Review of Soil Contamination Guidance

**M. A. Mueller
W. E. Kennedy, Jr.
J. K. Soldat**

August 1981

Prepared for UNC Nuclear Industries

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

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PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
Under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy \$ _____ *: Microfiche \$3.00

*Pages	NTIS
	Selling Price
001-025	\$4.00
026-050	\$4.50
051-075	\$5.25
076-100	\$6.00
101-125	\$6.50
126-150	\$7.25
151-175	\$8.00
176-200	\$9.00
201-225	\$9.25
226-250	\$9.50
251-275	\$10.75
276-300	\$11.00

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GUIDANCE

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(Contract No. DE-AC06-76RLO 183D)

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ABSTRACT

A review of existing and proposed radioactive soil contamination standards and guidance was conducted for United Nuclear Corporation (UNC), Office of Surplus Facilities Management. Information was obtained from both government agencies and other sources during a literature survey. The more applicable standards were reviewed, evaluated and summarized. Information pertaining to soil contamination for both facility operation and facility decommissioning was obtained from a variety of sources. These sources included: the Code of Federal Regulations, regulatory guides, the Federal Register, topical reports written by various government agencies, topical reports written by national laboratories, and publications from the American National Standards Institute (ANSI). It was difficult to directly compare the standards and guidance obtained from these sources since each was intended for a specific situation and different units or bases were used. However, most of the information reviewed was consistent with the philosophy of maintaining exposures at levels "as low as reasonably achievable" (ALARA).

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1.0 INTROOUCION

This report contains the results of a study sponsored by United Nuclear Corporation (UNC), Office of Surplus Facilities Management, to review and summarize the requirements of existing guidance and standards pertaining to radioactive contamination in soil. A literature survey was performed to locate decontamination of existing and proposed guidance related to radioactive contamination in soil. This topical report is a summary of the more applicable guidance and standards identified.

During the literature survey, we identified sixteen government information sources, including citations from the Code of Federal Regulations, the regulatory guides, the Federal Register, and topical reports published by various Federal agencies. Discussions of these government information sources are found in Chapter 2, and are summarized in Table 2.0-1. Nine other reports, written by national laboratories or sources other than government agencies, were identified as containing or using soil contamination information. These are discussed in Chapter 3 and summarized in Table 3.0-1. Chapter 4 contains a brief discussion of the results of this study.

2.0 REVIEW OF GOVERNMENT SOIL CONTAMINATION STANDARDS

A summary of the adopted and proposed soil contamination guidelines by government agencies is given in Table 2.0-1. When available, information is presented on the basis of the limit, the dose to the maximum individual, and the risk to the maximum individual. The Nuclear Regulatory Commission (NRC), the Environmental Protection Agency (EPA), and the former Atomic Energy Commission (AEC) have adopted criteria for operation and/or decommissioning of nuclear facilities. These criteria can be used to evaluate acceptable soil contamination levels for unrestricted release of property. The EPA has proposed two specific soil contamination standards: one for ^{226}Ra , and the other for transuranics. The standard for ^{226}Ra has been adopted as an interim standard. The State of Colorado has adopted a standard for permissible plutonium levels in soil in uncontrolled areas; however, the basis of this standard is not available for detailed review. Soil standards for Enewetak Atoll are based on a dose calculation model designed specifically for Enewetak. The basis of those standards are also not available for review. Neither the Colorado nor Enewetak standards are considered further in this study. Discussions of the other standards are given in the remaining sections of Chapter 2. It is difficult to directly compare the limits given in most of the standards since each is intended for a specific situation, and a variety of units are used. Thus, we have not attempted to develop relationships between the different standards, but rather we have summarized their major points.

2.1 Federal Register, Vol. 46, No. 27, "Nuclear Regulatory Commission, 10 CFR Parts 30, 40, 50, 70 and 72, Decommissioning Criteria for Nuclear Facilities; Notice of Availability of Draft Generic Environmental Impact Statement"

Since 1978 the U.S. Nuclear Regulatory Commission (NRC) has been reevaluating its regulatory requirements concerning decommissioning policy (Calkins 1978; Calkins 1980a). In particular it is the objective of the NRC to protect public health and safety by providing regulatory guidance for accomplishing the decommissioning of any nuclear fuel cycle facility. In support of regulations, an extensive data base on decommissioning

TABLE 2.01 Summary of Government Soil Contamination Standards

Reference	Radionuclide	Soil Contamination Limit	Basis of Limit	Resulting Dose to Maximum Individual	Resulting Risk to Maximum Individual	Comments
Federal Register Vol. 46, No. 27, pp. 11666-11668, "Nuclear Regulatory Commission 10 CFR Parts 30, 40, 50, 70, and 72, Decommissioning criteria for Nuclear Facilities; Notice of Availability of Draft Generic Environmental Impact Statement" (Federal Register 1981)	All	ALARA below the soil concentration resulting in a whole body dose equivalent of <10 mrem/yr for any radionuclide or mixture of radionuclides	A practical dose range using a calculational method to determine acceptable soil or surface contamination limits on a case-by-case basis	1 to 10 mrem/yr whole body dose equivalent	--(a)	Realistic Analyses indicate that a dose range is more practical as a limit than a specific dose or concentration limit. Technical or economic justification may be required to determine the exact release condition within a range of 1 to 10 mrem/yr whole body dose equivalent.
• NUREG-0436 (Rev. 1) (Supp. 2) Plan for Reevaluation of NRC Policy on Decommissioning of Nuclear Reactors (Calkins 1981)	All	Same as above	Same as above	Same as above	--	Proposes changes to 10 CFR parts 30, 40, 50, 70 and 72 to cover decommissioning requirements.
• NUREG-0436 (Rev. 1) (Supp. 2) Plan for Reevaluation of NRC Policy on Decommissioning of Nuclear Reactors (Calkins 1980a)	All	Same as above	Same as above	Same as above	--	Initial statement of current recommendations
• NUREG-0590 (Rev. 2) Thoughts on Regulations for Decommissioning (Draft Report) (Calkins 1980b)	All	Same as above	Same as above	Same as above	--	Initial statement of current recommendations
• NUREG-0613 Regional Radioactivity Limits for Decommissioning (Draft Report) (Conti 1979)	All	Soil concentration resulting in exposures of ≤5 mrem/yr	Calculated based on realistic exposure pathway analysis	≤5 mrem/yr	--	Preliminary NRC staff analysis concluded that a limit of 5 mrem/yr would be consistent with other current guidance and result in activity levels which can be effectively monitored.
• NUREG-0586 Draft Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities (Feldman 1981)	All	Same as above	Same as above	Same as above	--	Restatement of early NRC 5 mrem/yr position.
• NUREG/CR-0671 Decommissioning Commercial Nuclear Facilities: A Review and Analysis of Current Regulations (Schilling, et al. 1979)	--	--	--	--	--	An NRC review of existing regulations, with no recommendations for soil contamination limits.
10 CFR 140.84, "CRITERION I-Substantial Discharge of Radioactive Materials or Substantial Radiation Levels Offsite" (10 CFR 140.84 1980)	TRU Alpha Emitters	3.5 $\mu\text{Ci}/\text{m}^2$	Property near a site covered by an indemnity agreement.	--	--	Criterion I states that a substantial discharge has occurred when 100 m ² of offsite property is contaminated to the levels shown. The other offsite property category includes property that is contaminated during the transport of radioactive materials.
	Non-TRU Alpha Emitters	35 $\mu\text{Ci}/\text{m}^2$	Same as above	--	--	
	Beta-Gamma Emitters	40 mrad/hr @1 cm (with not more than 7 mg/cm ² of absorber)	Same as above	--	--	
	TRU Alpha Emitters	0.35 $\mu\text{Ci}/\text{m}^2$	Same as above	--	--	
	Non-TRU Alpha Emitters	3.5 $\mu\text{Ci}/\text{m}^2$	Same as above	--	--	
	Beta-Gamma Emitters	4 mrad/hr @1 cm (with not more than 7 mg/cm ² of absorber)	Same as above	--	--	
40 CFR 190, "Environmental Protection Standards for Nuclear Power Operations" (40 CFR 190 1980)	All	--	An annual dose limit to any member of the public from planned releases	≤25 mrem/yr - whole body ≤75 mrem/yr - thyroid ≤25 mrem/yr - other organs	--	This standard sets the maximum allowable doses to members of the public, and maximum release limits for ⁸⁵ Kr, ¹²⁹ I, and ²³⁹ Pu (and transuranics with half-lives greater than 1 year). Note: Uranium mine operations are not covered by this standard.
	⁸⁵ Kr	--	Release of ≤50,000 Ci/GWe yr			
	¹²⁹ I	--	Release of ≤5 mCi/GWe yr			
	²³⁹ Pu + TRU	--	Release of ≤0.5 mCi/GWe yr			

(a) Dashes indicate that no information for this column is contained in the reference cited.

TABLE 2.01 Summary of Government Soil Contamination Standards

TABLE 2.01 (Continued)

Reference	Radionuclide	Soil Contamination Limit	Basis of Limit	Resulting Dose to Maximum Individual	Resulting Risk to Maximum Individual	Comments
40 CFR 192, "Environmental Protection Standards for Uranium Mill Tailings," Subpart-B (40 CFR 192 1980)	Ra-226	5 pCi/g average concentration in 5 cm thickness within one foot of surface	--	--	--	
		5 pCi/g average concentration in 15 cm thickness below one foot	--	--	--	
		Same as above	Cost-benefit trade off	<80 mrad/yr γ dose 100% of occupancy	--	These limits will result in radon and gamma levels within the variation that occurs in undisturbed land areas
• EPA 520/4-80-611, Draft Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites (40 CFR 192) (EPA 1980)			Instrumentation Limitation	Same as above	--	
• Federal Register, Vol. 45, No. 79, "Proposal Cleanup Standards for Inactive Uranium Processing Sites; Invitation for Comment" (Federal Register 1980)		Same as above	Same as above	Same as above	--	
EPA 520/4-77-016, Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment. (EPA 1977)	Transuranics	Annual α dose rate: 1 mrad/yr to pulmonary lung 3 mrad/yr to bone	Added risk from exposure to transuranic elements to be small. Implementation to be feasible in terms of economic impacts.	<1 mrad/yr to pulmonary lung <3 mrad/yr to bone	<1 chance per 10 ⁶ per year and <10 chances per 10 ⁵ in a lifetime that an individual would develop a cancer from continuous exposure	EPA suggests a soil contamination level of 0.2 μ Ci/m ² for top 1 cm of soil for particle sizes under 2 mm is reasonable "screening level."
AEC Regulatory Guide 1.86 Termination of Operating for Nuclear Reactors (U.S. AEC 1974)	U-Natural, ²³⁵ U, ²³⁸ U, and Decay Products	Removable: 1000 dpm/100 cm ²	Acceptable methods and procedures for termination of operating licenses	--	--	Prior to unrestricted release of decommissioned property, the results of a comprehensive radiation survey shall not exceed the values summarized here.
	Transuranics, ²²⁶ Ra, ²²⁸ Ra, ²²⁸ Ac, ²³⁰ Th, ²³¹ Pa, ²²⁷ Ac, ¹²⁵ I, ¹²⁹ I	Removable: 20 dpm/100 cm ²	Same as above			
	Th-natural, ²³² Th, ⁹⁰ Sr, ²²³ Rn, ²²⁴ Ra, ²³² U, ¹²⁶ I, ¹³¹ I, ¹³³ I	Removable: 200 dpm/100 cm ²	Same as above			
	Other β - γ emitters 1000 dpm/100 cm ²	Removable: 1000 dpm β - γ /100 cm ²	Same as above			
Rules and Regulations Pertaining to Radiation Control, Subpart RH 4.21, "Permissible Levels of Radioactive Material in Uncontrolled Areas," 4.21.1 Plutonium, State of Colorado 1973 (Hayden 1980)	Plutonium 2.0 dpm/g dry soil or 0.01 mCi/m ²	Levels above limit requires special techniques of construction on such soil				
Standards used to cleanup Eniwetok Atoll (Barnes 1978)	Transuranics <160 pCi/g (Cond. A) <80 pCi/g (Cond. B) <40 pCi/g (Cond. C) <160 pCi/g (Cond. D)	Surface concentration averaged over: 21 m diameter circle (Condition A) a half hectare (Condition B) a quarter hectare (Condition C) Averaged over 21m circle, (Condition D) 5cm in depth				Surface concentration defined as apparent concentration, on surface as viewed by IMP detector (approximately 3 cm depth). Condition A applied to every island, Condition D to all known and suspected burial sites.

(a) Dashes indicate that no information for this column is contained in the reference cited.

TABLE 2.01 (Continued)

In support of regulations, an extensive data base on decommissioning various nuclear fuel cycle facilities is being developed in a series of studies conducted by Battelle, Pacific Northwest Laboratory. These studies generically address the technology, safety, and costs of decommissioning by alternative methods.

During decommissioning, radioactive or radioactively contaminated materials need to be removed from the facility or site so that the residual levels are low enough to permit unrestricted use. As part of its reevaluation of decommissioning policy, the NRC has addressed the problem of establishing acceptable levels of residual contamination. The information contained in the Federal Register notice of proposed regulatory change reflects the most current recommendations of the NRC (Federal Register 1981). It states that because of the variety of facilities and radioactive materials involved, a single dose limit is difficult to establish. Hence, the basis of their recommendations is that the doses from residual radionuclides are to be maintained as low as reasonably achievable (ALARA) within a practical maximum annual whole-body dose equivalent range. The NRC stresses that a range of values less than 10 mrem per year whole-body equivalent gives the needed flexibility for adequate cost and benefit effectiveness analysis. For special situations, a case-by-case analysis, including radiation dose pathway modeling, will determine the exact acceptable dose limit. For implementation, the dose limit must be converted to a contaminated material concentration that can be related to instrument measurability. In a support document, the NRC has published a methodology for calculating residual radioactivity levels following decommissioning (Eckerman and Young 1980). Also, Battelle, Pacific Northwest Laboratory has outlined a similar methodology based on calculating maximum annual dose (Oak et al. 1980).

The proposed NRC acceptable residual contamination level regulations are designed to modify 10 CFR Parts 30, 40, 50, 70 and 72. The recommended major provisions of the decommissioning criteria are summarized in Table 2.0-1. These recommendations have evolved from the secondary publications shown in Table 2.0-1.

In addition, the NRC funded a review and analysis of current regulations regarding decommissioning (Schilling et al 1979). This study is included in Table 2.0-1; however, it does not recommend soil contamination guidance.

2.2 10 CFR Part 140 "Financial Protection Requirements and Indemnity Agreements, Subpart E Extraordinary Nuclear Occurrences, Paragraph 84, Criterion I - Substantial Discharge of Radioactive Material or Substantial Radiation Levels Offsite"

The U.S. Nuclear Regulatory Commission (NRC) has issued a set of criteria for determining when a substantial release of radioactive materials or radiation has occurred from an extraordinary nuclear occurrence. These criteria were established for purposes of financial protection and indemnity settlements (10 CFR 140.84 1980). Criterion I gives guidelines for offsite surface contamination levels, and as its basis, it states that a substantial discharge has occurred when 100 m² of offsite property are contaminated to the levels shown in Table 2.0-1. The levels are listed for two types of offsite property: property that is contiguous to a site owned or leased by a person with whom an indemnity agreement is executed, and all other offsite property. Included in the category of other offsite property is property contaminated as a result of radioactive materials transportation. The levels shown in Table 2.0-1 for 10 CFR 140 are assumed to be the maximum levels above background that are observed or projected 8 hours or more after the initial deposition.

2.3 40 CFR Part 190 "Environmental Radiation Protection Standards for Nuclear Power Operations"

The U.S. Environmental Protection Agency (EPA) issued 40 CFR Part 190 to regulate radiation doses received by members of the public resulting from radiation or radioactive materials introduced into the environment during the operation of nuclear fuel cycle facilities (40 CFR 190 1980). A summary of the provisions of 40 CFR Part 190 is shown in Table 2.0-1. This regulation is based on limiting radiation doses to 25 mrem per year to whole body, 75 mrem per year to thyroid, and 25 mrem per year to any other organ of any member of the public. It also limits maximum quantities

released of specific radionuclides of concern in the uranium fuel cycle. These radionuclides and maximum quantities include: 50,000 Ci of ^{85}Kr , 5 mCi of ^{129}I , and 0.5 mCi of ^{239}Pu (and transuranic material) per gigawatt-year of electrical energy produced. The EPA also may grant a special variance to these standards based upon a determination that the variance is temporary, unusual operating conditions exist, and that continued operation of the facility is in the public interest. These standards could be used for estimating permissible soil standards for ^{129}I and ^{239}Pu through radiation dose pathway modeling analyses. For this study, however, we have not attempted to relate these dose limit standards to soil contamination levels since the relationship is highly site specific.

2.4 40 CFR 192 "Environmental Protection Standards for Uranium Mill Tailings, Subpart B"

The currently proposed standard for cleanup of open land contaminated with residual radioactive materials from inactive uranium processing sites is summarized in Table 2.0-1. It requires that remedial actions

"be conducted so as to provide reasonable assurance that a) the average concentration of radium-226 attributable to residual radioactive material from any designated processing site in any 5 cm thickness of soils or other materials on open land with 1 foot of the surface, or in any 15 cm thickness below 1 foot, shall not exceed 5 pCi/gm... c) The cumulative lifetime radiation dose equivalent to any organ of the body of a maximally exposed individual resulting from the presence of residual radioactive materials or byproduct materials shall not exceed the maximum dose equivalent which could occur from radium-226 and its decay products under paragraphs (a) and (b) of this section."

(40 CFR 192 1980).

The subject of paragraph (b) is acceptable levels of radioactivity in buildings. Four exceptions to the interim standard are given:

(a) Public health or safety would be unavoidably endangered in attempting to meet the requirements.

(b) The goal of environmental protection would be better served by not satisfying cleanup requirements for open land.

(c) The estimated costs of remedial actions to comply with the cleanup requirements are unreasonably high relative to benefits.

(d) There is no known remedial action to meet the requirements.

The purpose of the cleanup standard is to protect public health and the environment. Data from studies of underground miners and from groups exposed to gamma rays is used with a linear, nonthreshold dose-effect model in deriving estimates of risk to the general public. In arriving at the proposed standards, EPA considered such things as risk, costs, administrative difficulties, benefits and applicability to all inactive mill sites. "The proposed cleanup standard is EPA's judgment of the most stringent uniform cleanup condition that may reasonably be required for all the inactive mill sites." (40 CFR 192 1980)

The proposed standard is set at 5 pCi/gm for a 5 cm thickness within one foot of the surface in order to keep sampling costs within reason and to avoid having to clean large areas which contain little radioactivity. For contaminated material located more than 1 foot beneath the surface, the proposed standard of 5 pCi/gm for a 15 cm thickness is set due to measurement instrumentation limitations. EPA contends that the cost to implement the proposed cleanup standards is little more than the cost of one permitting residual contamination levels 2 to 4 times higher. Supporting information for the proposed cleanup standard is given in (Federal Register 1980), (EPA 1980) and (NRC 1980). Information such as implementation of the standard, potential health effects of radon and its decay products, and selection of the standards are included in the supporting documentation.

It must be remembered that these standards are currently just proposed standards, and that they have not been fully adopted. In testimony on June 24, 1981, before the Subcommittee on Procurement and Military Nuclear Systems, Committee on Armed Services, U.S. House of Representatives, the Honorable John Hernandez Deputy Administrator of the EPA said:

"Current EPA staff estimates are that revision and finalization of the cleanup and disposal standards for inactive sites will be accomplished by January 1983."

2.5 Proposed Guidance in Dose Limits for Persons Exposed to Transuranium Elements in the General Environment

The guidance proposed by the EPA to limit dose to the public exposed to transuranics (summarized in Table 2.0-1) is:

"1. The annual alpha radiation dose rate to members of the critical segment of the exposed population as the result of exposure to transuranium elements in the general environment should not exceed either:

- a. 1 millirad per year to the pulmonary lung, or
- b. 3 millirad per year to the bone.

2. For newly contaminated areas, control measures should be taken to minimize both residual levels and radiation exposures of the general public. The control measures are expected to result in levels well below those specified in paragraph one. Compliance with the guidance recommendations should be achieved within a reasonable period of time.

3. The recommendations are to be used only for guidance on possible remedial actions for the protection of the public health in instances of presently existing contamination or of possible future unplanned releases of transuranium elements. They are not to be used by Federal agencies as limits for planned releases of transuranium elements into the general environment." (EPA 1977)

The EPA identifies a soil contamination level of $0.2 \mu\text{Ci}/\text{m}^2$ for particle sizes under 2 mm collected in surface samples to a depth of 1 cm as a soil contamination level that can be reasonably predicted to result in dose rates less than the guidance recommendations.

The purpose of the proposed guidance is to establish maximum dose rates to the public that might receive radiation exposure to transuranics in the environment, which considers all possible pathways to humans and which the EPA judges to be protective of the public health. The primary criteria used in determining the guidance recommendations are: the added risk to an individual from exposure to transuranics be very small, and implementation of the guidance be feasible in terms of overall economic impacts. Information is given in the EPA report on implementation of the proposed guidance and on the environmental measurements to demonstrate compliance with them (1977).

2.6 U.S. AEC Regulatory Guide 1.86, "Termination of Operating Licenses for Nuclear Reactors"

The U.S. Atomic Energy Commission (AEC) issued Regulatory Guide 1.86 in support of 10 CFR 50.82 "Applications for Termination of Licenses" (U.S. AEC 1974; 10 CFR 5.82 1980). This guide contains descriptions of acceptable alternative methods for the termination of operating licenses for nuclear reactors. The guide also states that the licensee should make "a reasonable effort" to eliminate residual contamination in the facility. A comprehensive radiation survey is required of the premises prior to release for unrestricted use, and methods of determining residual contamination inside piping or equipment are briefly discussed. Limits for acceptable surface contamination levels are also given. A summary of these limits is shown in Table 2.0-1, and the exact limits are shown in Table 2.6-1. While these are not specifically for soil contamination, they could be applied to soil contamination for the termination of site licenses by using the removable contamination limits shown. The purpose of the limits shown in Table 2.6-1 is to define unrestricted release limits for decommissioned property and materials. These limits are based on levels that the NRC feels should prevent risk to the public health and safety.

TABLE 2.6-1 Regulatory Guide 1.86 Acceptable Surface Contamination Levels

Nuclide ^(a)	Average ^(b,c)	Maximum ^(b,d)	Removable ^(b,e)
U-nat, ²³⁵ U, ²³⁸ U and associated decay products	5,000 dpm α/100 cm ²	15,000 dpm α/100 cm ²	1,000 dpm α/100 cm ²
Transuranics, ²²⁶ Ra, ²²⁸ Ra, ²³⁰ Th, ²²⁸ Th, ²³¹ Pa, ²²⁷ Ac, ¹²⁵ I, ¹²⁹ I	100 dpm/100 cm ²	300 dpm/100 cm ²	20 dpm/100 cm ²
Th-nat, ²³² Th, ⁹⁰ Sr, ²²³ Ra, ²²⁴ Ra, ²³² U, ¹²⁶ I, ¹³¹ I, ¹³³ I	1000 dpm/100 cm ²	3000 dpm/100 cm ²	200 dpm/100 cm ²
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except ⁹⁰ Sr and others noted above	5000 dpm βγ/100 cm ²	15,000 dpm βγ/100 cm ²	1000 dpm βγ/100 cm ²

- (a) Where surface contamination by both alpha and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.
- (b) As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.
- (c) Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.
- (d) The maximum contamination level applies to an area of not more than 100 cm².
- (e) The amount of removable radioactive material per 100 cm² of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

3.0 REVIEW OF GUIDANCE ON SOIL CONTAMINATION LIMITS FROM OTHER SOURCES

Several studies have been made by sources independent of Federal agencies on acceptable levels of residual contamination in soil. A summary of the recommended soil contamination limits from these sources is given in Table 3.0-1. Also included in this table, when available, is the basis for each recommended limit, the resulting dose to the maximum individual and the resulting risk to the maximum individual. None of these recommendations have been adopted totally by a Federal or state agency. Discussions of the soil limits shown in Table 3.0-1 are given in the following sections. We have summarized the major points from each reference without attempting to develop relationships between the different limits and units presented.

3.1 Soil Decontamination Criteria Report, November 1980

This report (Hayden et al. 1980) reviews current soil contamination criteria and guidelines for transuranics and recommends goals and procedures for a soil decontamination process at DOE sites. The recommended guidelines, given in Table 3.0-1, use ^{239}Pu as the nuclide of concern because it is considered the most abundant transuranic radionuclide in the environment.

These authors propose a screening level of 30 dpm/g (derived from the EPA [1977] screening level of $0.2 \mu\text{Ci}/\text{m}^2$ and a soil density of $1.5 \text{ g}/\text{cm}^3$). Use of these authors' recommended levels will require land use monitoring so that the EPA dose rates are not exceeded.

Annual updates of soil decontamination criteria, goals, processes, and instrumentation will be provided throughout the Rocky Flats program.

3.2 Pathways and Cost-Risk-Benefit Analysis for INEL Contaminated Soil Areas Being Evaluated for Contamination and Decommissioning

Chapin (1980) prepared this report in support of efforts to decommission radioactively contaminated portions of the Idaho National Engineering Laboratory (INEL) site. The methods described are designed to help

TABLE 3.01 Summary of Soil Contamination Guidance from Other Sources

Reference	Radionuclide	Soil Contamination Limit	Basis of Limit	Resulting Annual Dose to Maximum Individual	Resulting Risk to Maximum Individual	Comments																				
RFP-3162, Soil Decontamination Criteria Report November 1980 (Hayden et al. 1980)	²³⁹ Pu	<30 dpm/g for unrestricted use, surface or sub-surface	Reference Sources (EPA 1977)	--(a)	--	Land use must be consistent with EPA dose guidance																				
		30 to 500 dpm/g for particles <100 μm, subsurface	(Healy 1974)	--	--																					
		30 to 1000 dpm/g for particles ≥100 μm, subsurface	(Healy 1974)	--	--																					
EGG-2041, Pathways and Cost-Risk-Benefit Analyses for INEL Radioactively Contaminated Soil Areas Being Evaluated for Decontamination and Decommissioning (Chapin 1980)	All	Soil concentrations resulting in exposures of 5 mrem/yr	Calculated based on realistic radiation exposure pathways defined for each decommissioning alternative	≤5 mrem/yr	--	Based on the preliminary NRC dose limit of 5 mrem/yr as discussed by Conti (1979).																				
RHO-CD-782, Surface Soil Contamination Standards (Booth 1979)	See Table 3.3-1	Range from 60 pCi/g to 30,000 pCi/g for average soil contamination; 10 pCi/cm ² to 4800 pCi/cm ² for areal contamination; 150 pCi to 70,000 pCi for spot activity	10% of MPBB, DOE MPC	--	--	Applicable only to 200 Areas of Hanford Reservation. For mixtures of radionuclides, the limit for the sum of the fractional limits is one. External radiation standard to be applied simultaneously with contamination limits																				
	³ H	50 μR/hr	500 mrem/yr	≤500 mrem/yr	--																					
79-UR-79-1865-Rev, Interim Soil Limits for D&D Projects (Healy, Rodgers, and Wienke 1979)	²³¹ Pa through ¹³⁷ Cs	Range from 50 pCi/g to 7x10 ⁶ pCi/g	0.5 rem/yr to maximum exposed organ	0.5 rem/yr to maximum exposed organ	--	Soil contamination limits based on mass loading air concentrations for inhalation of 200 μg/m ³ . Radionuclide concentrations in the daily diet are used as the basis of ingestion dose calculations.																				
La-7391-MS, A Preliminary Study of Radium-Contaminated Soils (Healy and Rodgers 1978)	²²⁶ Ra	Range from 3 pCi/g to limit Rn in home to 11 pCi/g for external dose to 7000 pCi/g for radium resuspension	0.01 WL 0.17 rem/yr critical group avg 0.01 μCi-bone	--	--	Most limiting pathway is emanation of radon into buildings; limiting values are comparable to those found naturally in many areas. See Table 3.5-1 for listing of recommended levels.																				
N13.12 Draft National Standard Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use (ANSI 1978)	Group 1	Radionuclides whose nonoccupational MPC _a is ≤2x10 ⁻¹³ Ci/m ³ or MPC _w is ≤2x10 ⁻⁷ Ci/m ³ ; removable 20 dpm/100 cm ²	No person should be exposed to a dose or hazard greater than currently exists from world-wide fallout.	Dose proportional to average dose from fallout from weapons testing.	Proportional to health risk from fallout.	Ingestion and inhalation relationships are established for ⁹⁰ Sr and ²³⁹ Pu based on minimum hazards determined from ratios of MPC _a and MPC _w . ANSI N13.12 specifically states that the problem of contaminated soils is beyond the scope of the proposed standard; however, the removable contamination limits are included in this table for an overall comparison.																				
	Group 2	Radionuclides not in Group 1 whose nonoccupational MPC _a is ≤1x10 ⁻¹² Ci/m ³ and whose MPC _w is ≤1x10 ⁻⁶ Ci/m ³ ; removable 200 dpm/100 cm ²																								
	Group 3	Those radionuclides not in Groups 1 or 2; removable 1000 dpm/100 cm ²																								
CONF-760202-3, Guidelines for Cleanup of Uranium Tailings from Inactive Mills (Goldsmith, Haywood, and Jacobs 1976)	²²⁶ Ra	0.5 pCi/g	Limit ²²² Rn concentration to 10% of ICRP MPC	--	--	Practicality of achieving limit was not considered.																				
	Each parent of ²²⁶ Ra	0.5 pCi/g		--	--																					
LA-5483-MS, A Proposed Standard for Plutonium in Soils (Healy 1974)	Plutonium	<table><tr><td>dpm per g</td><td>μCi/g</td><td>μCi/m²</td><td></td></tr><tr><td>500</td><td>2x10⁻⁴</td><td>0.4</td><td>Top 0.1 cm (1)</td></tr><tr><td>500</td><td>2x10⁻⁴</td><td>4</td><td>Any 1 cm layer</td></tr><tr><td>1000</td><td>4x10⁻⁴</td><td>0.8</td><td>Top 0.1 cm</td></tr><tr><td>1000</td><td>4x10⁻⁴</td><td>8</td><td>Any 1 cm layer</td></tr></table>	dpm per g	μCi/g	μCi/m ²		500	2x10 ⁻⁴	0.4	Top 0.1 cm (1)	500	2x10 ⁻⁴	4	Any 1 cm layer	1000	4x10 ⁻⁴	0.8	Top 0.1 cm	1000	4x10 ⁻⁴	8	Any 1 cm layer	Deposition in body of individual of 0.004 μCi, 1/3 of this value for suitable sample of population	≤1.5 to 3 rems/yr to mineral bore ≤1.5 rem/yr to lung	--	(1) For bare soil and sparsely vegetated areas. A 0.5 cm layer can be used where area is reasonably well vegetated and a reasonable root mat exists. (2) Where fraction of particle size less than 100 μm do not exceed limits given. If not known, use <100 μm limit for total.
dpm per g	μCi/g	μCi/m ²																								
500	2x10 ⁻⁴	0.4	Top 0.1 cm (1)																							
500	2x10 ⁻⁴	4	Any 1 cm layer																							
1000	4x10 ⁻⁴	0.8	Top 0.1 cm																							
1000	4x10 ⁻⁴	8	Any 1 cm layer																							
BNWL-SA-1510, Towards Interim Acceptable Surface Contamination Levels for Environmental PuO ₂ (Kathern 1968)	²³⁹ PuO ₂	Avg: 10 ³ dpm/100 cm ² , 0.04 μCi/m ² , 0.7 μg/m ²	1.5 rem/yr to lung	≤1.5 rem/yr to lung	--																					
		Max: 10 ⁴ dpm/100 cm ² , ≤10% of total area																								
		Avg: 10 ⁴ dpm/100 cm ² , 0.4 μCi/m ²																								
		Avg: 10 ⁵ dpm/100 cm ² , 4 μCi/m ²																								
		Avg: 10 ⁶ dpm/100 cm ² , 4 μCi/m ²																								

(a) Dashes indicate that no information for this column is contained in the reference cited.

TABLE 3.0-1 Summary of Soil Contamination Guidance from Other Sources

determine a cost-risk-benefit list of priorities for decontamination of soil areas. Acceptable dose to man for unrestricted use of the site is the basis for this study. The assumed dose limit is 5 mrem/yr, the limit described by the U.S. Nuclear Regulatory Commission (Conti 1979) as shown in Table 3.0-1. The report defines exposure pathways to man for four major decommissioning alternatives and dose calculations are used to determine compliance with the assumed 5 mrem/yr limit. These methods are actively being applied to evaluate contaminated areas of the INEL site. Chapin stressed that their evaluation is highly dependent upon local contamination characteristics, and that the results may change as further area characterization proceeds.

3.3 Surface Soil Contamination Standards

The surface soil contamination limits given by Boothe (1979) are derived specifically for the 200 Areas of the Hanford site. He assumes that access to these areas will always be restricted, and that restrictions in the use of the land will be maintained. Limits are derived for external radiation, average surface soil contamination, areal contamination and spot contamination. A summary of the limits is given in Table 3.0-1. Specific limits are given in Table 3.3-1.

The limits developed by Boothe are intended to give reasonable assurance that current population radiation protection standards are not exceeded. The surface soil contamination limits are based on the most restrictive of the following criteria to give reasonable assurance that:

"no individual in uncontaminated areas will receive in excess of 500 mrem per year from external radiation sources...

"no individual working or digging in uncontaminated areas will ingest radioactivity that would result in more than 1/10 the maximum permissible body burden...

"uncontaminated areas do not produce airborne concentrations of radioactive materials in excess of the limits specified in Department of Energy (DOE) MC 0524, Annex A, Table II...

TABLE 3.3-1. Surface Soil Contamination Limits (Booth 1979)

Isotope	Column I	Column II	Column III
	Avg. Soil Contamination Limits ¹ (pCi/g)	Areal Contamination Limits ² (pCi/cm ²)	Spot Activity Limits (pCi)
Americium-241	300	50	720
Antimony-125	1,000	160	2,400
Bismuth-207	600	100	1,400
Cadmium-109	2,000	320	4,800
Carbon-14	8,000	1,300	19,000
Cesium-137	400	60	960
Cobalt-60	300	50	720
Europium-152	800	130	1,900
Europium-154	200	30	480
Europium-155	200	30	480
Hydrogen-3	30,000	4,800	70,000
Iodine-129	2,000	320	4,800
Iron-55	20,000	3,200	48,000
Nickel-63	7,000	1,100	16,000
Plutonium-238	60	10	150
Plutonium-239	60	10	150
Plutonium-240	60	10	150
Promethium-147	2,000	320	4,800
Sodium-22	300	50	720
Strontium-90	400	60	960
Technetium-99	2,000	320	4,800

TABLE 3.3-I Surface Soil Contamination Limits (Booth 1979) - Continued

Isotope	Column I Avg. Soil Contamination Limits ¹ (pCi/g)	Column II Areal Contamination Limits ² (pCi/cm ²)	Column III Spot Activity Limits (pCi)
Thallium-204	600	100	1,400
Thorium-232	60	10	150
Uranium-234	250	40	600
Uranium-238	300	50	750
Yttrium-90	200	30	480
Other β - γ Emitters	10 times the maximum permissible concentration specified in DOE MC 0524 Annex A, Table II (Water-insoluble), where one ml of water is equivalent to one gram of solid material.	0.16(g/cm ²) times the limit specified in Column I of this Table A.	15(cm ²) times the limit specified in Column II of this Table A.
Other α Emitters	6.25 x 10 ⁷ times the maximum permissible concentration specified in DOE MC 0524 Annex A, Table II (Air-insoluble).	0.16(g/cm ²) times the limit specified in Column I of this Table A.	15 (cm ²) times the limit specified in Column II of this Table A.

¹ A suitable mass over which contamination may be averaged must be representative of the contamination (e.g., a 1 kg composite).

² A suitable area over which contamination may be averaged shall be 15 cm².

"uncontaminated areas would not result in water contamination in excess of the limits specified in DOE MC 0524, Annex A, Table III." (Boothe 1979)

Uncontaminated areas refers to land area which is not restricted for radiation protection purposes. The external radiation standard of 50 $\mu\text{R/hr}$ above background must be used simultaneously with the limits given in Table 3.3-1 to assure compliance with the first criterion. The sum of the fractional limits for mixtures of radionuclides is not to exceed one. A resuspension factor of $10^{-8}/\text{cm}$ is used and radionuclides are assumed to be insoluble. Areal and spot limits are based on the average surface soil limit.

3.4 Interim Soil Limits for D&D Projects

Healy, Rodgers, and Wienke (1978) prepared this report to serve as numerical guidance in the cleanup of former AEC radioactive materials processing sites. Soils at these sites contain residual radionuclides ranging from ^{232}Th and natural uranium to plutonium, americium, ^{90}Sr ^{137}Cs . As a basis for their numerical guidance, Healy, Rodgers and Wienke selected an annual dose limit of 0.5 rem to the critical organ of the maximally exposed individual by inhalation, ingestion, or direct exposure. The 0.5 rem/yr dose limit is also consistent with other Federal radiation exposure guidance. Because of the lack of ecological and metabolic data for many of the radionuclides of concern, conservative values are used for the radiation dose model parameters for inhalation and ingestion exposure pathways. This is done to assure that cleanup to the resulting concentrations will meet the requirements of existing and future Federal standards. The derived soil concentrations are summarized in Tables 3.0-1 and 3.4-1.

For inhalation, Class Y and/or Class W parameters are used in the ICRP Task Group on Lung Dynamics model to calculate radiation doses. Limiting air concentrations are calculated based on the annual dose limit of 0.5 rem. The soil contamination levels that result in these air concentrations are found using a conservative mass loading factor of $200 \mu\text{g}/\text{m}^3$ of soil in

TABLE 3.4-1 Summary of Soil Contamination Limits from
Healy, Rodgers, and Weinke (1978)

Radionuclide	Limiting Air Concentrations (pCi/m ³)	Inhalation Soil Limits (pCi/g)	Limiting Daily Ingestion Intakes (pCi/day)	Ingestion Soil Limits		External Radiation Soil Limits (pCi/g)	Recommended ^(a) Limits (pCi/g)
				Partial Diet (pCi/g)	Total Diet (pCi/g)		
²³¹ Pa	0.1	50	100	760	150	250	40
²²⁷ Ac	0.04	200	6.6	50	10	300	30
²³² Th	0.009	45	90	680	140	40	20
²²⁸ Th	0.2	1,000	5,000	38,000	7,700	55	30
²³⁸ U- ²³⁴ U	0.15	750	-- ^(b)	50	8	6,000	50
²³⁸ U+daughters	0.01	50	10	--	--	--	--
²³⁰ Th	0.06	300	600	4,500	930	36,000	200
⁹⁰ Sr	380	2x10 ⁶	--	100	19	--	100
¹³⁷ Cs	1,350	7x10 ⁶	--	800	1	50	50

(a) The recommended limits for soil account for individual exposures for all pathways. This is done by taking the reciprocal of the sum of the reciprocals of the values from individual exposure pathways.

(b) Dashes indicate that no values were reported.

the air breathed by the maximum exposed individual. A summary of the resulting soil concentrations for inhalation is shown in Table 3.4-1.

Ingested radionuclides are assumed to be primarily those contained in food produced from the contaminated soil. Limiting daily ingestion intakes that result in 0.5 rem/yr are calculated for the radionuclide of concern. Soil contamination limits for ingestion are estimated for both a case where a partial diet comes from the crops grown in the contaminated soil, and a case where the total diet comes from crops grown in the contaminated soil. The resulting soil contamination limits are summarized in Table 3.4-1.

Direct external exposure can be an important exposure pathway for people in close contact with soil, especially when beta-gamma emitters are present. Doses are estimated assuming a uniform soil distribution of radionuclides, and assuming a 100% occupancy of the area. The resulting soil limits for external radiation are shown in Table 3.4-1.

Healy, Rodgers, and Wienke (1978) further combined the results for these exposure pathways to arrive at the recommended soil contamination limits shown in Table 3.4-1. This is done by taking the reciprocal of the sum of the reciprocals of the values from the individual exposure pathways. The authors note that the limits for natural uranium are limited by ^{222}Rn resulting from ^{226}Ra . Compliance with the soil limits should be determined by averaging concentration levels over a reasonable area of about 100 m². The limits are also based on concentrations in surface soils that contribute to plant uptake or that can be distributed by man. For deeply buried contamination, consideration of the probability of the contamination reaching man is recommended.

3.5 A Preliminary Study of Radium-Contaminated Soils

"A preliminary study was made of the potential radiation exposures to people from radium contamination in the soil in order to provide guidance on limits to be applied in decontaminating land. Pathways included were inhalation of radium from resuspension; ingestion of radium with foods; external gamma radiation from radium daughters; inhalation of radon and

daughters, both in the open air and in houses; and the intake of ^{210}Pb and ^{210}Po from both inhalation and ingestion. The depth of the contaminated layer is of importance for external exposure and especially for radon emanation. The most limiting pathway was found to be emanation of the radon into buildings with limiting values comparable to those found naturally in many areas." (Healy and Rodgers 1978)

Radiation exposures from an area contaminated with radium depends on site-specific factors such as: (1) size of the area, which determines potential resuspension and occupancy; (2) distribution of radium in the soil profile, which affects possible resuspension, access to plant roots and degree of radon emanation to the atmosphere; and (3) character of the soil, in particular its looseness or compactness and ion absorption characteristics which influence radon emanation rate and plant uptake of radium. The authors found that inhalation of radium or intake through food is of little importance compared to the external radiation field. The importance of the daughters depends very strongly on the size of the contaminated area for outdoor conditions. When there is the possibility of a building being constructed on the area, the potential for radon emanation into the building becomes the limiting pathway. A summary of the soil limits derived by Healy and Rodgers are given in Tables 3.0-1 and 3.5-1. Limiting values based on external dose and Rn emanation into a home are given in Tables 3.5-2 and 3.5-3, respectively.

Criteria used by Healy and Rodgers in deriving their recommended limits are given in Table 3.5-1. The 0.01 WL criteria that they recommend is lower than the upper values of 0.05 WL adopted by the Surgeon General. However, Healy and Rodgers felt the lower limit justifiable because the action required, where no building exist, is considerably less than anticipated in the establishment of the Surgeon General's guidelines.

The criteria used for bone is based on 10% of the occupational limit derived by an advisor committee to the National Bureau of Standards in 1941. The NCRP whole body limit of 0.5 rems per year for the individual organ and an RBE of 10 for alpha particles is the basis used as the

TABLE 3.5-1. Summary of Radium Limits for Infinite Depth of Contamination and a Sandy Soil (Healy and Rodgers 1978)

Condition	Criteria Used	Derived Level (pCi/g Radium)
Radium Resuspension	0.01 μCi - bone 0.5 rem/y - lung	7,000 2,000
Radium in Foods	0.01 μCi - bone	
Home Gardener		300 - 700
All Foods		80
External Dose	0.17 rem/y	11 ^a
Rn Downwind	0.01 WL	
Small Area (35,000 m ²)		490
Large Area (6.6 x 10 ⁷ m ²)		5
Rn in Home	0.01 WL	3 ^b
²¹⁰ Pb - ²¹⁰ Po Downwind	0.5 rem/yr - kidney	
Small Area (35,000 m ²)		
Inhalation		300,000
Food - Home Gardens		120,000
Food - All		13,000
Large Area		
Inhalation		2,300
Food - Home		840
Food - All		90

^aSee Table 3.5-2 for depth profile.

^bSee Table 3.5-3 for depth profile.

TABLE 3.5-2. Limiting Values for ^{226}Ra in Soils as Based Upon External Dose (Healy and Rodgers 1978)

Thickness of Contaminated Layer (cm)	Ra Conc. (pCi/g)
10	21
20	16
40	13
∞	11

TABLE 3.5-3. Permissible Radium Levels in Soils to Limit Rn Daughters in Home (Healy and Rodgers 1978)

Depth of Contaminated Soils (cm)	Soil Type	
	Sand (pCi/g)	Loam (pCi/g)
1	150	150
10	15	15
100	2	3
1000	1	2.7

criteria for other organs. The limit of 0.17 rem per year for critical group average is based on the NCRP value for the radiation level above a uniform, infinitely deep radium-containing area.

3.6 ANSI, N13.12 Draft American National Standard, "Control of Radioactive Surface Contamination on Materials, Equipment and Facilities to be Released for Uncontrolled Use"

The American National Standards Institute, Inc. (ANSI) provided standard N13.12 as decontamination criteria for control of materials, equipment, and facilities that are released for uncontrolled use by the public (ANSI 1978). It specifically states that the problem of contaminated soils is beyond the scope of the proposed standard; however, a summary of the limits provided are included in Table 3.0-1 so that an overall comparison of its basis and limit values can be made. This standard is arbitrarily based on a comparison with the levels of ^{90}Sr found in the environment as a result of fallout from weapons testing. A scale of relative hazard is derived to divide the radionuclides into three groups. The first group is for radionuclides whose nonoccupational MPC_a is less than $2 \times 10^{-13} \text{ Ci/m}^3$. The second group is for radionuclides not in group 1, whose nonoccupational MPC_a is less than $1 \times 10^{-12} \text{ Ci/m}^3$ and whose nonoccupational MPC_w is less than $1 \times 10^{-6} \text{ Ci/m}^3$. The third group contains all radionuclides that are not in groups 1 or 2.

The surface contamination limits given in this ANSI Standard are shown in Tables 3.6-1 and 3.6-2. In both tables, the first entry indicates "nondetectable" total activity (i.e., fixed plus removable). This is inconsistent with the recommended removable contamination level of 20 dpm/100 cm^2 . (Perhaps the "nondetectable" refers to beta-gamma only and the alpha limit is missing.) Limits in the table are listed in units of dpm while the detection capabilities given in the footnotes have units of pCi and nCi. The "indirect survey" methods mentioned in the footnotes for use in areas of high background are never defined in the tables. Because of these difficulties, and since this standard is not recommended for soil contamination, information for this standard is included for comparison

TABLE 3.6-1 Surface Contamination Limits (ANSI 1978)

Radionuclide (a)	Activity Limit (dpm/100 cm ²)	
	Total	Removable
<u>Group 1:</u>		
Nuclides for which the nonoccupational MPC _a (b) is 2 x 10 ⁻¹³ Ci/m ³ or less or for which the nonoccupational MPC _w (c) is 2 x 10 ⁻⁷ Ci/m ³ or less; includes Ac-227; Am-241, -242m, -243; Cf-249, -250, -251, -252; Cm-243, -244, -245, -246, -247, -248; I-125, I-129; Np-237; Pa-231; Pb-210; Pu-238, -239, -240, -242, -244; Ra-226, -228; Th-228, -230.	Nondetectable (d)	20
<u>Group 2:</u>		
Those nuclides not in Group 1 for which the nonoccupational MPC _a is 1 x 10 ⁻¹² Ci/m ³ or for which the nonoccupational MPC _w is 1 x 10 ⁻⁶ Ci/m ³ or less; includes Es-254; Fm-256; I-126, -131, -133; Po-210; Ra-223; Sr-90; Th-232; U-232.	Nondetectable (B,Y) (e) 2 000 (a)	200
<u>Group 3:</u>		
Those nuclides not in Group 1 or Group 2.	5 000	1 000

(a) Values presented here are obtained from 10 CFR Part 20. The most limiting of all given MPC values (e.g., soluble vs. insoluble) are to be used. In the event of the occurrence of mixtures of radionuclides, the fraction contributed by each constituent of its own limit shall be determined and the sum of the fractions must be less than 1.

(b) MPC_a: maximum permissible concentration in air applicable to continuous exposure of members of the public as published by or derived from an authoritative source such as NCRP, ICRP or NRC (10 CFR Part 20 Appendix B Table 2, Column 1).

(c) MPC_w: maximum permissible concentration in water applicable to members of the public.

(d) The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of any Group-1 contaminants uniformly spread over 100 cm².

(e) The instrument utilized for this measurement shall be calibrated to measure at least 1 nCi of any Group-2 beta or gamma contaminants uniformly spread over an area equivalent to the sensitive area of the detector. NOTE: Direct survey for unconditional release should be performed in areas where the background is <100 c/m. When the survey must be performed in a background exceeding 100 c/m, it may be necessary to use the indirect survey method to provide the additional sensitivity required.

TABLE 3.6-2 Alternate Surface Contamination Limits^(a) (ANSI 1979)

Contamination Contingencies	Activity Limit dpm/100 cm ²	
	Total	Removable
Unidentified Contaminant	Nondetectable ^(b)	20
<ul style="list-style-type: none"> • Alpha emitters other than U_{nat} and its decay products and Th_{nat} are present • Beta emitters comprise ²²⁷Ac or ²²⁸Ra 		
Alpha emitters are U _{nat} and its decay products and Th _{nat}	2,000a	200
<ul style="list-style-type: none"> • Beta emitters while unidentified do not include ²²⁷Ac, ¹²⁵I, ²²⁶Ra and ²²⁸Ra 	Nondetectable ^(c)	
Alpha emitters are U _{nat} and its decay products or Th _{nat} and its decay products	5,000	1,000
<ul style="list-style-type: none"> • Beta emitters do not include ²²⁷Ac, ¹²⁵I, ¹²⁹I, ⁹⁰Sr, ²²³Ra, ²²⁸Ra, ¹²⁶I, ¹³¹I, and ¹³³I 		

(a) Levels may be averaged over 1 m² provided that the maximum activity in any 100 cm² area is less than three times the limit shown.

(b) The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of any Group 1 contaminants uniformly spread over 100 cm².

(c) The instrument utilized for this measurement shall be calibrated to measure at least 1 n Ci of any Group 2 beta or gamma contaminant spread uniformly over one detector area. Background should be ≤ 100 counts per minute, or indirect survey methods should be used.

purposes only. The standard can not, and should not, be used directly for soil contamination situations.

3.7 Guidelines for Cleanup of Uranium Tailings from Inactive Mills

Goldsmith, Haywood and Jacobs (1976) derived a guideline of 0.5 pCi/g ^{226}Ra above background as an acceptable level of residual contamination which would allow unrestricted access to an area which once contained uranium tailings. Each ^{226}Ra parent should also be restricted to a residual activity level of 0.5 pCi/g to avoid future problems caused by ^{226}Ra ingrowth. The recommended guideline (summarized in Table 3.0-1) is based on the most restrictive pathway of exposure, ^{222}Rn diffusion. The exposure pathways considered are given in Table 3.7-1. A maximum permissible concentration of 1 pCi/l ^{222}Rn for individuals is the basis of the recommended guideline. The 1 pCi/l represents 10% of the ICRP MPC recommendation for nonoccupational exposure to ^{222}Rn . Also, a concentration of 1 pCi/l of ^{222}Rn in equilibrium with its daughters can be related to about 0.01 WL.

3.8 A Proposed Interim Standard for Plutonium in Soils

Information on potential sources of exposure to people living in an area where the soils are contaminated with plutonium is analyzed in this report (Healy 1974) to arrive at estimates of intake. Ingestion, skin absorption and inhalation are considered. A recommended interim standard for the upper limit of plutonium concentration in soils in inhabited areas is derived from these intake estimates. The recommendation is based upon conservative assumptions where information is lacking. Healy stressed that the numerical values derived in this report should be regarded as provisional and should not be incorporated into rules and regulations which are difficult to change. These recommendations are conservatively based with the intention of revision upward as warranted by additional information.

In the derivation of numerical guidance, primary consideration is given to the health hazard to populations. Standards, as recommended by the NCRP and ICRP, are used as a basis for the potential harm to humans from intake and deposition of plutonium. The upper limit for deposition in

TABLE 3.7-1 Principal Radionuclides Involved in Pathways
from Tailings Piles to Man (Goldsmith,
Haywood and Jacobs 1976)

Pathway	Radionuclides	Pathways	Principal Exposure
Radon Diffusion	^{222}Rn	1. Diffusion to pile surface 2. Atmospheric transport 3. Inhalation	Inhalation of ^{218}Po , ^{214}Pb ^{214}Bi , ^{214}Po
Airborne Activity	^{230}Th , ^{231}Pa	1. Resuspension from pile surface 2. Atmospheric transport 3. Inhalation 4. Body surface contamination	Inhalation of air- borne activity carried by respira- ble particles
Terrestrial	^{226}Ra , ^{210}Pb	1. Resuspension from pile surface 2. Atmospheric transport 3. Deposition on soil or foliage 4. Uptake by plants 5. Uptake by animals 6. Consumption of contaminated plants, meat and milk 7. Consumption of contaminated soil	Ingestion of ^{226}Ra , ^{210}Pb
Aquatic	^{226}Ra , ^{210}Pb	1. Dissolution of radionuclide in pile 2. Migration through soil to water 3. Migration in water 4. a. Uptake by aquatic organisms b. Consumption of aquatic organism 5. a. Use of water for irrigation b. Uptake by plants c. Consumption of plants 6. Consumption of contaminated drinking water 7. Immersion in contaminated water	Ingestion of ^{226}Ra ; whole-body gamma irradiation
External Gamma	^{226}Ra daughters	1. Attenuation by pile material 2. Air-distance attenuation 3. External exposure	External exposure to gamma radiation pro- duced by the decay of ^{226}Ra and its daughters

the body of an individual in the population applied in this study is 0.004 μCi of plutonium with one-third of this value applied to a suitable sample of the population as defined by the FRC. This will result in a dose equivalent rate of 1.5 to 3 rems per year to the bone. The limiting lung dose applied is 1.5 rems per year calculated on the basis of an average dose to the entire lung.

Estimates of soil concentration for several mechanisms of exposure are given in Table 3.8-1. Healy's recommended interim standard for plutonium in soils is given in Table 3.0-1. Concentrations given for the top 1.0 mm of soil are for bare soil or areas with sparse vegetation. When greater than 50% of the area is covered with low vegetation and a reasonable root mat exists to hold the soil, concentrations can be applied to a 0.5 cm layer.

3.9 Towards Interim Acceptable Surface Contamination Levels for Environmental PuO_2

Kathren (1968) derived environmental PuO_2 surface contamination levels for four types of land use: urban, suburban and recreation areas, rural areas (truck farming, annual crops, grazing land, milkshed, etc.), rural areas (deep root perennial, e.g., nuts and certain fruits), and remote or controlled areas. These surface contamination levels, given in Table 3.0-1, are based primarily on inhalation and 1.5 rem/yr to the lung. Kathren notes "that the levels cited appear satisfactory also for children, partly because the long equilibrium time and smaller breathing volume offset the reduced mass of the pulmonary lymph nodes and the possible increase in radiosensitivity." (Kathren 1968)

TABLE 3.8-1. Estimates of Limiting Soil Concentrations for Several Mechanisms of Exposure (Healy 1974)

Mechanism	Soil Concentration		
	$\mu\text{Ci/g}$	dpm/g	$\mu\text{Ci/m}^2$
Ingestion			
Casual	5×10^{-3}	11,000	--
Deliberate	5×10^{-4}	1,100	--
Skin Absorption	6×10^{-4}	1,300	--
Inhalation			
Dust Loading	2.5×10^{-3}	5,500	--
General Resuspension			
Fresh Deposit	$*6 \times 10^{-5}$	*130	0.1
Aged Deposit	$*6 \times 10^{-4}$	*1,300	1
Resuspension Factor	2×10^{-4}	*330	0.3
Clothing	3×10^{-4}	600	--

*Based on 1 mm thickness of soil with a density of 1.6 g/cm^2

4.0 DISCUSSION OF RESULTS

Sixteen information sources were found that pertain to government guidance and standards on soil contamination. These are discussed in Chapter 2 and are summarized in Table 2.0-1. Four of the standards that relate directly to acceptable soil contamination levels for unrestricted release of land areas (10 CFR 140.84 1980; 40 CFR 91.80; Barnes 1978; Hayden et al. 1980 [Colorado State Regulations]) have been accepted by government agencies. Chapter 3 contains a review of nine sources in which soil contamination limits are used or recommended by sources other than government agencies. These are summarized in Table 3.0-1.

No two standards or sets of guidance are the same. For example, the number of radionuclides considered ranges from one, to several, to all radionuclides. Some limits specify concentration levels in the soil, others specify an acceptable dose or dose rate from the soil. Since each standard reviewed is intended for a specific situation, and since different units are used for the standards, we have not attempted to arrive at a numerical range of acceptable values. Rather, we left our comparison in form of the summaries found in Tables 2.0-1 and 3.0-1.

Most of the standards and guidance reviewed adopt the philosophy of maintaining radiation exposures "as low as reasonably achievable" (ALARA). In fact, the NRC in their latest recommendations for decommissioning criteria (Federal Register 1981) endorses the adoption of a range of acceptable annual doses between 1 and 10 mrem/yr, based on ALARA. To determine what is "reasonably achievable," the NRC further recommends that the exact annual dose limit should be determined by using a cost-benefit analysis technique. The range of dose limits and the cost-benefit analysis approach is felt by the NRC to provide adequate flexibility for decommissioning any nuclear fuel cycle facility on a case-by-case basis.

In a recent review of pertinent standards for decontamination and decommissioning, Dickson (1978) concluded that it had "become clear that one of the greatest deficiencies is the availability of accepted soil contamination standards." Because of the wide differences that we found among the existing standards and guidance, we also conclude that it is

difficult to directly apply existing soil contamination standards to circumstances for which they were not derived. However, methods have been proposed by Healy (1974, 1979) and in conceptual decommissioning studies performed for the NRC by both Battelle, Pacific Northwest Laboratory (Oak et al. 1980) and by Oak Ridge National Laboratory (Eckerman and Young 1980) that can be used to calculate acceptable soil contamination standards for any mixture of radionuclides. A similar method has also been applied by Chapin (1980) at the Idaho National Engineering Laboratory based on an assumed annual dose limit of 5 mrem/yr. These methods all involve a radiation exposure pathway analysis to determine the dose from contaminated limits based on an acceptable annual dose.

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