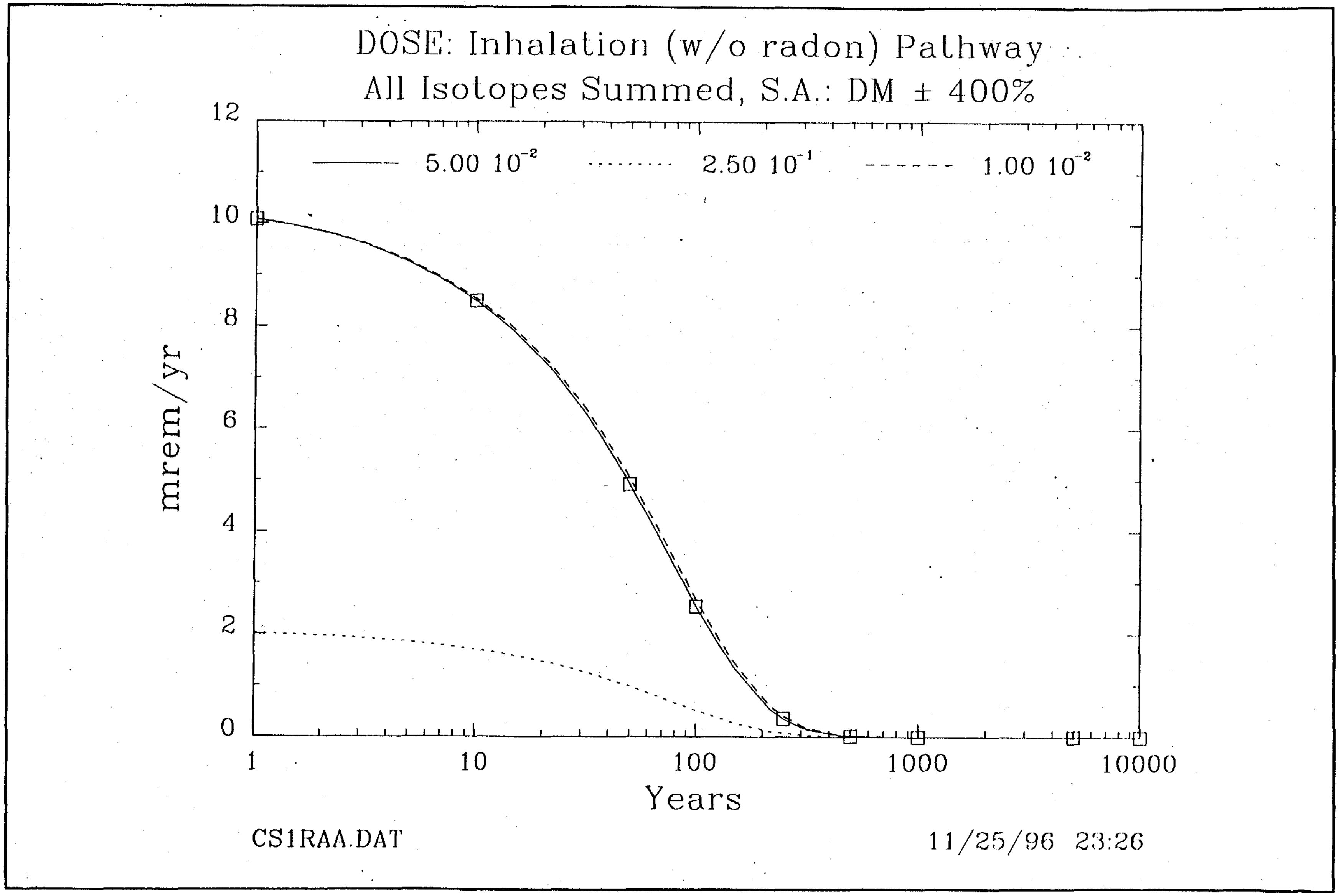

Figure 8-7
Inhalation Dose to the Rancher from all Isotopes as a Function of Time and Variability in the Mixing Depth (DM ± 400 Percent)

DOE Order 5400.5 requires that the ALARA process be adopted in planning, monitoring, cleanup, and control of residual radioactive material (DOE, 1993). In applying the ALARA process on the basis of either qualitative or quantitative analysis, the risk/cost incurred from implementing remedial action must first be justified by the reduction in risk (increasing the benefit) that will result. The ALARA process requires that the responsible persons use judgment with respect to what is "reasonably achievable." The economic, social, and technical factors influencing this judgment are highly variable and site-specific. The variability is due, in the most part, to the fact that the potential radiation risk must be calculated for populations that may exist hundreds or even thousands of years in the future. To realistically account for these uncertainties, it is reasonable to attach more weight to doses predicted for the present or the near future than to doses predicted for the distant future, especially when the use scenarios appear unlikely. In this assessment, the doses calculated for hypothetical individuals on the Clean Slate sites are based upon conservative, but reasonable, assumptions. These calculated doses are appropriate for use in an ALARA analysis of Clean Slate sites for future remediation activities.

9.0 References

Adams, S.R. 1996. *Methodology for Calculating Guideline Concentrations for Safety Shot Sites*. Prepared for DOE/NV. Las Vegas, NV: IT Corporation.

Adams, N. 1981. "Dependence on Age at Intake of committed dose Equivalents from Radionuclides." In *Phys. Med. Biology*, 26:1019-1034.

AIHC. See American Industrial Health Council.

American Industrial Health Council. 1994. *Exposure Factors Sourcebook.* Washington, DC: American Industrial Health Council.

Anspaugh, L.R., and J.I. Daniels. 1995. *Development of the Scientific Basis for Establishing the Boundary Conditions Between "Unrestricted Use" and "Posting" for Exposure Due to Residual Radioactive Contamination of Soil at the Nevada Test Site,* UCRL-JC-119936. Livermore, CA: Lawrence Livermore National Laboratory.

Burnett, W.D. 1964. *Health Physics Aspects of Operation Roller Coaster*, SC-4973 (RR). Albuquerque, NM: Sandia Corporation.

Calabrese, E.J., et al. 1990. "Preliminary Adult Soil Ingestion Estimates: Results of a Pilot Study." In *Regulatory Toxicology and Pharmacology*, 12:88-95.

Calabrese, E.J., and E.J. Stanek III. 1991. "A Guide to Interpreting Soil Ingestion Studies II: Qualitative and Quantitative Evidence of Soil Ingestion." In *Regulatory Toxicology and Pharmacology*, 13:278-292.

Cristy, M., et al. 1984. *Age-Dependent Dose-Conversion Factors for Selected Bone-Seeking Radionuclides*, NUREG/CR-3535, ORNL/TM-8929. Oak Ridge, TN: Oak Ridge National Laboratory.

Cristy, M., et al. 1986. *Relative Age-Specific Radiation Dose Commitment Factors for Major Radionuclides Released from Nuclear Fuel Facilities*, NUREG/CR-4628, ORNL/TM-9890. Oak Ridge, TN: Oak Ridge National Laboratory.

Clayton, C.A., et al. 1993. "Particle Total Exposure Assessment Methodology (PTEAM) Study: Distributions of Aerosol and Elemental Concentrations in Personal, Indoor, and Outdoor Air Samples in a Southern California Community." In *Journal of Exposure and Analysis of Environmental Epidemiology*, 6:227-250.

Culp, T., and D. Howard. 1995. *1993 Site Environmental Report, Tonopah Test Range, Tonopah, Nevada,* SAND94-1292. Albuquerque, NM: Sandia National Laboratories.

DOE. See U.S. Department of Energy.

EG&G. See EG&G Idaho, Inc.

EG&G Idaho, Inc. 1986. *Development of Criteria for Release of Idaho National Engineering Laboratory Sites Following Decontamination and Decommissioning*, EGG-2400. Idaho Falls, ID.

EPA. See U.S. Environmental Protection Agency.

Essington, E.H. 1977. "Soil Investigation for the Nevada Applied Ecology Group: A Historical Review and Current Status." In *Transuranics in Desert Environments*, NVO-153, edited by M.G. White, P.B. Dunaway, and D.L. Wireman. Las Vegas, NV: DOE/NV.

Gesell, T.F., and P.G. Voilleque, eds. 1990. "Evaluation of Environmental Radiation Exposures from Nuclear Testing in Nevada." In *Health Physics,* 59, No. 5. New York, NY.

Gilbert, R.O., et al. 1975 "Statistical Analysis of $^{239-240}$Pu and ^{241}Am Contamination of Soil and Vegetation of NAEG Study Sites." In *The Radioecology of Plutonium and Other Transuranics in Desert Environments*, NVO-181, edited by M.G. White, P.B. Dunaway, and D.L. Wireman. Las Vegas, NV: DOE/NV.

Gilbert, R.O. 1977. "Revised Total Amounts of $^{239-240}$Pu in Surface Soil at Safety-Shot Sites." In *Transuranics in Desert Environments*, NVO-153, edited by M.G. White, P.B. Dunaway, and D.L. Wireman. Las Vegas, NV: DOE/NV.

Gilbert, T.L., et al. 1983. *Pathways Analysis and Radiation Doses Estimates for Radioactive Residues at Formerly Utilized MED/AEC Sites,* ORO-832 (Rev.). Reprinted with corrections January 1984. Prepared by Argonne National Laboratory, Argonne, IL. Oak Ridge, TN: DOE Oak Ridge.

Gilbert, T.L., et al. 1989. *A Manual for Implementing Residual Radioactive Material Guidelines:* A Supplement to the U.S. Department of Energy Guidelines for Residual Radioactive Material at FUSRAP and SFMP Sites. ANL/ES-160, DOE/CH/8901. Prepared for U.S. Department of Energy. Argonne, IL: Argonne National Laboratory.

Great Lakes Basin Commission. 1975. *Great Lakes Basin Commission Framework Study, Appendix 6: Water Supply - Municipal, Industrial, and Rural.* Ann Arbor, MI: U.S. Environmental Protection Agency, Region V, Public Information Office.

Henderson, R.W., and R.F. Smale. 1990. "External Exposure Estimates for Individuals Near the Nevada Test Site." In *Health Physics,* 59:715-721. New York, NY.

ICRP. See International Commission on Radiological Protection.

International Commission on Radiological Protection. 1979-1982. *Limits for Intakes of Radionuclides by Workers,* ICRP Publication 30, Parts 1-3 and Supplements. New York, NY: Pergamon Press.

International Commission on Radiological Protection. 1991. *1990 Recommendations of the International Commission on Radiological Protection,* ICRP Publication 60. Oxford, England: Pergamon Press.

ITLV. See IT Corporation.

IT Corporation. 1996. *Sampling and Analysis Plan for Clean Slate 1,* ITLV/10972-178, Revision 0. Las Vegas, NV.

Jobst, J.E. 1977. *An Aerial Radiological Survey of Clean Slate 1, 2, and 3 and Double Track, Tonopah Test Range, Central Nevada*, EGG-1183-1737. Las Vegas, NV: EG&G Energy Measurements.

Kirchner, T.B., et al. 1996. "Estimating Internal Dose Due to Ingestion of Radionuclides from Nevada Test Site Fallout." In *Health Physics* 71:487-501. Baltimore, MD.

Kocher, D.C. 1981. *Radioactive Decay Data Tables: A Handbook of Decay Data for Application to Radiation Dosimetry and Radiological Assessments*. Oak Ridge, TN: Oak Ridge National Laboratory.

Layton, D.W. 1993. "Metabolically Consistent Breathing Rates for Use in Dose Assessments." In *Health Physics*, 64:23-36. Baltimore, MD.

Leddicotte, G.W., et al. 1978. "Suggested Concentration Limits for Shallow Land Burial of Radionuclides: Waste Management and Fuel Cycles 1978." In *Proceedings of the Symposium on Waste Management,* March 6-8, 1978. Tucson, AZ.

McKinley, J.R. 1996. Personal Memorandum to S.R. Adams about "Decay Product Activity of Weapons Grade Plutonium Isotopes from 1 Ci of Initial Material," 11 September.

Freeze, R.A., and J.A. Cherry. 1979. *Groundwater*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

National Council on Radiation Protection and Measurements. 1976. *Environmental Radiation Measurements,* NCRP Report No. 50. Washington, DC.

National Council on Radiation Protection and Measurements. 1985. *Radiological Assessment: Predicting the Transport, Bioaccumulation and Uptake by Man of Radionuclides Released to the Environment*, NCRP Report No. 76. Washington, DC.

NCR. See U.S. Nuclear Regulatory Commission.

NCRP. See National Council on Radiation Protection and Measurements.

Proctor, A.E., and T.J. Hendricks. 1994. *An Aerial Radiological Survey of the Tonopah Test Range*, Report No. EGG-11265-1145. Las Vegas, NV: EG&G/Energy Measurements.

REECo. See Reynolds Electrical & Engineering Co., Inc.

RSL. See Remote Sensing Laboratory.

Remote Sensing Laboratory. 1996. Draft, *Radiological Assessment Activities at the Clean Slate Sites.* Las Vegas, NV: Bechtel Nevada.

Reynolds Electrical & Engineering Co., Inc. 1973a. Clean Slate #1 Grid (As Built) Drawing No. 52-TTS-C-34.1. Prepared for the U.S. Atomic Energy Commission. Las Vegas, NV.

Reynolds Electrical & Engineering Co., Inc. 1973b. Clean Slate #2 Grid (As Built) Drawing No. 52-TTS-C-35.1. Prepared for the U.S. Atomic Energy Commission. Las Vegas, NV.

Reynolds Electrical & Engineering Co., Inc. 1973c. Clean Slate #3 Grid (As Built) Drawing No. 52-TTS-C-36.1. Prepared for the U.S. Atomic Energy Commission. Las Vegas, NV.

Rich, B.L., et al. 1988. *Health Physics Manual of Good Practices for Uranium Facilities,* EGG-2530. Idaho Falls, ID: EG&G Idaho, Inc.

Rope, S.K., and S.R. Adams. 1983. "Screening Levels for Radionuclides in Soil: Application to Decontamination and Decommissioning (D&D) Criteria." In *Proceedings of the Fourth DOE Environmental Protection Information Meeting*, CONF-821215. Denver, CO.

Roseberry, A.M., and D.E. Burmaster. 1992. "Lognormal Distributions for Water Intake by Children and Adults." In *Risk Analysis*, 12(1):99-104.

Rutz, E., et al. 1994. *Preliminary Risk Assessment of Safety Shot Sites at the NTS and Adjoining Lands.* Cincinnati, OH: Radiological Environmental Assessment Group, University of Cincinnati.

Sandia National Laboratories. *TTR Environmental Summary Yearly Reports, 1987, 1988, 1989, 1991, 1992.* Albuquerque, NM: Sandia National Laboratories.

Shinn, J.H., et al. 1986. *A Summary of Plutonium Aerosol Studies: Resuspension at the Nevada Test Site*, UCRL-90746. Livermore, CA: Lawrence Livermore National Laboratory.

Shinn, J. 1994. Personal Memorandum to R. Smiecinski, "Results of Air Monitoring from October 1993 to April 1994, Clean Slates 3 site at Tonopah Test Range," 14 September.

Shreve, J.D. 1964. *Operation Roller Coaster,* DASA-1644. Albuquerque, NM: Sandia Corporation.

SNL. See Sandia National Laboratories.

Tamura, T. 1975. "Characterization of Plutonium in Surface Soils from Area 13 of the Nevada Test Site." In *The Radioecology of Plutonium and other Transuranics in Desert Environments*, U.S. ERDA Report NVO-178, edited by M.G. White and P.B. Dunaway. Las Vegas, NV.

Tan, Z., et al. 1995. *Parameter Values and Risk Assessment for Safety Shot Areas at the Nevada Test Site Using the Spreadsheet Program NTSDOSE.* Cincinnati, OH: University of Cincinnati, Radiological Environmental Assessment Group.

Thomas, J., et al. 1986. "Ground-Water Levels in the Great Basin Region of Nevada, Utah, and Adjacent States," hydrologic investigations maps. Reston, VA: U.S. Geological Survey.

Till, J.E., and H.R. Meyer, eds. 1983. *Radiological Assessment A Textbook on Environmental Dose Analysis*. Washington, DC: U.S. Government Printing Office.

U.S. Department of Energy. 1993. *Radiation Protection of the Public and the Environment,* DOE Order 5400.5. Washington, DC.

U.S. Department of Energy, Nevada Operations Office. 1993. *Nevada Field Office Annual Site Environmental Report - 1994*, DOE/NV/10630-33. Las Vegas, NV: Reynolds Electrical & Engineering Co., Inc.

U.S. Department of Energy, Nevada Operations Office. 1994. *Resource Conservation Recovery Act Facility Investigation Work Plan, U.S. Department of Energy Environmental Restoration Sites, Tonopah Test Range, Nevada.* Las Vegas, NV: DOE/NV.

U.S. Department of Energy, Nevada Operations Office. 1993. *Nevada Field Office Annual Site Environmental Report - 1994*, DOE/NV/10630-33. Las Vegas, NV: Reynolds Electrical & Engineering Co., Inc.

U.S. Department of Energy, Nevada Operations Office. 1995. *Cost/Risk/Benefit Analysis of Alternative Cleanup Requirements for Plutonium-Contaminated Soils On and Near the Nevada Test Site,* Washington, DC: DOE, Offices of Program Integration, Southwestern Area, and Environmental Restoration.

U.S. Environmental Protection Agency. 1986. *Radiation Protection Criteria for Cleanup of Land and Facilities Contaminated with Residual Radioactive Materials*, 40 CFR 194.6. Washington, DC: U.S. Government Printing Office.

U.S. Environmental Protection Agency. 1989. Exposure Factors Handbook. Office of Health and Environmental Assessment, EPA/600/08-89/043. Washington, DC.

U.S. Environmental Protection Agency. 1990. *Exposure Factors Handbook*, EPA 600/8-89/043. Washington DC: Office of Health and Environmental Assessment.

U.S. Environmental Protection Agency. 1991. *Risk Assessment Guidance for Superfund, Vol. 1 - Human Health Evaluation Manual, Part B: Development of Risk-based Preliminary Remediation Goals,* OSWER Directive 9285.603. Washington, DC.

U.S. Environmental Protection Agency. 1993. "Radiation Site Cleanup Regulations: Advanced Notice of Rulemaking." In *Code of Federal Regulations*, 40 CFR 195.6. Washington, DC: U.S. Government Printing Office.

U.S. Environmental Protection Agency. 1994. Draft, *Radiation Site Cleanup Regulations: Technical Support Document for the Development of Radionuclide Cleanup Levels for Soil.* Washington DC: Office of Radiation and Indoor Air.

U.S. Nuclear Regulatory Commission. 1977. *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR, Part 50, Appendix I,* NRC Regulatory Guide 1.109, Revision 1. Washington, DC.

Whicker, F.W., et al. 1990. "Estimation of Radionuclide Ingestion: The PATHWAY Food-Chain Model." In *Health Physics,* 59:645-659. New York, NY.

Wille, L.E. 1996. Personal Memorandum to S.R. Adams, "Results of a Spread-Sheet Analysis for Determining the Area and Weighted Average Concentration of Pu-239 in Soil at Clean Slates 1, 2, and 3," 23 September.

Yu, C., et al. 1993a. *Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD,* Version 5.0. Argonne, IL: Environmental Assessment Division, Argonne National Laboratory.

Yu, C., et al. 1993b. *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil,* ANL/EAIS-8. Argonne, IL: Environmental Assessment and Information Sciences Division, Argonne National Laboratory.

Appendix A

Tables

Table 1
Contributions for Individual Radionuclides and Exposure Pathways at Clean Slate Sites for the Rural Resident Exposure Scenario Prior to Remediation
(mrem/year)[a]

Isotope	External Exposure	Inhalation	Meat Ingestion	Plant Ingestion	Soil Ingestion	Total
Am-241	0.44	0.11	0.08	0.70	0.69	2.02
Pu-238	0.00	0.01	0.01	0.06	0.06	0.15
Pu-239	0.03	1.25	1.82	8.34	8.26	19.7
Pu-240	0.00	0.12	0.17	0.79	0.78	1.87
Pu-241	0.00	0.01	0.01	0.08	0.08	0.19
Pu-242	0.00	0.00	0.00	0.00	0.00	0.00
U-234	0.00	0.00	0.00	0.00	0.00	0.00
U-235	0.00	0.00	0.00	0.00	0.00	0.00
U-238	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.48	1.50	2.09	9.97	9.88	24.0

[a]Doses are for the effective dose equivalent during the year of maximum dose, which is the first year after environmental restoration. Doses in the table are rounded to the nearest 0.01 mrem; the total doses are calculated by summing the individual doses and then rounding to the nearest 0.01 mrem.

Table 2
Dose Contributions for Individual Radionuclides and Exposure Pathways at Clean Slate Sites for the Rural Resident Exposure Scenario Subsequent to Remediation
(mrem/year)[a]

Isotope	External Exposure	Inhalation	Meat Ingestion	Plant Ingestion	Soil Ingestion	Total
Am-241	0.22	0.05	0.04	0.34	0.34	1.00
Pu-238	0.00	0.00	0.01	0.03	0.03	0.07
Pu-239	0.01	0.62	0.90	4.15	4.11	9.81
Pu-240	0.00	0.06	0.09	0.39	0.39	0.93
Pu-241	0.00	0.01	0.01	0.04	0.04	0.09
Pu-242	0.00	0.00	0.00	0.00	0.00	0.00
U-234	0.00	0.00	0.00	0.00	0.00	0.00
U-235	0.00	0.00	0.00	0.00	0.00	0.00
U-238	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.24	0.74	1.04	4.95	4.9	11.9

[a]Doses are for the effective dose equivalent during the year of maximum dose, which is the first year following environmental restoration. Doses in the table are rounded to the nearest 0.01 mrem; the total doses are calculated by summing the individual doses and then rounding to the nearest 0.01 mrem.

Table 3
Dose Contributions for Individual Radionuclides and Exposure Pathways at Clean Slate Sites for the Rancher Exposure Scenario Prior to Remediation
(mrem/year)[a]

Isotope	External Exposure	Inhalation	Meat Ingestion	Plant Ingestion	Soil Ingestion	Total
Am-241	0.87	1.46	0.22	0.70	3.94	7.19
Pu-238	0.00	0.13	0.04	0.06	0.36	0.59
Pu-239	0.06	17.40	5.37	8.34	47.12	78.30
Pu-240	0.00	1.65	0.51	0.79	4.47	7.42
Pu-241	0.00	0.17	0.05	0.08	0.45	0.75
Pu-242	0.00	0.00	0.00	0.00	0.00	0.00
U-234	0.00	0.00	0.00	0.00	0.00	0.00
U-235	0.00	0.00	0.00	0.00	0.00	0.00
U-238	0.00	0.00	0.00	0.00	0.00	0.01
Total	0.94	20.8	6.19	9.98	56.34	94.30

[a]Doses are for the effective dose equivalent during the year of maximum dose, which is the first year following environmental restoration. Doses in the table are rounded to the nearest 0.01 mrem; the total doses are calculated by summing the individual doses and then rounding to the nearest 0.01 mrem.

Table 4
Dose Contributions for Individual Radionuclides and Exposure Pathways at Clean Slate Sites for the Rancher Exposure Scenario Subsequent to Remediation
(mrem/year)[a]

Isotope	External Exposure	Inhalation	Meat Ingestion	Plant Ingestion	Soil Ingestion	Total
Am-241	0.43	0.72	0.11	0.35	1.95	3.56
Pu-238	0.00	0.07	0.02	0.03	0.18	0.30
Pu-239	0.03	8.64	2.67	4.15	23.42	38.90
Pu-240	0.00	0.82	0.25	0.39	2.21	3.67
Pu-241	0.00	0.08	0.03	0.04	0.22	0.37
Pu-242	0.00	0.00	0.00	0.00	0.00	0.00
U-234	0.00	0.00	0.00	0.00	0.00	0.00
U-235	0.00	0.00	0.00	0.00	0.00	0.00
U-238	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.47	10.33	3.07	4.95	27.98	46.80

[a]Doses are for the effective dose equivalent during the year of maximum dose, which is the first year following environmental restoration. Doses in the table are rounded to the nearest 0.01 mrem, the total doses are calculated by summing the individual doses and then rounding to the nearest 0.01 mrem.

Table 5
Dose Contributions for Individual Radionuclides and Exposure Pathways at Clean Slate Sites for the Industrial Worker Scenario Prior to Remediation
(mrem/year)[a]

Isotope	External Exposure	Inhalation	Meat Ingestion	Plant Ingestion	Soil Ingestion	Total
Am-241	0.23	0.11	0.00	0.00	0.50	0.84
Pu-238	0.00	0.01	0.00	0.00	0.05	0.06
Pu-239	0.01	1.29	0.00	0.00	6.01	7.31
Pu-240	0.00	0.12	0.00	0.00	0.57	0.69
Pu-241	0.00	0.01	0.00	0.00	0.06	0.07
Pu-242	0.00	0.00	0.00	0.00	0.00	0.00
U-234	0.00	0.00	0.00	0.00	0.00	0.00
U-235	0.00	0.00	0.00	0.00	0.00	0.00
U-238	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.25	1.54	0.00	0.00	7.18	8.97

[a]Doses are for the effective dose equivalent during the year of maximum dose, which is the first year following environmental restoration. Doses in the table are rounded to the nearest 0.01 mrem; the total doses are calculated by summing the individual doses and then rounding to the nearest 0.01 mrem.

Table 6
Dose Contributions for Individual Radionuclides and Exposure Pathways at Clean Slate Sites for the Industrial Exposure Scenario Subsequent to Remediation
(mrem/year)[a]

Isotope	External Exposure	Inhalation	Meat Ingestion	Plant Ingestion	Soil Ingestion	Total
Am-241	0.11	0.05	0.00	0.00	0.25	0.42
Pu-238	0.00	0.00	0.00	0.00	0.02	0.02
Pu-239	0.01	0.64	0.00	0.00	2.98	3.63
Pu-240	0.00	0.06	0.00	0.00	0.28	0.34
Pu-241	0.00	0.01	0.00	0.00	0.03	0.03
Pu-242	0.00	0.00	0.00	0.00	0.00	0.00
U-234	0.00	0.00	0.00	0.00	0.00	0.00
U-235	0.00	0.00	0.00	0.00	0.00	0.00
U-238	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.12	0.77	0.00	0.00	3.57	4.45

[a]Doses are for the effective dose equivalent during the year of maximum dose, which is the first year following environmental restoration. Doses in the table are rounded to the nearest 0.01 mrem; the total doses are calculated by summing the individual doses and then rounding to the nearest 0.01 mrem.

Table 7
Dose Contributions for Individual Radionuclides and Exposure Pathways at Clean Slate Sites for the Farming Exposure Scenario Prior to Remediation
(mrem/year)[a]

Isotope	External Exposure	Inhalation	Meat Ingestion	Plant Ingestion	Soil Ingestion	Total
Am-241	0.96	0.74	0.25	0.76	1.44	4.15
Pu-238	0.00	0.07	0.04	0.07	0.13	0.31
Pu-239	0.06	8.82	5.88	9.13	17.20	41.09
Pu-240	0.00	0.84	0.56	0.87	1.63	3.90
Pu-241	0.00	0.08	0.06	0.09	0.17	0.40
Pu-242	0.00	0.00	0.00	0.00	0.00	0.00
U-234	0.00	0.00	0.00	0.00	0.00	0.00
U-235	0.00	0.00	0.00	0.00	0.00	0.00
U-238	0.01	0.01	0.00	0.00	0.00	0.03
Total	1.04	10.55	6.78	10.93	20.57	49.90

[a]Doses are for the effective dose equivalent during the year of maximum dose, which is the first year following environmental restoration. Doses in the table are rounded to the nearest 0.01 mrem; the total doses are calculated by summing the individual doses and then rounding to the nearest 0.01 mrem.

Table 8
Dose Contributions for Individual Radionuclides and Exposure Pathways at Clean Slate Sites for the Farming Exposure Scenario Subsequent to Remediation
(mrem/year)[a]

Isotope	External Exposure	Inhalation	Meat Ingestion	Plant Ingestion	Soil Ingestion	Total
Am-241	0.42	0.33	0.11	0.34	0.64	1.84
Pu-238	0.00	0.03	0.02	0.03	0.06	0.14
Pu-239	0.03	3.93	2.62	4.10	7.66	18.34
Pu-240	0.00	0.37	0.25	0.39	0.73	1.74
Pu-241	0.00	0.04	0.03	0.04	0.07	0.18
Pu-242	0.00	0.00	0.00	0.00	0.00	0.00
U-234	0.00	0.00	0.00	0.00	0.00	0.00
U-235	0.00	0.00	0.00	0.00	0.00	0.00
U-238	0.00	0.00	0.00	0.00	0.00	0.01
Total	0.46	4.70	3.05	4.90	9.16	22.28

[a]Doses are for the effective dose equivalent during the year of maximum dose, which is the first year following environmental restoration. Doses in the table are rounded to the nearest 0.01 mrem; the total doses are calculated by summing the individual doses and then rounding to the nearest 0.01 mrem.

Table 9
Dose Contributions for Individual Radionuclides and Exposure Pathways at Clean Slate Sites for the Child Dose Receptor, Rancher Exposure Scenario Prior to Remediation
(mrem/year)[a]

Isotope	External Exposure	Inhalation	Meat Ingestion	Plant Ingestion	Soil Ingestion	Total
Am-241	0.74	0.74	0.12	0.74	0.76	3.10
Pu-238	0.00	0.07	0.02	0.07	0.07	0.23
Pu-239	0.05	8.81	2.94	8.86	9.14	29.80
Pu-240	0.00	0.83	0.28	0.84	0.87	2.82
Pu-241	0.00	0.08	0.03	0.08	0.09	0.28
Pu-242	0.00	0.00	0.00	0.00	0.00	0.00
U-234	0.00	0.00	0.00	0.00	0.00	0.00
U-235	0.00	0.00	0.00	0.00	0.00	0.00
U-238	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.79	10.53	3.39	10.59	10.93	36.23

[a]Doses are for the effective dose equivalent during the year of maximum dose, which is the first year following environmental restoration. Doses in the table are rounded to the nearest 0.01 mrem; the total doses are calculated by summing the individual doses and then rounding to the nearest 0.01 mrem.

Table 10
Dose Contributions for Individual Radionuclides and Exposure Pathways at Clean Slate Sites for the Child Dose Receptor, Rancher Exposure Scenario Subsequent to Remediation
(mrem/year)[a]

Isotope	External Exposure	Inhalation	Meat Ingestion	Plant Ingestion	Soil Ingestion	Total
Am-241	0.39	0.39	0.06	0.37	0.40	1.61
Pu-238	0.00	0.03	0.01	0.03	0.04	0.11
Pu-239	0.02	4.64	1.45	4.38	4.80	15.29
Pu-240	0.00	0.44	0.14	0.41	0.45	1.44
Pu-241	0.00	0.04	0.01	0.04	0.05	0.14
Pu-242	0.00	0.00	0.00	0.00	0.00	0.00
U-234	0.00	0.00	0.00	0.00	0.00	0.00
U-235	0.00	0.00	0.00	0.00	0.00	0.00
U-238	0.01	0.01	0.00	0.00	0.00	0.02
Total	0.42	5.55	1.67	5.23	5.74	18.61

[a]Doses are for the effective dose equivalent during the year of maximum dose, which is the first year following environmental restoration. Doses in the table are rounded to the nearest 0.01 mrem; the total doses are calculated by summing the individual doses and then rounding to the nearest 0.01 mrem.

Table 11
Parameter Values Used in the RESRAD Code for Calculating Dose to a Resident, Rancher, Farmer, and Industrial Worker on the Clean Slate Sites [a]
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Parameter	Unit	Scenario Value	Reference
Dose Limit	mrem/yr	100	DOE, 1993
Dose conversion factors for inhalation	mrem/pCi		
Ac-227+D		6.72E+0	RESRAD default
Am-241		4.40E-1	RESRAD default
Np-237+D		5.40E-1	RESRAD default
Pa-231		1.28E+0	RESRAD default
Pb-210+D		2.32E-2	RESRAD default
Pu-238		3.92E-1	RESRAD default
Pu-239		4.29E-1	RESRAD default
Pu-240		4.29E-1	RESRAD default
Pu-241+D		8.25E-3	RESRAD default
Pu-242		4.11E-1	RESRAD default
Ra-226+D		8.60E-3	RESRAD default
Ra-228+D		5.08E-3	RESRAD default
Th-228+D		3.45E-1	RESRAD default
Th-229+D		2.16E+0	RESRAD default
Th-230		3.26E-1	RESRAD default
Th-232		1.64E+0	RESRAD default
U-233		1.35E-1	RESRAD default
U-234		1.32E-1	RESRAD default
U-235+D		1.23E-1	RESRAD default
U-236		1.25E-1	RESRAD default
U-238+D		1.18E-1	RESRAD default

Table 11
Parameter Values Used in the RESRAD Code for Calculating Dose to a Resident, Rancher, Farmer, and Industrial Worker on the Clean Slate Sites [a]
(Page 2 of 10)

Parameter	Unit	Scenario Value	Reference
Dose conversion factors for ingestion	mrem/pCi		
Ac-227+D		1.48E-2	RESRAD default
Am-241		3.64E-3	RESRAD default
Np-237+D		4.44E-3	RESRAD default
Pa-231		1.06E-2	RESRAD default
Pb-210+D		7.27E-3	RESRAD default
Pu-238		3.20E-3	RESRAD default
Pu-239		3.54E-3	RESRAD default
Pu-240		3.54E-3	RESRAD default
Pu-241+D		6.85E-5	RESRAD default
Pu-242		3.36E-3	RESRAD default
Ra-226+D		1.33E-3	RESRAD default
Ra-228+D		1.44E-3	RESRAD default
Th-228+D		8.08E-4	RESRAD default
Th-229+D		4.03E-3	RESRAD default
Th-230		5.48E-4	RESRAD default
Th-232		2.73E-3	RESRAD default
U-233		2.89E-4	RESRAD default
U-234		2.83E-4	RESRAD default
U-235+D		2.67E-4	RESRAD default
U-236		2.69E-4	RESRAD default
U-238+D		2.69E-4	RESRAD default

Table 11
Parameter Values Used in the RESRAD Code for Calculating Dose to a Resident, Rancher, Farmer, and Industrial Worker on the Clean Slate Sites [a]
(Page 3 of 10)

Parameter	Unit	Scenario Value	Reference
Plant/Soil concentration ratio	none		
Ac-227+D		2.50E-3	RESRAD default
Am-241		1.00E-3	RESRAD default
Np-237+D		2.00E-2	RESRAD default
Pa-231		1.00E-2	RESRAD default
Pb-210+D		1.00E-2	RESRAD default
Pu-238		1.00E-3	RESRAD default
Pu-239		1.00E-3	RESRAD default
Pu-240		1.00E-3	RESRAD default
Pu-241+D		1.00E-3	RESRAD default
Pu-242		1.00E-3	RESRAD default
Ra-226+D		4.00E-2	RESRAD default
Ra-228+D		4.00E-2	RESRAD default
Th-228+D		1.00E-3	RESRAD default
Th-229+D		1.00E-3	RESRAD default
Th-230		1.00E-3	RESRAD default
Th-232		1.00E-3	RESRAD default
U-233		2.5E-3	RESRAD default
U-234		2.5E-3	RESRAD default
U-235+D		2.5E-3	RESRAD default
U-236		2.5E-3	RESRAD default
U-238+D		2.5E-3	RESRAD default
Area of contaminated zone	m^2		Wille, 1996
Clean Slate 1		2.48E+5	
Clean Slate 2		1.35E+6	
Clean Slate 3		1.77E+7	
Thickness of contaminated zone	m	0.05	Clean Slate CAIP, 1996
Length parallel to acquifer flow	m		Wille, 1996
Clean Slate 1		1640	
Clean Slate 2		1000	
Clean Slate 3		2300	
Time since placement of material	years	0	Assumption
Times for calculation 10, 50, 100, 250, 500, 1000, 5000, 10 000	years	na	User assumption

Table 11
Parameter Values Used in the RESRAD Code for Calculating Dose to a Resident, Rancher, Farmer, and Industrial Worker on the Clean Slate Sites [a]
(Page 4 of 10)

Parameter	Unit	Scenario Value	Reference
Initial principal radionuclide concentration in soil prior to remediation, Clean Slate 1	pCi/g		
Am-241		2.65E+1	Calculated based upon in situ gamma analysis, (RSL, 1996), weapons grade plutonium, and depleted uranium (Rich, 1988; McKinley, 1996) See Attachment 1 for details.
Pu-238		2.74E+0	
Pu-239		3.26E+2	
Pu-240		3.09E+1	
Pu-241		1.61E+2	
Pu-242		6.57E-4	
U-234		7.93E-3	
U-235		1.38E-3	
U-238		8.53E-2	
Principal radionuclide concentration in soil subsequent to remediation, Clean Slate 1	pCi/g		
Am-241		1.31E+1	Calculated based upon in situ gamma analysis, (RSL, 1996), weapons grade plutonium, and depleted uranium (Rich, 1988; McKinley, 1996) See Attachment 1 for details.
Pu-238		1.36E+0	
Pu-239		1.62E+2	
Pu-240		1.53E+1	
Pu-241		8.0E+1	
Pu-242		3.26E-4	
U-234		3.93E-3	
U-235		6.83E-4	
U-238		4.23E-2	
Initial principal radionuclide concentration in soil prior to remediation, Clean Slate 2	pCi/g		
Am-241		3.40E+1	Calculated based upon in situ gamma analysis, (RSL, 1996), weapons grade plutonium, and depleted uranium (Rich, 1988; McKinley, 1996) See Attachment 1 for details.
Pu-238		3.52E+0	
Pu-239		4.18E+2	
Pu-240		3.97E+1	
Pu-241		2.07E+2	
Pu-242		8.43E-4	
U-234		2.16E-2	
U-235		3.76E-3	
U-238		2.33E-3	

Table 11
Parameter Values Used in the RESRAD Code for Calculating Dose to a Resident, Rancher, Farmer, and Industrial Worker on the Clean Slate Sites [a]
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Parameter	Unit	Scenario Value	Reference
Principal radionuclide concentration in soil subsequent to remediation, Clean Slate 2 Am-241 Pu-238 Pu-239 Pu-240 Pu-241 Pu-242 U-234 U-235 U-238	pCi/g	 1.31E+1 1.35E+0 1.61E+2 1.52E+1 7.95E+1 3.24E-4 8.32E-3 1.44E-3 8.94E-2	Calculated based upon in situ gamma analysis, (RSL, 1996), weapons grade plutonium, and depleted uranium (Rich, 1988; McKinley, 1996) See Attachment 1 for details.
Initial principal radionuclide concentration in soil prior to remediation, Clean Slate 3 Am-241 Pu-238 Pu-239 Pu-240 Pu-241 Pu-242 U-234 U-235 U-238	pCi/g	 2.90E+1 3.00E+0 3.57E+2 3.39E+1 1.77E+2 7.20E-4 1.83E-2 3.18E-3 1.97E-1	Calculated based upon in situ gamma analysis, (RSL, 1996), weapons grade plutonium, and depleted uranium (Rich, 1988; McKinley, 1996) See Attachment 1 for details.
Principal radionuclide concentration in soil subsequent to remediation, Clean Slate 3 Am-241 Pu-238 Pu-239 Pu-240 Pu-241 Pu-242 U-234 U-235 U-238	pCi/g	 1.29E+1 1.34E+0 1.59E+2 1.51E+1 7.86E+1 3.20E-4 8.17E-3 1.42E-3 8.78E-3	Calculated based upon in situ gamma analysis, (RSL, 1996), weapons grade plutonium, and depleted uranium (Rich, 1988; McKinley, 1996) See Attachment 1 for details.
Concentration of radionuclides in groundwater	pCi/L	not used	RESRAD calculates from input data
Cover depth	m	0	Conservative assumption
Density of contaminated, saturated, and unsaturated zone	g/cm^3	1.5	RESRAD default

Table 11
Parameter Values Used in the RESRAD Code for Calculating Dose to a Resident, Rancher, Farmer, and Industrial Worker on the Clean Slate Sites [a]
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Parameter	Unit	Scenario Value	Reference
Contamination zone erosion rate	m/yr	3.1E-5	Shinn, 1986
Total porosity of contamination zone, unsaturated zone, and saturated zone	-	0.30	DOE, 1994
Effective porosity of the contaminated, unsaturated, and saturated zone	-	0.30	DOE, 1994
Hydraulic conductivity of the contaminated, unsaturated, and saturated zone	m/yr	1000	Table 5.4, page 31 Yu et al., 1993b
"b" parameter of the contaminated, unsaturated, and saturated zone	-	4.05	Table 13.1, page 77 Yu et al., 1993b
Evapotranspiration coefficient	-	0.68	Calculated using formula in Yu, et al., 1993
Precipitation	m/yr	0.127	Culp and Howard, 1995
Irrigation	m/yr	1.53	Calculated from rainfall
Irrigation mode	-	ditch	User assumption
Runoff coefficient	-	0.2	RESRAD default
Watershed area for pond	m^2	3.11E+5	Minimum area for RESRAD input.
Accuracy for water/soil computations	none	1.00E-3	RESRAD default
Water table drop rate	m/yr	1.0E-4	DOE, 1994
Well pump intake depth (below water table).	m	10	RESRAD default
Well pumping rate	m^3/yr	5.18E+6	Area × Irrigation rate
Model: nondispersion (ND) or mass balance (MB)	-	ND	RESRAD default
Number of unsaturated zones	-	1	DOE, 1994
Unsaturated zone thickness	m	55	USGS, 1986

Table 11
Parameter Values Used in the RESRAD Code for Calculating Dose to a Resident, Rancher, Farmer, and Industrial Worker on the Clean Slate Sites [a]
(Page 7 of 10)

Parameter	Unit	Scenario Value	Reference
Distribution coefficient (all zones)			
Uranium isotopes	cm^3/g	35	Table 32.1 Yu et al., 1993B
Plutonium isotopes	cm^3/g	550	
Americium isotopes	cm^3/g	1900	
Actinium isotopes	cm^3/g	450	
Neptunium isotopes	cm^3/g	5	
Protactinium isotopes	cm^3/g	550	
Lead isotopes	cm^3/g	270	
Radium isotopes	cm^3/g	500	
Thorium isotopes	cm^3/g	3200	
Inhalation rate	m^3/yr		Calculated from data in Yu et al., 1993b and Layton, 1993
Rural Resident		6820	
Rancher		8110	
Farmer		8110	
Industrial worker		3150	
Child		4330	
Mass loading for inhalation	g/m^3		Calculated from data in Yu et al., 1993b
Rural Resident		1.50E-5	
Rancher		1.54E-5	
Farmer		2.14E-5	
Industrial worker		1.36E-5	
Dilution length for airborne dust inhalation	m	3	RESRAD default
Exposure duration	years	30	RESRAD default
Shielding factor, inhalation	-		
Rural Resident		1	Clayton, 1993
Rancher		1	Clayton, 1993
Farmer		1	Clayton, 1993
Industrial worker		0.4	RESRAD Default
Shielding factor from external radiation (all scenarios)	-	0.7	RESRAD default
Fraction of time spent indoors	-		Calculated from data in Whicker, et al.,1990 and AIHC 1994
Rural Resident		0.5800	
Rancher		0.3503	
Farmer		0.3503	
Industrial worker		0.228	

Table 11
Parameter Values Used in the RESRAD Code for Calculating Dose to a Resident, Rancher, Farmer, and Industrial Worker on the Clean Slate Sites [a]
(Page 8 of 10)

Parameter	Unit	Scenario Value	Reference
Fraction of time spent outdoors (on site)	-		
Rural Resident		0.0155	Calculated from data in Whicker, et al.,1990 and AIHC 1994
Rancher		0.584	
Farmer		0.584	
Industrial worker		0.0571	
Shape factor flag, external gamma	-	1	RESRAD default
Soil ingestion rate	g/yr		
Rural Resident		37.4	Calculated from data in Yu et al., 1993b
Rancher		43.92	
Farmer		43.92	
Industrial worker		18.25	
Consumption of Fruit, vegetable, and grain grown on site	kg/yr		
Rural Resident		120.5	Whicker et al., 1990
Rancher		120.5	Whicker et al., 1990
Farmer		120.5	Whicker et al., 1990
Industrial worker		0	not a exposure pathway
Child		130.9	NCRP, 1985
Consumption of leafy vegetables grown on site	kg/yr		
Rural Resident		10.0	Whicker et al., 1990
Rancher		10.0	Whicker et al., 1990
Farmer		10.0	Whicker et al., 1990
Industrial worker		0	not a exposure pathway
Child		6.1	NCRP, 1985
Milk and milk product consumption from on site livestock	L/yr		
Resident		203.2	Whicker et al., 1990
Rancher		203.2	Whicker et al., 1990
Farmer		203.2	Whicker et al., 1990
Industrial worker		0	not a exposure pathway
Child		388.3	NCRP, 1985
Meat consumption from on site livestock	kg/yr		
Rural Resident		93.3	Whicker et al., 1990
Rancher		93.3	Whicker et al., 1990
Farmer		93.3	Whicker et al., 1990
Industrial worker		0	not a exposure pathway
Child		50.5	NCRP, 1985
Fish consumption	kg/yr	0	not an exposure pathway

Table 11
Parameter Values Used in the RESRAD Code for Calculating Dose to a Resident, Rancher, Farmer, and Industrial Worker on the Clean Slate Sites [a]
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Parameter	Unit	Scenario Value	Reference
Other seafood consumption	kg/yr	0	not an exposure pathway
Drinking water intake Rural Resident Rancher Farmer Industrial worker Child	L/yr	 444.6 634.26 634.26 218.75 112.7	Calculated from AIHC, 1994; except for child where data is from NCRP, 1985
Contamination fraction of drinking, household, and irrigation water	-	1	RESRAD default
Contamination fraction of plant food	-	1	RESRAD computes fraction based upon area of contamination
Mass loading for foliar deposition Rural Resident Rancher Farmer Industrial worker	g/m^3	 2.21E-5 2.21E-5 2.21E-5 no used	Calculated from data in Shinn et al., 1984 and 1994. See Attachment 1
Depth of soil mixing layer Rural Resident Rancher Farmer Industrial worker	m	 0.15 0.05 0.15 Not used	0.15 is RESRAD default value for farming and gardening, 0.05 is thickness of contamination.
Depth of roots	m	0.9	RESRAD default
Drinking, household, and irrigation, water fraction from groundwater	-	1	RESRAD default
Storage time for Fruits, nonleafy vegetables, and grain Leafy vegetables Drinking water	 d d d	 14 1 0	 RESRAD default RESRAD default RESRAD default
Thickness of building foundation	m	0.15	RESRAD default
Bulk density of building foundation	g/cm^3	2.4	RESRAD default
Total porosity of building foundation	-	0.1	RESRAD default
Volumetric water content of the foundation	-	3.0E-2	RESRAD default

Table 11
Parameter Values Used in the RESRAD Code for Calculating Dose to a Resident, Rancher, Farmer, and Industrial Worker on the Clean Slate Sites [a]
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Parameter	Unit	Scenario Value	Reference
Diffusion coefficient for radon gas in foundation material in contaminated zone soil	m/s	 3.0E-7 2.0E-6	 RESRAD default RESRAD default
Radon vertical dimension of mixing	m	2	RESRAD default
Average annual wind speed	m/s	3.4	Culp and Howard, 1995
Average building air exchange rate	per hour	0.5	RESRAD default
Height of the building (room)	m	2.5	RESRAD default
Building interior area factor	-	0.0	RESRAD default
Building depth below ground surface	m	0	RESRAD default
Emanating power of radon gas Rn-222 gas Rn-220 gas	 - -	 0.20 0.15	 RESRAD default RESRAD default
Summary of pathways selected extermal gamma inhalation without radon plant ingestion drinking water soil ingestion radon	na	na	Scenario dependent

[a]Scenario specific data is noted in the parameter column. All other data is pertinent to all three scenarios.

Attachment 1

Calculation of DU and Plutonium Isotope Concentration in Soil at Clean Slate 1, 2, and 3 and other RESRAD Input

RESRAD Input for Clean Slate Sites Dose Assessment

Calculation of Radiological Source Term for RESRAD Input: Activity of Isotope in Soil (pCi/g)

Radiological Source Term for Clean Slate Sites

Given: The mass ratio of depleted uranium to plutonium = 47.2 (Shreve, 1964)

Therefore, there is 47.2 g of depleted uranium for each gram of Pu

The mass fraction and specific activity of each depleted uranium isotope is (Rich, 1988; Shleien, 1992)

Isotope	Mass Fraction (g/100g DU)	Specific Activity (pCi/g)	Activity of U Isotope per 47.2 g of DU (pCi)	Fraction of Total DU Activity	pCi of Isotope per g DU
U-238	99.75	3.36E+05	1.58E+07	9.02E-01	3.35E+05
U-235	0.25	2.16E+06	2.55E+05	1.46E-02	5.41E+03
U-234	0.0005	6.23E+09	1.47E+06	8.39E-02	3.11E+04
Total =			1.75E+07	1	

For each 47.2 g of DU there is 1 g of Pu. The activity in 1 g of Pu is calculated in the following manner

Source: Radiological Assessment Activities at the Clean Slate Sites, Table 6 (Shreve, 1964)

The Pu-239/240: Am-241 activity = 14:1 (RSL, 1996)

Pu = The Pu-238, 239, 240, 241, 242, and Am-241 in standard weapons grade plutonium

Ao = The initial total acitivity of standard weapons grade Pu in 1963 (McKinley, 1995)

SA = Specific Activity based upon Table 8.4.1 of Shleien, 1992

Isotope	Ci of isotope in 34 yr old Pu Ao = 1 Ci	Fraction of Total Pu Activity	Inverse of SA (g/pCi)	g per pCi of Pu	Fraction of Total Pu Mass
Pu-238	2.29E-03	5.00E-03	5.84E-14	2.92E-16	2.97E-05
Pu-239	2.73E-01	5.95E-01	1.61E-11	9.59E-12	9.73E-01
Pu-240	2.59E-02	5.65E-02	4.39E-12	2.48E-13	2.52E-02
Pu-241	1.35E-01	2.95E-01	9.71E-15	2.86E-15	2.90E-04
Pu-242	5.50E-07	1.20E-06	2.55E-10	3.06E-16	3.11E-05
Am-241	2.22E-02	4.84E-02	2.91E-13	1.41E-14	1.43E-03
Total	**4.58E-01**	**1**		**9.853E-12**	**1**

1 pCi of Pu = **9.8531E-12** g

Pu-239/240 soil concentration is based on in situ measurements and a 14:1 activity ratio to Am-241 (RSL, 1996)

The activity of each Pu isotope in a gram of 34 year old weapons grade Pu is calculated below:

Isotope	SA (pCi/g)	Grams of Isotope per g Pu	pCi of Isotope per g Pu	Fraction of Pu-239/240 Activity	**Abundance by Radioactivity (pCi of isotope per 100 pCi of Pu-239/240)**
Pu-238	1.71E+13	2.97E-05	5.08E+08	7.68E-03	**7.68E-01**
Pu-239	6.21E+10	9.73E-01	6.04E+10	9.13E-01	**9.13E+01**
Pu-240	2.28E+11	2.52E-02	5.73E+09	8.66E-02	**8.66E+00**
Pu-241	1.03E+14	2.90E-04	2.99E+10	4.52E-01	**4.52E+01**
Pu-242	3.92E+09	3.11E-05	1.22E+05	1.84E-06	**1.84E-04**
Am-241	3.44E+12	1.43E-03	4.91E+09	7.42E-02	**7.14E+00**

Note - The Am-241 activity fraction is reduced from .074 to .0714 of Pu-239/240 to correct for Clean Slate site specific measurements that demonstrated a Pu-239/240:Am-241 activity ratio of 14:1

Radiological Source Term for Clean Slate Sites

The concentration of Pu in soil at the Clean Slate Sites is derived from in situ measurements of Am-241

The concentration of Pu-239/240 in soil at the Clean Slate Sites is listed in the following table (Wille, 1996)

Site	Pu-239/240 Concentration Prior to Remediation (pCi/g)	Pu-239/240 Concentration Subsequent to Remediation (pCi/g)
Clean Slate 1		
Average for area >100	357	177
Average for entire area	122	81
Clean Slate 2		
Average for area >100	458	176
Average for entire area	153	86
Clean Slate 3		
Average for area >100	391	174
Average for entire area	142	87

The DU:Pu activity ratio for Clean Slate Sites is listed below, obtained from Shreve (1964)

Clean Slate 1 the DU: Pu Mass Ratio =	47.2
Mass of DU per g of Clean Slate 1 Source Term (g) =	0.97925
Mass of Pu per g of Clean Slate 1 Source Term (g) =	0.020747
Clean Slate 2 the DU: Pu Mass Ratio =	100.4
Mass of DU per g of Clean Slate 2 Source Term (g) =	0.9901381
Mass of Pu per g of Clean Slate 2 Source Term (g) =	0.0098619
Clean Slate 3 the DU: Pu Mass Ratio =	99.7
Mass of DU per g of Clean Slate 3 Source Term (g) =	0.9900695
Mass of Pu per g of Clean Slate 3 Source Term (g) =	0.0099305

Clean Slate 1 Source Term

Isotope	Activity in 1g of Source Material (pCi)	Fraction of Pu-239/240 Activity	Concentration at CS-1 Prior to Cleanup (pCi/g of Soil)	at CS-1 Subsequent to Cleanup (pCi/g Soil)
U-238	3.28E+05	2.39E-04	8.53E-02	4.23E-02
U-235	5.29E+03	3.86E-06	1.38E-03	6.83E-04
U-234	3.05E+04	2.22E-05	7.93E-03	3.93E-03
Pu-238	1.05E+07	7.68E-03	2.74E+00	1.36E+00
Pu-239	1.25E+09	9.13E-01	3.26E+02	1.62E+02
Pu-240	1.19E+08	8.66E-02	3.09E+01	1.53E+01
Pu-241	6.20E+08	4.52E-01	1.61E+02	8.00E+01
Pu-242	2.53E+03	1.84E-06	6.57E-04	3.26E-04
Am-241	1.02E+08	7.42E-02	2.65E+01	1.31E+01
Total Activity =	2.11E+09	1.53E+00	5.48E+02	2.72E+02

Calculation of DU and Plutonium Isotope Concentration in Soil at Clean Slate 1, 2, and 3 and other RESRAD Input

Clean Slate 2 Source Term

Isotope	Activity in 1g of Source Material (pCi)	Fraction of Pu-239/240 Activity	Concentration at CS-2 Prior to Cleanup (pCi/g of Soil)	Concentration at CS-2 Subsequent to Cleanup (pCi/g Soil)
U-238	3.32E+05	5.08E-04	2.33E-01	8.94E-02
U-235	5.35E+03	8.20E-06	3.76E-03	1.44E-03
U-234	3.08E+04	4.73E-05	2.16E-02	8.32E-03
Pu-238	5.01E+06	7.68E-03	3.52E+00	1.35E+00
Pu-239	5.96E+08	9.13E-01	4.18E+02	1.61E+02
Pu-240	5.65E+07	8.66E-02	3.97E+01	1.52E+01
Pu-241	2.95E+08	4.52E-01	2.07E+02	7.95E+01
Pu-242	1.20E+03	1.84E-06	8.43E-04	3.24E-04
Am-241	4.84E+07	7.42E-02	3.40E+01	1.31E+01
Total Activity =	1.00E+09	1.53E+00	7.03E+02	2.70E+02

Radiological Source Term at Clean Slate 3

Isotope	Activity in 1g of Source Material (pCi)	Fraction of Pu-239/240 Activity	Concentration at CS-3 Prior to Cleanup (pCi/g of Soil)	oncentration at CS-3 Subsequent to Cleanup (pCi/g Soil)
U-238	3.32E+05	5.05E-04	1.97E-01	8.78E-02
U-235	5.35E+03	8.15E-06	3.18E-03	1.42E-03
U-234	3.08E+04	4.69E-05	1.83E-02	8.17E-03
Pu-238	5.04E+06	7.68E-03	3.00E+00	1.34E+00
Pu-239	6.00E+08	9.13E-01	3.57E+02	1.59E+02
Pu-240	5.69E+07	8.66E-02	3.39E+01	1.51E+01
Pu-241	2.97E+08	4.52E-01	1.77E+02	7.86E+01
Pu-242	1.21E+03	1.84E-06	7.20E-04	3.20E-04
Am-241	4.88E+07	7.42E-02	2.90E+01	1.29E+01
Total Activity =	1.01E+09	1.53E+00	6.00E+02	2.67E+02

Contaminated Area for each of the Clean Slate sites (Wille, 1996)

Clean Slate 1 Area =	**2449 bits x (33x33) sq ft/bit =**	2.67E+06 sq ft =	**2.48E+05** m**2
Clean Slate 2 Area =	**13374 bits x (33x33) sq ft/bit =**	1.46E+07 sq ft =	**1.35E+06** m**2
Clean Slate 3 Area =	**17520 bits x (33x33) sq ft/bit =**	1.91E+07 sq ft =	**1.77E+06** m**2

Calculated values used as RESRAD input for dose assessment to hypothetical individuals living and or working on Clean Slate 1, 2, and 3 sites

Parameter	**Calculational Methodology**
Dose Conversion Factors	RESRAD default values
Food Transfer Factors	RESRAD default values
Bioaccumulation factors, fresh water	not applicable, not used
Thickness of contamination	**0.05** m (RSL, 1996)
Length parallel to aquifer flow	Measured from Figures 2-7, 3-2,3-3, CS CADD
Clean Slate 1	**1640 m**
Clean Slate 2	**1000 m**
Clean Slate 3	**2300 m**
Time since placement of material	0, source term is corrected for 1997
Time for calculations	0, 1, 10, 50, 250, 500, 1000, 5000, 10 000 years
Initial principal radionuclides	U-234, 235, 238; Pu-238, 239, 240, 241, 242; Am-241
Initial concentration in groundwater =	0
Cover depth (m) =	0
Soil density in all zones (g/m**3) =	1.5 RESRAD default
Contaminated zone erosion rate (m/yr) =	**3.1X10-5** Calculational method shown below

CZR =Contaminated Zone Erosion Rate = RF x t X dc where

RF is the average annual resuspension factor from Shinn (1986) in units of (fraction/s)

t is the number of seconds per year

DC is the depth of the contaminated zone (m)

RF =	1.94E-11
t =	3.15E+07
DC =	0.05
CZR =	3.0584E-05

Total porosity all zones =	0.3 Groundwater (Freeze and Cherry, 1979)
Effective porosity all zones =	0.3 Groundwater (Freeze and Cherry, 1979)
Hydraulic conductivity, all zones	1000 (Yu et al., 1993b) (Table 5-1, pg. 28, clear sand)
Zone b parameter, all zones	4.05 (Yu et al., 1993b) (Table 13-1, pg. 77, sand)
Evapotranspiration Coefficient =	**0.679125**

Ce = ETr/((1-Cr)Pr +IRr) where

Ce = Evapotranspiration coefficient

ETr = evapotranspiration rate, Figure 12-1, pg. 72 (Yu et al., 1993b) =	1.11	m/yr
Cr = runoff coefficient, Table 10-1, pg. 66 (Yu et al., 1993b) (default) =	**0.2**	
Pr = precipitation (Culp and Howard, 1995) =	**0.127**	m/yr
IRr = irrigation rate = assuming a 70% irrigation efficiency =	**1.53**	m/yr
Ce =	0.679125	

IRr = (1.2 -0.127)/.07

1.2 = water required per year to raise garden or farm (m/yr)

0.127 = average precipitation (m/yr) at TTR, (Culp & Howard, 1995)

0.7 is the assumed irrigation efficiency, mid-range, pg. 68 (Yu et al., 1993b)

IRr = 1.532857

Irrigation Mode = ditch
Runoff Coefficient = 0.2 (Yu et al., 1993b) (Table 10-1, pg. 66)
Watershed Area for Nearby Stream or Pond = area of Clean Slate site, RESRAD minimum area
Note: The area of contamination is the minimum area that RESRAD will accept and still execute, even if no water pathways are analyzed by the code user.
Accuracy for Water/Soil Computations = 0.001 RESRAD default
Saturated Zone Hydraulic Gradient = 1E-4 RCRA & FIWP for TTR (DOE, 1994)
Water Table Drop Rate (m/yr) = 1E-4 RCRA & FIWP for TTR (DOE, 1994)
Well Pump Intake Depth = 10 m below the water table, RESRAD default
Model: Nondispersion or Mass Balance ND (nondispersion) RESRAD default value

Well Pumping Rate:

Clean Slate 1	**538560**	m**2 = area x irrigation rate
Clean Slate 2	**4712400**	m**2 = area x irrigation rate
Clean Slate 3	**4911300**	m**2 = area x irrigation rate

Number of Unsaturated Zones = 1 RCRA & FIWP for TTR, (DOE,1994a)
Unsaturated Zone Thickness = 55 m (USGS,1986)

Distribution Coefficients Table 32-1, pg. 105, sandy soil (Yu et al., 1993b)

Element	d.c. (cm**3/g)	
U	**35**	
Th	**3200**	
Pa	**550**	
Ra	**500**	
Pb	**270**	
Pu	**550**	
Am	**35**	note- <value in Table 32.1, based on advice of W. Hansen LANL
Ac	**450**	
Np	**5**	

Inhalation Rates for the Resident Rancher, Resident, and Industrial Worker Exposure Scenarios

Rancher and Farmer Scenarios

Activity	Percent of waking hours	hours/day	m**3/h	m**3/day	days/yr	m**3/yr	Occupancy Corrected
Sleeping	0	7	0.4095	2.8665	341	9.77E+02	1.06E+03
Light work/resting	56	9.52	0.611	5.81672	341	1.98E+03	2.15E+03
Moderate work	37	6.29	1.625	10.22125	341	3.49E+03	3.78E+03
Very heavy work	7	1.19	4.088	4.86472	341	1.66E+03	1.80E+03
Total =	100	24				8.11E+03	**8.78E+03**
Rural Resident							
Not Applicable	100	24	0.833333333	20	341	6820	**7386.647**
Industrial Worker							
Not Applicable	100	24	0.525	12.6	250	3150	**4599**
Child							
Not Applicable	100	24	0.5125	12.3	352	4329.6	**4489.5**

Breathing Rates for Rancher and Farmer Exposure Scenario
Percentage of time spent on different activities from pg. 124 (Yu et al., 1993b)
Breathing rates from (Layton, 1993), pg. 33, Table 7
Breathing Rates for Rural Resident, Industrial Worker and Child from Tables A.1, A.2 & A3 (EPA, 1993)
Occupancy Factor Correction: RESRAD takes the user input for inhalation and multiplies it by the fraction of the time the dose receptor is on site. The breathing rates have been increased by the Occupancy Factor
Occupancy Factor for Rancher, Farmer, and Rural Resident = 365/341 = **1.0703812**
Occupancy Factor for Industrial worke r = 365/250 = **1.46**
Occupancy Factor for Child = 365/352 = **1.0369318**

Calculation of Mass Loading for Inhalation

AML = (1/FO) x Z (ML x Fm x t x FC) where

AML =	adjusted annual average mass loading of contaminated dust in the air for exposure scenarios (g/m**3)
FO =	occupancy factor for the exposure scenario (d/yr)
Z =	summation of the subsequent arithmetic expression over each activity in each exposure scenario
ML =	the present annual average mass loading at the safety shot sites (Shinn, 1994)(g/m**3)
ML =	1.36E-05
Fm =	increase in mass loading, exposure and activity specific (unitless)
t =	time period that an activity takes place in an exposure scenario (d/yr)
FC =	correction factor for pulmonary deposition of large resuspended particles, (Shinn, 1986) . FC is set to 1.0 because there is insufficient characterization data on the particle size distribution of resuspended particles from farming type activities at the Clean Slate sites

Farming activitiesare divided into 3 categories: very intense activities, such as plowing, that result in large increases in the mass loading; intense activities, such as cultivating, that cause some increase in the mass loading; and less intense activities, such as irrigating, that do not result in significant increases in the mass loading.

Mass Loading Calculation for the Farming Scenario

	Values		
Parameters	**Very Intense Activities**	**Intense Activities**	**Less Intense Activities**
FO	341	341	341
ML	1.36E-05	1.36E-05	1.36E-05
Fm	150	2	1
t	1	50	286
FC	1	1	1

AML = **2.14E-05**

Mass Loading for the Rancher Scenario

	Values		
Parameters	**Very Intense Activities**	**Intense Activities**	**Less Intense Activities**
FO	341	341	341
ML	1.36E-05	1.36E-05	1.36E-05
Fm	150	2	1
t	0	50	287
FC	1	1	1

AML = **1.54E-05**

Mass Loading for the Rural Resident Scenario

Parameters	Values: Very Intense Activities	Values: Intense Activities	Values: Less Intense Activities
FO	341	341	341
ML	1.36E-05	1.36E-05	1.36E-05
Fm	150	2	1
t	2.5	0	0
FC	1	1	1

AML = **1.50E-05**

Mass Loading for the Industrial Worker Scenario

AML = **1.36E-05**

Dilution length for airborne dust =	3	m RESRAD default value
Exposure duration =	30	y RESRAD default value
Shielding factor (inhalation)		
Rancher =	**1**	(Clayton,1993) maximun RESRAD
Farmer =	**1**	(Clayton,1993) maximum RESRAD
Rural Resident =	**0.4**	(EPA, 1993)
Industrial Worker =	**0.4**	(EPA, 1993)
Shielding factor (external gamma) =	0.7	RESRAD default value

Fraction of time hypothetical individuals spend indoors and outdoors on site at Clean Slate 1,2,3 (FO)

OFrf,i =	Fraction of time Rancher & Farmer spend indoors on site (Henderson and Smale, 1990)
OFrf,i =	(9 hrs/d x 341 d/yr)/8760 hrs/y
OFrf,o =	Fraction of time Rancher & Farmer spend outdoors on site (Henderson and Smale, 1990)
OFrf,o =	(15 hrs/d x 341 d/yr)/8760 hrs/yr
OFrr,i =	Fraction of time Rural Resident spends indoors on site (EPA, 1993)
OFrr,i =	(14.9 hrs/d x 341 d/yr)/8760 hrs/yr
OFrr,o =	Fraction of time Rural Resident spends outdoors on site (EPA, 1993)
OFrr,o	(0.4 hrs/d x 341 d/yr)/8760 hrs/yr
OFiw,i =	Fraction of time Industrial Worker spends indoors on site (EPA, 1993)
OFiw,i =	(8 hrs/d x 250 d/yr)/8760 hrs/yr
OFiw,o =	Fraction of time Industrial Worker spends outdoor on site (EPA, 1993)
OFiw,o =	(2 hrs/d x 250 d/yr)/8760 hrs/yr

OFc,i = Fraction of time Child spends indoors on site (Henderson and Smale, 1990)
OFc,i = (18.4 hrs/d x 352 d/yr)/8760 hrs/yr
OFc,o = Fraction of time Child spends outdoors on site (Henderson and Smale, 1990)
OFc,o = (5.6 hrs/d x 352 d/yr)/8760 hrs/yr

OFrf,i =	3.50E-01
OFrf,o =	5.84E-01
OFrr,i =	5.80E-01
OFrr,o =	1.56E-02
OFiw,i =	2.28E-01
OFiw,o =	5.71E-02
OFc,i =	7.39E-01
OFc,o =	2.25E-01

OFrf = Occupancy factor for rancher and farmer = fraction of time on site = OFrf,i + OFrf,o
OFrf = 9.34E-01
OFrr = Occupancy factor for rural resident = fraction of time on site = OFrr,i +OFrr,o
OFrr = 5.96E-01
OFiw = Occupancy factor for industrial worker = fraction of time on site = OFiw,i + OFiw,o
OFiw = 2.85E-01
OFc = Occupancy factor for child = fraction of time child on site =
OFc = 9.64E-01

Note: RESRAD corrects dietary consumption, soil ingestion, and inhalation intake that are inputted by the code user by multiplying the input by the occupancy factor; therefore, the calculated inputs have to be divided by the occupancy factor. to calculate the value that should be inputted to RESRAD

Shape Flag = -1 RESRAD default value, corrects external exposure rate, not a significant pathway

Food Consumption Rates

Consumption of fruits, vegetables, grains is calculated using the information in Table 1 (Whicker, 1990)
Rancher/farmer, resident consumption rate from data in Table 1 (Whicker, 1990)
Milk = Milk = (.477 kg/d + .436 kg/2) x 341 d/yr (assume milk density = 1kg/L)
Cheese = (.163kg/d + .146 kg/d/2) x 341 d/yr

Milk =	203.236 L/yr

Meat = Beef, lamb, poultry, eggs = meat consumption for rancher and rural resident, data from (Whicker, 1990)
Meat = Beef + Lamb + Poultry + Eggs (kg/d)

Beef =	(.178+.116)/2 =	0.147 kg/d
Lamb =	(.029 + .016)/	0.0225 kg/d
Poultry =	(.049+.041)/2 =	0.045 kg/d
Eggs =	(.07 + .048)/2 =	0.059 kg/d
Total (kg/d) =		0.2735
Total (kg/yr) =		93.2635

Meat =	93.2635 kg/yr

Produce = Fruits, vegetables, grains consumed by farmer and rural resident (Whicker et al., 1990)
Produce = ((.282 + .269)/2) + ((.09 + .066) /2)) x 341 =
.282 = kg/d of other vegetables & fruits for adult males
.09 = kg/d of grains consumed for adult males
.269 = kg/d of other vegetables & fruits consumed by adult females
.066 = kg/d of grains consumed by adult females
341 = days per year individuals onsite (Henderson and Smale, 1990)

Produce =	120.5435 kg/yr

L. vegs = Leafy vegetable consumption rate by farmer and rural resident (Whicker et al., 1990)
L. vegs = (.03 + .029/2) x 341
.03 = kg/d consumption of leafy vegetables by adult males
.029 = kg/d consumption of leafy vegetables by adult females

L. vets =	10.0595 kg/yr

Soil Ingestion Rate

IRs,fr = Soil Ingestion Rate for Rancher and Farmer
IRs,fr = (.48g/d x 50d/yr) + (.1 x 50 d/yr) + (.05 g/d x 241 d/yr) x (365/341)
.48 g/d for outside workers during intense soil work (Yu et al., 1993b)
.1 g/d standard EPA (1990b) referenced by RESRAD (Yu et al., 1993b)
.05 g/d workplace recommendation (EPA, 1991) referenced by RESRAD
365/341 = occupancy factor correction used by RESRAD

IRs,fr =	43.72507331 g/yr

IRs,rr = Soil Ingestion Rate for rural Resident
IRs,rr = 0.1 g/d x 350 d/yr x 365/341 occupancy factor

IRs,rr =	36.5	g/yr

IRs,iw = Soil Ingestion Rate for Industrial Worker
IRs,iw = 0.05 g/d x 250 d/yr x (365/250)

IRs,iw =	18.25	g/yr

IRs,c = Soil Ingestion Rate for a Child
IRs,c = 0.024 g/d x 352 d/yr x 365/352 (Calabrese and Stanek, 1991)

IRs,c =	8.76	g/yr

Calculation of DU and Plutonium Isotope Concentration in Soil at Clean Slate 1, 2, and 3 and other RESRAD Input

Tap Water Ingestion Rate (l/YR)

IRw,rf = Ingestion Rate of tap water for the rancher and farmer
IRw,rf = 1.86 L/d x 341 d/y
1.86 L/d is from pg. 6.36, Table 21 AIHC (AIHC, 1994)

IRw,rf =	**634.26 L/yr**

IRw,rr = Ingestion Rate of tap water for the rural resident
IRw,rr = 1.4 L/d x (14.9 hrs/d on site/16 hr/d awake 341 x 365/341
1.4 l/d is from mean tap water ingestion rate recommeded by AIHC for risk assessment (AIHC,1994)
14.9 hr/d is the occupancy time of the rural resident on site (EPA,1993)

IRw,rr =	**444.57875 L/yr**

IRw,iw = Ingestion Rate of tap water for the industrial worker
IRw,iw = .875 L/d x 250 d/yr
0.875 L/d = 1.4 L/d x (10 hr/d on site/16 hr/d awake and ingesting water) (AIHC,1994)
250 d/yr = days per year industrial worker is on site (EPA, 1993)

IRw,iw =	**218.75 L/yr**

IRw,c = Ingestion Rate of tap water by the child
IRw,c = 0.32 x 352 where
0.329 L/d is the weighted ingestion rate of water for children, Table 5-9 NCRP Report No. 76 (NCRP,1985)
352 d/yr = is the days per year on site for children <12 in rural NV, (Henderson & Smale, 1990)

IRw,c =	**115.808 L/yr**

Fraction of tap water that is contaminated = 1

Ingestion Pathway Data, Nondietary Parameters

Livestock fodder intake for meat (kg/yr) =	68	RESRAD default (Yu et al., 1993b)
Livestock fodder intake for milk (kg/yr) =	55	RESRAD default (Yu et al., 1993b)
Livestock water intake for meat (:Ld) =	50	RESRAD default (Yu et al., 1993b)
Livestock water intake for milk (L/d) =	160	RESRAD default (Yu et al., 1993b)
Livestock soil ingestion rate (kg/d) =	0.5	RESRAD default (Yu et al., 1993b)
Mass Loading for foliar deposition (g/m**3)		

MLFD f,rr = Mass Loading for foliar deposition for the farmer and rural resident
MLFD f,rr = [(90 x 1.36E-5) + (150 x 2 x 1.36E-5)]/240 where

90 =	days per year when gardening/farming will not increase resuspension
150 =	days per year when gardening/farming increases mass loading by 2 (Leddicotte, 1978)
1.36E-5 =	average annual mass loading at Clean Slate 3 (g/m**3) (Shinn, 1994)
240 =	estimated growing season at TTR

MLFC f,rr	**2.21E-05 g/m**3**

Note: When very high resuspension activities occurring (e.g., rototilling, plowing) the edible parts of the plant do not exist, only considered effect when plants emerge.

Depth of Soil Mixing

DSMr,iw = Depth of Soil Mixing for the Rancher and Industrial Worker; no soil mixi

DSMr,iw =	**0.05 m**

DSMf,rr = Depth of Soil Mixing for the Farmer and Rura Resident (Yu et al., 1993b)

DSMf,rr =	**0.15 m**

Depth of Roots =	0.9	RESRAD default (Yu et al., 1993b)
Drinking Water Fraction from Groundwater =	1	no surface water at TTR
Household Water Fraction from Groundwater =	1	no surface water at TTR
Livestock Water Fraction from Groundwater =	1	no surface water at TTR
Irrigation Fraction from Groundwater =	1	no surface water at TTR
Storage Time of Contaminated Foodstuffs (days)		
Fruits, non-leafy vegetables, and grains	14	RESRAD default (Yu et al., 1993b)
Leafy vegetables	1	RESRAD default (Yu et al., 1993b)
Milk	1	RESRAD default (Yu et al., 1993b)
Meat and poultry	20	RESRAD default (Yu et al., 1993b)
Fish	not used as an exposure pathway	
Crustracea and mollusks	not used as an exposure pathway	
Well water	1	RESRAD default (Yu et al., 1993b)
Surface water	1	RESRAD default (Yu et al., 1993b)
Livestock fodder	45	RESRAD default (Yu et al., 1993b)

RADON Exposure Pathway

As this pathway will result in < 1 mrem to the hypothetical individual, all RESRAD default values used except residence is placed on soil surface (see Yu et al., 1993b).

Child Exposure Scenario Parameters for Safety Shot Dose Assessments

CHILD EXPOSURE SCENARIO - PARAMETER VALUES

Child Specific Parameters are listed below in the order they are input to RESRAD

RO17 Inhalation and External Gamma Parameters

Inhalation Rates from Table 5 Layton (1993)

Age	Daily Inhalation rate (m**3/d)	
<1	4.5	
1	6.8	
2	6.8	
3	8.3	
4	8.3	
5	8.3	
6	9	
7	9	
8	9	
9	13.5	note (average of boy and girl respiratory rate)
10	13.5	note (average of boy and girl respiratory rate)
11	13.5	note (average of boy and girl respiratory rate)
Mean	**12.28**	**m**3/d**

Mass Loading in the air is assumed to be the same as for adults

Dilution length for airborne dust, inhalation is assumed to be the same as for adults

Exposure duration = 9 years

Shielding factor, inhalation = same as for adults, this varies with exposure scenario

Shielding factor, external gamma = the same as for adults, 0.7

Fraction of time spent indoors

When the child is in elementary school (ages 5-11) time indoors is based upon Figure 2 (Henderson and Smale, 1990). This data is based upon surveys performed in rural areas and small communities in the vicinity of the Nevada Test Site. The data from the figure was analyzed using the methods described in Adams (1996).

Measurements taken from Figure 2 (Henderson and Smale, 1990) were used to obtain the following data

Time spent per week performing the different activities (hours per week)

Activity	Indoors On Site	Outside On Site	Off Site
Summer			
Automobile Riding	0.00	0.00	0.00
Outdoors	0.00	56.92	0.00
Other Bldg.	2.13	0.00	0.00
Living Room	39.95	0.00	0.00
Bedroom	66.82	0.00	0.00
Other	0.00	0.00	2.18
Total Hours, Summer	1419.59	742.04	28.36
Spring and Fall			
Automobile Riding	0.00	0.00	1.06
Outdoors	0.00	27.29	0.00
Other Bldg.	28.99	0.00	0.00
Living Room	44.21	0.00	0.00
Bedroom	65.28	0.00	0.00
Other	0.00	0.00	1.16
Spring and Fall, Total	3610.16	711.49	58.10

Winter			
Automobile	0.00	0.00	0.00
Outdoors	0.00	29.69	0.00
Other Bldgs.	31.55	0.00	0.00
Living Room	38.41	0.00	0.00
Bedroom	66.61	0.00	0.00
Other	0.00	0.00	1.75
Total Hours, Winter	1780.21	386.97	22.81

Total hours spent indoors on site =	6809.971	Fraction of time annually =	0.777394
Total hours spent outdoors on site =	1840.51	Fraction of time annually =	0.210104
Total hours spent off site =	109.2778	Fraction of time annually =	0.012475
Summation of hours in year =	8760		
Summation of hours on and off site =	8759.759	(check on the method, difference <.003%)	

No data were found on the fraction of time spent indoors, outdoors, and off site for children less than 5 years old. The U.S. EPA Exposure Factors Handout and the American Industrial Health Council (AIHC, 1994) Exposures Factors Sourcebook recommend that for children ages 3 - 11 that 27 hour per week be assumed as the time spent away from home. The fraction of time spent off site by children ages 3 - 4 in this analysis will be 27/168 = 0.160714

The AIHC Exposure Factors Sourcebook recommends that the fraction of time spent indoors for children is .86, and the fraction of time spent outdoors is 0.09.

For children 3-4 the fraction of time spent indoors on-site, outdoors on site, and off site are

Fraction of time spent indoors on site = (1 - 0.160714) x 0.86 = 0.721785714

Fraction of time spent outdoors on site = (1 - 0.160714) x 0.09 = 0.075535714

Fraction of time spent off site = 0.160714286

For very young children, <3 years old, neither the EPA nor the AIHC provide guidance. For the purpose of this analysis, it is assumed that the fraction of time spent off site and outdoors on site by children <3 years old is one-half of that for children ages 6 to 11, based upon the site-specific data of Henderson and Smale (1990).

Fraction of time 0 - 2 yr olds spend indoors on site = 1 - [(.21/2)+(.012/2)] = 0.888711

Fraction of time 0 - 2 yr olds spend outdoors on site = 0.21/2 = 0.105052

Fraction of time 0 - 2 yr olds spend off site = 0.012475/2 = 0.006237

Fraction of time spent indoors on site, outdoors on site, and off site for children 0 to 11 years old

Fraction of time spent indoors on site = [(7x.777)+(2x.72)+(3x.8887)]/12 = OFc,i

OFc,i = 0.7960

Fraction of time spent outdoors on site =[(7x.21)+(2x.076)+(3x.105)]/12 = OFc,o

OFc,o = 0.1614

Fraction of time spent off site = [(7x.096)+(2x.16)+(3x.048)]/12 = 0.035622

Offsite fraction is equivalent to 0.035622 x 365 d/yr = 13.002 d/yr

Therefore, for calculating ingestion rates, inhalation rates, and external exposure rates the child is assumed to be on site 365 days - 13 days = 352 days

Child Exposure Scenario Parameters for Safety Shot Dose Assessments

RO18 - Ingestion Pathway Data, Dietary Parameters
Ingestion of Fruits, Vegetables and Grains (kg/yr)
Data from Table 5-3, "Best estimates" of average daily intake of various foods by age
NCRP 76, Radiological Assessment: Predicting the Transport, Bioaccumulation, and Uptake by Man of Radionuclides Released to the Environment, (NCRP , 1985)

Food	Age <1 g/day	Age<1 kg/yr	Age 1 - 11 g/day	Age 1 - 11 kg/yr
Vegetable				
Potatoes	6	2.11	49	17.25
Yellow	12	4.22	7	2.46
Legume	12	4.22	22	7.74
Other	50	17.60	58	20.42
Fruits				
Citris, To	23	8.10	74	26.05
Dried	3	1.06	2	0.70
Other	112	39.42	112	39.42
Grains	21	7.39	87	30.62
Total	239	84.13	411	144.67

Ingestion rate of fruits, vegetables, and grains by children ages 0 - 11 (kg/yr)	139.63

Ingestion of Leafy Vegetables

Food	Age<1 g/day	Age<1 kg/yr	Age 1 - 11 g/day	Age 1 - 11 kg/yr
Leafy Veg	2	0.704	20	7.04

Ingestion rate of leafy vegetables by children ages 0 - 11 years (kg/yr) =	6.51

Milk Consumption

Food	Age<1 mL/day	Age<1 L/yr	Age 1 - 11 mL/day	Age 1 - 11 L/yr
Milk, Fluid	696	244.99	542	190.78
Milk Prod.	795	279.84	606	213.31
Total	1491	524.83	1148	404.10

Milk consumption of milk by children ages 0 to 11 years of age (L/yr) =	414.16

Meat and Poultry Consumption (kg/yr)

Food	Age <1 g/day	Age<1 kg/yr	Age 1 - 11 g/day	Age 1 - 11 kg/yr
Eggs	17	5.98	25	8.80
Beef	7	2.46	38	13.38
Pork	4	1.41	41	14.43
Poultry	3	1.06	18	6.34
Other	34	11.97	39	13.73
Total	65	22.88	161	56.67

Meat and poultry consumption by children ages 0 to 11 years of age (kg/yr)=	**53.86**

Consumption of fish raised on or contaminated from the site is assumed to be 0.0 kg/yr
Other seafood consumption raised on or contaminated from the land is assumed to be 0.0 kg/yr
RO18 Ingestion Pathway Data, Dietary parameters (continued)

Soil ingestion rate assumed is based upon the quantifiable soil ingestion rates obtained for the tracer element zirconium (Cabreses and Stanek, 1991). The median soil ingestion value for children reported was 16 mg/d, with a 97.5 percentile of 24 mg/d. The proposed regulatory default value of 200 mg/d is at the extreme end of every study reviewed.

Ingestion Rate (g/d) = 0.024

Ingestion rate (g/yr)=	**8.45**

Drinking water intake (L/yr)
Drinking water intake is taken from Table 5.9, NCRP Publication 76 "Average and range of daily intake of tap water and beverages other than milk for various age groups" (NCRP, 1985).

	Age <1	Age 1 - 11
Tap Water Consumption (mL/d)	223	329
Tap Water Consumption (L/yr)	78.496	115.808

Tap water consumption by children ages 0 to 11 years of age (L/yr) =	**112.70**

Contamination fraction of drinking water = 1
Contamination fraction of household water = 1
Contamination fraction of livestock water = 1
Contamination fraction of irrigation water = 1
Contamination fraction of aquatic food = not used, not an exposure pathway
Contamination fraction of plant food = -1 (RESRAD assumes that 50% of food grown on site)
Contamination fraction of meat = -1 (RESRAD assumes that 50% of food grown on site)
Contamination fraction of milk = -1 (RESRAD assumes that 50% of food grown on site)

RO19 Ingestion Pathway Data, Nondietary Parameters
All RO19 parameters are the same for both children and adults

C-14 Parameters - Not appropriate for Safety Shots, C-14 not a principal radionuclide

STOR Storage times of contaminated foodstuffs (days) is the same for children and adults

RO21 Radon Parameters are the same for children and adults

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