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M-589

Formerly Utilized Sites Remedial Action Program (FUSRAP)

ADMINISTRATIVE RECORD

for Maywood, New Jersey

U.S. Department of Energy

0489-0613.1

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State of New Jersey MAR 15 3 47 PM '96

Christine Todd Whitman
Governor

Department of Environmental Protection

Robert C. Shinn, Jr.
Commissioner

Ms. Susan Cange, Site Manager
Former Sites Restoration Division
United States Department of Energy
Oak Ridge Operations Office
P.O. Box 2001
Oak Ridge, Tennessee 37831-8723

MAR 13 1996

Dear Ms. Cange:

Re: New Jersey Sites, Cleanup Criteria, Applicable or Relevant and Appropriate Requirements (ARAR's)

Please be advised that I am in receipt of your February 1, 1996 correspondence and received in this office, February 14, 1996. Your letter presents a number of possible interpretations of New Jersey statutes and this response will discuss them in the order presented. Additionally, I have attached a copy of a February 14, 1995 letter from Assistant Commissioner Richard Gimello to the United States Environmental Protection Agency (USEPA) Region II Director Kathy Callahan which defines site remediation requirements in P.L.1993, c.139 and codified as N.J.S.A. 13:1K-6 et.seq. as well s N.J.S.A. 58:10B-1 et.seq. . The responses are as follows:

1) The New Jersey Department of Environmental Protection identified the subject legislation as an ARAR under Section 121(d) of the Comprehensive Environmental Response Compensation and Liability Act in a letter dated July 6, 1993 to the USEPA.

2) With regard to the placing an "unnecessary burden on many New Jersey residents whose property is subject to cleanup under FUSRAP", the proposed NJDEP's site specific cleanup criteria are premised upon the one in one million cancer risk pursuant to N.J.S.A. 58:10B-12d, providing for the health and safety of New Jersey residents. This statutory "risk requirement" may limit options with regard to site remediation. Nevertheless, and aside from the statutory requirements noted above, the cost associated with this level of protection versus that relative to the risk range of one in ten thousand to one in one million as proposed by the United States Department of Energy (USDOE) must be viewed in a framework of protection of human health for

the very residents whose property rights the USDOE is purportedly striving to protect.

3) Pursuant to N.J.S.A. 58:10B-12, NJDEP must determine cleanup criteria on a case by case basis in the absence of adopted minimum remediation standards. "The remediation standards must ensure that the potential for harm to the public health and safety and to the environment is minimized to acceptable levels, taking into consideration the location, the surroundings, the intended use of the property, the potential exposure to the discharge and the surrounding ambient conditions, whether naturally occurring or man-made." N.J.S.A 58:10B-12(b) and (c) go on to list particular criteria the NJDEP must consider in establishing standards.

4) As the NJDEP has not approved a remedial action work plan or similar plan utilizing the USDOE proposed cleanup criteria for the remediation of FUSRAP sites in New Jersey, the NJDEP has **not** in fact "compelled" the USDOE to adopt a new or different remediaition standard. The NJDEP developed the site specific cleanup criteria in the absence of applicable New Jersey State standards as described in item #3 above. These were provided to you in our letter of January 25, 1995. As these site specific criteria have not met with the acceptance of the USDOE, I have enclosed a copy of the proposed "Draft Rule" which, when promulgated, would provide New Jersey State Cleanup Standards. This generic criteria is to be applied state-wide as N.J.A.C. 7:28-12, "Remediation Standards for Radioactive Materials. Pursuant to the above discussions, said statute will be considered as an ARAR by the State of New Jersey.

5) With regard to cleanup criteria agreed upon by the USEPA and the USDOE, as you are aware, the NJDEP has repeatedly provided cleanup criteria that are statutorily mandated for the State of New Jersey. The State of New Jersey was not involved in the cleanup criteria dispute resolution between the USEPA and USDOE. Consequently, the State of New Jersey is not a party to the agreement reached by the agencies relative to cleanup criteria.

6) As noted in item #2 above, New Jersey State statues require soil remediation standards that result in a health risk of no greater than one in one million. Additionally, subsurface soil cleanup criteria must reflect the New Jersey acceptable health risk requirements.

Based upon the above evaluation the NJDEP can not concur with the USDOE findings. However, the NJDEP proposes that the USDOE adopt the conservative assumptions used

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ENCLOSURE 1

OPPORTUNITIES FOR PUBLIC COMMENT

Submit written comments by **May 10, 1996** to:

Bob Stern, Chief
Bureau of Environmental Radiation
CN 415
Trenton, NJ 08625-0415

Public Comments will be heard:

April 9, 1996
6:30 pm - 9:00 pm
Sommerset County Environmental Education Center
Basking Ridge, NJ

and

April 22, 1996
1:00 pm - 4:00 pm
Burlington County College
Technology & Engineering Center (TEC)
Mt. Laurel, NJ

Please call to confirm dates before attending public meetings
(609) 984-5400

to develop the remedial strategies employed at Lodi during the Phase II remediation which included both residential and non-residential properties.

The NJDEP is committed to protecting the health and safety of the residents of New Jersey and their environment. Further, we hope this resolves the issue with the USDOE and allows them to fulfill our common goal. Please feel free to call me at (609) 633-1495 should you have questions with regard to the above.

Sincerely,

Nicholas L. Marton, MPH
Research Scientist II/Case Manager
Bureau of Federal Case Management

attachments

c: Angela Carpenter, USEPA
Bob Stern, ESHAP

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State of New Jersey
Department of Environmental Protection

Christine Todd Whitman
Governor

Robert C. Shinn, Jr.
Commissioner

REMEDIATION STANDARDS FOR RADIOACTIVE MATERIALS

The Commission on Radiation Protection, pursuant to its authority to promulgate rules in accordance with N.J.S.A. 26:2D et seq., and to the legislative direction in the Industrial Site Recovery Act (ISRA), is proposing generic cleanup standards for sites contaminated with radioactive materials.

ISRA directed the Department of Environmental Protection to prepare generic standards for hazardous substances, which includes radionuclides. The statute provides two general criteria for developing standards. First, to achieve less than a one in a million lifetime risk and second, so as not to exceed normal background levels of a contaminant. Because the risks associated with radioactive materials even in their natural state exceed the one in a million criteria, the program has utilized the background concept to develop the standards described below.

The basic radiation dose criterion used in the draft standards is 15 millirems per year (mrem/yr). This was derived based on the variation in natural background radiation (exclusive of radon) that is expected to consistently occur in New Jersey. A similar criterion of 3 picocuries per liter (pCi/L) was derived for radon.

These radiation dose and radon in air concentrations were translated, through fairly extensive pathway analysis into allowed radionuclide in soil concentrations. The results of this analysis are embodied in Tables 1 and 2 of the proposed rule, which present the allowed concentration of the radionuclides of greatest interest as a function of the vertical extent of the residual contamination This is a technically valid and innovative approach that permits greater flexibility in meeting the radiation dose criteria of 15 mrem/yr.

We would appreciate your comments on the enclosed draft rule and the supporting technical document A Pathway Analysis Approach for Determining Generic Cleanup Standards. We believe these standards will provide for remedial options that are both protective of the public and cost effective. Public comment opportunities are presented in Enclosure 1. If you have any questions please call Bob Stern or Jenny Moon at (609) 984-5400.

Sincerely,

Henry J. Powsner, M.D., Chairman,
Commission on Radiation Protection

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N.J.A.C. 7:28 - 12

Remediation Standards for Radioactive Materials

February 1996

New Jersey Commission on Radiation Protection

For information contact:
New Jersey Department of Environmental Protection
Bureau of Environmental Radiation
Bob Stern or Jenny Moon
(609) 984-5400

140232

DIVISION OF ENVIRONMENTAL SAFETY, HEALTH, AND ANALYTICAL PROGRAMS
BUREAU OF ENVIRONMENTAL RADIATION

Notice of Pre-Proposal
N.J.A.C. 7:28-12
Remediation Standards for Radioactive Materials

Authorized By: The Commission on Radiation Protection
Authority: Radiation Protection Act (N.J.S.A. 26:2D) and Industrial Site Recovery Act (N.J.S.A. 58:10B)

Take notice that the New Jersey Commission on Radiation Protection, pursuant to its authority to promulgate rules in accordance with N.J.S.A. 26:2D et seq., is considering proposing remediation standards for radioactive materials.

Summary

The Environmental Cleanup Responsibility Act P.L. 1983, c.330 (N.J.S.A. 13:1K-6 et seq.) was amended by the legislature via bill S-1070 in June, 1993. The amendments included, among other things, changing the name of the act to the "Industrial Site Recovery Act" (ISRA) and directed the Department to establish generic soil cleanup criteria for the remediation of contaminated sites. The criteria for soil standards were to be based on either: 1) an incremental lifetime risk of cancer of one in one million persons exposed, or 2) naturally occurring background levels that are consistently encountered. Under ISRA, the Department is charged with developing generic soil cleanup standards for hazardous substances, which includes radionuclides, so that contaminated sites can be returned to productive use.

The scope of this rule extends to:

(1) any naturally occurring radionuclide whose concentration has been enhanced by man made physical or chemical processes,

(2) accelerator produced radionuclides,

(3) as applicable, relevant, and appropriate, to any remediation involving radioactive materials pursued under authority of the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and

(4) remediations involving any radioactive materials within or outside the boundary of a federally owned, operated or licensed site when the federal government has not assumed responsibility for said remediation.

Consequently, the scope of this rule extends to the remediation of sites contaminated with naturally occurring or accelerator produced material and to sites contaminated with any radioactive material to be remediated under CERCLA authorities.

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General Approach to Standard Setting

The basis for the clean-up standards for radioactive materials is premised on the amendments to P.L.1983, c.330, hereafter referred to S-1070, which were promulgated in June, 1993. This law establishes cleanup criteria for contaminated sites in New Jersey and directed the Department to promulgate generic remediation standards that could be consistently applied across the State. The intent was to move the Department away from establishing cleanup standards on a case by case basis, while allowing the use of alternative standards for significantly different site circumstances.

Section 35 d.(1) of S-1070 tasks the Department with establishing remediation standards that will not result in more than an additional cancer risk of one in one million. Since the risk associated with naturally occurring background radiation exceeds that number, the Department has looked to Section 35 g.(4) of S-1070 for legislative direction. That section states that remediation shall not be required beyond the regional natural background levels for any particular contaminant. S-1070 further defines regional natural background levels as the concentration of a contaminant consistently present in the environment of the region of the site and which has not been influenced by localized human activities.

Since naturally occurring concentrations of the radionuclides involved here, e.g., uranium, thorium, radium, cause lifetime risks substantially greater than 1 in one million, it is not possible to use that as a clean-up criteria; therefore, the Department has used natural background as the remediation criteria for radioactive materials. In doing so, it has recognized that background radiation varies with time and from place to place, and has utilized the naturally occurring variability in radiation that people encounter in their day to day lives as the radiation dose increment to be achieved by a remediation. Further, S-1070 directs that regional natural background should be defined as the levels "<u>consistently</u>" found in the region of the site. Recognizing the statistical nature of background radiation, the Department has utilized a one-standard deviation, or approximation thereto, as the measure of the variation that is "consistently" encountered.

Consequently, the approach taken in this rule is to define the one-standard deviation in naturally occurring background radiation doses for each of the three major sources of radiation; external gamma radiation, intakes of radionuclides, and inhalation of radon gas. The standard deviations for external gamma and intakes were then summed statistically to approximate a one standard deviation figure for both pathways. Radon was kept separate because of its unique character. The resulting one standard deviation for the sum of the gamma and intake backgrounds is the allowed incremental radiation level following a remediation; and was used as the fundamental criteria for soil standard setting. For radium 226 the one standard deviation radon background concentration variation was also used as a constraining criteria. To translate those radiation dose criteria into generic soil standards, the Department has made extensive calculations of radiation doses to individuals, for both unrestricted (residential) and restricted (non-residential) uses, as a function of both the vertical extent of the contaminated material remaining after remediation (V) and the residual radionuclide in soil concentration in that material (C). For diffuse materials and soils these dose relationships are first expressed as the ratio of the dose received per year divided by the activity in the material in picocuries per gram (pCi/g) and termed the dose factor. These dose factors are then divided into the allowed background dose criteria to determine what contamination extents and residual concentrations are acceptable, as depicted below;

The allowed soil concentration (C) is:

C = Background Allowance/Dose Factor;

where the dose factor is calculated as a function of V. For a given value of V, the vertical extent of contamination remaining, the value of C that does not cause any of the background variation allowances to be exceeded is then selected as the standard. This method was used for each radionuclide and its decay chain. However, in order to account for ingrowth of progeny, the doses for certain decay chains were combined. An example of such a combination is the Ra-226, Pb-210 decay chain.

In establishing these soil remediation standards the Department had to consider the term "contaminant" as defined in Section 23 of S-1070. For the purpose of this rule, "radiation" is considered the contaminant which must be controlled, and not each individual radionuclide. This position is based on the fact that it is the collective radiation, not the individual radionuclide that causes the harmful health effect. Additionally, radiation from different sources may vary in energy intensity and physical state (gamma ray vs. alpha particle), and cause different degrees of harm to the body. Only the use of established measures of radiation dose can reduce these differences to a common measure of relevance. Furthermore, because "terrestrial" and "in the body" natural background radiation is the sum of all available ambient radionuclides, and because natural background is the soil remediation goal, it is logical to establish "radiation" as the contaminant for this application.

The proposed NJ cleanup standards, herein, establish an incremental annual total effective dose equivalent (TEDE) of 15 mrem per year from external radiation and intake for both unrestricted sites and restricted sites. For radon, a concentration of 3 picocuries per liter (pCi/L) above background is the proposed standard criteria. The allowed generic soil radionuclide concentrations derived herein from the dose limits are different for each radionuclide because of their differing properties.

The Department's assumptions, equations, and detailed methodology in arriving at these generic cleanup standards is presented in A Pathway Analysis Approach for Determining Generic Cleanup Standards for Radioactive Materials which is available by writing to the address below, by calling (609) 984-5923, or by faxing the request to (609) 633-2210.

Robert Stern, Ph.D., Chief
Bureau of Environmental Radiation
CN 415
Trenton, NJ 08625-0415

The agency's pre-proposal follows:

SUBCHAPTER 12. REMEDIATION STANDARDS FOR RADIOACTIVE MATERIALS

Legal Authority: Radiation Protection Act (N.J.S.A. 26:2D), Industrial Site Recovery Act (N.J.S.A. 58:10B)

7:28-12.1 **Purpose and Scope**

The purpose of this Subchapter is to establish minimum standards for the remediation of real property including soils and structures contaminated by radioactive materials.

7:28-12.2 **Applicability**

(a) These standards are applicable to:

(1) remediation of contamination of real property by any naturally occurring radionuclide whose concentration has been enhanced by man made physical or chemical processes;

(2) remediation of contamination of real property by accelerator produced radionuclides;

(3) any remediation involving radioactive contamination pursued under authority of the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and

(4) remediations involving any radioactive contamination within or outside the boundary of a federally owned, operated, or licensed site, when the federal government has not assumed responsibility for said remediation.

(b) These standards are not applicable to:

(1) materials containing naturally occurring radionuclides whose concentrations have not been enhanced by man made physical or chemical processes, such as coal or quarry stone.

(2) coal ash that has been or is being:

(A) disposed of in landfills, or where a signed contract exists for such disposal;

(B) recycled into building materials where the activity of the resulting material is within natural background levels for that type of material; or

(C) used as fill material prior to the promulgation of this rule.

7:28-12.3 **Definitions**

"Active engineering controls" means any mechanism to contain or stabilize contamination or to ensure the effectiveness of a remedial action. Active engineering controls may include, without limitation, caps, covers, dikes, trenches, leachate collection systems, signs, fences and access controls.

"Committed dose equivalent" means the total dose equivalent averaged throughout any body tissue in the 50 years after intake of a radionuclide into the body.

"Committed effective dose equivalent" means the sum of the products of the committed dose equivalent multiplied by the appropriate organ or tissue weighting factor in International Commission on Radiological Protection (ICRP) Publication 26, or subsequent revisions thereto.

"Deep-Dose Equivalent", applied to external whole-body exposure, is the dose equivalent at a tissue depth of 1 centimeter.

"Design features" means those features of a remediation that do not rely on additional expenditures after installation to achieve their intended purpose.

"Dose Equivalent" means the product of the absorbed dose, the quality factor, and any other modifying factors.

"Institutional control" means a mechanism used to limit human activities at or near a contaminated site, or to ensure the effectiveness of the remedial action over time, when contaminants remain at a contaminated site in levels or concentrations above the applicable remediation standard that would allow unrestricted use of that property. Institutional controls may include, without limitation, structure, land, and natural resource use restrictions, well restriction areas, and deed restrictions.

"Intake dose" means the annual radiation dose to a person from all potential intake pathways (exclusive of radon inhalation) including the ingestion of water, direct ingestion of soil, intake of foods, and the inhalation of resuspended particulate matter (in committed effective dose equivalent).

"Natural background variation" means the naturally experienced variations in radiation dose from mean levels that are commonly and consistently experienced by persons in the state.

"Natural Background Radionuclide Concentration" means the value of a particular radionuclide concentration in soils measured in areas in the vicinity of the site, not more than one mile from the site boundary in an area that has not been influenced by localized human activities, including the site's prior or current operations.

"Radioactive contamination" means the presence of one or more radionuclides in matter at concentration levels above natural background radionuclide concentrations.

"Radionuclide" means a type of atom that spontaneously under goes radioactive decay.

"Responsible Party" includes any person who executes or is otherwise subject to an oversight document, and any person who is performing the remediation, for example, a contractor or consultant, and any person who has control over the person who is performing the remediation, including, without limitation, an owner or operator who is subject to the Industrial Site Recovery Act.

"Restricted use" means all site uses other than unrestricted use.

"Total Effective Dose Equivalent" means the sum of the deep-dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures).

"Unrestricted use" means those lands where the existing buildings and/or other structures are used or are intended to be used as domiciles, residences or other forms of habitation by humans, and/or lands zoned for such uses. For the purpose of this rule, schools, daycare centers, nursing homes, family farms, and other similar uses are considered unrestricted uses. Also, the land on which buildings or other structures are converted from restricted to unrestricted use shall be considered unrestricted and shall comply with unrestricted use soil standards.

"Vertical extent" means the average depth, measured in feet, of the post-remediation radioactive contamination over an affected area not to exceed 50,000 square feet. The depth of the contamination within the area to be averaged must not differ by more than a factor of 3.

7:28-12.4 **General Requirements**

(a) Any site remediation undertaken pursuant to this section shall be conducted, as appropriate, in accordance with the requirements of:

(1) N.J.A.C. 7:26E-1.1 et seq., Technical Requirements for Site Remediation

(2) N.J.A.C. 7:26-9.10, Financial requirements for facility closure and

(3) N.J.A.C 7:26-9.12 Financial requirements for facility post-closure care.

(b) Compliance with this section shall not relieve any person from complying with more stringent cleanup standards or provisions imposed by any other applicable statute or regulation.

7:28-12.5 **Sampling, Surveying and Laboratory Requirements**

(a) In addition to the requirements in N.J.A.C. 7:26E-2.1 et seq. "Quality Assurance for Sampling and Laboratory Analysis" and Appendix A of N.J.A.C. 7:26E-1.1 et seq., "Laboratory Data Deliverables Format", for radionuclides, analytical methods contained in the following publications, or equivalents as approved by the Department, shall be used for determining radionuclide concentrations and/or radiation levels:

(1) U.S. Environmental Protection Agency; "Prescribed Procedures for Measurement of Radioactivity in Drinking Water", EPA 600/4-80-32;

(2) U.S. Department of Energy; "Environmental Measurements Laboratory - Procedures Manual", HASL-300, 27th Ed., Vol. 1.

(3) Eastern Environmental Radiation Facility; "Radiochemistry Procedures Manual", EPA 520/5-84-006.

(b) Any laboratory providing radiological analysis for soil must have participated in and passed a soil intercomparison analysis administered by either the International Atomic Energy Agency or the U.S. Department of Energy's Environmental Measurements Laboratory within the year preceding the radiological analysis.

7:28-12.6 **Preliminary Assessment and Site Investigation**

Preliminary Assessment and Site Investigations for all sites contaminated with radioactive materials shall be conducted in accordance with the relevant portions of N.J.A.C. 7:26E, Subchapter 3, including any subsequent revisions thereto.

7:28-12.7 Remedial Investigations

Remedial Investigations for all sites contaminated with radioactive materials shall be conducted in accordance with the relevant portions of N.J.A.C. 7:26E, Subchapter 4, and any subsequent revisions thereto.

7:28-12.8 Remedial Alternative Analysis

Remedial Alternative Analyses for all sites contaminated with radioactive material shall be in accordance with the relevant portions of N.J.A.C. 7:26E, Subchapter 5, and any subsequent revisions thereto.

7:28-12.9 Remedial Action Requirements

The Remedial Action Requirements for all sites contaminated with radioactive material shall be in accordance with N.J.A.C. 7:26E, Subchapter 6, and any subsequent revisions thereto.

7:28-12.10 Radiation Dose Standards Applicable to Remediation of Radioactive Contamination of All Real Property.

Sites shall be remediated so that the radiation dose to any person, under either an unrestricted or a restricted scenario, from any residual radioactive contamination at the site will be less than natural background variations, as specified below:

(a) For the sum of annual external gamma radiation dose (in millirems (mrem) per year effective dose equivalent) and intake dose (in mrem per year committed effective dose equivalent): 15 mrem per year total effective dose equivalent.

(b) For radon inhalation: the committed effective dose equivalent received from inhalation of air containing 3 picocuries per liter (pCi/L) of radon gas.

(c) Site remediations shall not result in exceedances of the New Jersey Groundwater Quality Standards in N.J.A.C. 7:9-6.1 et seq.

7:28-12.11 Generic Remediation Standards for Radionuclide Contamination of Soil.

For radioactive contamination in soils, the requirements of N.J.A.C. 7:28-10 shall be considered to be met for a specific radionuclide if:

(a) the concentration of the radionuclide does not exceed the value in Table 1 or 2 below for the intended use:

Table 1: Allowed Concentration (C) of Individual Radionuclides in Soils (pCi/g); Unrestricted Use[1]

Element(s)	Vertical Extent (V, in feet) <1	2	3	4	5	6	7	9
U-238,234,or 235[(2)]	65	44	27	21	14	12	10	8
Th-230	625	340	231	231	231	224	224	224
Ra226	3	3	2.8	2.8	2.6	2.6	1.9	1.9
Th232	6.8	4.0	3.1	3.1	2.5	2.1	1.7	1.7
Pa-231	4.2	2.6	2.1	2.1	2.1	2.1	2.0	2.0

Table 2: Allowed Concentration (C) of Individual Radionuclides in Soils (pCi/g); Restricted Use[1]

Element(s)	Vertical Extent (V in feet) <1	2	3	4	5	6	7	9
U-238,239,or 235	250	135	83	60	50	38	38	30
Ra226	9	9	9	9	9	9	9	9
Th232	50	25	17	11	10	8	6	6
Pa-231	50	26	19	19	19	17	14	11

1 The allowed Incremental Concentrations from Table 1 or 2 are added to the natural background radionuclide concentration to obtain the absolute value of the allowed radionuclide concentration following site remediation.

2 These concentrations may be limited by chemical toxicity. Applicants should inquire with Site Remediation for chemical standards for uranium.

;and,

(b) a clean soil cover at least two feet deep, with the upper 6 inches consisting of top soil, is placed over the remediated area, and

(c) where more than one radionuclide remains at the site, their concentrations meet a sum of fractions constraint as described below:

$$\text{Sum of} \quad \frac{CA_i}{C_i} \leq 1$$

where:

CA_i = the concentration of radionuclide i at the site, and

C_i = the allowed concentration of radionuclide i from Table 1 or 2, <u>if</u> it were the <u>only</u> remaining radionuclide at the site.

7:28-12.12 Alternative Cleanup Standards For Radioactive Contamination

(a) In lieu of using the generic remediation standards for radionuclide contamination of soil found at N.J.A.C. 7:28-12.11, a person may petition the Department for an alternative soil standard for radioactive contamination. Such an alternate soil standard:

(1) shall not result in doses exceeding 15 mrem per year total effective dose equivalent; and

(2) shall not result in doses exceeding, for radon gas, the dose from 3 pCi/L of radon in indoor air in the lowest level of the building; and

(3) shall not result in radionuclide in groundwater levels exceeding those in the New Jersey Groundwater Quality Standards in N.J.A.C. 7:9-6.1 <u>et.seq.</u>

(b) The Department will not consider petitions for an alternative soil standard for radionuclides that is supported by varying, in any manner, the following parameters used by the Department in establishing the generic soil standards as described in the technical document <u>A Pathway Analysis Approach for Determining Generic Cleanup Standards for Radioactive Materials</u>:

(1) Dose conversion factors
(2) Breathing, soil ingestion, vegetation uptake and water consumption rates
(3) Indoor and outdoor occupancy times
(4) Exposure duration times
(5) Vegetation uptake factors
(6) Building and other shielding factors
(7) Background dose values, and for background radon, concentration in air values

(c) The Department will consider petitions in cases where site specific or waste specific factors, and/or site design features are used in performing the dose assessment, and which are different than those used by the Department in establishing the soil concentrations in N.J.A.C. 7:28-12.11. Factors which the Department will consider in such a petition for an alternate soil standard include, but are not limited to:

(1) The chemical or physical state of the radioactive material.

(2) Site specific soil characteristics, depth to groundwater and other geological and/or hydrogeological characteristics which may substantially change the potential dose from radionuclides, as compared to the dose estimates contained in A Pathway Analysis Approach for Determining Generic Cleanup Standards for Radioactive Materials.

(3) Use of caps, covers, sealants, geotextile membranes, limits on the vertical extent of contamination remaining on site and/or other engineering or institutional controls that reduce potential exposures to radioactive materials.

(d) The petition for an alternate soil standard shall include an analysis demonstrating how and why the difference in factors such as those in (c) above, as compared to those used by the Department in A Pathway Analysis Approach for Determining Generic Cleanup Standards for Radioactive Materials will result in substantially different soil standards than those in N.J.A.C. 7:28-12.11. For the purpose of this subchapter, substantially different soil standards means a change of 50% or more in the allowed soil concentration of the radionuclide or radionuclides in question.

(e) If the petitioner fails in the opinion of the Department to demonstrate that the resultant soil standard will differ from the established soil standard in N.J.A.C. 7:28-12.11 by 50% or greater, the Department shall not consider the request.

(f) Regardless of the factors used by the petitioner, the Department shall not approve proposals where the resultant alternate soil radionuclide concentration exceeds those in N.J.A.C. 7:28-12.11 by 10 times.

(g) In the event the Department determines that sufficient evidence exists to support consideration of an alternative soil standard, the petitioner shall submit an analysis to demonstrate compliance with the dose limits in N.J.A.C. 7:28-12 including:

(1) The remedial action informational requirements of N.J.A.C. 7:26E Subchapter 6, and

(2) A dose assessment analysis, including:

(A) An estimate of the radiation doses received by a post-remediation on-site resident for a unrestricted use scenario, and by an employee for a restricted use scenario;

(B) A presentation of all equations or other mathematical techniques used, either directly or embodied in a computer model, to predict the movement of radionuclides and/or their resulting radiation dose;

(C) Groundwater radionuclide concentration calculations which shall be extended for a period of 1000 years.

(D) A presentation of all numerical input parameters to equations or computer models, the range of values for those parameters, including reference sources, the value selected for use and the basis for that selection. Any input parameters used shall consider those used by the USEPA in its CERCLA documents such as the Human Health Evaluation Manual and document the results of that consideration.

(E) A presentation of other relevant factors and assumptions used in the analyses, such as site-specific geology, land use, etc.;

(F) An analysis of which input parameters, when varied, would most significantly affect radiation dose results, commonly referred to as a sensitivity analysis; and

(G) An analysis of both continued use of existing structures and future use scenarios. Future use scenarios shall include, at a minimum, the construction of buildings for either unrestricted or restricted use, including excavations for basements and/or footings.

(h) Active engineering controls or institutional controls may be incorporated as part of the petition for an alternative remediation standard provided that these controls will be durable and implemented for sufficiently long periods of time to achieve their intended purpose.

(i) For the purpose of this subchapter, a sufficiently long period of time means for the length of time required for the radionuclides to decay 10 half-lives, but not to exceed 100 years.

(j) Computer models acceptable to the Department may be used by the petitioner for an alternative soil standard to confirm that the requirements of N.J.A.C. 7:28-12.11 have been and will continue to be met.

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7:28-12.13 **Requirements Pertaining to Active Engineering or Institutional Controls**

(a) All remediation proposals shall designate the intended use(s) of the property. Such uses shall be consistent with current local zoning designations. For sites not remediated to the unrestricted standards in N.J.A.C. 7:28-12.11, the Department shall define the nature and duration of all appropriate engineering or institutional controls necessary to meet the standards in N.J.A.C. 7:28-12.11 or N.J.A.C. 7:28-12.12(a).

(b) Engineering controls may be either active or passive.

(c) Engineering controls may include covers or other barriers restricting or reducing radionuclide releases, and/or migration off-site.

(d) Institutional controls may include site use restrictions, site access controls, and well restriction areas, and shall be implemented in accordance with N.J.S.A. 58:10B-13.

(e) For any remediation under this subchapter requiring active engineering controls or institutional controls to meet the standards in N.J.A.C. 7:28-12.11 or N.J.A.C. 7:28-12.12(a), the responsible party, in addition to meeting the provisions of N.J.S.A. 58:10B-13 shall:

(1) implement all the necessary actions, as determined by the Department, to assure that such active engineering or institutional controls are being implemented and maintained for a sufficiently long period of time.

(2) establish a post-remediation funding source in accordance with paragraph 12.13(e)3 to reimburse the State for costs incurred by the State in the performance of inspections of the site at 5 year intervals for the purpose of assuring that the requisite land uses and/or active engineered, or institutional controls are being maintained in a manner that results in meeting their intended health and safety protection purposes.

(3) as part of the establishment of the remediation funding source, provide for sufficient financial assurance, as determined by the Department, to defray the costs of implementing and maintaining the requisite active engineered, or institutional controls, including the State costs associated with paragraphs 12.13(e)2 for a sufficiently long period of time. Such financial assurance shall be in the form of funds placed into an account segregated from the person's assets and outside the person's administrative control and employ a surety bond, performance bond. letter of credit, self bonding, or fully funded trust fund per N.J.A.C. 7:26B-6.1 et. seq., an environmental insurance policy, a self-guarantee, or other mechanism approved by the Department.

(f) Any subsequent proposed use of a property that is different from the intended use described in the original remediation proposal, other than unrestricted use, shall require a review and approval by the Department. To initiate that review, the property owner proposing such use shall:

(1) prepare and submit to the Department and the affected municipality(ies) a brief description of the new proposed use as compared to the intended use upon which the original remediation was based including all planned soil excavations, and any additional remedial actions to be implemented.

(2) if the Department determines that the proposed new use may cause the dose limitations of N.J.A.C. 7:28-12.10 to be exceeded, the owners shall be required to:

(A) prepare and submit to the Department a dose assessment analyses, containing the information required under N.J.A.C. 7:28-12.12(g)(2), 12(h), 12(i), and 12(j), to ascertain whether the dose limitation requirements of N.J.A.C. 7:28-12.10 will be met for the proposed new use.

(B) in preparing the dose assessment analyses, the person may incorporate into the new use plan new remedial measures such as different radionuclide in soil concentrations, or contamination vertical extents, and/or new engineering or institutional controls, provided that for active engineering, or institutional controls, financial assurance is provided for per Paragraph 13.13(e)(3).

(3) within 15 calendar days of a change in land use, the owner or successor of the land must notify all interested parties and agencies, including the Bureau of Environmental Radiation, of such change and the reason for the change in use.

7:28-12.14 **Requirements Pertaining to the Final Status Survey**

(a) The final status survey and the interpretation of survey results shall be in accordance with the Nuclear Regulatory Commission's NUREG/CR-5849 ORAU-92/C57 Manual for Conducting Radiological Surveys in Support of License Termination and any subsequent revisions thereto.

(b) The requirements of N.J.A.C. 7:28-12.14(a) may be modified upon written approval of the Department.

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ERRATA

page 3-6: Replace equations for D_u for Slab on Grade as follows:

Residential Slab on Grade Excavation

$$D_u = C \times DCF \times 350/365 \times 16.4/24 \times .3 \times .1 \times .54 \times 1 = .0106C \times DCF$$

Non-Residential Slab on Grade

$$D_u = C \times DCF \times 250/365 \times 7/24 \times .3 \times .1 \times .6 \times 1 = .0036C \times DCF$$

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Chapter 1

INTRODUCTION AND EXECUTIVE SUMMARY

1.1 BACKGROUND

The Radiation Protection Act of 1958 , N.J.S.A. 26:2D-1 et seq., regulates the possession, handling, disposal, transportation and use of sources of radiation within the State of New Jersey. Pursuant to the Act, New Jersey's Radiological Health Program, now known as the Radiation Protection Program (the "program"), was established in the Department of Environmental Protection (the "department"). The Act also created the Commission on Radiation Protection ("CORP") and vested in that body the authority to promulgate rules and regulations, as may be necessary to prohibit and prevent unnecessary radiation. Additionally, the Act empowers the department to administer the rules promulgated by CORP.

In addition, the Environmental Cleanup Responsibility Act P.L. 1983, c.330 (N.J.S.A. 13:1K-6 et seq.) was amended by the legislature via bill S-1070 in June, 1993. The amendments included, among other things, changing the name of the act to the "Industrial Site Recovery Act" (ISRA) and established soil cleanup criteria for the remediation of contaminated sites. The criteria for soil standards are either: 1) an incremental lifetime risk of cancer of one in one million persons exposed, or 2) where naturally occurring levels of a contaminant exist at levels that result in incremental lifetime cancer risks greater than one in one million, a return of the site to regional background levels. Under ISRA, the department is charged to develop generic soil cleanup standards for hazardous substances, which includes radionuclides, so that contaminated sites can be returned to productive use.

The department has become aware of certain industries which are accumulating or have accumulated large volumes of radioactive waste on their facility grounds. While the wastes normally involve low to moderate concentrations of radioactivity; the contamination often extends to tens to hundreds of thousands of cubic yards of material. The industries generating such wastes are not primarily involved in working with radioactive materials, but rather the residue from various industrial processes contains naturally occurring radionuclides which become concentrated in the waste as a result of processing.

Because of the large volumes involved, there is significant risk to any persons who might construct residences or other buildings, or otherwise make use of land containing these wastes. If such sites were not remediated, these risks could readily exceed a lifetime fatal cancer rate of one in a thousand for concentrations frequently encountered at these sites. Where radium is present - the precursor to radon gas - the risks can be even higher; on the order of 1 in one hundred, or greater. Such risks substantially exceed the 1 in one million criteria of ISRA, described above. Consequently sites containing such materials must be remediated before they can be returned to productive use.

Unfortunately, again because of the large volumes involved, such remediation may not be easy to accomplish. While there is a commercial facility in Utah that accepts such materials, the cost of excavating, transporting, and disposing of substantial volumes of material there may be prohibitive. In this rule development, the department has been cognizant of such costs, and has sought to create opportunities for less costly remediation, while still maintaining the health and safety protection mandated under ISRA and the Radiation Protection Act.

1.2 SCOPE

Radioactive materials are generally divided into two classes: naturally occurring and accelerator-produced radioactive materials(NARM) regulated by the State, and source, by-product, and special nuclear materials regulated under the federal Atomic Energy Act (AEA). One subset of NARM, called naturally occurring radioactive material (NORM) wastes, tend to be accumulated in diffuse form; i.e. in large volumes having relatively low concentrations of radioactivity.

The radioactive materials regulated under the AEA, are under the jurisdiction of the federal Environmental Protection Agency (EPA), the Nuclear Regulatory Commission (NRC) or the Department of Energy (DOE). These are source, special nuclear and by-product materials. For example, pursuant to the AEA, the NRC regulates the private use of "source material" which is defined at 10 C.F.R. 20.3(15) as "uranium or thorium, or any combination thereof, in any physical or chemical form; or ores which contain by weight one-twentieth of one percent (0.05%) or more of (a) uranium, (b) thorium or (c) any combination thereof". The .05% concentration is equivalent to about 168 picocuries per gram (pCi/g) of uranium and 54 pCi/g for thorium. NRC also regulates "by-product material", which is defined at 10 C.F.R. 30.4 as "any radioactive material which (except special nuclear material) is yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material". The final area of NRC or DOE jurisdiction is "special" nuclear material which is defined at 10 C.F.R. 70 as "plutonium, uranium 233, uranium enriched in the isotope 233 or the isotope 235, and any other material which the NRC, determines to be special nuclear material.

Similarly the DOE regulates source, byproduct, and special nuclear materials for defense and nuclear research and development purposes. Also under the AEA (42 USC 2201/AEA 161: 42 USC 2021/AEA 274 and Reorganization Plan 3), EPA is authorized to develop federal guidance and regulations to protect public health and the environment from the effects of radiation.

The State is generally preempted from regulation of materials under AEA jurisdiction. However, some sites containing source, byproduct, or special nuclear materials requiring remediation are also under the scope and procedures of CERCLA, the Comprehensive, Environmental Response, Compensation, and Liability Act. CERCLA authorizes the President to take response action whenever there is a release or threat of a release of hazardous substances, which includes radionuclides. CERCLA also provides for the incorporation into the response action of State standards that are applicable, relevant, and appropriate (ARAR) to the situation. Because these standards herein are state-wide standards based on radiation dose criteria, which are a common denominator of health impact, regardless of the radionuclide involved, the department believes that these standards constitute an ARAR pursuant to 40 CFR 300, Subpart E (n300.400(g)) and are therefore applicable to any site being remediated under CERCLA authority - including clean ups of federal facilities pursuant to Section 120 of the Superfund Amendments and Reauthorization Act of 1986. This is true regardless of whether the radionuclide involved is NARM or source, byproduct, or special nuclear material.

In addition, there have been situations where the federal government has not assumed responsibility for cleanups of AEA materials or materials deriving their radioactivity from AEA. These situations include cleanups involving AEA materials deposited beyond the fenceline of a NRC licensed facility and cleanups of materials involving former source material radionuclides whose concentrations have been diluted below the .05% threshold. Pending any change in federal interpretation of its legal responsibility, the State, in the interest of public health and safety protection, will apply these standards to any cleanup involving any radionuclide/material for which the federal government denies responsibility.

Therefore, the scope of this rule extends to:

(1) any naturally occurring radionuclide whose concentration has been enhanced by man made physical or chemical processes,

(2) accelerator produced radionuclides,

(3) as applicable, relevant, and appropriate, to any remediation involving radioactive materials pursued under authority of the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and

(4) remediations involving any radioactive materials within or outside the boundary of a federally owned, operated or licensed site when the federal government has not assumed responsibility for said remediation.

Consequently, the scope of this rule extends to the remediation of sites contaminated with NARM material and to sites contaminated with any radioactive material to be remediated under CERCLA authorities.

Pursuant to its authorities, the NRC is developing standards governing the decontamination and decommissioning of its licensed facilities. Pursuant to its authorities under the AEA and its delegated authorities under CERCLA, the EPA is developing regulations that will set forth requirements for cleanup levels for sites contaminated with radionuclides. These regulations will be designed to protect human health and the environment from exposure to ionizing radiation, and will be applicable to all sites under the authority of the Comprehensive Environmental Response, Compensation and Liability Act (i.e., Superfund sites), including but not limited to Federal facilities.

Because the department regards these standards as an ARAR for Superfund sites, and because at other sites AEA materials may involve the same elements as NARM materials and may be intermingled with NARM, the department has worked closely with EPA and NRC to provide for reasonable compatibility between the various standards.

1.3 COMPLIANCE WITH NEW JERSEY P.L. 1995, c.65 and EXECUTIVE ORDER NUMBER 27

P.L. 1995, c.65 and Executive Order No. 27 (1994), require that administrative agencies adopting, readopting or amending state regulations "...under the authority of or in order to implement, comply with, or participate in any program established under federal law or under a state statute that incorporates or refers to federal law, federal standards or federal requirements" include: "... a statement as to whether the rule or regulation in question contains any standards or requirements which exceed the standards or requirements imposed by federal law. Such statement shall include a discussion of the policy reasons and a cost-benefit analysis that supports the agency's decision to impose the standards or requirements and also supports the fact that the state standard or requirement to be imposed is achievable under current technology, not withstanding the federal government's determination that lesser standards or requirements are appropriate."

As discussed above, two federal agencies, the NRC and EPA, are currently developing cleanup standards for sites contaminated with radioactive materials under their jurisdiction. The NRC is responsible for all radioactive materials governed by the Atomic Energy Act (AEA), i.e source, byproduct and special nuclear material. The NRC does not license naturally occurring radioactive materials unless it reaches "source material" concentrations. The NRC regulation will establish cleanup standards for the decommissioning and decontamination of lands and facilities under NRC license. The NRC has proposed a 15 mrem

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annual total effective dose equivalent (TEDE) for release of a site, with the As Low As Reasonably Achievable (ALARA) principle invoked where appropriate which could reduce the annual TEDE even further. The standards proposed herein apply to different radioactive materials than those regulated by the NRC and thus are not imposed by federal law or under state statute referring to federal law. Therefore, a comparison with the NRC standard is not legally required. Nevertheless, it should be noted that the primary remediation criteria herein is also 15 millirem (mrem) per year, and is thus identical with the NRC proposal.

The EPA has jurisdiction over any radioactive materials being addressed under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). Because the Department is proposing that these standards be an ARAR standard under CERCLA requirements, a comparison with EPA efforts is appropriate. An EPA draft of its rule dated May 11, 1994, included an incremental 15 mrem annual TEDE as its primary limit for remediations. The EPA also limits residual soil radionuclide concentrations so that the dose from drinking groundwater does not exceed the standards in 40CFR Part 141, the National Primary Drinking Water Regulations.

The proposed NJ cleanup standards, herein, also establish an incremental annual total effective dose equivalent TEDE of 15 mrem from external radiation and intake for both residential sites and non-residential sites. For radon, a concentration of 3 pCi/l above background is the proposed standard. The allowed generic soil radionuclide concentrations derived herein as required by ISRA from the dose limits are different for each radionuclide because of their differing properties. These concentrations presented herein cannot be compared to EPA soil concentration numbers because EPA is leaving that analysis to case-by-case site review.

As proposed, these cleanup standards meet the requirements legislated in S-1070, and the primary cleanup criteria of 15 mrem per year is consistent with developing federal regulations. These standards will also allow remedial options that may reduce the financial impacts associated with site cleanup. The standards provide a clear target to assist responsible parties in their planning efforts, and allow for an expedited review by the department thus conserving department resources. The proposed standards are protective of public health and safety, are consistent with developing federal initiatives, are a cost effective approach for departmental oversight, and will likely result in less expensive remediations.

Furthermore, the proposed regulation requires certain financial assurance instruments to ensure that sufficient funds are available to complete the remediation. Also, the proposed cleanup standards consider the National Primary Drinking Water regulations when establishing residual soil radionuclide concentrations. The financial assurance requirements and groundwater standards are, to date, consistent with the developing federal regulations discussed above.

The proposed soil standards facilitate compliance by increasing the likelihood that remediations are technically and financially feasible. This results because the rule allows the responsible party latitude, depending on site characteristics and contaminant concentrations, in selecting remedies for meeting the incremental 15 mrem standard. Examples are: 1) rather than removing all contaminated soil to an authorized disposal facility, the allowed dose may be attainable by removing part of the contamination and placing clean cover material over the residual contamination, 2) dispersing contaminated soil(provided the soil was contaminated with naturally occurring radionuclides) over uncontaminated portions of the site, or 3) removing the most contaminated soil and covering, or dispersing, the remainder. Such options encourage remediation by reducing the overall costs while maintaining public health and safety to within the limits imposed by S-1070. Depending on the radionuclide involved, the initial concentration of the contaminated soil and its vertical extent, cost savings on the order of up to 70% relative to the cost of full removal and off-site disposal may be realized if these options are implemented.

1.4 GENERAL APPROACH TO STANDARD SETTING

The basis for the clean-up standards for radioactive materials is premised on the amendments to P.L.1983, c.330, hereafter referred to S-1070, which were promulgated in June, 1993. This law establishes cleanup criteria for contaminated sites in New Jersey and directed the department to promulgate generic remediation standards that could be consistently applied across the State. The intent was to move the department away from establishing cleanup standards on a case by case basis, while allowing the use of alternative standards for significantly different site circumstances.

Section 35 d.(1) of S-1070 tasks the Department with establishing remediation standards that will not result in more than an additional cancer risk of one in one million. Since the risk associated with naturally occurring background radiation exceeds that number, the department has looked to Section 35 g.(4) of S-1070 for legislative direction. That section states that remediation shall not be required beyond the regional natural background levels for any particular contaminant. S-1070 further defines regional natural background levels as the concentration of a contaminant consistently present in the environment of the region of the site and which has not been influenced by localized human activities.

Since naturally occurring concentrations of the radionuclides involved here, e.g., uranium, thorium, radium, cause lifetime risks substantially greater than 1 in a million, it is not possible to use that as a clean-up criteria; therefore, the department has used natural background as the remediation criteria for radioactive materials. In doing so, it has recognized that background radiation varies with time and from place to place, and has utilized the naturally occurring variability in radiation that people encounter in their day to day lives as the radiation dose increment to be achieved by a remediation. Further, S-1070 directs that regional natural background should be defined as the levels "consistently" found in the region of the site. Recognizing the statistical nature of background radiation, the department has utilized a one-standard deviation, or approximation thereto, as the measure of the variation that is "consistently" encountered.

Consequently, the approach taken in this rule is to define the one-standard deviation in naturally occurring background radiation doses for each of the three major sources of radiation; external gamma radiation, intakes of radionuclides, and inhalation of radon gas. The standard deviations for external gamma and intakes were then summed statistically to approximate a one standard deviation figure for both pathways. Radon was kept separate because of its unique character. The resulting one standard deviation for the sum of the gamma and intake backgrounds is the allowed incremental radiation level following a remediation; and was used as the fundamental criteria for soil standard setting. For Ra226 the one standard deviation radon background concentration variation was also used as a constraining criteria. To translate those radiation dose criteria into generic soil standards, the department has made extensive calculations of radiation doses to individuals, for both residential and non-residential uses, as a function of both the vertical extent of the contaminated material remaining after remediation (V) and the residual radionuclide in soil concentration in that material (C). For diffuse materials and soils these doses are expressed as the ratio of the dose received per year divided by the activity in the material in pCi/gm and termed the dose factor (DF). These dose estimates are then divided into the allowed background dose criteria to determine what contamination extents and residual concentrations are acceptable, as depicted below;

The allowed soil concentration (C) is:

C = Background Allowance/Dose Factor;

where the dose factor is calculated as a function of V. For a given value of V, the vertical extent of contamination remaining, the value of C, that does not cause any of the background variation allowances to be exceeded is then selected as the standard. This method was used for each radionuclide and its decay chain However, in order to account for ingrowth of progeny, the doses for certain decay chains were combined. An example of such a combination is the Ra-226, Pb-210 decay chain.

1.5 SITE USE SCENARIOS

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In performing its generic dose calculations, the department considered both residential and non-residential uses of the site. For each use it considered future slab on grade and basement excavations for buildings - which results in contaminated material being brought to the surface - as the scenarios upon which to derive generic soil standards. These construction scenarios are depicted in Figures 1-1 and 1-2. Other scenarios are of course possible and can be dealt with in the alternate standards section of the rule.

For residential construction, a house of 25' x 40' and a plot size of 50' x 100' was assumed; for non-residential use a building of 40' x 60' and a plot size of one-quarter acre was assumed. For slab on grade construction, a footing excavation around the perimeter of the house 4' deep and 1' wide was assumed. For basement construction, a 7' depth of excavation was assumed over the full area of the structure. In deriving the generic standards herein the dose calculation results for slab on grade and basement excavation were compared and the more restrictive concentration was used. Thus, adherence to that concentration would allow any type of construction on site, in essence unrestricted use of the site. If an applicant wishes to restrict the type of construction on site, the alternate standard approach can be used. Such an approach can be either be based on the generic analysis done by the Department for slab on grade and basement excavations or the applicants own analysis pursuant to N.J.A.C. 7:28-12.12.

S-1070 also allows an applicant or licensee to propose alternatives to the generically derived soil concentrations based on unique site or waste characteristics. Any such alternative soil remediation standards shall be based on a department approved dose assessment and be as protective of human health and the environment as the generic standards established in this rule. The alternative remediation standard shall be based solely on physical site characteristics that may vary from those used by the department in developing the soil remediation standards. Alternative risk assessment methodologies shall be consistent with those developed by the U.S. Environmental Protection Agency pursuant to the "Comprehensive Environmental Response, Compensation and Liability Act," 42 U.S.C. §9601 et seq. and other statutory authorities as applicable.

In establishing these soil remediation standards the Department had to consider the term "contaminant" as defined in Section 23 of S-1070. For the purpose of this rule, "radiation" is considered the contaminant which must be controlled, and not each individual radionuclide. This position is based on the fact that it is the collective radiation, not the individual radionuclide that causes the harmful health effect. Additionally, radiation from different sources may vary in energy intensity and physical state (gamma ray vs. alpha particle), and cause different degrees of harm to the body. Only the use of established measures of radiation dose can reduce these differences to a common measure of relevance. Furthermore, because "terrestrial" and "in the body" natural background radiation is the sum of all available ambient radionuclides, and because natural background is the soil remediation goal, it is logical to establish "radiation" as the contaminant for this application.

Figure 1-1

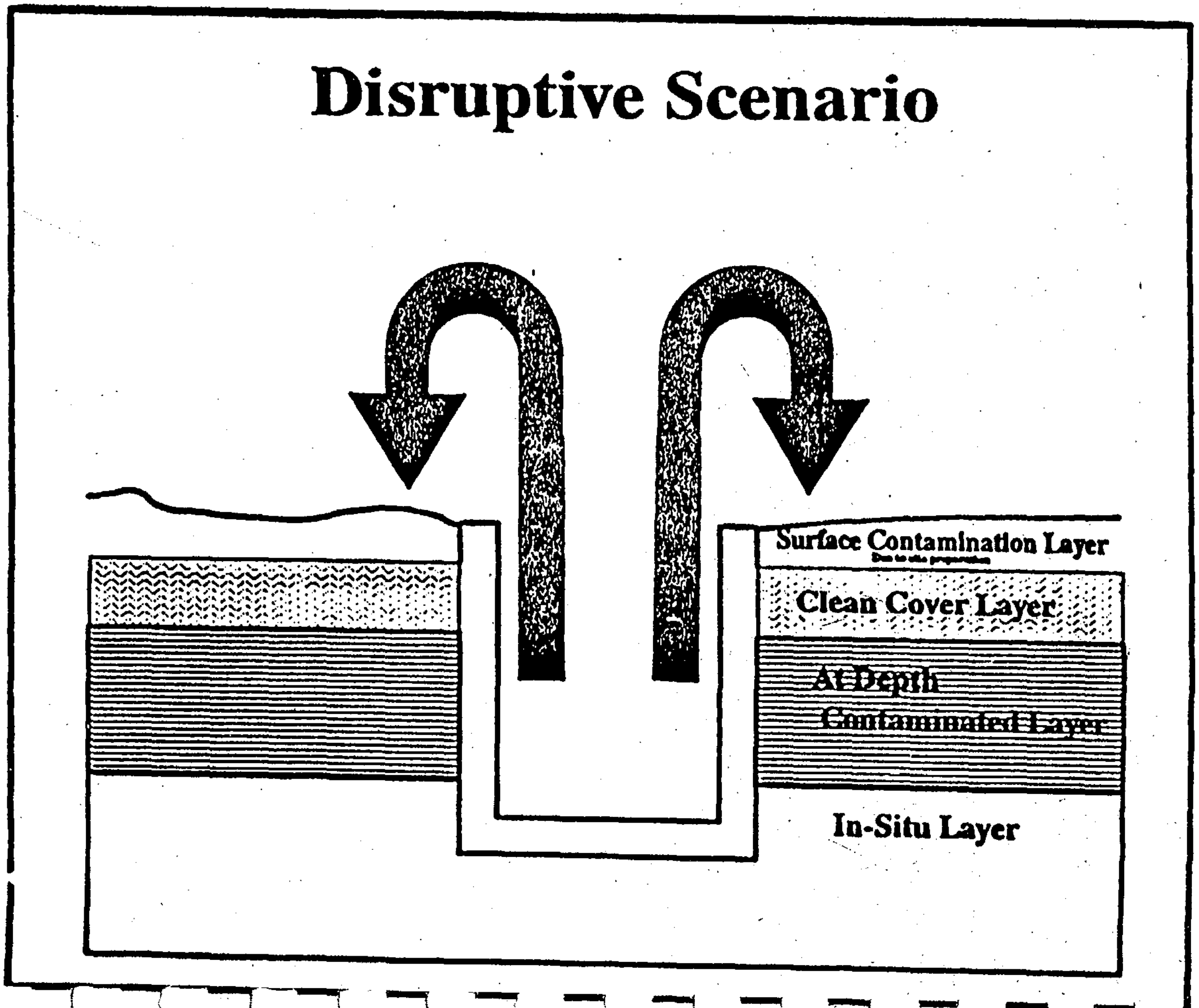
Disruptive Scenario
Surface Contamination Layer
Clean Cover Layer
At Depth
Contaminated Layer
In-Situ Layer

FIGURE 1-2

Construction Senarios

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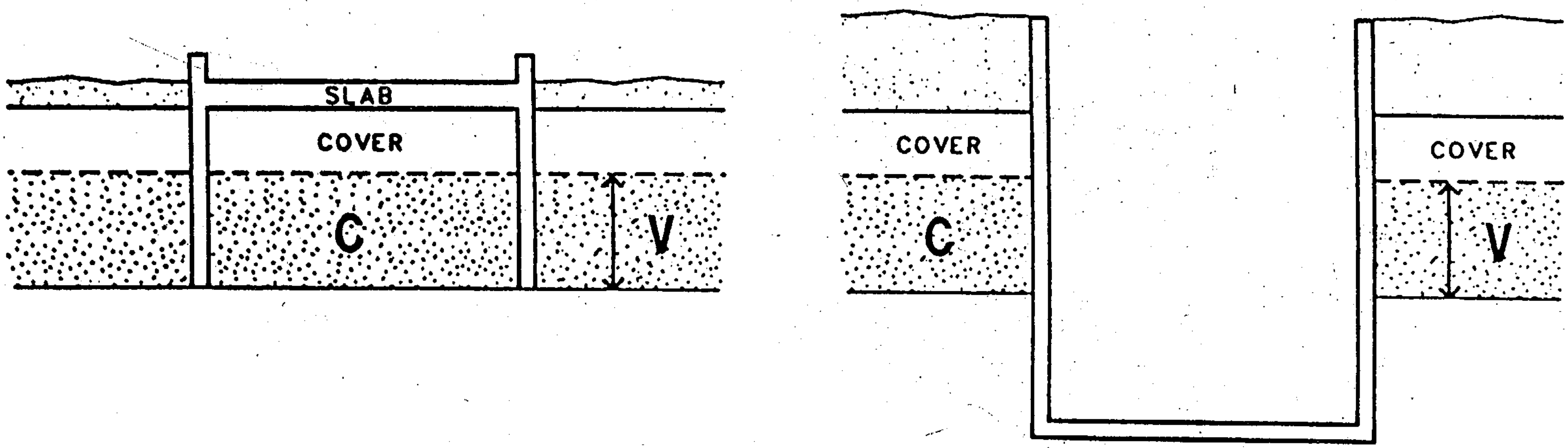
Slab On Grade

Basement



C-Buried concentration

V-Vertical extent

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Chapter 2

ALLOWABLE BACKGROUND RADIATION LEVELS

In response to the provisions in S-1070 regarding the establishment of a regional natural background level, the department has analyzed the radiation from "natural background" sources of relevance. The natural background levels for three pathways have been considered : 1) external gamma radiation, 2) indoor radon, and 3) internally deposited radionuclides. The derivation of allowed background derived radiation levels for sum of the external gamma and intake, and for the radon paths are described below. These pathways are depicted in Figure 2-1.

2.1 EXTERNAL GAMMA

For external terrestrial gamma background, the department used terrestrial background radiation data as reported in the National Council of Radiation Protection (NCRP) Report Number 94. Terrestrial background was the most appropriate criterion because contaminated soil is certainly part of the "terrestrial" component. National data was used because (1) it was readily available; (2) there is a limited amount of New Jersey-specific data on terrestrial radiation, and (3) it is difficult to measure terrestrial radiation separate from cosmic radiation.

Because natural background varies from place to place, a statistical approach was needed to determine what levels are consistently present in the environment of the region. To accommodate such variation, natural background for terrestrial gamma radiation is being defined as one standard deviation from the national mean value of 23 millirad/year (mrad/yr). Based on the distribution of the NCRP data, one standard deviation is approximately 21 mrad/yr. One standard deviation was used because it represents a variation that many people encounter simply by differing physical locations. A greater variation was not used because significantly fewer people are exposed to the higher levels of terrestrial radiation and therefore these levels cannot be considered to be "consistently present in the environment".

Since dose conversion factors are presented as effective dose equivalent (millirem/year) per nuclide concentration (picocuries per gram), a conversion from absorbed dose to dose equivalent is necessary. A body shielding factor of .7 is used to convert from mrad/yr to millirem/year (mrem/yr). In order to determine the background gamma dose variation, the following formula is used:

$$1\sigma \times BSF \times [(21.6/24 \times SF \times AF) + (21.6/24 \times SF \times AF) + (2.4/24 \times SF \times AF)] = AGD$$

Where

1σ = 21.2 mrad/yr[3]
BSF = Body Shielding Factor
SF = Shielding Factor
AF = Area Factor
AGD = Allowed Gamma Dose Increment,

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and the first term in parenthesis represents the contribution from material under the house while the person is indoors, the second term from material outside the house perimeter, while the person is indoors, and the third term from material outside the house perimeter while the person is outdoors.

Assumptions:

Total time spent inside = 21.6 hours/day[4]
Total time spent outside = 2.4 hours/day[5]
Shielding Factor
Basement = 0.3
Walls = 0.85
House is 25′ x 40′
Area factor for under house = .54
Area factor for side contribution = .46
One standard deviation of gamma dose distribution = 21.2 mrad/yr
Body Shielding Factor = .7

21.2 mrad/yr x.7[(21.6/24 x .3 x .54)+(21.6/24 x .85 x .46) + (2.4/24 x 1 x 1)] = **8.9 mrem/yr**

Therefore, the background gamma dose variation is equal to 9 mrem/yr.

3 Obtained from NCRP Report No. 94
4 Assumes the same gamma dose off-site indoors as on-site indoors
5 Obtained from NRC Policy and Guidance Directive PG-8-08

2.2 INTAKE

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For the internally deposited component of dose, the one standard deviation was determined as follows:

Human Intake of radionuclides occurs from three main sources; drinking water consumption, food intake, and air inhalation. The average radiation dose (effective dose equivalent) from such intakes in the U.S. is estimated at 40 mrem per year (NCRP 94; pg. 148). Most of that dose comes from potassium 40 (K-40), and the Pb 210 - Po 210 chain, each contributing about 20 mrem per year (NCRP 94; pg. 142).

Data on variations of intake dose is more limited than that for external gamma radiation. However for K-40, NCRP 94; Fig. 26 illustrates the variations in K-40 concentration as functions of sex and age. It can be seen from Figure 26 that the extreme variations about a mean age of 40 years and mean concentrations of 1.7 gms potassium per kg of body weight are about .5/1.7 or about 30% of the mean. Assuming these extremes are represented by about 3 standard deviations; the one sigma variation for the K-40 component alone is 10% x 20 mrem/year or about 2 mrem/year.

The variation for the Pb210 - Po210 component is greater. According to Fisenne (1993) Table 9; pg. 241; the standard deviation of Pb210 and Po210 in human bone ash is about 50% of the mean based on New York area data. The dose corresponding to a one standard deviation variation is therefore about .5 x 20 mrem/year or 10 mrem/year.

The one-sigma variation for both components is given by the square root of the sum of the variances for each component;

$$\sigma \text{ intake} = ((2)^2 + (10)^2)^{1/2}$$
$$\cong 10 \text{ mrem/year}$$

Therefore 10 mrem/year has been taken as the one standard deviation value for intake dose variation.

2.3 SUM OF GAMMA AND INTAKE VARIATIONS

The allowed background radiation dose for the sum of the gamma and intake pathways was derived as follows. Assuming the individual distributions are statistically independent the standard deviation of their sum would be:

$$\sigma \text{ combined} = ((9^2) + (10)^2)^{1/2} = 13.5 \text{ mrem/year}$$

If the two dose distributions (terrestrial gamma and intake) were fully correlated, i.e., the same radionuclides were contributing proportionally to each dose distribution, then the standard deviation of the combined distribution would be 10 + 9 = 19 mrem per year.

The primary radionuclides contributing to each dose, and its variations, are illustrated below:

Percentage of Dose Contribution

Radionuclide	Terrestrial Gamma Radiation (Source; NCRP 94)	Intake (Source:Fisenne, U.S. DOE EML, 1993)
K-40	36%	30%
Th series	47%	---
Uranium series		
° Ra226-Po214	17%	6%
° Pb210-Po210	0	50%

It can be seen that, aside from K-40, which contributes about one-third of the gamma and intake doses, there is not strong correlation of the radionuclides contributing to the two dose distributions. Therefore, considering the correlations, a better estimate of the combined distribution standard deviation would be 13.5 mrem/year plus one-third of the difference between 19 mrem/year and 13.5 mrem/year, or about 15.3 mrem/year.

The NRC and the EPA have initially proposed limits for remediations of 15 mrem/year from all pathways, exclusive of radon. Radon is treated separately because it is only a problem for Ra226 presence and the dose generally attributed to it is much greater than 15 mrem/year. As discussed previously, it would be desirable to achieve consistency with federal standards to facilitate remediations of sites where both federal and state regulated materials are present. Therefore, because the value of 15.3 mrem/year is very close to 15 mrem/year, the Department has adopted a dose limit of 15 mrem/year as its basic criteria for remediations of soils and structures.

2.4 RADON

The approach used in deriving an allowed incremental radon level is presented below.

Radon levels tend to be distributed log-normally. In other words there are a large number of low activity samples and a small number of high activity samples.

The department maintains a database of radon test results since the start of the mandatory certification regulations N.J.A.C. 7:28-27 (Certification of Radon Testers and Mitigators) on May 13, 1991. These regulations require certified radon measurement businesses to submit monthly reports containing the county and incorporated municipality in which the radon test was deployed; the measurement device used (charcoal canister, alpha track, electret, etc.); building level tested; testing purpose (real estate, screening, follow-up, pre-mitigation, post-mitigation, diagnostic, blank or duplicate): dates and times the measurement device was deployed; and the radon/radon progeny test result.

New Jersey has six distinct geo-provincial regions; Valley and Ridge, Highlands, Innercoastal Plain, Outercoastal Plain, Southern Piedmont and Northern Piedmont. All 567 incorporated municipalities in New Jersey were classified according to the geo-province in which they are affiliated.

For this study, the department analyzed radon tests deployed on the lowest house level or (in the absence of lowest level readings) the next level; and real estate and non-real estate screening tests. When these radon test results were analyzed according to geo-province, the following geometric means and standard deviations were obtained:

Geological Province	Geometric Mean (pCi/L)	Geometric Standard Deviation (pCi/L)
Valley and Ridge	2.25	3.21
Highlands	2.00	3.13
Innercoastal Plain	1.17	3.01
Outercoastal Plain	0.80	2.52
Southern Piedmont	1.88	3.12
Northern Piedmont	1.07	2.50
Statewide Average	1.35	2.95

As seen in the above table, the geometric mean varies from 0.8 pCi/L to 2.25 pCi/L. However, the geometric standard deviation in all provinces tends to be close to 3.0 pCi/L. This value was selected as the allowed increment.

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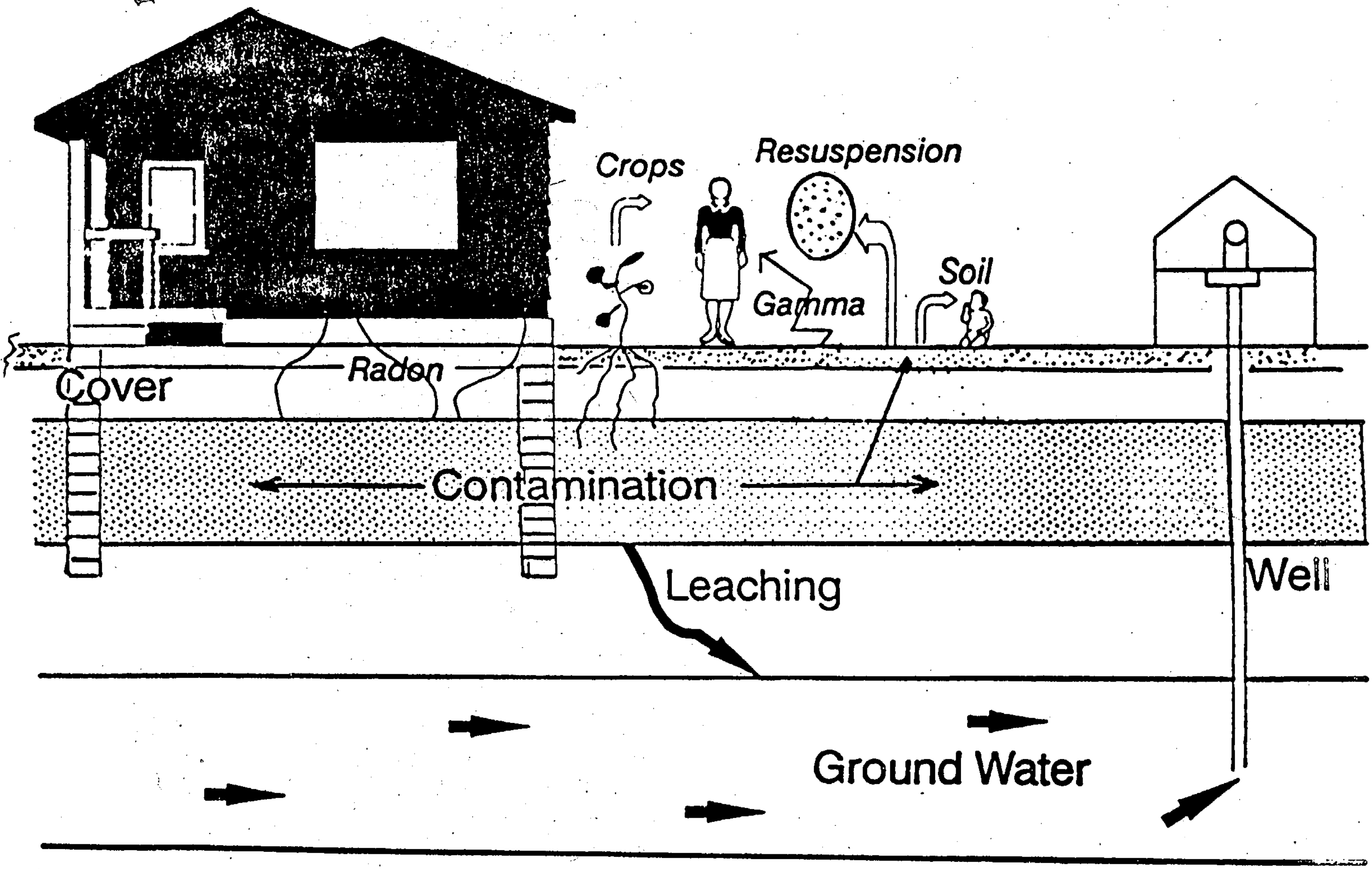
Figure 2 - 1 RADIATION EXPOSURE PATHWAYS



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Dose contribution from sides while inside (D_s)

D_s = C x DCF x 250 days/365 days x TI/24 hrs x SF x CF x AF x MF x DF

Dose contribution from outside (D_o)
D_o = C x DCF x 250 days/365 days x TO/24 hrs x SF x CF x AF x MF x DF

Where

C = concentration of buried material (pCi/g)
DCF = Dose Conversion Factor from EPA Federal Guidance No. 12 (mrem/yr per pCi/g)
SF= Shielding Factor; 0.3 through slab, 0.85 through walls
CF = Cover factor, which accounts for shielding from clean soil
AF= Area Factor
MF= mixing factor = V/D_e
where V = vertical extent of contaminated zone
OD_e = depth of excavation
DF= Depth Factor

Total gamma dose equivalent

$$D = D_u + D_s + D_o$$

Explanation of terms

Shielding Factor - Used to account for the shielding from an assumed 4 inch concrete slab from contaminated soil underneath a house (0.3). This value was chosen based on a literature search which included NUREG/CR-5512 PNL-7994 Volume 1 Residual Radioactive Contamination From Decommissioning, a DOE analysis for the Maywood site using the Microshield computer model, and an article in Health Physics, Vol. 33, No.4, p.287 , "Structure Shielding in Reactor Accident", by Z. Burson and A.E. Profio. The shielding factor for the sides of the structure (0.85) is from a DOE analysis for the Maywood site using the computer model Microshield.

Cover Factor - Used to account for the shielding from clean soil. A generic value is .1 for every 1 foot of clean soil. In other words, 1 foot of clean soil reduces the gamma exposure by 90%. This value was obtained from a personnel conversation with Alan Richardson of the US EPA.

Area Factor - A correction factor used to take into account that the dose conversion factors given in Federal Guidance Report No. 12 assume an infinite lateral extent. The area factors are taken from Table A.2 of Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0, ANL/EAD/LD-2, September 1993. Linear interpretation of the table was used for the assumed dimensions of the buildings.

Mixing Factor - Defined as the vertical extent of contamination divided by the depth of excavation. For slab on grade construction, we assume the depth of excavation is 4 feet. For basement construction, we assume the depth of excavation is 7 feet. If the vertical extent of contaminated material were 3 feet, then for slab on grade construction the mixing factor would be 3/4 or 0.75. For basement construction the mixing factor would be 3/7 or 0.43. We assume that the clean material on the surface will get mixed with the contaminated layer below to dilute the concentration of the material that is brought to the surface from construction activities on the remediated site.

Depth Factor - Used to account for the depth of contaminated material. The depth of contaminated material is determined in the following way: For basement construction, determine the volume of material that will be excavated. Divide this number by the area of the lot minus the area of the constructed house. For residential areas we assume a lot is 50′ by 100′.

For Residential Basement Excavation:

24′ x 40′ x 7′ = 6720 ft^3

50′ x 100′ lot	= 5000 ft^2
- 24′ x 40′	960
	4040 ft^2

6720 ft^3/4040 ft^2 = 1.7 ft = .5 meters

For Non-residential basement construction, the same procedure is followed. We assume the lot size is 1/4 acre.

For Non-Residential Basement Excavation:

40′ x 60′ x 7′ = 16,800 ft^3

1/4 acre lot	= 10,890 ft^2
- 40′ x 60′	2,400 ft^2
	8,490 ft^2

16,800 ft^3/8,490 ft^2 = 1.9 ft = .6 meters

For Slab on Grade construction, we assume a perimeter excavation of 4 feet deep and 2 feet wide. Therefore,

For Residential Slab on Grade Excavation:

$$\frac{2' \times 4' \times 128' = 1024\ ft^3}{50' \times 100' = 5000\ ft^2} = .2\ ft \text{ or } 6\ cm$$

For Non-Residential Slab on Grade Excavation

$$\frac{2' \times 4' \times 200' = 1600\ ft^3}{1/4 \text{ acre lot} = 10{,}890\ ft^2} = .147\ ft \text{ or } 4.5\ cm$$

Federal Guidance No. 12 has tables of dose conversion factors for ground surface, and soil contaminated to a depth of 1 cm, 5 cm, 15cm, and an infinite depth. For slab on grade construction, both residential and non-residential, we used the 5 cm dose conversion factors. Because these numbers already account for shielding and scatter due to material thickness, the depth factor is eliminated in these equations.

For depths between 15cm and infinite (we assume infinite to be anything beyond 1.0 meter), the Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0 has a table of values for depth factors of 0.15m, 0.5 m and 1.0 m. To obtain values between these depths, the procedure outlined in section A.2.1 of the RESRAD Manual was used.
To determine Depth Factors for values other than those listed in Table A.3 of the RESRAD Manual:

1) Interpolate Table A.3 for appropriate density (we assume 1.6 g/cm^3)
2) Determine k_i

$$k_i = \frac{-\ln[1-DF_i, .15m]}{.15m\ (1600\ kg/m^3)}$$

3) Determine Depth Factor for specific depth (.5 and .6 meters)

$$DF_i = 1 - e^{-ki(m2/kg) \times 1600(kg/m3) \times depth\ (m)}$$

SUBCHAIN	Residential (.5m)	Non-Residential (.6m)
U-238 + D	1.0	1.0
Ra-226 + D	.98	.998
U-235 + D	1.0	1.0
Pa-231	1.0	1.0
Ac-227 + D	.992	.998
Ra-228 + D	.992	.998
Th-228 + D	.985	.993

The following equations were used to calculate the "Formulas for Determining Allowed Concentration" (Tables 3-1 and 3-2). The Dose Conversion Factors are obtained from Federal Guidance No.12.

Residential - Basement Excavation

D_u = C x DCF x 350/365 x TI/24 hrs x SF x CF x AF x MF x DF
D_u = C x DCF x 350/365 x 16.4/24 x .3 x 1 x .54 x 1 x 1 = .106C x DCF

D_s = C x DCF x 350/365 x TI/24 hrs x SF x CF x AF x MF x DF
D_s = C x DCF x 350/365 x 16.4/24 x .85 x 1 x .46 x V/7 x DF = .037CV x DCF x DF

D_o = C x DCF x 350/365 x TO/24 hrs x SF x CF x AF x MF x DF
D_o = C x DCF x 350/365 x 2.4/24 x 1 x 1 x 1 x V/7 x DF = .0137CV x DCF x DF

Non-Residential - Basement Excavation

D_u = C x DCF x 250/365 x 7/24 x .3 x 1 x .6 x 1 x 1 = .036C x DCF

D_s = C x DCF x 250/365 x 7/24 x .85 x 1 x .4 x V/7 x DF = .01CV x DCF x DF

D_o = C x DCF x 250/365 x 1.75/24 x 1 x 1 x 1 x V/7 x DF = .007CV x DCF x DF

Residential - Slab on Grade Excavation

D_u = C x DCF x 350/365 x 16.4/24 x .3 x 1 x .54 x 1 = .106C x DCF

D_s = C x DCF[1] x 350/365 x 16.4/24 x .85 x 1 x .46 x V/4 = .064CV x DCF

D_o = C x DCF[1] x 350/365 x 2.4/24 x 1 x 1 x 1 x V/4 = .024CV x DCF

Non-Residential - Slab on Grade

D_u = C x DCF x 250/365 x 7/24 x .3 x 1 x .6 x 1 = .036C x DCF

D_s = C x DCF[1] x 250/365 x 7/24 x .85 x 1 x .4 x V/4 = .017CV x DCF

D_o = C x DCF[1] x 250/365 x 1.75/24 x 1 x 1 x 1 x V/4 = .012CV x DCF

[1] DCF's for 5 cm were readily available from Federal Guidance No.12, eliminating the need for a depth factor calculation.

Based on these formulas, Tables of Dose in mrem per year per pCi/g were created. Subchains were combined to account for ingrowth of radionuclides. Values were calculated for Basement and Slab on Grade construction, various vertical extents of the buried contaminated layer, and assuming 1) there is 1 foot of cover remaining under the slab after grading and construction (meaning the site would have to be left with at least two feet of clean cover after remediation) (See Table 3-1, and 3-2) and 2) there is no cover remaining under the slab after grading and construction (meaning the site would be left with one foot of clean cover after remediation)(See Table 3-2). It was assumed that one foot of cover would be removed during construction grading.

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Table 3-1

Formulas for Determining External Gamma Doses Per Unit Radionuclide in Soil Concentration (Dose in mrem/year/pCi/gm)

Assuming 1 foot of clean cover remaining after grading and construction[1]

SUBCHAIN	Residential Slab on Grade[2] 1' cover under slab	Residential Basement[3]	Non-Residential Slab on Grade[2] 1' cover under slab	Non-Residential Basement[3]
U-238 + D	.001 + .007V	.014 + .007V	0 + .002V	.005 + .002V
U-234	0V	0V	0V	0V
Total	**.001 + .007V**	**.014 + .007V**	**0 + .002V**	**.005 + .002V**
Th-230	0V	0V	0V	0V
Ra-226 + D	.12 + .52V	1.2 + .56V	.04 + .171 V	.402 + .19V
Pb-210 + D	0V	0V	0V	0V
Total	**.12 + .52V**	**1.2 + .56V**	**.04 + .171V**	**.402 + .19V**
U-235 + D	.008 + .047V	.08 + .038V	.003 + .015V	.027 + .013V
Pa-231	.002 + .011 V	.02 + .01V	0 + .003 V	.007 + .003V
Ac-227 + D	.021 + .113V	.212 + .101V	.007 + .037V	.072 + .034V
Total	**.023 + .124V**	**.232 + .111V**	**.007 + .04V**	**.079 + .037V**
Th-232	0V	0V	0V	0V
Ra-228 + D	.063 + .284V	.633 + .3V	.021 + .094V	.215 + .101V
Th-228 + D	.108 + .442V	1.08 + .51V	.037 + .146V	.37 + .172V
Total	**.171 + .726V**	**1.713 + .81V**	**.058 + .24V**	**.585 + .273V**

[1] Must leave site with at least 2 feet of clean cover.

[2] For vertical extent greater than 3 feet, V is always equal to 3.

[3] For vertical extent less than or equal to 6 feet, the first term is 0. For vertical extent greater than 6 feet, V is always equal to 6.

Table 3-2
Formulas for Determining Gamma Dose/pCi/gm in Soil
Assuming no clean cover remaining after grading and construction[1]

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SUBCHAIN	Residential Slab on Grade[2]	Residential Basement[3]	Non-Residential Slab on Grade[2]	Non-Residential Basement[3]
U-238 + D	.014+ .007V	.014+.007V	.005 + .002V	.005 + .002V
U-234	0V	0V	0V	0V
Total	**.014 + .007V**	**.014 + .007V**	**.005 + .002V**	**.005 + .002V**
Th-230	0V	0V	0V	0V
Ra-226 + D	1.2 + .52V	1.2 + .56V	.403 + .171V	.402 + .19V
Pb-210 + D	0V	0V	0V	0V
Total	**1.2 + .52V**	**1.2 + .56V**	**.403 + .171V**	**.402 + .19V**
U-235 + D	.08 + .047V	.08 + .038V	.03 + .015V	.027 + .013V
Pa-231	.02 + .011V	.02 + .01V	.007 + .003V	.007 + .003V
Ac-227 + D	.212 + .113V	.212 + .101V	.072 + .037V	.072 + .034V
Total	**.232 + .124V**	**.232 + .111V**	**.079 + .04V**	**.079 + .037V**
Th-232	0V	0V	0V	0V
Ra-228 + D	.633 + .284V	.633 + .3V	.215 + .094V	.215 + .101V
Th-228 + D	1.08 + .442V	1.08 + .51V	.37 + .146V	.37 + .172V
Total	**1.713 + .726V**	**1.713 + .81V**	**.585 + .24V**	**.585 + .273V**

[1] Site left with at least 1 foot of clean cover after remediation.
[2] For vertical extent greater than 4 feet, V is always equal to 4.
[3] For vertical extent less than or equal to 7 feet, the first term is 0. For vertical extent > 7 feet, V is always equal to 7

Table 3-3

GAMMA DOSE PER pCi/g

1' COVER

GAMMA RADIATION PATHWAY ONLY

RESIDENTIAL

SLAB ON GRADE[1]

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Vertical Extent	1'	2'	3'	5'	6'	7'	9'
U-238 + D U-234	.01	.015	.022	.022	.022	.022	.022
Ra-226 + D Pb-210 + D	.64	1.15	1.68	1.68	1.68	1.68	1.68
U-235 + D	.05	.10	.15	.15	.15	.15	.15
Pa-231 Ac-227 + D	.15	.27	.4	.4	.4	.4	.4
Th-232 Ra-228 + D Th-228 + D	.89	1.62	2.3	2.3	2.3	2.3	2.3

RESIDENTIAL

BASEMENT

Vertical Extent	1'	2'	3'	5'	6'	7'	9'
U-238 + D U-234	.007	.014	.02	.035	.042	.056	.056
Ra-226 + D Pb-210 + D	.56	1.11	1.68	2.78	3.42	4.45	4.45
U-235 + D	.038	.076	.114	.19	.23	.31	.31
Pa-231 Ac-227 + D	.11	.22	.33	.56	.68	.89	.89
Th-232 Ra-228 + D Th-228 + D	.81	1.62	2.47	4.05	4.94	6.4	6.4

[1] Assumes 1 foot of clean cover remaining under the slab after grading and construction

1' COVER

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Table 3-4

GAMMA DOSE PER pCi/g

GAMMA RADIATION PATHWAY ONLY

NON-RESIDENTIAL

SLAB ON GRADE[1]

Vertical Extent	1'	2'	3'	5'	6'	7'	9'
U-238 + D U-234	.002	.004	.006	.006	.006	.006	.006
Ra-226 + D Pb-210 + D	.21	.38	.56	.56	.56	.56	.56
U-235 + D	.02	.03	.05	.05	.05	.05	.05
Pa-231 Ac-227 + D	.05	.09	.13	.13	.13	.13	.13
Th-232 Ra-228 + D Th-228 + D	.3	.54	.78	.78	.78	.78	.78

NON-RESIDENTIAL

BASEMENT

Vertical Extent	1'	2'	3'	5'	6'	7'	9'
U-238 + D U-234	.002	.004	.006	.01	.01	.02	.02
Ra-226 + D Pb-210 + D	.19	.38	.57	.95	1.14	1.53	1.53
U-235 + D	.01	.03	.04	.06	.08	.10	.10
Pa-231 Ac-227 + D	.04	.07	.11	.19	.22	.3	.3
Th-232 Ra-228 + D Th-228 + D	.27	.55	.82	1.37	1.65	2.23	2.23

[1] Assumes 1 foot of clean cover remaining under the slab after grading and construction

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3.2 RADON PATHWAY

As discussed in Section 2.4, the one-standard deviation in the background level of radon found in New Jersey was derived as 3 pCi/l, and used as the allowed radon increment. With a natural background of 1 ± 3 pCi/l in structures, the total allowable ^{222}Rn level in a structure is 4 pCi/l.

Since ^{222}Rn is a progeny of ^{226}Ra, the important question associated with the radon pathway is not, what is the dose from 3 pCi/l of ^{222}Rn, but rather, what ^{226}Ra soil concentration will result in 3 pCi/l of ^{222}Rn in a structure.

3.2.1 ^{226}Ra:^{222}Rn Ratio

The relationship between the radium content in soil and potential radon levels in a structure which is built on the soil is not a simple correlation. A first approximation to this relationship would be to compare the average New Jersey soil radium content to the average New Jersey indoor radon concentration. Limited data on New Jersey's soil radium content suggests an average soil radium concentration of about .9 pCi/g[1]. From the discussion presented above, the statewide average geometric mean ^{222}Rn concentration in New Jersey homes is about 1.3 pCi/l. This information therefore results in about a 1:1.4 ratio for ^{226}Ra:^{222}Rn. Of course, integrated in this approach for determining the ^{226}Ra:^{222}Rn ratio are all the various soil types and water contents, housing and foundation types, variations in soil radium content and any other factors which effect the environmental relationship between ^{226}Ra and ^{222}Rn. This ratio can vary depending on the conditions at a particular site, therefore, the Department investigated another approximation for this ratio which could allow for consideration of more site specific conditions, and determine whether additional conservatism, i.e., a number higher than the mean needs to be used.

A review of recent literature seems to show that interest in the generation, transport and flux in radon in environmental systems began in the 1970's with the modeling of the migration of radionuclide gases through soils overlying uranium ore deposits. Over the past 20 years the models have evolved not only in dimensions examined but in complexity of systems studied. Most of the papers read are related to radon models developed by Rogers & Associates Engineering Corporation. Based on the frequent usage or reference of models in the literature it appears that such modeling would be a generally accepted method by which to set a radium clean-up standard based on the radon inhalation exposure pathway. More specifically, the use of the RAETRAD model and some of the conclusions reached in the paper "Foundation Soil Cleanup Depths and Radium Limits for Avoiding Elevated Indoor Radon" (foundation paper), which take into consideration various soil conditions seem directly applicable for establishing a radium/radon relationship for the purposes herein.

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The model runs examined in the foundation paper were calculated under the condition that an indoor radon concentration of 4 pCi/l be met in a hypothetical reference house located on the surface of a contaminated site. Three types of soils, under three water content conditions were analyzed; and one replacement soil type with varying radium concentrations of 1, 2 or 4 pCi/g was analyzed. A summary of the results of the model runs are:

> "Radium concentrations exceeding about 4 pCi/g required remediation for any of the soils. Radium concentrations of hundreds of pCi/g could be remediated with several meters of replacement soil under wet conditions, but drier soils (at -15 bar matric potential) required deeper excavation and replacement, particularly if the replacement soils contained slightly elevated (4 pCi/g) radium concentrations. ... The water contents of the replacement soil also were important in determining the required excavation depths, but water contents in the contaminated soil had relatively little effect."

Although the model is designed to estimate, for various soil types and ^{226}Ra contamination levels, the amount of remediation (depth of) necessary to ensure that an average indoor ^{222}Rn level of 4 pCi/l is not exceeded, the foundation paper does discuss some unexcavated scenarios:

> "For the coarsest soil (loamy sand), approximately 4 pCi/g radium may cause 4 pCi/l of indoor radon regardless of the moisture content. ... For the intermediate-textured soil (sandy clay loam) without excavation, the radium causing 4pCi/l indoor radon varied from 4 pCi/g for the dry case to nearly 6 pCi/g for the wet case. ... For the fine-textured soil (clay loam) without excavation, the radium causing 4 pCi/l indoor radon varied from about 5 pCi/g for the dry case to 13 pCi/g for the wet case."

Based on the foundation paper model runs for an unexcavated scenario, the ^{226}Ra pCi/g:^{222}Rn pCi/l ratio vary by a factor of 13 with contaminated soil type and contaminated soil moisture content. Examination of only the dry (soil) ratios shows that they vary from 1 - 1.25. This information seems to substantiate the information ascertained in the first approximation, and therefore lends a general validation to this model.

One of the authors, V.C. Rogers, was asked if based on the parameters used in the modeling run conducted for the foundation paper whether the ratio of about ^{226}Ra 1 pCi/g: ^{222}Rn 1 pCi/l represented a scientifically valid mean value? His response was:

".. 1 pCi/g ^{226}Ra : 1 pCi/l ^{222}Rn ratio is a good scientifically based value only for certain soil conditions (assuming dwelling properties similar to those of the reference house) such as intermediate to coarse-textured soils with about 20% emanation. For fine-textured soils, this ratio is conservative, since the ratio can be 2:1 or even as high as 3:1. In some regions (e.g. Florida), we find that emanation can reach 50% or higher, potentially making your 1:1 ratio non-conservative by a factor of 2-3.".[1]

The department agrees that Mr. Roger's points are correct and that a ratio greater than one would be required to encompass many NJ soils.

In light of the above and assuming that New Jersey's pervasive and higher than average radon levels stem from higher than 20% emanation levels, it appears that some additional conservatism beyond a 1:1 ratio is appropriate. This observation correlates with the measured ratio discussed above, and therefore, the department proposes to use 1:1.4 as the ^{226}Ra:^{222}Rn ratio.

[1] Rogers, V.C., 1994, written personal communication.

3.2.2 Radon Dose Equation

Following in the same format as for the other pathways discussed in this document, a dose equation will be developed for radon. The allowed dose equation for radon based on an indoor radon 1 δ value of 3 pCi/l is:

$$Dose_A\left(\frac{mrem}{yr}\right) = C_{Rn}\left(\frac{pCi}{l}\right) \cdot TotInD\left(\frac{hours}{day}\right) \cdot BR\left(\frac{l}{min}\right) \cdot \left(\frac{60min}{hours}\right) \cdot \left(\frac{365\,days}{year}\right) \cdot DCF\left(\frac{mrem}{pCi}\right) \qquad (1)$$

where: $Dose_A$ is the dose from 3 pCi/l of radon

C_{Rn} is the radon concentration (3 pCi/l)

TotInD is the total time spent indoors (21.6 hours)

BR is the breathing rate (.83 m^3/h or 13.8 l/min)

DCF is the dose conversion factor (5.5 $x10^{-5}$ mrem/pCi)[2]

Solving equation (1) results in an allowable dose of:

$$Dose_A\left(\frac{mrem}{yr}\right) = 3 \cdot 21.6 \cdot 13.8 \cdot 60 \cdot 365 \cdot 5.5x10\text{-}5 \qquad (2)$$

$$= 1077$$

The following equation is used to determine the dose due to radon exposure based on a certain ^{226}Ra soil concentration:

---

[2] **Calculation of radon dose conversion factor:**

Dose estimate from BEIR IV: .3-1 rad/WLM

$$.3\left(\frac{rad}{WLM}\right) \cdot 20\left(\frac{rem}{rad}\right) \cdot 1000\left(\frac{mrem}{rem}\right) \cdot .12\left(\begin{matrix}\text{weighting factor}\\ \text{for lung}\end{matrix}\right) = 720\left(\frac{mrem}{WLM}\right)$$

720 - 2400 mrem/WLM with a central value of 1560 mrem/WLM

Convert to mrem/pCi (assuming 50% equilibrium):

$$1560\left(\frac{mrem}{WLM}\right) \cdot \left(\frac{WL}{200\frac{pCi}{l}}\right) \cdot \left(\frac{M}{170hours}\right) \cdot \left(\frac{min}{13.8\,l}\right) \cdot \left(\frac{hour}{60min}\right) = 5.5x10^{-5}\left(\frac{mrem}{pCi}\right)$$

The following equation is used to determine the dose due to radon exposure based on a certain ^{226}Ra soil concentration:

$$Dose\ (\frac{mrem}{year}) = C_{Ra}\ (\frac{pCi}{g}) \cdot RF\ (\frac{\frac{pCi}{l}}{\frac{pCi}{g}}) \cdot BR\ (\frac{l}{min}) \cdot \quad (3)$$

$$(\frac{60min}{hours}) \cdot TotInOs\ (\frac{hours}{day}) \cdot OcDOs\ (\frac{day}{year}) \cdot DCF(\frac{mrem}{pCi})$$

where: C_{Ra} is the radium concentration (pCi/g)

RF is the radium to radon correlation factor (1 pCi/g ^{226}Ra: 1.4 pCi/l ^{222}Rn)[3]

TotInOs is total time spent indoors at a remediated site
16.4 hours for residential
7 hours for non-residential

OcDOs is number of occupancy days at a remediated site
350 days for residential
250 days for non-residential

To find the ^{226}Ra concentration which will result in the incremental increase equal to the variability in the indoor value of ^{222}Rn, C_{Ra} can be solved for by equating equations (1) and (3):

$$C_{Ra} \cdot RF \cdot BR \cdot 60 \cdot TotInOs \cdot OcDOs \cdot DCF = C_{Rn} \cdot TotInD \cdot E$$

$$C_{Ra} \cdot RF \cdot TotInOs \cdot OcDOs = C_{Rn} \cdot TotInD \cdot 3 \quad (4)$$

$$C_{Ra} = \frac{C_{Rn} \cdot TotInD \cdot 365}{RF \cdot TotInOs \cdot OcDOs}$$

As discussed above, correlation factor is based on measured NJ radium and radon levels, and confirmed by information provided in: Rogers, V., K.K. Nielson and V.C. Rogers, 1992, "Foundation Soil Cleanup Depths and Radium Limits for Avoiding Elevated Indoor Radon", RAE-8964/18-2.

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Inputing the necessary values and solving equation (4) for the residential and nonresidential categories results in the following incremental ^{226}Ra soil concentration values in order to meet the incremental ^{222}Rn value of 3pCi/l:

$$C_{Ra\text{-}residential} = \frac{3 \cdot 21.6 \cdot 365}{1.4 \cdot 16.4 \cdot 350}$$

$$= 3 \frac{pCi}{g}$$

$$C_{Ra\text{-}nonresidential} = \frac{3 \cdot 21.6 \cdot 365}{1.4 \cdot 7 \cdot 250}$$

$$= 9.3 \frac{pCi}{g}$$

The values used for RAETRAD modeling runs are summarized in Table 3-5.

Table 3-5 - RAETRAD Input Values

Indoor radon concentration (2-9)

$$C_h = \frac{0.035\ ft^3/l\ Q}{A_h\ h\ \lambda_h}$$

Radon entry rate into the dwelling (2-8) $Q = F_c A_{cr} + F_s (A_h - A_{cr})$

Fluxes between different soil layers or regions and at the top surface or interface (2-5) $F = -D f_s \nabla C_s + \nabla[p(1-S)V_p C_s]$

Steady-state radon generation and transport equation

$$(2\text{-}3) \quad \frac{\delta C_b}{\delta t} = \nabla f_s (D \nabla C_b / f_s) - \nabla p(1-S)(V_p C_b / f_s) - \lambda C_b + Rp\lambda E$$

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Ref. Pg.	Term	Units	Definition	Model Conditions\\ Equation/Value	Ranges Examined	Comments
2-3	A_{cr}	ft^2	area of a perimeter shrinkage crack	$\pi [r_c^2 - (r_c - w_c)^2] R_{asp}$		
2-1	A_h	ft^2	area of a house	$\pi r_m^2 R_{asp}$	$143.3 m^2$ (3-3)	The area used for the reference house is 10% above the U.S. person (rectangular house translated weighted average.[1] If house volume and crack area were to remain to ellipse of equal area)constant, increases in area would have minimal effect on the indoor radon concentration level. This is because the radon entering through the crack is generally the dominant contributor to the overall indoor radon concentration. In practice, however, a change in the floor area of a house would cause a resulting change in volume and perimeter crack area.[2]

Unless noted, equations and information come from: Rogers, V. K.K. Nielson and V.C. Rogers, 1992, "Foundation Soil Cleanup Depths and Radium Limits for Avoiding Elevated Indoor Radon", RAE-8964/18-2.

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[1] [illegible] "Radon Entry Through Cracks in Slab-on-Grade" (PC91114) Florida Department of Community Affairs, October 1990

[2] [illegible]

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Ref. Pg.	Term	Units	Definition	Equation/Value	Model Conditions\\ Ranges Examined	Comments
2-4	b	kg/m$_3$	adsorption moisture			Generally lie between 10-15 but can be much higher.[3] This correlation constant parameter was not used in this model run since k_a was defined as zero.[2]
2-3	C_a	Bq/m$_3$	^{222}Rn concentration in air-filled pore space	C_v/f_a		
4	C_d	Bq/m^3	^{222}Rn concentration in slab	$\frac{C_B - C_T}{t}$		
2-3	C_b	Bq/m^3	^{222}Rn concentration in the total bulk space			
4	C_B		^{222}Rn concentration at the bottom of the slab			
2-9	C_h	pCi/l	indoor ^{222}Rn concentration			
4	C_T		^{222}Rn concentration at the top of the slab			
2-6	d	m	arithmetic mean soil particle diameter; excluding >#4 mesh			
3-3	d_f	cm	depth of footing		61 cm	Depth of footing mainly affects the advective transport of radon into the dwelling. If advection is the major contributor to indoor radon generally in cases with high pressure differences such as -10 Pa), an increased footing depth will reduce advective transport and the resulting indoor radon. However, some footings are formed from porous blocks instead of poured concrete. In these cases, the advection-driven radon generally flows through the blocks instead of around them, creating little change in indoor radon with increases in footing depth.[2] This depth is typical construction practice.

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[3] [illegible] and [illegible] Nielson, 1991. "Multiphase Radon Generation and Transport in Porous Materials", Health Physics, 60(6), 807-815.

[4] [illegible] 1991 personal communication [illegible]

Ref. Pg.	Term	Units	Definition	Equation/Value	Model Conditions\\ Ranges Examined	Comments
2-3	D	m^2/s	diffusion coefficient for ^{222}Rn in soil pores	$D_a\, p\, exp(-6Sp-6S^{14p})$ (2-6)	$1.3x10^{-2}$ - $7.3x10^{-3}$ m^2/s for three types of soils and 3 moisture contents (3-5)	
4	D_{cr}	m^2/s	diffusion coefficient for ^{222}Rn through crack		.06 cm^2/s (3-3) [reference value from sensitivity study]\\.01-.1 (6-5)	The value of .06 cm2/s is typical of dry, sandy material and was chosen to represent dry loosely-packed floor dirt and debris that accumulates in floor cracks.[2]
3-3	D_g	cm^2/s	gravel diffusion coefficient		.06cm^2/s	Typical value dry, porous medium
2-6	D_a	m^2/s	diffusion coefficient for ^{222}Rn in air	1.1 x 10^{-5}		
4	D_s	m^2/s	diffusion coefficient for ^{222}Rn through slab	$8x10^{-4}$ cm^2/s (3-4)		mean of measured values (3-4)
2-4	E		total ^{222}Rn emanation coefficient (air + water)	.2 (3-4)		best default value of nominal soils[5]
4	f_a		effective porosity in which ^{222}Rn is distributed, including gas and liquid phase components (809)	$p\,(1 - S + Sk_H)$ (2-4)		
4	f_e		effective porosity in which ^{222}Rn is distributed, including gas and liquid phase components and equivalent pore volume for ^{222}Rn adsorbed on solid pore surfaces (809)	$p\,(1 - S + Sk_H) + \rho\, k_a$ (2-4)		

[illegible] 1988 "Radon Emanation and Transport in Porous Media", Proceedings of the 1988 Symposium on Radon and Radon Technology, Denver, CO.; additional note [illegible] the value used for E is based on [illegible] widely diverse normal soils that gave E values ranging from .08-.33 with one outlier at .48, the mean value was .22 ± .07

[illegible] "Correlations for Predicting Air Permeabilities and ^{222}Rn Diffusion Coefficients of Soils", Health Physics, 61(2), 225-230.

Ref. Pg.	Term	Units	Definition	Equation/Value	Model Conditions\\ Ranges Examined	Comments
2-5	F	Bq/m^2s	bulk flux of ^{222}Rn	$-D f_a \nabla C_a + \nabla[p(1-S)V_p C_a]$		
2-8	F_c	pCi/m^2s	^{222}Rn flux through foundation crack	$-D_{cr} f_a \nabla C_a + \nabla[p(1-S)V_p C_a]$(4)		
2-8	F_s	pCi/m^2s	^{222}Rn flux through the concrete slab	$-D_s f_a \nabla C_a$(4)		
2-9	h	ft	height of indoor living area		8 ft	The value of 8 ft. is typical of most U.S. housing.[2]
[illegible]	k_a	m^3/kg	^{222}Rn surface adsorption coefficient	$k_a^\circ \exp(-bS)$ (2-4)	0 cm^3/g (3-4)	assume negligible adsorption (3-4)
2-[illegible]	k_a°	m^3/kg	dry surface adsorption coefficient for ^{222}Rn			
2-4	k_d	m^3/kg	radium distribution coefficient		500 cm^3/g (3-4)	assume negligible solubility (3-4)
2-4	k_H	$(Bq/m^3)aq/(Bq/m^3)air$	^{222}Rn distribution coefficient from Henry's law at 20° C		.26 (3-3)	
2-4	K	m^2	bulk soil air permeability (2-6)	$(p/500)^2 d^{4/3} \exp(-12S^4)$	1.2×10^{-7} - 6.9×10^{-10} m^2 for 3 types of soils and 3 moisture contents (3-5)	
2-6	K_{cr}	cm^2	air permeability of floor crack opening		10^{-4} cm^2 [reference value from sensitivity study]\\$10^{-9}$ - 10^{-2} (6-6)	The value used is an intermediate value, as shown in the sensitivity analyses, and is higher than any soil values, but may be typical of the loose debris accumulated in floor cracks.[2]
3-3	K_g	cm^2	air permeability of gravel		2 x 10^{-4} cm^2	nominal value measured by LBL[7]
3-3	K_s	cm^2	concrete slab permeability		10^{-12} cm^2	mean of measured value[8]

7 [illegible] 1991. "Influence of Subslab Aggregate Permeability on SSV Performance", Lawrence Berkley Laboratory report LBL-31160.

8 [illegible] 1991. "Indoor Radon Entry from Concrete Foundations", RAE-912711-1.

Ref. Pg.	Term	Units	Definition	Equation/Value	Model Conditions\\ Ranges Examined	Comments
2-4	λ	s^{-1}	^{222}Rn decay constant	2.1×10^{-6}		
2-9	λ_h	s^{-1}	house air ventilation rate		.35/h (3-3)	US Energy Efficiency Goal (3-3); The indoor radon concentration is inversely proportional to the house ventilation rate. For, example, doubling the ventilation rate results in an indoor radon concentration that is one-half of the original level.[2]
2-1	L	ft	length of house			
2-4	μ	Pa s	dynamic viscosity of air	1.8×10^{-5}		
2-7	M_w		soil water content (dry weight percent)		.106-.780 for natural and backfill soils, for three types of soils and three moisture contents (3-5)	
2-4	p		soil porosity	$1 - \rho/\rho_g$ (2-7)	.41 (3-4)	
6-1	p_{cr}		porosity of perimeter floor crack		.7 [reference value from sensitivity study]\\.25-1	The value of .7 is approximately the value that is obtained when earthen materials accumulate in a crevice, but are not mechanically compacted.[2]
[illegible]	p_{sl}		slab porosity		.22 (3-4)	mean of measured values (3-4)
2-4	∇P	Pa/m	air pressure gradient			
3-3	P_i	Pa	indoor air pressure		-2.4 Pa [reference value from sensitivity study]\\ 0-40 (6-10)	A value of -2.4 Pa is typical of long-term averages of wind-induced and thermally-induced indoor pressures across the floor slab (based on Florida Residential Data).[2]
2-8	Q	pCi/s	total ^{222}Rn entry rate	$F_c A_{cr} + F_s (A_h - A_{cr})$		
2-4	ρ	kg/m^3	soil bulk density (dry basis)		1.6 g/cm^3 (3-4)	The bulk density of the contaminated soil is directly associated with the amount of radium per unit volume of soil. In addition, the soil porosity is inversely proportional to the soil density.[2]
[illegible]	[illegible]		slab density		2.1 g/cm^3(3)	This is a typical density of concrete.[2]

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study, (6-9)]\\0-15 (6-9)

Ref. Pg.	Term	Units	Definition	Equation/Value	Model Conditions\\ Ranges Examined	Comments
2-3	r_c	ft	crack location as a minor radius from the center		at perimeter (3-3)[reference value from sensitivity	Because of concrete shrinkage, cracks develop at weakest points, which are typically at the cold joint between the slab and the footing walls.[2]
2-7	ρ_g	kg/m³	soil specific gravity		2.7 g/cm³(²)	This is a typical specific gravity for siliceous soils.
2-1	r_m	ft	ellipse minor radius	$\sqrt{A_b/(\pi R_{asp})}$		
2-7	ρ_w	kg/m³	density of water			
2-4	R	Bq/kg	soil ^{226}Ra concentration			The paper gives a full range of radium concentrations calculated based on differing soil types.
2-1	R_{asp}		ellipse aspect ratio	L/W	1.9 (3-3) [reference value from sensitivity study (6-14)]\\ 1-4.2 (6-14)	This is the length/width ratio of the house chosen to represent a plausible rectangular house shape.[2]
3-3	R_{sl}	pCi/g	concrete slab ^{226}Ra concentration		0 pCi/g	run excludes building materials as a source\\The runs considered in the paper give results from the contaminated soil only. However according to (RAE91), concrete usually contains a 0.1-1 pCi/g concentration of radium.[2]
2-4	S		soil water saturation fraction (2-7)	$[\rho M_w/(\rho_w p)]/100$		The moistures used for the differing soil classifications were calculated based on Soil Conservation Service parameters and -0.1, -0.3 and 15.0 bar suction pressures.
•	t		thickness of slab		10 cm (3-4)	typical construction practice (3-4)\\A value of 10 cm is the minimum slab thickness required by most US residential building codes.[2]
3-3	t_f	cm	fill soil thickness		30 cm	typical construction practice
3-3	t_g	cm	gravel thickness		10 cm\\0-30	typical construction practice
3-3	V_h	m³	house volume		350 m³	typical, 10% above US person-weighted average
2-4	V_p	m/s	air velocity in air-filled space	$K/[\mu p(1-S)]\nabla P$		

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Ref. Pg	Term	Units	Definition	Equation/Value	Model Conditions\\ Ranges Examined	Comments
2-3	w_c	ft	crack width		.2 cm (3-3)[reference value from sensitivity study (6-8)]\\ .01-10 (6-8)	According to ([1]), on average, concrete can be expected to shrink $500 x 10^{-6}$ inches for every inch in length. Therefore, for the reference aspect ratio and house area, the width of a typical shrinkage crack along the length of the house would be 0.22 cm, while the typical crack width along the width of the house would be 0.41 cm. Combining these in a length-weighted average gives a shrinkage crack width of 0.28 cm².
2-1	W	ft	width of house			

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3.3 INTAKE PATHWAYS

The intake dose is actually the sum of 4 elements; direct soil ingestion, inhalation of resuspended particles, drinking water intake and vegetative consumption. Each component is calculated as a function of the allowed radionuclide in soil concentration (C) and the vertical extent of the remaining contamination (V). Then the results are summed and added to the gamma doses previously derived. The sum of the intake and gamma doses are then set equal to the allowed dose level of 15 mrem per year to derive a value for C for a given vertical contamination extent (V).

The component of the intake dose from direct soil ingestion is derived below.

3.3.1 SOIL INGESTION

A component of the dose from internally deposited radionuclides arises through the ingestion of contaminated soil. Soil ingestion, especially among children, is an exposure pathway to consider when assessing the potential health risks associated with radioactive contaminated sites. Numerous attempts have been made to estimate the soil ingestion rates for both children and adults (Lepow et al, 1975, Binder et al, 1986, Kimbraugh 1984, Calabrese 1989, 1990, 1991 and Hixson et al, 1992). Initially, soil ingestion studies were based on observations of mouthing behaviors in children. There were orders of magnitude variation in the results derived from these qualitative evaluations and the risk assessment community showed little confidence in the findings. Attempting to reduce the subjectivity in the findings, studies were later designed to track the movement of various elements (aluminum, silicon and titanium) through the digestive tracts of test subjects. These elements are found in varying abundance in soil and make good tracers because they are not readily absorbed by the human digestive tract. By establishing the concentrations of these elements in soils and then measuring their levels in feces, a quantitative analysis is made that more closely reflects the actual soil ingestion rate. However, even these methods have shortcomings such as small sample groups and the difficulty in determining the contribution of these elements from foodstuffs consumed during the study. Although ingestion rates as high as 10,000 milligrams (mg) per day have been reported for children exhibiting pica, the consumption of abnormally high amounts of non-foodstuffs, the mean soil intakes for children are reported to be between 180-250 mg per day. The USEPA recommends a daily ingestion rate of 200 mg per day for children. The data for adults is somewhat limited with values in the 50 to 100 mg per day range. The USEPA uses 100 mg per day in its risk assessments for adults (USEPA 1991).

In this proposal, soil standards for internally deposited radionuclides are based on one standard deviation of the mean natural background dose determined from national data (NCRP 94). This approach differs from that of the USEPA (USEPA 1991), which uses a lifetime excess cancer risk based analysis for determining allowable incremental soil concentrations. Such an approach requires that a time weighted average for soil ingestion be taken in account. EPA uses a thirty year average in its calculation of soil ingestion rates, acknowledging that soil intakes vary over the age of the individual. In addition, EPA has developed a Soil Ingestion Factor that takes into account the body weights of individuals over time to establish the soil ingestion input. The purpose is to account for the higher body burden that children, due to their lower body weights, experience when they consume toxic materials. The proposed soil ingestion pathway analysis herein does not consider the lifetime risk, but the annual dose, therefore negating the need to calculate soil ingestion rates for a lifetime. In this instance, because children are at the greatest risk from soil ingestion, and to insure that DEP considers the reasonable maximally exposed individual, the soil rate used in this analysis is 200 mg per day for the residential scenario. For non-residential scenarios, the USEPA recommended value of 50 mg per day is used.

The equation to calculate the annual dose from soil ingestion is as follows:

Dose = C x V/DEX x ED x SI x DCF

Dose = committed dose equivalent per year in millirems per year (mrem/yr)

C = concentration of radionuclide in soil in picocuries per gram (pCi/g)

V = vertical extent of contamination in soil in feet (ft)

DEX = depth of excavation : basement construction - 7 ft
slab on grade construction - 4 ft

ED = days on site per year residential - 350
days on site per year non-residential - 250

SI = soil ingestion rate in grams per day residential - 0.2
soil ingestion rate in grams per day non-residential - 0.05

DCF = dose conversion factors from Table 2.2 in "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion", Federal Guidance Report Number 11, EPA-520/1-88-020, September 1988.

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The V/DEX factor provides the ratio of soil mixing that would be expected if the site was disrupted by the construction of housing or other structures.

References

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Calabrese,E.,R.Barnes,E.Stanek,H.Pastides,C.Gilbert,P.Veneman,X.Wang,A.Lasztity and K.Kostecki. (1989) "How Much Soil Do Young Children Ingest: An Epidemiological Study", Regulatory Toxicology and Pharmacology, 10:123-137.

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3.3.2 INHALATION PATHWAY

Evaluating the impact of inhaled resuspended contaminated soil (IRCS) involves several factors which can vary significantly depending on the circumstances. In order to determine the impact of the IRCS pathway, it was necessary to account for all the parameters involved and then use parameter values that are reasonably representative of situations commonly encountered. After reviewing the various models for determining resuspension of deposited contaminated soil, it was determined that the Mass Loading (ML) model was the most appropriate. The ML approach, in which an average value of the airborne dust concentration is specified on the basis of empirical data, eliminates the need to evaluate in detail the resuspension mechanism or the effective depth of the distribution layer. For this rule, the outdoor ML values for the residential and commercial scenario were 100 $\mu g/m^3$ and 200 $\mu g/m^3$ respectively as per the RESRAD default values listed in ANL/ES-160, DOE/CH/8901, "A Manual for Implementing Residual Radioactive Material Guidelines". This reference also provided values for indoor dust levels which were equal to 40% of the outdoor values.

The adult breathing rates used for the residential and commercial scenarios were taken from the EPA report on Risk Assessment Guidance For Superfund Value I: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors" Interim Final, March 25, 1991. According to the Project Manager and Technical Coordinator for EPA's Office of Emergency and Remedial Response Toxics Integration Branch, the breathing rates for an adult, whether in a residential or commercial setting, were basically the same, $\approx 18m^3$/day. This value was rounded out to $20m^3$/day or 0.83 m^3/hour. Of the total quantity of dust particles inhaled, only about 30% are actually respired according to Cowherd, et. al. (C. Cowherd, G. Muleski, P. Englehart and G. Gillette. Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites. EPA Control No. 68-01-6861. U.S. Environmental Protection Agency, Washington, DC, 1968). Of the material not respired, a portion is swallowed and ingested according to Dennis J. Paustenbach, about 25% of the total quantity of dust particles inhaled is eventually ingested. (Dennis J. Paustenbach, "A Comprehensive Methodology for Assessing the Risks to Humans and Wildlife Posed by Contaminated Soils: A Case Study Involving Dioxin").

The quantity of material inhaled or ingested is a function of the time individuals spend in a given environment. According to "USNRC Policy and Guidance Directive PG-0-08" people spend 1.75 hours/day out of doors on the job and 2.4 hours/day out of doors while at their residence and, the "USEPA Exposure Factor Handbook" reports that people spend 7.0 hours/day indoors on the job and 16.4 hours/day indoors while at their residence. Also, according to the Risk Assessment Guidance for Superfund: Volume 1, "Human Health Evaluation Manual" (Part B, Development of Risk - Based on Preliminary Remediation Goals) Interim; EPA/540/R-

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92/003, December 1991, people spend 350 days per year at their residence and 250 days per year on the job.

The dose a person receives is calculated by multiplying the total quantity of radioactive material inhaled and ingested by the appropriate dose conversion factors listed in Federal Guidance 11. The values described above have been plugged into the following formulas to arrive at the tables of dose conversion factors for the commercial and residential scenarios.

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Inhalation (Respirable) Pathway Doses
Resulting from Soil Resuspension
Residential Scenario

Equation:

$$DR = V \times \frac{1}{DE} \times C \times [BA \times RP \times RY]$$

$$\times MO$$

$$\times [TO + IT \times ID]$$

$$\times DCR \times AF \times 10^{-6}\ g/\mu g$$

$$DR = 0.0784\ \frac{DCR \times V \times C}{DE}$$

Where the terms in the equation are defined as follows:

DR - Respirable Inhalation Dose (mrem/yr)
V - Vertical depth of contaminated soil (in ft.)
DE - Excavation depth during construction = (7 ft. for basement; 4' for slab on grade)
C - Concentration of radionuclide in contaminated soil = (pCi/g)
BA - Breathing rate of adult (upper bound) = (0.83 m^3/hr) [ref. 1]
RP - Respirable portion of material inhaled = (30%) [ref. 2]
RY - Residence days per year = (350 days/yr) [ref. 3]
MO - Outdoor Mass Loading = (100 $\mu g/m^3$) [ref. 4]
TO - Outdoor Time per day = (2.4 hr/day) [ref. 5]
TI - Indoor Time per day = (16.4 hr/day) [ref. 6]
ID - Indoor Dust Level as a percent of outdoor level = (40%) [ref. 7]
DCR - Dose Conversion Factor for inhaled(mrem/pCi) [ref. 8]
AF - Area Factor, this has not been experimentally tested; the accuracy and range of the values in this factor are not known, therefore = (1.0) [ref. 9].

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References:

1. Risk Assessment Guidance for Superfund: Volume 1, "Human Health Evaluation Manual (Part A). SUPPLEMENTAL GUIDANCE "STANDARD DEFAULT EXPOSURE FACTORS" INTERIM FINAL

2. C. Cowherd, G. Muleski, P. Englehart and G. Gillette. Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites. EPA Control No. 68-01-6861. U.S. Environmental Protection Agency, Washington, DC, 1968.

3. Risk Assessment Guidance for Superfund: Volume 1, "Human Health Evaluation Manual" (Part B, Development of Risk - Based on Preliminary Remediation Goals) Interim; EPA/540/R-92/003, December 1991.

4. RESRAD default value "A Manual for Implementing Residual Radioactive Material Guidelines" ANL/ES-160, DOE/CH/8901.

5. USNRC Policy and Guidance Directive PG-0-08.

6. USEPA Exposure Factors Handbook.

7. RESRAD default value, see ref. 4 above.

8. Federal Guidance 11.

9. See ref. 4 above.

Inhalation (Not Respired, but Ingested) Pathway Doses Resulting from Soil Resuspension Residential Scenario

Equation:

$$DI = V \times \frac{1}{DE} \times C \times [BA \times IP \times RY]$$

$$\times MO$$

$$\times [TO + TI \times ID]$$

$$\times DCI \times AF \times 10^{-6}\ g/\mu g$$

$$DI = 0.0653 \frac{DCI \times V \times C}{DE}$$

Where the terms in the equation are defined as follows:

DI - Ingestible Inhalation Dose (mrem/yr)
V - Vertical depth of contaminated soil (in ft.)
DE - Excavation depth during construction = (7 ft. for basement; 4' for slab on grade)
C - Concentration of radionuclide in contaminated soil = (pCi/g)
BA - Breathing rate of adult (upper bound) = (0.83 m^3/hr) [ref. 1]
IP - Ingested portion of material inhaled, not respired = (25%) [ref. 2]
RY - Residence days per year = (350 days/yr) [ref. 3]
MO - Outdoor Mass Loading = (100 $\mu g/m^3$) [ref. 4]
TO - Outdoor Time per day = (2.4 hr/day) [ref. 5]
TI - Indoor Time per day = (16.4 hr/day) [ref. 6]
ID - Indoor Dust Level as a percent of outdoor level = (40%) [ref. 7]
DCI - Dose Conversion Factor for ingested(mrem/pCi) [ref.8]
AF - Area Factor, this has not been experimentally tested; the accuracy and range of the values in this factor are not known, therefore = (1.0) [ref. 9].

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References:

1. Risk Assessment Guidance for Superfund: Volume 1, "Human Health Evaluation Manual (Part A). SUPPLEMENTAL GUIDANCE "STANDARD DEFAULT EXPOSURE FACTORS" INTERIM FINAL

2. Dennis J. Paustenbach, "A Comprehensive Methodology for Assessing the Risks to Humans and Wildlife Posed by Contaminated Soils: A Case Study Involving Dioxin".

3. Risk Assessment Guidance for Superfund: Volume 1, "Human Health Evaluation Manual" (Part B, Development of Risk - Based on Preliminary Remediation Goals) Interim; EPA/540/R-92/003, December 1991.

4. RESRAD default value "A Manual for Implementing Residual Radioactive Material Guidelines" ANL/ES-160,DOE/CH/8901.

5. USNRC Policy and Guidance Directive PG-0-08.

6. USEPA Exposure Factors Handbook.

7. RESRAD default value, see ref. 4 above.

8. Federal Guidance 11.

9. See ref. 4 above.

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Table 3-6
halation Respirable, Ingestion and Combination Pathway Dose Factors (DF) f
Soil Resuspension Residential Scenario
(mrem/yr per pCi/gm)

Decay Chain U-238		xxxxxxxxxxxxxx DOSE FACTORS xxxxxxxxxx		
		Respirable +	Ingestion =	Combinati
Subchain: Radionuclides				
	U-238	0.00925	-	0.009274
	Th-234	-	-	-
	Pa-234	-	-	-
U-238 + D		0.00925	-	0.00927
	U-234	0.0103	-	0.01032
U-238 + D + U-234		0.0196	-	0.0196
	Th-230	0.0256	-	0.0256
	Ra-226	0.000673	-	0.000759
	Rn-222	-	-	-
	Po-218	-	-	-
	Pb-214	-	-	0.000001
	Bi-214	-	-	0.000001
	Po-214	-	-	-
Ra-226 + D		0.000674	-	0.000760
	Pb-210	0.00107	0.00035	0.00142
	Bi-210	-	-	-
	Po-210	0.000737	0.000124	0.000861
	Pb-206	-	-	-
Pb-210 + D		0.00182	0.000474	0.00230
Ra-226 + D + Pb-210 + D		0.00249	0.000560	0.00306
Th-230 → Pb-210 + D		0.0281	0.000596	0.0287
U-234 → Pb-210 + D		0.0384	0.000632	0.0390
U-238 → Pb-210 + D		0.0477	0.000649	0.0483

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Table 3-6(cont.)

Inhalation Respirable, Ingestion and Combination Pathway Dose Factors (DF) f
Soil Resuspension Residential Scenario
(mrem/yr per pCi/gm)

Decay Chain U-235		xxxxxxxxxxxxxxxx DOSE FACTORSxxxxxxxxx		
		Respirable +	Ingestion =	Combinatic
Subchain:	Radionuclides			
	U-235	0.00964	-	0.00966
	Th-231	-	-	-
U-235 + D		0.00964	-	0.00966
	Pa-231	0.100	0.000692	0.101
	Ac-227	0.525	-	0.526
	Th-227	0.00127	-	0.00127
	Ra-223	0.000615	0.00004	0.000658
	Rn-219	-	-	-
	Po-215	-	-	-
	Pb-211	-	-	-
	Bi-211	-	-	-
	Tl-207	-	-	-
	Pb-207	-	-	-
Ac-227 + D		0.527	0.000967	0.528
Pa-231 + Ac-227 + D		0.627	0.00166	0.629
U-235 + D → Ac-227 + D		0.637	0.00168	0.639

Table 3-6 (cont.)
nhalation Respirable, Ingestion and Combination Pathway Dose Factor (DF) fo
Soil Resuspension Residential Scenario
(mrem/yr per pCi/gm)

Decay Chain Th-232		xxxxxxxxxxxxxx DOSE FACTORS xxxxxxxxxxx Respirable	+ Ingestion	= Combination
Subchain:	Radionuclides			
	Th-232	0.129	0.000178	0.129
	Ra-228	0.000374	-	0.000467
	Ac-228	-	-	-
Ra-228 + D		0.000398	-	0.000491
	Th-228	0.0268	-	0.0268
	Ra-224	0.000248	-	0.000272
	Rn-220	-	-	-
	Po-216	-	-	-
	Pb-212	-	-	-
	Bi-212	-	-	-
	Po-212	-	-	-
	Tl-208	-	-	-
	Pb-208	-	-	-
Th-228 + D		0.0271	-	0.0271
Th-232 → Th-228 + D		0.156	0.000324	0.157

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Inhalation (Respirable) Pathway Doses Resulting from Soil Resuspension Non-Residential Scenario

Equation:

$$\text{Dose (mrem/yr)} = V \times \frac{1}{DE} \times C \times [BA \times RP \times WY]$$

$$\times\ MO$$

$$\times\ [WO + WI \times ID]$$

$$\times\ DCR \times AF \times 10^{-6}\ g/\mu g$$

$$\text{Dose (mrem/yr)} = 0.0569\ \frac{DCR \times V \times C}{DE}$$

Where the terms in the equation are defined as follows:

V - Vertical depth of contaminated soil (in ft.)
DE - Excavation depth during construction = (7 ft. for basement; 4 ft. for slab on grade)
C - Concentration of radionuclide in contaminated soil = (pCi/g)
BA - Breathing rate of average adult performing moderate activities = (0.83 m^3/hr) [ref. 1]
RP - Respirable portion of material inhaled = (30%) [ref. 2]
WY - Work days per year = (250 days/yr) [ref. 3]
MO - Outdoor Mass Loading = (200 $\mu g/m^3$) [ref. 4]
WO - Outdoor Work per day = (1.75 hr/day) [ref. 5]
WI - Indoor Work per day (7.0 hr/day) [ref. 6]
ID - Indoor Dust Level as a percent of outdoor level = (40%) [ref. 7]
DCR - Dose Conversion Factor for inhaled(mrem/pCi) [ref. 8]
AF - Area Factor, this has not been experimentally tested; the accuracy and range of the values in this factor are not known, therefore = (1) [ref. 9].

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References:

1. Risk Assessment Guidance for Superfund: Volume 1, "Human Health Evaluation Manual (Part A). SUPPLEMENTAL GUIDANCE "STANDARD DEFAULT EXPOSURE FACTORS" INTERIM FINAL

2. C. Cowherd, G. Muleski, P. Englehart and G. Gillette. Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites. EPA Control No. 68-01-6861. U.S. Environmental Protection Agency, Washington, DC, 1968.

3. Risk Assessment Guidance for Superfund: Volume 1, "Human Health Evaluation Manual" (Part B, Development of Risk - Based on Preliminary Remediation Goals) Interim; EPA/540/R-92/003, December 1991.

4. RESRAD default value "A Manual for Implementing Residual Radioactive Material Guidelines" ANL/ES-160, DOE/CH/8901.

5. DOE Analysis at Maywood, New Jersey.

6. DOE Analysis at Maywood, New Jersey.

7. NCRP Report 76 and RESRAD default value, see ref. 4 above.

8. Federal Guidance 11.

9. See ref. 4 above.

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Inhalation (Not Respired, but Ingested) Pathway Doses Resulting from Soil Resuspension Non-Residential Scenario

Equation:

$$\text{Dose (mrem/yr)} = V \times \frac{1}{DE} \times C \times [BA \times IP \times WY]$$

$$\times\ MO$$

$$\times\ [WO + WI \times ID]$$

$$\times\ DCI \times AF \times 10^{-6}\ g/\mu g$$

$$\text{Dose (mrem/yr)} = 0.0474\ \frac{DCI \times V \times C}{DE}$$

Where the terms in the equation are defined as follows:

V - Vertical depth of contaminated soil (in ft.)
DE - Excavation depth during construction = (7 ft. for basement; 4 ft. for slab on grade)
C - Concentration of radionuclide in contaminated soil = (pCi/g)
BA - Breathing rate of average adult performing moderate activities = (0.83 m^3/hr) [ref. 1]
IP - Ingested portion of material inhaled, not respired = (25%) [ref. 2]
WY - Work days per year = (250 days/yr) [ref. 3]
MO - Outdoor Mass Loading = (200 $\mu g/m^3$) [ref. 4]
WO - Outdoor Work per day = (1.75 hr/day) [ref. 5]
WI - Indoor Work per day (7.0 hr/day) [ref. 6]
ID - Indoor Dust Level as a percent of outdoor level = (40%) [ref. 7]
DCI - Dose Conversion Factor for ingested(mrem/pCi) [ref. 8]
AF - Area Factor, this has not been experimentally tested; the accuracy and range of the values in this factor are not known, therefore = (1.0) [ref. 9].

References:

1. Risk Assessment Guidance for Superfund: Volume 1, "Human Health Evaluation Manual (Part A). SUPPLEMENTAL GUIDANCE "STANDARD DEFAULT EXPOSURE FACTORS" INTERIM FINAL

2. Dennis J. Paustenbach, "A Comprehensive Methodology for Assessing the Risks to Humans and Wildlife Posed by Contaminated Soils: A Case Study Involving Dioxin".

3. Risk Assessment Guidance for Superfund: Volume 1, "Human Health Evaluation Manual" (Part B, Development of Risk - Based on Preliminary Remediation Goals) Interim; EPA/540/R-92/003, December 1991.

4. RESRAD default value "A Manual for Implementing Residual Radioactive Material Guidelines" ANL/ES-160,DOE/CH/8901.

5. USNRC Policy and Guidance Directive PG-0-08.

6. USEPA Exposure Factors Handbook.

7. RESRAD default value, see ref. 4 above.

8. Federal Guidance 11.

9. See ref. 4 above.

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Table 3-7
Inhalation Respirable, Ingestion and Combination Pathway Dose Factors (DF) for Soil Resuspension Non-Residential Scenario
(mrem/yr per pCi/gm)

Decay Chain U-238		xxxxxxxxxxxxxx DOSE FACTORS xxxxxxxxxxx		
		Respirable +	Ingestion =	Combination
Subchain:	Radionuclides			
	U-238	0.00671	-	0.00672
	Th-234	0	-	0.000003
	Pa-234	-	-	-
U-238 + D		0.00671	-	0.00672
	U-234	0.00751	-	0.00752
U-238 + D + U-234		0.0142	-	0.0142
	Th-230	0.0185	-	0.0185
	Ra-226	0.000488	-	0.000551
	Rn-222	-	-	-
	Po-218	-	-	-
	Pb-214	-	-	-
	Bi-214	-	-	-
	Po-214	-	-	-
Ra-226 + D		0.000489	0.000063	0.000552
	Pb-210	0.000774	0.000254	0.00103
	Bi-210	-	-	0.000012
	Po-210	0.000535	-	0.000625
	Pb-206	-	-	-
Pb-210 + D		0.00132	0.000344	0.00167
Ra-226 + D + Pb-210 + D		0.00181	0.000407	0.00222
Th-230 → Pb-210 + D		0.0203	0.000433	0.0207
U-234 → Pb-210 + D		0.0278	0.000446	0.0282
U-238 → Pb-210 + D		0.0345	0.000460	0.0350

Table 3-7 (cont.)
Inhalation Respirable, Ingestion and Combination Pathway Dose Factors (DF) fo
Soil Resuspension Non-Residential Scenario
(mrem/yr per pCi/gm)

Decay Chain U-235		xxxxxxxxxxxxxx DOSE FACTORS xxxxxxxxxxx Respirable	+ Ingestion	= Combination
Subchain:				
Radionuclides				
	U-235	0.00700	0.000013	0.00701
	Th-231	-	-	-
U-235 + D		0.00700	0.000013	0.00701
	Pa-231	0.0728	0.000502	0.0733
	Ac-227	0.381	0.000668	0.382
	Th-227	0.000921	0.000002	0.000923
	Ra-223	0.000446	0.000031	0.000477
	Rn-219	-	-	-
	Po-215	-	-	-
	Pb-211	-	-	-
	Bi-211	-	-	-
	Tl-207	-	-	-
	Pb-207	-	-	-
Ac-227 + D		0.382	0.000701	0.383
Pa-231 + Ac-227 + D		0.4548	0.00120	0.456
U-235 → Ac-227 + D		0.462	0.00121	0.463

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Table 3-7 (cont.)
Inhalation Respirable, Ingestion and Combination Pathway Dose Factors (DF) for Soil Resuspension Non-Residential Scenario
(mrem/yr per pCi/gm)

Decay Chain Th-232		xxxxxxxxxxxxxxx DOSE FACTORS xxxxxxxxxxx		
		Respirable +	Ingestion =	Combination
Subchain:				
Radionuclides				
	Th-232	0.0933	0.000129	0.0934
	Ra-228	0.000271	0.000068	0.000339
	Ac-228	0.000018	-	0.000018
Ra-228 + D		0.000289	0.000068	0.000357
	Th-228	0.0195	0.000019	0.0195
	Ra-224	0.000180	0.000017	0.000197
	Rn-220	-	-	-
	Po-216	-	-	-
	Pb-212	0.000010	0.000002	0.000012
	Bi-212	0.000001	-	0.000001
	Po-212	-	-	-
	Tl-208	-	-	-
	Pb-208	-	-	-
Th-228 + D		0.0197	0.000038	0.0197
Ra-228 + D + Th-228 + D		0.0200	0.000106	0.0201
Th-232 → + Th-228 + D		0.113	0.000235	0.113

3.3.3 DRINKING WATER PATHWAY

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The drinking water component of the ingestion dose was evaluated by assuming the groundwater pathway is the primary route by which radioactive contaminants can potentially reach drinking water. Surface water pathways result in greater dilution than the groundwater pathway. Therefore, it is conservative to assume that all residual contamination is susceptible to processes involved in the groundwater pathway. Conceptually, the groundwater pathway refers to the following scenario:

1.) contaminants in the soil leach into water as it percolates through the contamination zone;
2.) contaminants travel through the unsaturated zone to an aquifer, where they are susceptible to saturated transport processes;
3.) a well is eventually placed in the aquifer directly under the residual contamination, providing a primary source of drinking water.

The expectation under S-1070 is that generic cleanup standards be developed for application to any site in New Jersey. Furthermore, while the standards are specific to each radionuclide subchain, they are expected under S-1070 to be applied to any chemical form in which the radionuclides may be found. The expectations of generic standards pose some difficulty, since leach and transport rates are strongly influenced by the physicochemical properties of both the contamination and the soil.

In order to overcome the difficulties inherent in developing generic cleanup standards, a conservative bounding approach was used to assess the groundwater pathway. The approach estimated the maximum groundwater contamination that could reasonably be expected over a wide range of site characteristics and chemical forms of contamination. Care was taken in the development of these standards to avoid "redundant conservatism." Groundwater concentration to soil concentration ratios, as well as dose to soil concentration ratios, were developed for each radionuclide subchain. Given current knowledge regarding leach and transport processes for near surface contamination, it is expected that groundwater contamination and resultant doses for most sites in New Jersey would not exceed the ratios developed for this application. While a quantitative modeling tool was used to derive groundwater to soil concentration ratios as well as dose to soil concentration ratios, professional judgment also played a critical role in assessing the groundwater pathway.

Regulatory Aspects

Dose to soil radionuclide concentration ratios for the groundwater pathway may be used to estimate whether the concentrations of residual radionuclides in the soil will result in exposure that exceeds the allowed background dose variation for gamma and intake. New Jersey Groundwater Criteria also require that such concentrations not cause the groundwater to exceed the Maximum Contaminant Levels (MCLs) specified in the U.S. Safe Drinking Water Act. Therefore, the groundwater pathway was assessed relative to both the currently applicable Interim Drinking Water Standards (40CFR141.15-16) and the Proposed Drinking Water Standards. The following table compares the MCLs from the Interim and Proposed Standards:

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INTERIM VS. PROPOSED MAXIMUM CONTAMINANT LEVELS	
Interim	Proposed
Ra226+Ra228 ≤ 5 pCi/l	Ra226 ≤ 20 pCi/l
	Ra228 ≤ 20 pCi/l
	Rn222 ≤ 300 pCi/l
	Uranium < 30 pCi/l (20 mg/l)
man-made beta/photon emitters ≤ 4 mrem/yr.	beta/photon emitters (excl. Ra228) ≤ 4 mrem/yr.
gross alpha (incl. Ra226; excl. Rn, U) ≤ 15 pCi/l	gross alpha (excl. Ra226, U, Rn222) ≤ 15 pCi/l

The beta/photon and gross alpha groups are defined differently in the proposed MCLs than in the interim MCLs. While most of the NORM MCLs will be higher if the proposed standards are promulgated, uranium and radon will have new MCLs. Interim standards only regulate uranium inasmuch as U238 produces Ra226 as a distant progeny. Each MCL was evaluated separately for each subchain to obtain maximum permissible soil concentrations. The most limiting soil concentration for each subchain was identified.

Methodology

A semi-analytical model, GWSCREEN Version 2.03 (Rood, 1994), was used to estimate the groundwater activity concentrations and ingestion doses resulting from near surface contamination. GWSCREEN was developed to assess the groundwater pathway from leaching of radioactive and non-radioactive substances from surface or buried sources. The model makes several simplifying assumptions that are designed to assess the groundwater pathway when field data are limited. A mass balance approach was used to model three processes: contaminant release from a source volume, contaminant transport in the unsaturated zone, and contaminant transport in the saturated zone. Contaminant transport in the saturated zone was minimized by placing the drinking water well under the source material at the point of discharge from the unsaturated zone to the aquifer. Committed Effective Dose Equivalent was then calculated from the resultant well water concentrations.

Release from the source volume was modeled as a first-order leaching process that accounts for decay and sorption (distribution between solid and liquid media). Solubility-limited release was assumed to be negligible. This assumption is accurate for diffuse waste and conservative for more concentrated sources. Site parameters important to the leaching model include net water percolation rate (m/yr), volumetric moisture content and bulk density of source volume, thickness of source volume, and contaminant half-life (years). A sorption coefficient (also called distribution coefficient, ml/g) was assumed for each subchain.

Dispersion in the unsaturated zone was assumed to be negligible, leaving a simple plug-flow model. As long as the transport time in the unsaturated zone is less than ten times the half-life of the contaminant, dispersion will have the effect of lowering the peak concentration slightly. Therefore, it is conservative to consider dispersion negligible. The thickness of the unsaturated zone was reduced when necessary to [illegible] the condition of the transit time being less than ten times the half-life of the contaminant. Contaminant flux to the aquifer was obtained by calculating the fraction of activity that remains after transit through the unsaturated zone. Site parameters important to the unsaturated transport model include thickness of unsaturated zone (distance from base of source volume to top of aquifer, m), percolation rate (m/yr), volumetric moisture content, and bulk density in the unsaturated zone. Sorption coefficients were assumed to be the same as in the source volume for each subchain.

Assuming uniform steady flow in homogeneous isotropic media, the advection-dispersion equation for contaminant transport in saturated soil was approximated using an analytical solution. The activity concentration in the aquifer at some point downgradient from the center of the area source was solved in terms of Green's functions and vertically averaged over the well screen thickness. Aquifer parameters important to the saturated transport model include groundwater pore velocity (m/yr), dispersivity (m), effective porosity (m^3/m^3), well screen thickness, and bulk density. Sorption coefficients for each subchain were assumed to be the same in the aquifer as in the source volume and unsaturated zone.

The concentration of individual progeny in a decay chain was calculated as a function of the parent concentration. Partitioning differences (as reflected in the sorption coefficients) among progeny were taken into account. Decay-ingrowth factors were calculated based on the decay constants of the parent and progeny.

Assumptions

A number of simplifying assumptions are implicit in the code (GWSCREEN) used to make calculations for the groundwater pathway analyses. For instance, the contaminant is assumed to be homogeneously mixed in a finite volume, and a constant infiltration rate is assumed. Recall that the code is not a predictive tool, but is intended to provide bounding calculations when field data are limited. For more information on the uses and limitations of GWSCREEN, refer to Rood (1994).

The peak concentrations calculated to occur between 1-1,000 years were used for all analyses. Even conservative bounding calculations become tenuous when carried out over long periods of time. Therefore it was decided to limit the calculations to 1,000 years. Practically, this decision affected results for four subchains. The Thorium subchains (Th230 and Th232) were calculated to take over 5,000 years to move through ½ meter of unsaturated soil. Consequently, none of the Thorium had reached the aquifer after the 1,000 year calculations. Also, Ra226+D and Pa231 had not reached their peak concentrations, having transit times calculated to be 800 and 900 years, respectively. The long transit times of these four contaminants reflects their strong tendency to sorb onto soil instead of desorbing into water. Other pathways will remove the residual contamination from these subchains substantially over the course of a millennium. To calculate peak concentration from the groundwater pathway over long periods of time without considering other removal processes would unreasonably overestimate the drinking water component. Since uncertainties preclude quantifying such loss mechanisms, it is reasonably conservative to calculate peak concentrations from 1-1,000 years.

Though the simplifying assumptions in GWSCREEN are intended to yield conservative bounding approximations, the degree of conservatism depends great part on the input parameters used in the analyses. The table be...

lists the generic site input parameters. The unsaturated zone was assumed to extend only ½ meter below the contaminated soil. The combination of relatively slow pore velocity in the aquifer and small well screen thickness ensures conservatism for most New Jersey sites. The drinking water well was assumed to be placed in the aquifer directly under the contaminated soil.

GENERIC SITE INPUT PARAMETERS	
Dimensions of contaminated zone, LxWxD (m)	100x100x 1
Percolation rate (vertical Darcy velocity, m/yr)	0.5
Volumetric water content in contaminated zone (m3/m3)	0.35
Volumetric water content in unsaturated zone (m3/m3)	0.2
Bulk density of contaminated zone (g/cm3)	1.6
Bulk density of unsaturated zone (g/cm3)	1.6
Bulk density of saturated zone (g/cm3)	1.6
Unsaturated zone thickness (distance from bottom of source to aquifer, m)	0.5
Porosity of aquifer	0.45
Longitudinal dispersivity in aquifer (m)	2.25
Transverse dispersivity in aquifer (m)	1
Pore velocity in aquifer (m/yr)	4
Well screen thickness (mixing depth, m)	10
Horizontal distance to well (m)	0

Subchains in each of the three naturally occurring radioactive material (NORM) decay series were evaluated as if they decayed directly into one another. For instance, the Uranium decay series was simplified as follows: U238+D→U234→Th230→Ra226+D→Pb210+D→Pb206. Progeny of each subchain parent were assumed to be in secular equilibrium with the parent subchain. Assumptions specific to each subchain are listed in the table below. Sorption coefficients (also called distribution coefficients) were taken from the geometric mean of typical sorption coefficients in sand, as found in Table 32.1 of the Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil (Yu et al, 1993, pp.105-106). Sorption coefficients represent the tendency of a contaminant to remain bound (sorbed) in the soil; the lower the sorption coefficient, the greater tendency has the contaminant to leach (desorb) into the groundwater. Sorption coefficients vary greatly with chemical form and site characteristics such as soil type. Using the geometric mean for sand provides a conservative sorption coefficient relative to the range observed over many soil types and conditions. Dose conversion factors, taken from Federal Guidance 11, were summed for all progeny in each subchain. This approach is consistent with the assumption of secular equilibrium.

SUBCHAIN SPECIFIC INPUT					
Subchain	Sorption coefficients (ml/g)	Dose Conversion Factor (mrem/pCi)	Dose Conversion Factor for Beta/Photon (mrem/pCi)	Interim Alpha Multiplier	Proposed Alpha Multiplier
U238+D	35	2.70E-04	1.58E-05	0	0
U234	35	2.83E-04	0.00E+00	0	0
Th230	3,200	5.48E-04	0.00E+00	1	1
Ra226+D	500	1.32E-03	9.08E-07	3	2
Pb210+D	270	7.27E-03	5.37E-0	1	1
U235+D	35	2.67E-04	1.35E-06	0	0
Pa231	550	1.06E-02	0.00E+00	1	1
Ac227+D	450	1.48E-02	1.41E-02	4.01	5.01
Th232	3,200	2.73E-03	0.00E+00	1	1
Ra228+D	500	1.43E-03	2.16E-06	0	0
Th228+D	3,200	8.09E-04	4.66E-05	4	5

In order to evaluate each subchain relative to the Interim and Proposed Drinking Water standards, three new inputs were developed. While the interim MCL for beta/photon emitters excludes all NORM, the proposed MCL for beta/photon emitters excludes only Ra228. Beta/photon dose conversion factors for each subchain were obtained by adding the dose conversion factors of beta/photon emitting progeny (except Ra228). Similarly, alpha multipliers were developed to calculate the gross alpha based on the concentration of each subchain parent. Assuming secular equilibrium with each subchain, the gross alpha may be obtained by multiplying each subchain parent concentration by the number of alpha emitters in the subchain. When multiplied by the groundwater concentration for each subchain, the alpha multipliers provide the gross alpha concentration as defined by the interim and proposed standards. For instance, the gross alpha from Ra226+D is three times the Ra226 concentration for the interim standard and two times the Ra226 concentration for the proposed standard. The interim standard for gross alpha includes Ra226, Po218, and Po214; the proposed standard for gross alpha includes only Po218 and Po214. Since subchains decay into one another within a series, an alpha multiplier of zero does not necessarily mean a subchain does not contribute to gross alpha. For instance, while the interim alpha multiplier for U235+D is zero, U235+D will contribute to the interim gross alpha because it decays into Pa231. Gross alpha concentration to soil concentration ratios were calculated by multiplying the concentration of the parent subchain and subsequent subchain concentrations by their respective alpha multipliers, and then adding alpha concentrations together.

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According to New Jersey Groundwater Criteria, MCLs are applied as fixed limits rather than increments. In other words, the residual contamination must not leach into the groundwater to such an extent that existing groundwater contaminant levels are pushed over the MCLs. In order to calculate limiting soil concentrations, background groundwater contaminant levels had to be assumed. The table below lists the background groundwater contaminant levels assumed for contaminants for which MCLs were specified in the interim or proposed standards.

BACKGROUND CONTAMINANT LEVELS		
Contaminant	Background	Units
U238+D	2.70E-01	pCi/l
U234	7.20E-01	pCi/l
Ra226+D	4.00E-01	pCi/l
U235+D	0.00E+00	pCi/l
Ra228+D	7.00E-01	pCi/l
Interim gross alpha	3.10E+00	pCi/l
Proposed gross alpha	2.70E+00	pCi/l
proposed beta/photon	4.00E-01	mrem/yr

Dose calculations were performed by placing a hypothetical drinking water well directly under the area of residual contamination. Residential scenario calculations assumed 2 liters/day intake for 350 days/year, while non-residential scenario calculations assumed 1 liter/day intake for 250 days/year.

Results

Results in the Table 3-8 are expressed as groundwater to soil concentration ratios and dose to soil concentration ratios, the latter being given for both residential and commercial scenarios. It should be noted that even using a conservative generic methodology, four of the subchains (Pb210+D, Ac227+D, Ra228+D, and Th228+D) were estimated to decay to stable forms before they reach the groundwater. Table 3-9 presents dose to soil concentration ratios for various vertical extents of contamination. Notice that vertical extent of contamination affects dose to soil concentration ratios differently for different subchains.

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Table 3-8: CALCULATED RATIOS*				
Subchain	[Groundwater] (pCi/l) to [Soil] (pCi/g) Ratio	Dose (mrem/yr) to [Soil] (pCi/g) Ratio		Peak Time (yr)
		Residential	Commercial	
U238+D	2.83E+00	5.35E-01	1.91E-01	759
U234	2.82E+00	5.61E-01	2.00E-01	752
Th230	NONE IN AQUIFER AFTER 1000 YEARS			30,500**
Ra226+D	1.51E-02	1.58E-01	5.66E-02	2,230**
Pb210+D	DECAYS OUT			n/a
U235+D	2.83E+00	5.78E-01	2.06E-01	759
Pa231	1.17E-02	2.35E-01	8.39E-02	6,980**
Ac227+D	DECAYS OUT			n/a
Th232	NONE IN AQUIFER AFTER 1000 YEARS			68,900**
Ra228+D	DECAYS OUT			n/a
Th228+D	DECAYS OUT			n/a

*Vertical extent of contamination = 1m; Depth to saturated zone = 0.5m
**For peak times greater than 1,000 years, maximum dose between 1-1,000 years is used
[Groundwater], [Soil] = groundwater concentration, soil concentration

Table 3-9: DOSE (mrem/yr) to SOIL (pci/g) RATIOS for VARIOUS VERTICAL EXTENTS of CONTAMINATION (v)*						
Subchain	V = 1 ft.	V = 3 ft.	V = 5 ft.	V = 6 ft.	V = 7 ft.	V = 9 ft.
U238+D	1.64E-01	4.90E-01	8.08E-01	9.61E-01	1.11E+00	1.39E+00
U234	1.71E-01	5.13E-01	8.46E-01	1.01E+00	1.16E+00	1.46E+00
Th230	NONE IN AQUIFER AFTER 1000 YEARS					
Ra226+D	1.38E-01	1.57E-01	1.62E-01	1.63E-01	1.64E-01	1.65E-01
Pb210+D	DECAYS OUT					
U235+D	1.72E-01	5.27E-01	8.83E-01	1.06E+00	1.22E+00	1.55E+00
Pa231	2.17E-01	2.35E-01	2.38E-01	2.39E-01	2.39E-01	2.40E-01
Ac227+D	DECAYS OUT					
Th232	NONE IN AQUIFER AFTER 1000 YEARS					
Ra228+D	DECAYS OUT					
Th228+D	DECAYS OUT					

*Numbers given are for residential scenario: commercial = residential×0.357

Using the same generic approach, maximum soil concentrations were developed such that Interim (Table 3-10) and Proposed (Table 3-11) Drinking Water Standards would not reasonably be expected to be exceeded. Mean background contaminant levels in the groundwater were assumed in order to estimate maximum soil concentrations that would not contaminate groundwater above the Maximum Contaminant Levels specified in the U.S. Safe Drinking Water Act.

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Table 3-10: MAXIMUM SOIL CONCENTRATIONS FOR INTERIM DRINKING WATER STANDARDS						
Subchain	[Ra226+Ra228] (pCi/l) to [Soil] (pCi/g) Ratio	Limiting [Soil] (pCi/g) to meet 5 pCi/l [Groundwater] limit for Ra226+Ra228	[Alpha] (pCi/l) to [Soil] (pCi/g) Ratio	Limiting [Soil] (pCi/g) to meet 15 pCi/l [Alpha] Limit	Limiting [Soil] (pCi/g) to meet 4 mrem/yr Dose limit for man-made beta/photon emitters	Most Limiting [Soil] (pCi/g)
U238+D	1.48e-07	3.11e+07	9.15e-07	1.30e+07	N/A	1.30e+07
U234	1.97e-04	2.34e+04	1.14e-03	1.05e+04	N/A	1.05e+04
Th230	NONE IN AQUIFER AFTER 1000 YEARS				N/A	NO LIMIT
Ra226+D	1.51e-02	3.05e+02	7.37e-02	1.61e+02	N/A	1.61e+02
Pb210+D	N/A	N/A	DECAYS OUT		N/A	NO LIMIT
U235+D	N/A	N/A	1.45e-02	8.21e+02	N/A	8.21e+02
Pa231	N/A	N/A	6.91e-02	1.72e+02	N/A	1.72e+02
Ac227+D	N/A	N/A	DECAYS OUT		N/A	NO LIMIT
Th232	NONE IN AQUIFER AFTER 1000 YEARS				N/A	NO LIMIT
Ra228+D	DECAYS OUT				N/A	NO LIMIT
Th228+D	N/A	N/A	DECAYS OUT		N/A	NO LIMIT

Table 3-11: MAXIMUM SOIL CONCENTRATIONS FOR PROPOSED DRINKING WATER STANDARDS								
Subchain	Limiting [Soil] (pCi/g) to meet 30 pCi/g [U] limit	Limiting [Soil] (pCi/g) to meet 20 pCi/g [Ra226orRa228] limit	Limiting [Soil] (pCi/g) to meet 300 pCi/g [Rn222] limit*	[Alpha] (pCi/l) to [Soil] (pCi/g) Ratio	Limiting [Soil] (pCi/g) to meet 15 pCi/l [Alpha] Limit	Dose (mrem/yr) to [Soil] (pCi/g) Ratio for beta/photon	Limiting [Soil] (pCi/g) to meet 4 mrem/yr Dose limit	Most Limiting [Soil] (pCi/g)
U238+D	1.02e+01	1.32e+08	2.03e+09	7.67e-07	1.60e+07	3.13e-02	1.15e+02	1.02e+01
U234	1.03e+01	9.95e+04	1.52e+06	9.41e-04	1.31e+04	1.27e-03	2.83e+03	1.03e+01
Th230	NONE IN AQUIFER AFTER 1000 YEARS							NO LIMIT
Ra226+D	N/A	1.30e+03	1.99e+04	5.86e-02	2.10e+02	1.07e-01	3.37e+01	3.37e+01
Pb210+D	N/A	N\A	N\A	DECAYS OUT				NO LIMIT
U235+D	1.03e+01	N\A	N\A	1.75e-02	7.04e+02	3.21e-02	1.12e+02	1.03e+01
Pa231	N/A	N\A	N\A	8.34e-02	1.47e+02	1.41e-01	2.55e+01	2.55e+01
Ac227+D	N/A	N\A	N\A	DECAYS OUT				NO LIMIT
Th232	NONE IN AQUIFER AFTER 1000 YEARS							NO LIMIT
Ra228+D	N/A	DECAYS OUT	N\A	DECAYS OUT				NO LIMIT
Th228+D	N/A	N\A	N\A	DECAYS OUT				NO LIMIT

*Rn222 background is assumed to be 0 since actual mean background exceeds 300 pCi/l standard

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3.3.4 CROP INGESTION PATHWAY

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In order to determine the dose an individual will receive from eating vegetation which has been contaminated with radionuclides, something has to be known about the following: the concentration of the radionuclide in the soil in which the vegetation is grown, how much of the radionuclide is taken up by the vegetation and how much of the vegetation an individual eats. This particular pathway is not dependent on time spent on location but is based on the amount of vegetation which is grown at the location and consumed by individuals at the location. An example of a nonresidential scenario which would be appropriate for this pathway is a farm. The basic equation for calculating the dose an individual will receive from a unit intake of vegetation is:

$$DCF \cdot 44.2 \cdot B_{iv} \cdot C_{z2} \cdot \frac{v}{2.9} \cdot (.283 + 1) \cdot 1000$$

$$DCF \cdot B_{iv} \cdot C_{z2} \cdot v \cdot 19555 \qquad (1)$$

$$K \cdot C_{z2} \cdot v$$

where: DCF is the dose conversion factor

I is the amount of vegetation an individual consumes

B_{iv} is the amount of radionuclide which is transferred from the soil to the vegetation by root uptake

C is the radionuclide soil concentration.

This basic equation can be found in several publications.[2,3] The input values selected for each of these variables is discussed below.

SELECTION OF INPUTS

<u>Dose Conversion Factor</u>

Seven publications, dating 1979-1993, which contain dose

[2] Till, J.E. and R.E. Moore, 1988, "A Pathway Approach for Determining Acceptable Levels of Contamination of Radionuclides in Soil", Health Physics, 55 (3), 541-548.

conversion factors were reviewed.[2,3,4,5,6,7,8] These reports in turn cite six further references published over the period 1977-1988.[9,10,11,12,13,14] Table 3-12 shows that the dose conversion factor values presented in the reviewed publications are essentially the same except for those values reported in Kennedy and Peloquin (1990). The author of this publication was contacted and stated that they received many comments on the dose conversion factors which were presented in the report. Mr. Kennedy stated that the commentors pointed out that the dose factors presented in the paper were not presented in the normal manner in which dose factors are usually presented, i.e. dose conversion factors are normally given in millirem (mrem) per picoCurie (pCi); Kennedy and Peloquin 1990, presents the dose conversion factors in mrem per year per pCi per gram of soil. Therefore, it was decided that these values were inappropriate for use as inputs. It should be noted that subsequent to the initial literature review for dose conversion

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[3] International Commission on Radiological Protection, 1979, *Limits for Intakes of Radionuclides by Workers*, ICRP Publication 30, Part 1; Ann. ICRP 2(3/4).

[4] Eckerman, K.F., A.B. Wolbarst and A.C.B. Richardson, 1988, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, Federal Guidance Report No. 11, 225p.

[5] Gilbert, T.L., C. Yu, Y.C. Yuan, A.J. Zielen, M.J. Jusko and A. Wallo III, 1989, *A Manual for Implementing Residual Radioactive Material Guidelines*, UC-511.

[6] Kennedy, W.E. and R.A. Peloquin, 1990, *Residual Radioactive contamination from Decommissioning Technical Basis for Translating Contamination Levels to Annual - Draft Report for Comment*, NUREG/CR-5512//PNL-7212.

[7] Wang, Y.-Y., B.M Biwer and C. Yu, 1993, *A Compilation of Radionuclide Transfer Factors for the Plant, Meat, Milk and Aquatic Food Pathways and the Suggested Default Values for the RESRAD Code*, ANL/EAIS/TM-103.

[8] Kennedy, W.E. and J.L. Strenge, 1993, *Residual Radioactive Contamination From Decommissioning-Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent*, NUREG/CR-5512//PNL-7994.

[9] International Commission on Radiological Protection, 1977, *Recommendations of the International Commission on Radiological Protection*, ICRP Publication 26; Ann. ICRP 1(4).

[10] 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 50, Appendix 2*, Regulatory Guide 1.109, Office of Standards Development, Rev. 1, Washington, D.C., Oct.

[11] Oztunali, O.I., G.C. Re, P.M. Moskowitz, E.D. Picazo and C.J. Pitt, 1981, *Data Base for Radioactive Waste Management: Impacts Analyses Methodology Report, Vol. 3*, NUREG/CR-4370.

[12] Johnson, J.R. and D.W. Dunford, 1983, *Dose Conversion Factors for Intakes of Selected Radionuclides by Infants and Adults*, Atomic Energy of Canada Limited Report, AECL-7919.

[13] Corley, J.P. (ed.), 1986, "Committed Dose Equivalent Tables for U.S. Department of Energy Population Dose Calculations", Appendix C.

[14] U.S. Department of Energy, 1988, *Internal Dose Conversion Factors for Calculation of Dose to the Public*, DOE/EH-0071.

factors, Kennedy and Strenge (1993) was published. The dose conversion factors appearing in this publication are in good agreement with the values listed in the other six primary publications. The values in Kennedy and Strenge (1993) are included in Table 3-12 for comparison.

Table 3-12

Ingestion Dose Conversion Factors (mrem/pCi)

Radionuclide	ICRP 1979	Eckerman 1988	Till 1988	Gilbert, 1989 Wang, 1993	Kennedy[1] 1990	Zach 1991	Kennedy 1993
Th 228+D		4×10^{-4}		7.5×10^{-4}	1×10^{-1}		4×10^{-4}
Th 229+D	3.5×10^{-3}	3.5×10^{-3}		4.3×10^{-3}	4.3×10^{-1}	8.9×10^{-2}	3.5×10^{-3}
Th 230		5.5×10^{-4}		5.3×10^{-4}	4.2×10^{-1}		5.5×10^{-4}
Th 232		2.7×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.2		2.7×10^{-3}
Ra 226+D	1.2×10^{-3}	1.3×10^{-3}		1.1×10^{-3}	8.6×10^{-1}	1.2×10^{-3}	1.3×10^{-3}
Ra 228+D		1.4×10^{-3}	1.2×10^{-3}	1.2×10^{-3}	3.4×10^{-1}		1.4×10^{-3}
Pb 210+D		5.4×10^{-3}		6.7×10^{-3}	1.7		5.4×10^{-3}
U 238+D	2.3×10^{-4}	2.5×10^{-4}	2.3×10^{-4}	2.5×10^{-4}	7.3×10^{-3}	2.8×10^{-4}	2.5×10^{-4}
U 234		2.8×10^{-4}	2.6×10^{-4}	2.6×10^{-4}	1.3×10^{-2}		2.8×10^{-4}
U 235+D		2.7×10^{-4}	2.5×10^{-4}	2.5×10^{-4}	7×10^{-3}		2.7×10^{-4}

[1] These values are reported $\frac{\text{mrem/yr}}{\text{pCi/g of soil}}$

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Vegetative Intake

Eight publications, dating from 1987-1993, which contain values for vegetative intake were reviewed.[2,6,7,8,16,17,18,19] These reports in turn cite eight further references published over the period 1974-1989.[11,20,21,22,23,24,25,26,27] Table 3-13 shows that the vegetative intake values presented in the reviewed publications vary considerably. Although the primary publications report similar values for total consumption of a particular group of foods, they vary greatly on their estimates of the percentage of food consumed that is grown on contaminated soil. It seems unlikely that 100% of a persons diet would be homegrown (grown on contaminated soil), therefore a reasonable assumption of the percentage of consumed homegrown food must be ascertained.

EPA (1989a) is the only publication which attempts to provide

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[16] Center for Disease Control, 1987, "Health Assessment for Montclair, Glen Ridge and West Orange, N.J.".

[17] U.S. Environmental Protection Agency, 1989a, *Risk Assessment Methodology: Environmental Impact Statement NESHAPS for Radionuclides: Background Information Document - Volume 1*, EPA 520 1-89-005.

[18] U.S. Environmental Protection Agency, 1991a, *Risk Assessment Guidance for Superfund: Volume 1: Human Health Evaluation Manual Supplemental Guidance: Standard Default Exposure Factors: Interim Final*, OSWER Directive: 9285 6-03.

[19] U.S. Environmental Protection Agency, 1991b, *Risk Assessment Guidance for Superfund: Volume 1: Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals*, EPA/540/R-92/003.

[20] U.S. Department of Agriculture, 1974, *Food Consumption, Prices and Expenditures*, AER-138.

[21] Rupp, E.M., 1979, "Dietary Intake and Inhalation Rates, U_{ap}", in Hoffman, F.O. and C.F. Baes III (eds.), *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides* ORNL/NUREG/TM-282.

[22] U.S. Department of Agriculture, 1980, *Food and Nutrient Intakes of Individuals in One Day in the United States: Spring 1977: Nationwide Food Consumption Survey 1977-1978: Preliminary Report No. 2.*

[23] Pao, E.M., et al., 1982, *Foods Commonly Eaten by Individuals: Amount Per Day and Per Eating Occasion*, Home Economics Report No. 44, U.S. Department of Agriculture, Washington, D.C.

[24] Brodsky, A., 1982, *CRC Handbook of Environmental Radiation*, 475 p.

[25] U.S. Department of Agriculture, 1983, *Food Consumption: Households in the United States, Seasons, and Year 1977-1978*, Government Printing Office, Washington, D.C.

[26] U.S. Environmental Protection Agency, 1989b, *Exposure Factors Handbook*, EPA/600/8-89-043.

[27] Yu, C., C. Loureiro, J.-J. Cheng, L.G. Jones, Y.Y. Wang, Y.P. Chia and E. Faillace, 1993, "Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil", ANL/EAIS-8.

a logical justification for a particular vegetative intake value. This publication utilizes national survey data reported in USDA (1980) on the average amounts of total fruits and vegetables consumed on any one day.

Table 3-13

Vegetative Intake

Vegetation Type	CDC 1987	Till 1988	Gilbert, 1989 Wang, 1993	EPA 1989a	EPA 1991a,b	Kennedy 1990
Fruits, Vegetables and Grains	56 kg/yr	176 kg/yr	160 kg/yr	176 kg/yr	15 kg/yr	47.5 kg/yr
Leafy Vegetable		18 kg/yr	14 kg/yr	18 kg/yr	29.2 kg/yr	
Meat and Poultry		94 kg/yr	63 kg/yr			19.2 kg/yr
Milk		112 l/yr	92 l/yr			27.5 l/yr
Fish			5.4 kg/yr			
Crustaceans and Mollusks			.9 kg/yr			

It is not known how representative these estimates are of consumption during the entire year. It is known that consumption rates vary by region. Then information from USDA (1983) on the weight ratio of homegrown to total fruits and vegetables consumed was examined. These ratios vary from 0.1 to 0.7 for various types of vegetables and fruits and for the rural, city and suburban populations. The authors, of EPA (1989b), determined that the over-all average homegrown fraction for vegetables was 0.25 and for fruits 0.2. From this analytical information the authors "judged what a reasonable worst-case portion would be" and arrived at 0.4 for vegetables and 0.3 for fruit.

The value for total homegrown food consumed given in EPA (1989b), 44.2 kg/yr, was selected as the intake input value because it was the only value for which information and explanation is provided. It should also be pointed out that the intake numbers in the EPA (1989b) publication are those used in EPA (1991a) which is a supplemental risk assessment guidance document for SUPERFUND. ISRA directs the Department to make use of the guidance and regulations for exposure assessment developed by the federal Environmental Protection Agency.

<u>Soil to Vegetable Transfer Factor</u>

Nine publications, dating 1982-1993, which contain soil to vegetable transfer factors were reviewed.[2,3,6,7,8,17,28,29,30] These publications in turn cite at least two additional references published over the period 1977-1987.[11,31] [Please note that Baes (1984) references a rather lengthy list of publications on which his paper is based; those references are not included here.] Table 3-14 shows that the soil to vegetable transfer factor values presented in the reviewed publications vary by approximately two orders of magnitude depending on the radionuclide and whether it is a composite value or a value for a particular type of vegetation, i.e. vegetable transfer factor versus a fruit transfer factor.

In 1993, Wang et. al published a review document on the soil to vegetable transfer factor. This report discusses three

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[28] International Atomic Energy Agency, 1982, *Generic Models and Parameters for Assessing the Environmental Transfer of Radionuclides from Routine Releases; Exposure of Critical Groups*, Safety Series No. 57.

[29] Baes, C.F., R.D. Sharp, A.L. Sjoreen and R.W. Shor, 1984, "A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture", DE85-000287/ORNL-5786.

[30] National Council on Radiation Protection and Measurements, 1991, unpublished data. (referenced in Wang et al., 1993)

[31] King, C.M., W.L. Marter, B.B. Looney and J.B. Pickett, 1987, *Methodology and Parameters for Assessing Human Health Effects for Waste Sites at the Savannah River Plant*, DPST-86298, E.I. DuPont de Nemours and Co., Savannah River Plant, Aiken, SC 29408.

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parameters to consider when reviewing soil to vegetable transfer factors from various sources. First, it is difficult to compare the soil to vegetable factors for root uptake used in the various publications because this factor can be reported in one of two different formats. The transfer factor can be reported as the ratio: pCi per gram plant (wet)/pCi per gram soil (dry) or pCi per gram plant (dry)/pCi per gram soil (dry). The Wang et al. (1993) document uses the wet plant factors since vegetation consumed by humans is most frequently reported in fresh weight.

Table 3-14

Soil to Vegetable Transfer Factor, B_{IV}

Radionuclide	IAEA[1] 1982	Baes[2] 1984		Till 1988		EPA 1989a	
	Composite	Vegetable	Fruit	Edible[1]	Pasture[2]	Produce[1]	Pasture[2]
Th	5×10^{-4}	8.5×10^{-4}	8.5×10^{-5}	3.6×10^{-5}	8.5×10^{-4}	3.6×10^{-5}	8.5×10^{-4}
Ra	4×10^{-2}	1.5×10^{-2}	1.5×10^{-3}	6×10^{-3}	1.5×10^{-2}	6.4×10^{-4}	1.5×10^{-2}
Pb	1×10^{-2}	4.5×10^{-2}	9×10^{-3}			3.9×10^{-3}	4.5×10^{-2}
Po	2×10^{-4}	2.5×10^{-3}	4×10^{-4}			1.7×10^{-3}	2.5×10^{-2}
U	2×10^{-3}	8.5×10^{-3}	4×10^{-3}	1.7×10^{-3}	8.5×10^{-3}	1.7×10^{-3}	8.5×10^{-3}
Ac	1×10^{-3}	3.5×10^{-3}	3.5×10^{-4}			1.5×10^{-4}	3.5×10^{-3}
Pa	4×10^{-2}	2.5×10^{-3}	2.5×10^{-4}			1.1×10^{-4}	2.5×10^{-3}
Bi	1×10^{-1}	3.5×10^{-2}	5×10^{-3}			2.1×10^{-3}	3.5×10^{-2}
Tl		4.3×10^{-3}	4×10^{-4}			1.7×10^{-4}	4×10^{-3}

[1] Wet plant weight to dry soil weight

[2] Dry plant weight to dry soil weight

Table 3-14 (continued)

Soil to Vegetable Transfer Factor, B_{iv}

Radionuclide	Gilbert[3] 1989	Kennedy[1] 1990		NCRP[1] 1991	Zach[1,4] 1991	Wang[1] 1993
		Leafy Vegetable	Root Vegetable	Composite		Composite
Th	4.2×10^{-3}	4.2×10^{-2}	1.7×10^{-2}	1×10^{-3}	2.1×10^{-4}	1×10^{-3}
Ra	1.4×10^{-3}	1.4×10^{-1}	5.6×10^{-2}	4×10^{-2}	3.3×10^{-3}	4×10^{-2}
Pb	6.8×10^{-2}	4×10^{-2}	1.6×10^{-2}	4×10^{-3}		1×10^{-2}
Po	9×10^{-3}	1×10^{-2}	1×10^{-2}	1×10^{-3}		1×10^{-3}
U	2.5×10^{-3}	2.5×10^{-2}	1×10^{-2}	2×10^{-3}	2.1×10^{-3}	2.5×10^{-3}
Ac	2.5×10^{-3}	1×10^{-2}	1×10^{-2}	1×10^{-3}		2.5×10^{-3}
Pa	2.5×10^{-3}	5×10^{-2}	5×10^{-2}	1×10^{-2}		1×10^{-2}
Bi	1.5×10^{-1}	1.5	6×10^{-1}	1×10^{-1}		1×10^{-1}
Tl		9.9×10^{-4}	9.9×10^{-4}			

[3] Paper does not state but assume the factor is for both leafy and non-leafy vegetables

[4] Paper reflects these values are for food and feed crops

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A second consideration associated with transfer factors is that comprehensive data in the literature is available for relatively few nuclides in different crops grown on various soils. Data for radionuclides for which little or no experimental information exists have been customarily estimated on the basis of the assumption that chemically similar elements act similarly in the soil-plant environment[29]. Relationships between transfer factors for an element and those for other elements of the same or adjacent periods or groups were established and examined for possible trends. Investigators often extrapolate such trends to the element in question.

A third consideration for transfer factors is whether the value represents a composite value from various food and feed crops or separate values for forage vegetation and edible portions of various vegetables and produce. If doses were being calculated for a particular vegetation type it might be advantageous to use the factor for that vegetation type. However, given the sparsity of data on which any of these factors are based, and that we do not know what kind of vegetation might be grown on a reclaimated site, it seems reasonable to use a composite factor.

Wang et al's (1993) composite transfer factors were chosen as input values because of the thorough, recent literature review which the authors conducted and the reasonable assumptions they made in proposing their values. A review of the range of values for each food class (which make up the composite class) shows that normally forage plant transfer factors are higher than those of either the root vegetable, fruits and grain class or the leafy vegetable class. It is uncertain how Wang et al. (1993) arrived at the exact composite transfer factor values they selected, but the forage values do not seem to have greatly influenced their choice. In fact, a cursory look at the range of values by food class leads one to believe that the root vegetables, fruits and grains had a greater influence on their choice of composite transfer factor values and the selected values are at the higher end of the range of the root vegetable, fruits and grain food class. It should be noted that Wang et al's (1993) values are in good agreement with the 'composite' values published in other references.[6,28,30]

Site Parameters

As directed by S-1070, this rule is proposing soil cleanup standards for residential or nonresidential site use. Since remediated sites could be used for any purpose, this rule is addressing the effects of disruption to the site e.g., excavation for house construction, on the doses which will be received by the public.

The thickness of the layer of contaminated soil that will be brought to the surface as a result of soil excavation to construct a particular building foundation is based on the site and structural dimensions. In the case of a slab-on-grade foundation a perimeter will be excavated, concrete blocks or other suitable material will be placed in the perimeter and finally a slab will be poured within the boundaries of the perimeter. The following assumptions are made in this discussion: calculations for the residential scenario are based on a lot size of 100′ x 50′ and a house size of 40′ x 25′; calculations for the nonresidential scenario will be based on a lot size of ¼ acre and a structure size of 60′ x 40′; all the soil removed for the perimeter will be evenly redistributed on the surface of the lot. The thickness of contaminated soil which will be brought to the surface (T_{z1}) can be calculated using the following equation:

$$T_{z1} = \frac{\text{Volume of Material Excavated}}{\text{Area of Plot - Area of Slab}}$$

$$= \frac{2(L_H + W_H) \cdot W_{FB} \cdot d_e}{(L_P \cdot W_P) - (L_H \cdot W_H)} \qquad (2)$$

where: L_H is the length of the structure
(residential: 40 feet)
(nonresidential: 60 feet)

W_H is the width of the structure
(residential: 25 feet)
(nonresidential: 40 feet)

W_{FB} is the width of the foundation blocks (1 foot)

d_e is the excavation depth of the perimeter of a structure (in feet)

L_P is the length of the plot
(residential: 100 feet)
(nonresidential: 104 feet)

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W_p is the width of the plot
(residential: 50 feet)
(nonresidential: 104 feet)

Inserting the numbers and solving equation (2) in terms of d_e gives the following:

$$T_{z1} = HF \cdot \bar{d}_e \tag{3}$$

where HF = .0325 (residential)
= .024 (nonresidential)

Concentration

Equation (1) holds true for the original undeveloped, reclaimed site which is assumed to have a 'clean' surface soil layer of thickness T_{cz} followed by an at depth uniform layer of contaminated soil. However, the radionuclide concentration available for plant uptake can be modified in two ways. First, in order to develop the site for residential or nonresidential use the surface will need to be graded, at which time some of the 'clean' surface soil layer will be removed. (For purposes of this discussion, it is assumed that 1 foot of clean soil remains at the surface after the site has been graded.) Next the ground will need to be prepared for the foundation type, slab-on-grade, basement or crawlspace, that will be constructed. It is assumed that during the preparation phase, the site will be excavated to a depth that will bring contaminated soil to the surface. However, the concentration of the radionuclide in the surface layer will not be the same as that at depth because it will have been mixed with 'clean' soil which is also being disturbed during the excavation. The mathematical representation of the mixing factor (MF) is:

$$MF = \frac{v}{d_e} \tag{4}$$

where: v is the thickness of the at depth contaminated layer (in feet)

Second, not all the radionuclide at a site will be available for uptake by a plant. The amount of radionuclide available will depend on the type of soil layers (clean versus contaminated layers), the concentration of a radionuclide in a particular layer and the depth of the vegetation root system. As in the case outlined above for the mixing factor, there are four soil layers which develop once a site has been disturbed (Figure 1-1). The first is a surface contamination layer that has a radionulide concentration which is modified by the MF. The second layer is the clean layer which is assumed to have no radionuclide concentration. The third layer is the at depth contamination layer which has a radionuclide concentration of C_{z2}. And, assuming that the at depth contamination layer is not infinite in thickness, the fourth layer is the in situ soil of the location (assumed in this discussion to have no radionuclide concentration). The depth factor (D_f) takes into account the depth of the roots of crops and the layers or type of soil through which the roots pass or in which they lie.

There are three references which discuss what will be referred to as depth factors.[6,2,7] Gilbert et al. (1989) uses a simple factor which accounts for the percentage of the root within a particular layer. Gilbert's factor is based on the assumption of a sharp boundary between the bottom of any uncontaminated cover and the top of the contaminated zone. The effect of mixing uncontaminated and contaminated soil in a surface layer by plowing or other disturbance of the soil close to the ground surface is not taken into account. Gilbert's general 'depth factor' equation, in the variables used in this discussion, is:

$$D_F = \frac{T_{z1}}{d} \quad (5)$$

where: d is the maximum root depth (2.9 ft).[6]

Recently, investigators and modelers have begun to incorporate factors to account for the soil layers from which plants can uptake contaminants. However, a standard methodology for this factor has not yet evolved. At this time Gilbert et al's (1989) methodology seems a simple and reasonable first approach at taking the root depth and layers of soil through which the root passes into account.

There are three cases for the concentration of the radionuclide available for uptake by vegetation. Case 1 is where the thickness of the surface contaminated layer (T_{z1}) and the thickness of the clean layer (T_{cz}) are <u>greater</u> than the 'standard' root depth ($T_{z1} + T_{cz} \geq d$) (Figure 2a). In this case only the radionclide in the surface layer is available for uptake by vegetation. The concentration of radionuclide in the surface layer can be written in terms of C_{z2} which has been modified by the MF. Since the vegetation roots will pass through the surface layer and into the subsurface clean layer, only a certain percentage of the root will be in the contaminated surface layer. This percentage of the root is DF. Therefore, in Case 1 the total concentration of radionuclide available for uptake (C) is:

$$C = C_{z2} \cdot MF \cdot D_F \quad (6)$$

Substituting equation (3) and (4) into equation (6) results in the following:

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$$C = C_{z2} \cdot \frac{v}{d_e} \cdot \frac{T_{z1}}{d}$$

$$= C_{z2} \cdot \frac{v}{d_e} \cdot \frac{HF \cdot d_e}{d} \qquad (7)$$

$$= C_{z2} \frac{v \cdot HF}{d}$$

In Case 2, the thickness of the surface contaminated layer and the thickness of the clean layer are less than the 'standard' root depth ($T_{z1} + T_{cz} < d$) and the thickness of the surface contaminated layer plus the thickness of the clean layer plus the thickness of the at depth contaminated layer are greater than the 'standard' root depth ($T_{z1} + T_{cz} + v > d$), the contribution of radionclides in the at depth contaminated layer must also be taken into consideration (Figure 2b). In this case, the total concentration of radionuclide available for uptake is the same as in the first case plus the concentration of the radionuclide in the at depth contaminated layer. The concentration of the radionuclide in the at depth contaminated layer is modified to account for the percentage of the root that grows into that layer. In this case the concentration of radionuclide available for uptake is:

$$C = C_{z2}\left[\frac{v}{d_e} \cdot \frac{T_{z1}}{d}\right] + C_{z2}\left[\frac{(d - (T_{z1} + T_{cz})}{d}\right]$$

$$= C_{z2}\left[\frac{v}{d_e} \cdot \frac{HF \cdot d_e}{d}\right] + C_{z2}\left[\frac{(d - HF \cdot d_e - T_{cz})}{d}\right] \qquad (8)$$

$$= C_{z2}\left[\frac{v \cdot HF}{d} + \frac{(d - HF \cdot d_e - T_{cz})}{d}\right]$$

$$= \frac{C_{z2}}{d}\left[v \cdot HF + d - HF \cdot d_e - T_{cz}\right]$$

where: T_{cz} is the thickness of the clean layer (1 foot).

In Case 3, the thickness of the at depth contaminated layer is limited and the root system passes through the at depth contaminated layer ($T_{z1} + T_{cz} + v \leq d$) (Figure 2c), the total concentration of radionuclide available for uptake is the same as the first case plus the concentration of the radionuclide in the at depth contaminated layer. The concentration of the radionuclide in the at depth contaminated layer is modified to account for the percentage of the root that will grow through that layer. Therefore, in Case 3, the concentration of radionuclide available for uptake is:

$$C = C_{z2}\left[\frac{v}{d_e}\cdot\frac{T_{z1}}{d}\right] + C_{z2}\cdot\frac{v}{d}$$

$$= C_{z2}\left[\frac{v}{d_e}\cdot\frac{T_{z1}}{d} + \frac{v}{d}\right]$$

$$= C_{z2}\left[\frac{v}{d_e}\cdot\frac{HF\cdot d_e}{d} + \frac{v}{d}\right] \qquad (9)$$

$$= C_{z2}\left[\frac{v\cdot HF}{d} + \frac{v}{d}\right]$$

$$= C_{z2}\cdot\frac{v}{d}\left[HF + 1\right]$$

Figure 2a

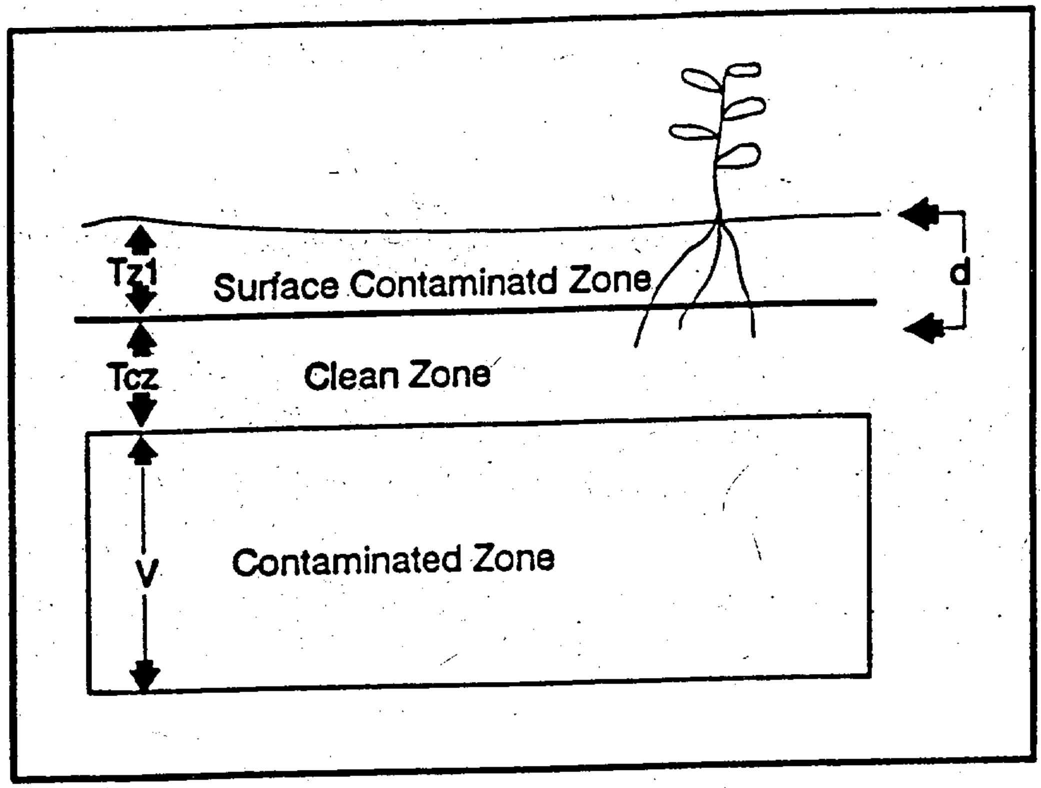


Figure 2b

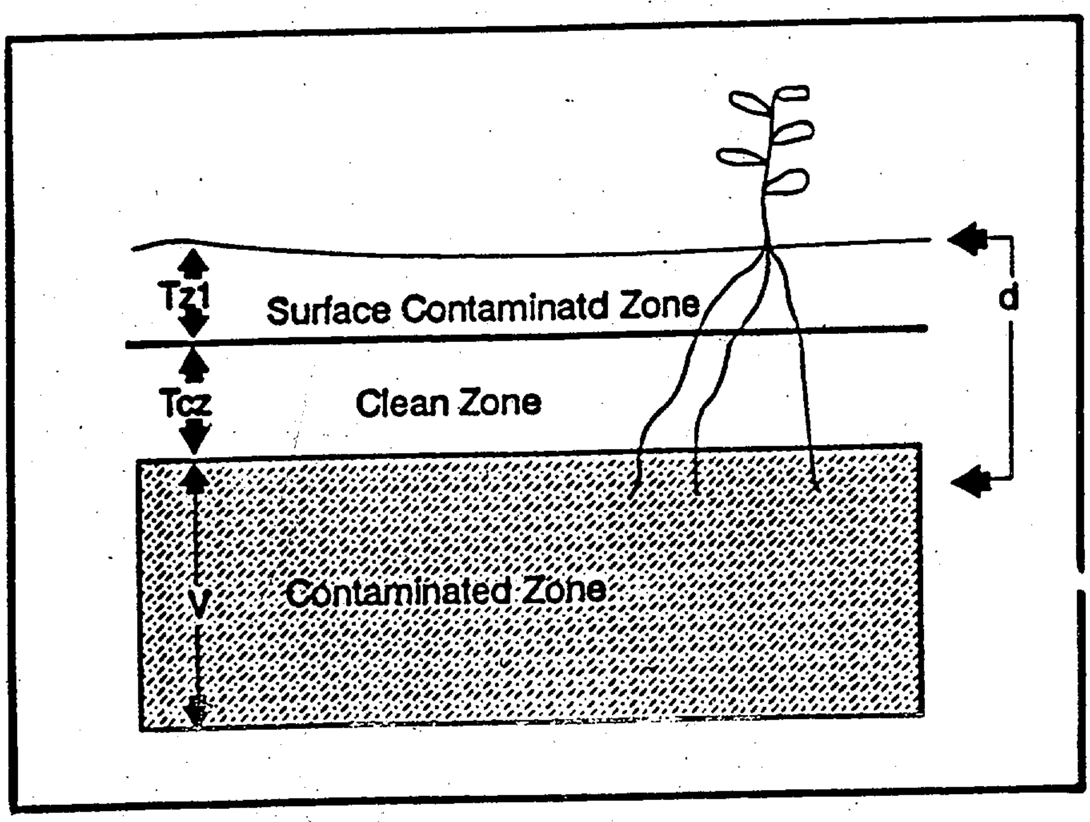
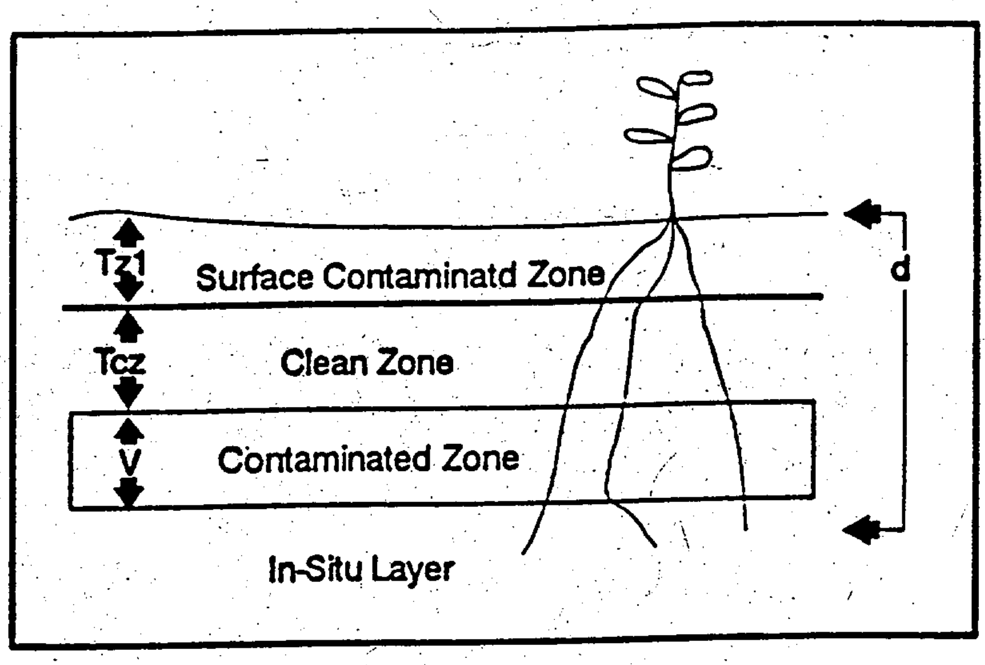


Figure 2c


Tz1
Surface Contaminatd Zone
Tcz
Clean Zone
V
Contaminated Zone
In-Situ Layer
d

DEVELOPMENT OF EQUATIONS FOR CALCULATION OF RADIONUCLIDE DOSE FOR THE VEGETATIVE PATHWAY-Slab on Grade Scenario

To determine the dose received from vegetation it is necessary to solve equation (1) for each scenario and case. Substituting equation (7) into equation (1) gives the solution for **Case 1, $T_{z1} + T_{cz} \geq d$:**

$$Dose = DCF \cdot I \cdot B_{iv} \cdot C_{z2} \cdot \frac{v \cdot HF}{d} \cdot 1000 \qquad \textbf{(10)}$$

Solving equation (10) for the **residential scenario** and in terms of C_{z2} and v gives:

$$\begin{aligned} Dose &= DCF \cdot 44.2 \cdot B_{iv} \cdot C_{z2} \cdot \frac{v \cdot .0325}{2.9} \cdot 1000 \\ &= DCF \cdot B_{iv} \cdot C_{z2} \cdot v \cdot 495 \qquad \textbf{(11)} \\ &= K \cdot C_{z2} \cdot v \end{aligned}$$

where: K_1 = DCF · B_{iv} · 495 (for each radionuclide)

Solving equation (10) for the **nonresidential** scenario and in terms of C_{z2} and v gives:

$$Dose = DCF \cdot 44.2 \cdot B_{iv} \cdot C_{z2} \cdot \frac{v \cdot .024}{2.9} \cdot 1000$$

$$= DCF \cdot B_{iv} \cdot C_{z2} \cdot v \cdot 366 \qquad (12)$$

$$= K \cdot C_{z2} \cdot v$$

where: K_2 = DCF · B_{iv} · 366 (for each radionuclide)

Substituting equation (8) into equation (1) gives the solution for **Case 2, $T_{z1} + T_{cz} < d$ and $T_{z1} + T_{cz} + v > d$:**

$$Dose = DCF \cdot I \cdot B_{iv} \cdot \frac{C_{z2}}{d}\left[v \cdot HF + d - HF \cdot d_e - T_{cz}\right] \qquad (13)$$

Solving equation (13) for the **residential** scenario and in terms of C_{z2} and v gives:

$$e = DCF \cdot 44.2 \cdot B_{iv} \cdot \frac{C_{z2}}{2.9}\left[.0325v + 2.9 - .0325d_e - 1\right] \cdot 1$$

$$= DCF \cdot B_{iv} \cdot C_{z2} \cdot 15241\left[.0325v - .0325d_e + 1.9\right] \qquad (14)$$

$$= K \cdot C_{z2}\left[.0325v - .0325d_e + 1.9\right]$$

where: K_3 = DCF · B_{iv} · 15241 (for each radionuclide)

Solving equation (13) for the **nonresidential scenario** and in **terms** of C_{z2} and v gives:

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$$Dose = DCF \cdot 44.2 \cdot B_w \cdot \frac{C_{z2}}{2.9}\left[0325v + 2.9 - .0325d_e - 1\right] \cdot 1000$$

$$= DCF \cdot B_w \cdot C_{z2} \cdot 15241\left[.0325v - .0325d_e + 1.9\right] \quad (15)$$

$$= K \cdot C_{z2}\left[0325v - .0325d_e + 1.9\right]$$

where: $K_4 = DCF \cdot B_{iv} \cdot 15241$ (for each radionuclide)

Substituting equation (9) into equation (1) gives the solution for **Case 3,**
$T_{z1} + T_{cz} + v \leq d$:

$$Dose = DCF \cdot I \cdot B_{iv} \cdot C_{z2} \cdot \frac{v}{d}\left[HF + 1\right] \cdot 1000 \quad (16)$$

Solving equation (16) for the **residential scenario** and in terms of C_{z2} and v gives:

$$Dose = DCF \cdot 44.2 \cdot B_{iv} \cdot C_{z2} \cdot \frac{v}{2.9}\ (.0325 + 1) \cdot 1000$$

$$= DCF \cdot B_{iv} \cdot C_{z2} \cdot v \cdot 15737 \quad (17)$$

$$= K \cdot C_{z2} \cdot v$$

where: $K_5 = DCF \cdot B_{iv} \cdot 15737$ (for each radionuclide)

Solving equation (16) for the **nonresidential scenario** and in terms of C_{z2} and v gives:

$$Dose = DCF \cdot 44.2 \cdot B_{iv} \cdot C_{z2} \cdot \frac{v}{2.9}\left[.024 + 1\right] \cdot 1000$$

$$= DCF \cdot B_{iv} \cdot C_{z2} \cdot v \cdot 15607 \quad (18)$$

$$= K \cdot C_{z2} \cdot v$$

Disruptive Scenario: Basement

In the scenario of a basement foundation, a hole will be excavated, concrete blocks or other suitable material will be placed on the sides and finally a slab will be poured at the bottom of the hole. The default values introduced for the slab-on-grade scenario will apply in this scenario, as needed. The thickness of contaminated soil which will be brought to the surface (T_{z1}) for the basement scenario can be calculated using the following equation: Inserting the appropriate numbers given with equation (2) and solving equation (19) in terms of d_e gives the following:

$$T_{z1} = \frac{Volume\ of\ Material\ Excavated}{Area\ of\ Plot - Area\ of\ Basement\ Slab} \qquad (19)$$

$$= \frac{L_H \cdot W_H \cdot d_e}{(L_P \cdot W_P) - (L_H \cdot W_H)}$$

$$T_{z1} = HF \cdot d_e \qquad (20)$$

where: HF is the housing factor, which is a combination of the values inserted into
equation (2) (unitless)
(residential: .25)
(nonresidential: .283)

DEVELOPMENT OF EQUATIONS FOR CALCULATION OF RADIONUCLIDE DOSE FOR THE VEGETATIVE PATHWAY-Basement Scenario

The development of equations for the basement scenario is the same as it was for the slab-on-grade scenario. The same input values are also used except for the housing factor (HF). The HF values for the basement scenario are now used in the equations instead of the slab-on-grade HF values.

For Case 1 where $T_{z1} + T_{cz} \geq d$, the dose equation for the residential scenario is:

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$$Dose = DCF \cdot 44.2 \cdot B_{iv} \cdot C_{z2} \cdot \frac{v \cdot .25}{2.9} \cdot 1000$$

$$= DCF \cdot B_{iv} \cdot C_{z2} \cdot v \cdot 3810 \qquad (21)$$

$$= K \cdot C_{z2} \cdot v$$

where: K_7 **= DCF · B_{iv} · 3810 (for each radionuclide)**

For the nonresidential scenario the equation is:

$$Dose = DCF \cdot 44.2 \cdot B_{iv} \cdot C_{z2} \cdot \frac{v \cdot .283}{d} \cdot 1000$$

$$= DCF \cdot B_{iv} \cdot C_{z2} \cdot v \cdot 4313 \qquad (22)$$

$$= K \cdot C_{z2} \cdot v$$

where: $K_8 = DCF \cdot B_{iv} \cdot 4313$ (for each radionuclide)

For Case 2 where $T_{z1} + T_{cz} < d$ and $T_{z1} + T_{cz} + v > d$, the dose equation for the residential scenario is:

$$Dose = DCF \cdot 44.2 \cdot B_{iv} \cdot \frac{C_{z2}}{2.9}\left[.25v + 2.9 - .25d_e - 1\right] \cdot 100$$

$$= DCF \cdot B_{iv} \cdot C_{z2} \cdot 15241\left[.25v - .25d_e + 1.9\right] \qquad (23)$$

$$= K \cdot C_{z2}\left[.25v - .25d_e + 1.9\right]$$

where: $K_9 = DCF \cdot B_{iv} \cdot 15241$ (for each radionuclide)

For the nonresidential scenario the equation is:

$$Dose = DCF \cdot 44.2 \cdot B_{iv} \cdot \frac{C_{z2}}{2.9}\left[.283v + 2.9 - .283d_e - 1\right] \cdot 10$$

$$= DCF \cdot B_{iv} \cdot C_{z2} \cdot 15241\left[.283v - .283d_e + 1.9\right] \qquad (24)$$

$$= K \cdot C_{z2}\left[.283v - .283d_e + 1.9\right]$$

where: $K_{10} = DCF \cdot B_{iv} \cdot 15241$ (for each radionuclide)

For Case 3 $T_{z1} + T_{cz} + v \le d$ the residential scenario equation is:

$$Dose = DCF \cdot 44.2 \cdot B_{iv} \cdot C_{z2} \cdot \frac{v}{2.9} \cdot (.25 + 1) \cdot 1000$$

$$= DCF \cdot B_{iv} \cdot C_{z2} \cdot v \cdot 19052 \qquad (25)$$

$$= K \cdot C_{z2} \cdot v$$

where: K_{11} = DCF · B_{iv} · 19052 (for each radionuclide)

For the **nonresidential scenario** the equation is:

$$Dose = DCF \cdot 44.2 \cdot B_{iv} \cdot C_{z2} \cdot \frac{v}{2.9} \cdot (.283 + 1) \cdot 1000$$

$$= DCF \cdot B_{iv} \cdot C_{z2} \cdot v \cdot 19555 \qquad (26)$$

$$= K \cdot C_{z2} \cdot v$$

where: K_{12} = DCF · B_{iv} · 19555 (for each radionuclide)

CALCULATION OF RADIONUCLIDE DOSE FOR THE VEGETATION PATHWAY

Table 3-15 and Table 3-16 provides the solution of the K values for each radionuclide for residential and nonresidential use, the slab-on-grade and basement scenarios and for each case. Inserting these values into their appropriate equation allows one to solve the dose equation for C given the ingestion limiting dose value (which was discussed in the background section of this discussion) and a variety of combinations for v and d_e.

Table 3-15

Ingestion Pathway Doses

Crop Ingestion

Residential Use[1]

Dose as a Function of C, v and d_e

Radionuclide/Chain	$T_{z1} + T_{cz} \geq d$		$T_{z1} + T_{cz} < d$ and $T_{z1} + T_{cz} + v > d$	
	Slab	Basement	Slab	Basement
	K_1 to use in equation (11)	K_7 to use in equation (21)	K_3 to use in equation (14)	K_9 to use in equation (23)
^{238}U	.000314	.00242	.00968	.00968
^{234}Th	.00000673	.0000518	.000207	.000207
^{234}Pa	.0000107	.0000823	.000329	.000329
^{238}U (+D)	.000331	.00255	.0102	.0102
^{234}U	.00035	.0027	.0108	.0108
^{238}U (+D) + ^{234}U	.000681	.00525	.021	.021
^{230}Th	.000271	.00209	.00835	.00835
^{226}Ra	.0261	.201	.805	.805
^{214}Pb	.00000309	.0000238	.0000952	.0000952

[1] Calculations based on the following house parameters: House dimensions: 40 x 25 feet, lot size: 100 x 50 feet; slab piling width: 1 foot

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Radionuclide/Chain	$T_{z1} + T_{cz} \geq d$		$T_{z1} + T_{cz} < d$ and $T_{z1} + T_{cz} + v > d$	
	Slab	Basement	Slab	Basement
	K_1 to use in equation (11)	K_7 to use in equation (21)	K_3 to use in equation (14)	K_9 to use in equation (23)
^{214}Bi	.000014	.000108	.000431	.000431
^{226}Ra (+D)	.0261	.201	.805	.805
^{210}Pb	.0265	.204	.817	.817
^{210}Bi	.000317	.00244	.00975	.00975
^{210}Po	.00094	.00724	.029	.029
^{210}Pb (+D)	.0278	.213	.856	.856
^{226}Ra (+D) + ^{210}Pb (+D)	**.0539**	**.414**	**1.66**	**1.66**
^{232}Th	.00135	.0104	.0416	.0416
^{228}Ra	.0283	.218	.872	.872
^{228}Ac	.00000267	.0000206	.0000823	.0000823
^{228}Ra (+D)	.0283	.218	.872	.872
^{228}Th	.000196	.00151	.00604	.00604
^{224}Ra	.00725	.0558	.223	.223
^{212}Pb	.000225	.00173	.00693	.00693
^{212}Bi	.0000525	.000404	.00162	.00162
^{228}Th (+D)	.00772	.0594	.238	.238

Radionuclide/Chain	$T_{z1} + T_{cz} \geq d$		$T_{z1} + T_{cz} < d$ and $T_{z1} + T_{cz} + v > d$	
	Slab	Basement	Slab	Basement
	K_1 to use in equation (11)	K_7 to use in equation (21)	K_3 to use in equation (14)	K_9 to use in equation (23)
^{232}Th + ^{228}Ra(+D) + ^{228}Th(+D)	.0374	.288	1.15	1.15
^{235}U	.000329	.00253	.0101	.0101
^{231}Th	.000000668	.00000514	.0000206	.0000206
^{235}U(+D)	.000329	.00253	.0101	.0101
^{231}Pa	.0525	.404	1.62	1.62
^{227}Ac	.0174	.134	.537	.537
^{227}Th	.0000188	.000145	.000581	.000581
^{223}Ra	.013	.1	.402	.402
^{211}Pb	.0000026	.00002	.00008	.00008
^{227}Ac(+D)	.0304	.234	.939	.939
^{231}Pa + ^{227}Ac(+D)	.0829	.638	2.56	2.56

Table 3-15 (continued)

Ingestion Pathway Doses

Crop Ingestion

Residential Use

Dose as a Function of C, v and d_e

Radionuclide/Chain	$T_{z1} + T_{cz} + v \leq d$	
	Slab	Basement
	K_5 to use in equation (17)	K_{11} to use in equation (25)
^{238}U	.00999	.0121
^{234}Th	.000214	.000259
^{234}Pa	.00034	.000412
$^{238}U(+D)$	.0105	.0127
^{234}U	.0111	.0135

Radionuclide/Chain	$T_{z1} + T_{cz} + v \le d$	
	Slab	Basement
	K_5 to use in equation (17)	K_{11} to use in equation (25)
^{238}U(+D) + ^{234}U	**.0216**	**.0262**
^{230}Th	**.00862**	**.0104**
^{226}Ra	.831	1
^{214}Pb	.0000984	.000119
^{214}Bi	.000445	.000539
^{226}Ra(+D)	.831	1
^{210}Pb	.844	1.02
^{210}Bi	.0101	.0122
^{210}Po	.0299	.0362
^{210}Pb(+D)	.884	1.07
^{226}Ra(+D) + ^{210}Pb(+D)	**1.72**	**2.07**
^{232}Th	.043	.052
^{228}Ra	.9	1.09
^{228}Ac	.000085	.000103
^{228}Ra(+D)	.9	1.09
^{228}Th	.00623	.00754
^{224}Ra	.23	.279

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Radionuclide/Chain	$T_{z1} + T_{cz} + v \le d$	
	Slab	Basement
	K_s to use in equation (17)	K_{11} to use in equation (25)
^{212}Pb	.00716	.00867
^{212}Bi	.00167	.00202
^{228}Th (+D)	.245	.297
^{232}Th + ^{228}Ra (+D) + ^{228}Th (+D)	1.19	1.44
^{235}U	.0105	.0127
^{231}Th	.0000212	.0000257
^{235}U (+D)	.0105	.0127
^{231}Pa	1.67	2.02
^{227}Ac	.555	.672
^{227}Th	.0006	.000726
^{223}Ra	.415	.502
^{211}Pb	.0000826	.0001
^{227}Ac (+D)	.97	1.17
^{231}Pa + ^{227}Ac (+D)	2.64	3.19

Table 3-16 (continued)

Ingestion Pathway Doses

Crop Ingestion

Nonresidential Use[2]

Dose as a Function of C, v and d_e

Radionuclide/Chain	$T_{z1} + T_{cz} \geq d$		$T_{z1} + T_{cz} < d$ and $T_{z1} + T_{cz} + v > d$	
	Slab	Basement	Slab	Basement
	K_2 to use in equation (12)	K_8 to use in equation (22)	K_4 to use in equation (15)	K_{10} to use in equation (24)
^{238}U	.000232	.00274	.00968	.00968
^{234}Th	.00000498	.0000586	.000207	.000207
^{234}Pa	.00000791	.0000932	.000329	.000329
^{238}U (+D)	.000244	.00289	.0102	.0102
^{234}U	.000259	.00305	.0108	.0108
^{238}U (+D) + ^{234}U	.000503	.00594	.021	.021
^{230}Th	.0002	.00236	.00835	.00835
^{226}Ra	.0193	.228	.805	.805
^{214}Pb	.00000229	.000027	.0000952	.0000952

[2] Calculations based on the following building parameters: Building dimensions 60 x 40 feet, lot size ¼ acre (10,890 square feet); slab piling width: 1 foot

Radionuclide/Chain	$T_{z1} + T_{cz} \geq d$		$T_{z1} + T_{cz} < d$ and $T_{z1} + T_{cz} + v > d$	
	Slab	Basement	Slab	Basement
	K_2 to use in equation (12)	K_8 to use in equation (22)	K_4 to use in equation (15)	K_{10} to use in equation (24)
^{214}Bi	.0000104	.000122	.000431	.000431
^{226}Ra (+D)	.0193	.228	.805	.805
^{210}Pb	.0196	.231	.817	.817
^{210}Bi	.000234	.00276	.00975	.00975
^{210}Po	.000695	.00819	.029	.029
^{210}Pb (+D)	.0205	.242	.856	.856
^{226}Ra (+D) + ^{210}Pb (+D)	**.0398**	**.47**	**1.66**	**1.66**
^{232}Th	.000999	.0118	.0416	.0416
^{228}Ra	.0209	.247	.872	.872
^{228}Ac	.00000198	.0000233	.0000823	.0000823
^{228}Ra (+D)	.0209	.247	.872	.872
^{228}Th	.000145	.00171	.00604	.00604
^{224}Ra	.00536	.0631	.223	.223
^{212}Pb	.000166	.00196	.00693	.00693
^{212}Bi	.0000388	.000457	.00162	.00162
^{228}Th (+D)	.00571	.0672	.238	.238

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Radionuclide/Chain	$T_{z1} + T_{cz} \geq d$		$T_{z1} + T_{cz} < d$ and $T_{z1} + T_{cz} + v > d$	
	Slab	Basement	Slab	Basement
	K_2 to use in equation (12)	K_8 to use in equation (22)	K_4 to use in equation (15)	K_{10} to use in equation (24)
$^{232}Th + ^{228}Ra$ (+D) + ^{228}Th (+D)	.0276	.326	1.15	1.15
^{235}U	.000243	.00287	.0101	.0101
^{231}Th	.000000494	.00000582	.0000206	.0000206
^{235}U (+D)	.000243	.00287	.0101	.0101
^{231}Pa	.0388	.457	1.62	1.62
^{227}Ac	.0129	.152	.537	.537
^{227}Th	.0000139	.000164	.000581	.000581
^{223}Ra	.00965	.114	.402	.402
^{211}Pb	.00000192	.0000226	.00008	.00008
^{227}Ac (+D)	.0226	.266	.939	.939
$^{231}Pa + ^{227}Ac$ (+D)	.0614	.723	2.56	2.56

Table 3-16 (continued)

Ingestion Pathway Doses

Crop Ingestion

Nonresidential

Dose as a Function of C, v and d_e

Radionuclide/Chain	$T_{z1} + T_{cz} + v \le d$	
	Slab	Basement
	K_6 to use in equation (18)	K_{12} to use in equation (26)
^{238}U	.00991	.0124
^{234}Th	.000212	.000266
^{234}Pa	.000337	.000422
^{238}U(+D)	.0104	.0131
^{234}U	.011	.0138
^{238}U(+D) + ^{234}U	.0214	.0269
^{230}Th	.00855	.0107
^{226}Ra	.824	1.03
^{214}Pb	.0000975	.000122

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Radionuclide/Chain	$T_{z1} + T_{cz} + v \le d$	
	Slab	Basement
	K_6 to use in equation (18)	K_{12} to use in equation (26)
^{214}Bi	.000442	.000553
^{226}Ra (+D)	.824	1.03
^{210}Pb	.836	1.05
^{210}Bi	.00999	.0125
^{210}Po	.0296	.0372
^{210}Pb (+D)	.876	1.1
^{226}Ra (+D) + ^{210}Pb (+D)	1.7	2.13
^{232}Th	.0426	.0534
^{228}Ra	.893	1.12
^{228}Ac	.0000843	.000106
^{228}Ra (+D)	.893	1.12
^{228}Th	.00618	.00774
^{224}Ra	.228	.286
^{212}Pb	.0071	.0089
^{212}Bi	.00165	.00207
^{228}Th (+D	.243	.305

Radionuclide/Chain	$T_{z1} + T_{cz} + v \leq d$	
	Slab	Basement
	K_6 to use in equation (18)	K_{12} to use in equation (26)
${}^{232}Th$ + ${}^{228}Ra$ (+D) + ${}^{228}Th$ (+D)	1.18	1.48
${}^{235}U$	.0104	.013
${}^{231}Th$	.0000211	.0000264
${}^{235}U$ (+D)	.0104	.013
${}^{231}Pa$	1.65	2.07
${}^{227}Ac$	.55	.689
${}^{227}Th$	.000595	.000745
${}^{223}Ra$	.411	.515
[illegible]Pb	.0000819	.000103
${}^{227}Ac$ (+D)	.961	1.2
${}^{231}Pa$ + ${}^{227}Ac$ (+D)	2.61	3.27

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Chapter 4

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DERIVATION OF ALLOWED CONCENTRATIONS

Using the above equations, intake doses per unit concentration of radionuclide (pCi/gm) were calculated for each dose component as a function of the vertical extent of contamination (V) and summed. These results are provided for both slab on grade and basement excavations in Tables 4-1 and 4-2 for residential and non-residential scenarios respectively. The gamma doses per pCi/gm previously derived are then added to the intake dose. The allowed soil radionuclide concentration (C) for a given V is then found by dividing the allowed dose, 15 mrem/year, by the gamma and intake dose sum per pCi/gm.

The resulting allowed concentrations are provided in Tables 4-3 and 4-4 for the residential and non-residential use scenarios respectively in terms of V - the vertical extent of the contamination remaining. For Ra226 the results for the sum of the gamma and intake pathways, and the radon pathway were compared and the least value selected, i.e., the value that will allow both radionuclide background constraints to be met. These least values then become the radionuclide in soil concentrations in the rule.

It should be emphasized that the allowed concentrations in Tables 4-3 and 4-4 are incremental to the natural background radionuclide concentration. For example, if the mean natural background concentration of a particular radionuclide is 0.9 pCi/gm, and the allowed incremental concentration from Table 4-3 or Table 4-4 were 3.0 pCi/gm for that radionuclide, then the allowed concentration of that radionuclide following site remediation would be 3.9 pCi/gm.

It can be seen from Tables 4-1 and 4-2 that the pathway dominating the result varies considerably from radionuclide to radionuclide. For example, for Ra226 both the vegetative intake and gamma doses are major and comparable contributors to the total dose. For Th232, the gamma dose component is dominant, especially at higher values of vertical extent of contamination. For uranium, ingestion of groundwater is the dominant dose component.

The allowed concentrations as a function of V are illustrated graphically in Figures 4-1 through 4-5. For most radionuclides the allowed concentration is derived from the 15 mrem/year constraint on the gamma and intake pathway. For Ra226 the radon pathway constraint is shown also, and the radon background constraint can be limiting for certain V, especially for the non-residential case. The dependence of allowed concentration on vertical extent reflects the fact that overall radiation dose for diffuse radioactive materials depends on both the volume and the concentration of radioactive materials at a site. This becomes especially important in the economic impact analyses, because it indicates, that within certain ranges, some contaminated materials can be left behind at a site and S-1070 standards still met. This will be useful in cost reduction, as described in the Economic Impact Analyses.

Figures 4-1 through 4-5 illustrate the relationships between the slab on grade and basement excavation scenarios. For Th232 and Ra226 allowed concentrations decrease with V until limiting depths are reached and then stay constant because no additional contamination is excavated as V increases further. For slab on grade excavation, the limiting depth is four feet (1 foot of cover assumed to remain after grading for construction plus 3 feet of contamination). For basement excavation, the limiting depth is 8 feet. For uranium, the allowed concentration continues to decrease because the results are dominated by the groundwater pathway which is dependent on the degree of leaching throughout the entire depth of contamination.

It can be seen from the figures that there are "cross over" values of V where the basement excavation scenario becomes more restrictive than the slab on grade scenario. This is due to the combination of greater volumes excavated, as compared to the slab on grade scenario, and the diminished effect of mixing as V increases. If both slab on grade and basement excavation is to be allowed at the site, then the lesser of the concentrations for a particular value of V, must be used as the soil concentration limit.

Table 4-1: Dose Intakes per unit Soil Concentration
(Dose/C; mrem/yr per pCi/gm)
Residential Use
(2' clean cover after remediation)*

	V =1 foot		3		5		6		7		9	
	S	B	S	B	S	B	S	B	S	B	S	B
U-238+D												
Soil Ingest(SI)	.005	.003	.015	.008	.015	.014	.015	.016	.015	.016	.015	.016
Resuspension (RS)	.002	.001	.007	.004	.007	.007	.007	.008	.007	.008	.007	.008
Vegetative (V)	.01	.004	.019	.009	.019	.014	.019	.017	.019	.017	.019	.017
Water (W)	.16	.16	.49	.49	.81	.81	.96	.96	1.11	1.11	1.39	1.39
Intake Sum	.18	.17	.53	.51	.85	.84	1.0	1.0	1.15	1.15	1.43	1.43
Gamma	.01	.007	.022	.02	.022	.035	.022	.042	.022	.056	.022	.056
C	78.9	84.7	27.3	28.3	17.2	17.0	14.7	14.4	12.5	12.5	10.0	10.0
U234												
SI	.005	.003	.015	.008	.015	.014	.015	.017	.015	.017	.015	.017
RS	.003	.001	.008	.004	.008	.007	.008	.009	.008	.009	.008	.009
V	.011	.004	.020	.009	.020	.015	.020	.018	.020	.018	.020	.018
W	.17	.17	.51	.51	.85	.85	1.01	1.01	1.16	1.16	1.46	1.46
Intake Sum	.19	.18	.55	.53	.89	.89	1.05	1.05	1.2	1.2	1.50	1.50
Gamma	.01	.007	.022	.02	.022	.035	.022	.042	.022	.056	.022	.056
C	75.0	79.0	26.0	27.0	16.5	16.7	13.6	13.6	12.5	11.5	10.0	9.4

Key: S = Slab on grade excavation
B = Basement excavation
* Assumes 1' remaining after site grading for foundation excavation

Th-230												
SI	.01	.005	.03	.016	.03	.027	.03	.033	.03	.033	.03	.033
RS	.006	.004	.019	.011	.02	.018	.02	.02	.02	.02	.02	.02
V	.008	.003	.016	.007	.016	.007	.016	.014	.016	.014	.016	.014
W	0	0	0	0	0	0	0	0	0	0	0	0
Intake Sum	.024	.012	.065	.034	.065	.034	.066	.067	.066	.067	.066	.067
Gamma	--	--	--	--	--	--	--	--	--	--	--	--
C	625.	1250.	230.8	441.2	230.8	441.2	227.3	223.9	227.3	223.9	227.3	223.9

Key: S = Slab on grade excavation
B = Basement excavation
* Assumes 1' remaining after site grading for foundation excavation

Table 4-1 Continued	V = 1 S	B	3 S	B	5 S	B	6 S	B	7 S	B	9 S	B
Ra226+D Pb210+D												
SI	.15	.086	.45	.26	.45	.43	.45	.52	.45	.51	.45	.51
RS	.001	-	.002	.001	.003	.002	.003	.003	.003	.003	.003	.003
V	1.72	.66	3.10	1.49	3.1	2.32	3.1	2.74	3.1	2.74	3.1	2.74
W	.14	.14	.16	.16	.16	.16	.16	.16	.16	.16	.17	.17
Intake Sum	2.0	.89	3.71	1.91	3.71	2.91	3.71	3.42	3.71	3.42	3.72	3.42
Gamma	.64	.56	1.68	1.68	1.68	2.78	1.68	3.42	1.68	4.45	1.68	4.45
C	5.7	10.3	2.8	4.2	2.8	2.6	2.8	2.2	2.8	1.9	2.8	1.9
TH232+ Ra228+D +Th228+D												
SI	.087	.05	.26	.15	.26	.25	.26	.3	.26	.3	.26	.3
RS	.04	.02	.12	.07	.12	.11	.12	.13	.12	.13	.12	.13
V	1.15	.45	2.14	1.03	2.1	1.60	2.14	1.89	2.14	1.89	2.14	1.89
W	0	0	0	0	0	0	0	0	0	0	0	0
Intake Sum	1.28	.52	2.32	1.25	2.52	1.96	2.52	2.32	2.52	2.32	2.52	2.32
Gamma	.89	.81	2.3	2.47	2.3	4.05	2.3	4.94	2.3	6.4	2.3	6.4
C	6.8	11.5	3.1	4.1	3.1	2.5	3.1	2.1	3.1	1.7	3.1	1.7
U-235												
SI	.005	.003	.014	.01	.014	.013	.014	.02	.014	.02	.014	.02
RS	.002	.001	.007	.004	.007	.007	.007	.008	.007	.008	.007	.00
V	.010	.016	.019	.009	.019	.014	.019	.017	.019	.017	.019	.017
W	.17	.17	.53	.53	.88	.88	1.06	1.06	1.22	1.22	1.55	1.55
Intake Sum	.19	.18	.57	.55	.42	.914	1.1	1.1	1.26	1.26	1.59	1.59
Gamma	.05	.038	.15	.114	.75	.19	.15	.23	.15	.31	.15	.31
C	65.2	69.	20.8	22.4	12.8	13.6	12	11.3	10.6	9.5	8.6	7.9

Key: S = Slab on grade excavation
B = Basement excavation
• Assumes 1' remaining after site grading for foundation excavation

Table 4-1 Continued	V = 1 S	B	3 S	B	5 S	B	6 S	B	7 S	B	9 S	B
Pa231 +Ac227+D												
SI	.44	.25	1.3	.76	1.3	1.29	1.3	1.5	1.3	1.5	1.3	1.5
RS	.16	.09	.47	.27	.47	.45	.47	.54	.47	.54	.47	.54
V	2.64	1.02	4.8	2.3	4.8	4.2	4.8	4.2	4.8	4.2	4.8	4.2
W	.22	.22	.24	.24	.24	.24	.24	.24	.24	.24	.24	.24
Intake Sum	3.96	1.58	6.01	3.57	6.81	6.48	6.81	6.48	6.81	6.48	6.81	6.48
Gamma	.15	.11	.4	.33	.4	.56	.4	.68	.4	.89	.4	.89
C	3.6	8.9	2.3	3.8	2.1	2.1	2.1	2.1	2.1	2.0	2.1	2.0

Notes; (1) water ingestion dose modeling carried out to 1000 years.

Key: S = Slab on grade excavation
B = Basement excavation
* Assumes 1' remaining after site grading for foundation excavation

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Table 4-2: Dose Intakes Per Unit Soil Concentration
(Dose/C; mrem/yr per pCi/gm)
Non-Residential Use*
(2' clean cover after remediation)*

Vertical Extent of Contamination (V ft.)

	V =1		3		5		6		7		9	
	S	B	S	B	S	B	S	B	S	B	S	B
U-238+D												
Soil Ingest (SI)	--	--	.003	.001	.003	.002	.003	.003	.003	.003	.003	.003
Resuspension (RS)	.002	--	.005	.003	.005	.005	.005	.006	.005	.006	.005	.006
Vegetative (V)	--	--	--	--	--	--	--	--	--	--	--	--
Water (W)	.06	.06	.17	.17	.029	.29	.34	.34	.40	.40	.50	.50
Intake Sum	.062	.06	.178	.174	.298	.297	.348	.349	.408	.409	.508	.509
Gamma	.002	.002	.006	.006	.006	.01	.006	.01	.006	.02	.006	.02
C	234.	242	83.3	83.3	50.	50.	37.5	34.9	36.5	36.5	29.	28.
U234												
SI	--	--	.003	.001	.003	.002	.003	.003	.003	.003	.003	.003
RS	.002	.001	.006	.003	.006	.005	.006	.006	.006	.006	.006	.006
V	--	--	--	--	--	--	--	--	--	--	--	--
W	.06	.06	.175	.175	.30	.30	.36	.36	.40	.40	.50	.50
Intake Sum	.062	.061	.184	.179	.309	.307	.369	.369	.409	.409	.509	.509
Gamma	.002	.002	.006	.006	.006	.01	.006	.01	.006	.02	.006	.02
C	234.	245	79.	75.	50.	47.	40	40	37.5	37.5	30.	30.
Th-230												
SI	.002	--	.005	.003	.005	.005	.005	.006	.005	.006	.005	.006
RS	.005	.003	.014	.008	.014	.013	.014	.016	.014	.016	.014	.016
V	--	--	--	--	--	--	--	--	--	--	--	--
W	0	0	0	0	0	0	0	0	0	0	0	0
Intake Sum	.007	.003	.019	.011	.019	.018	.019	.022	.019	.022	.019	.022
Gamma	--	--	--	--	--	--	--	--	--	--	--	--
C	2142.9	5000	789.5	1363.6	789.5	833.3	789.5	681.8	789.5	681.8	789.5	681.8

Table 4-2 Continued	V = 1 S	B	3 S	B	5 S	B	6 S	B	7 S	B	9 S	B
Ra226+D Pb210+D												
SI	.03	.015	.08	.046	.08	.077	.08	.092	.08	.092	.08	.092
RS	--	--	.002	.001	.002	.002	.002	.002	.002	.002	.002	.002
V	--	--	--	--	--	--	--	--	--	--	--	--
W	.05	.05	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06
Intake Sum	.08	.065	.142	.107	.142	.139	.142	.154	.142	.154	.142	.154
Gamma	.21	.19	.78	.57	.78	.95	.78	1.14	.78	1.53	.78	1.53
C	50.	50.	16.7	21.4	16.7	13.6	16.7	11.6	16.7	8.9	16.7	8.9
TH232+ Ra228+D +Th228+D												
SI	.015	.009	.047	.027	.047	.053	.047	.053	.097	.053	.047	.053
RS	.028	.016	.084	.048	.084	.081	.084	.097	.084	.097	.084	.097
V	--	--	--	--	--	--	--	--	--	--	--	--
W	0	0	0	0	0	0	0	0	0	0	0	0
Intake Sum	.043	.025	.131	.075	.131	.134	.131	.15	.181	.15	.131	.15
Gamma	.3	.27	.78	.82	.78	1.37	.78	1.65	.78	2.23	.78	2.23
C	50.	50.	16.7	16.7	16.7	10.	16.7	8.3	16.7	6.3	16.7	6.3
U-235												
SI	--	--	.003	.001	.003	.002	.003	.003	.003	.003	.003	.003
RS	.002	.001	.005	.003	.005	.005	.005	.006	.005	.006	.005	.006
V	--	--	--	--	--	--	--	--	--	--	--	--
W	.06	.06	.19	.19	.32	.32	.38	.38	.44	.44	.55	.55
Intake Sum	.062	.061	.198	.194	.328	.327	.388	.389	.448	.449	.558	.559
Gamma	.02	.01	.05	.04	.05	.06	.05	.08	.05	.10	.05	.10
C	150.	150.	60.	75.	37.5	37.5	18.8	30.	30.	30.	25.	21.4

Table 4-2 Continued	1		3		5		6		7		9	
	S	B	S	B	S	B	S	B	S	B	S	B
Pa231 +Ac227+D												
SI	.079	.045	.238	.136	.238	.227	.238	.272	.238	.272	.238	.272
RS	.11	.065	.34	.195	.34	.33	.34	.39	.34	.39	.34	.59
V	--	--	--	--	--	--	--	--	--	--	--	--
W	.08	.08	.09	.09	.09	.09	.09	.09	.09	.09	.09	.09
Intake Sum	.27	.19	.67	.42	.67	.65	.67	.75	.67	.75	.67	.95
Gamma	.05	.04	.13	.11	.13	.19	.13	.22	.13	.30	.13	.30
C	47.	65.2	18.75	30.	18.75	18.75	18.75	16.7	18.75	13.6	18.75	11.5

* Non-agricultural

Notes; (1) water ingestion dose modeling carried out to 1000 years.

Table 4-3<1

Allowed Soil Radionuclide Concentrations<2 (pCi/g) Considering All Pathways
Residential Use; 2 feet of cover after remediation, slab on grade and basement construction permitted

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Vertical Extent of Contamination Remaining (V, in feet)

	1	2	3	4	5	6	7	9
U238, 234, or 235	65	44	27	21	14	12	10	8
Th230	625	340	231	231	231	224	224	224
Ra226	3.0	3.0	2.8	2.8	2.6	2.6	1.9	1.9
Pa231	4.2	2.6	2.1	2.1	2.1	2.1	2.0	2.0
Th232	6.8	4.0	3.1	3.1	2.5	2.1	1.7	1.7

<1 values are for each nuclide if present alone. If more than one nuclide is present a sum of fractions calculation employing the relative ratios of the nuclides present, should be performed.

<2 The concentrations shown are to be added to the natural background radionuclide concentration to obtain the absolute value of the allowed radionuclide concentration following site remediation.

Table 4-4[<1]

Allowed Soil Radionuclide Concentrations[<2] (pCi/g) Considering All Pathways
Non-Residential Use; 2 feet of cover after remediation, slab on grade and basement construction permitted

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Vertical Extent of Contamination Remaining (V, in feet)

	1	2	3	4	5	6	7	9
U238,234, 235	250	135	83	60	50	38	38	30
Ra226	9	9	9	9	9	9	9	9
Pa231	50	26	19	19	19	17	14	11
Th232	50	25	17	11	10	8	6	6

<1 values are for each nuclide if present alone. If more than one nuclide is present a sum of fractions calculation employing the relative ratios of the nuclides present, should be performed.

<2 The concentrations shown are to be added to the natural background radionuclide concentration to obtain the absolute value of the allowed radionuclide concentration following site remediation.

Figure 4-1

1140232

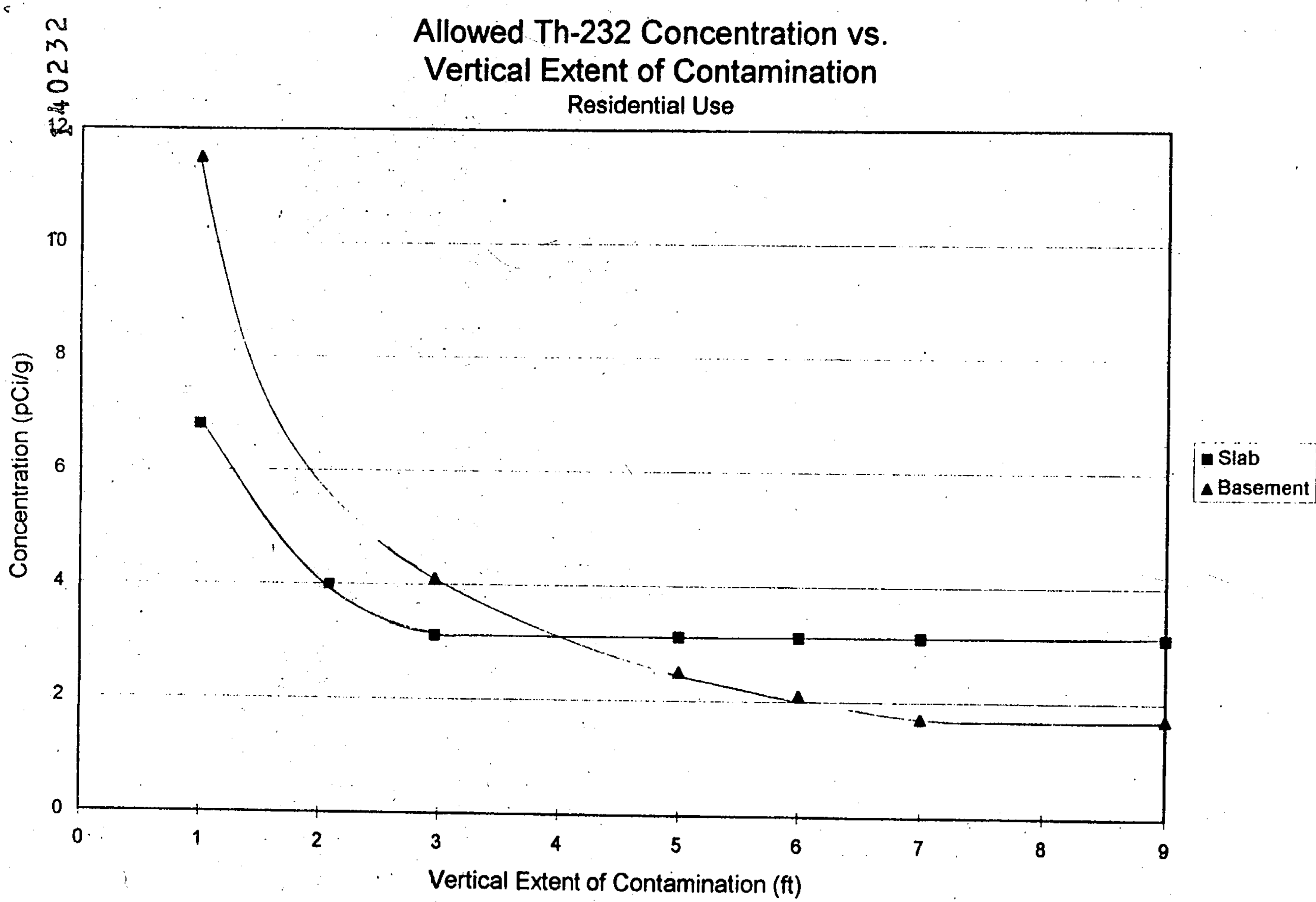

Figure 4-2

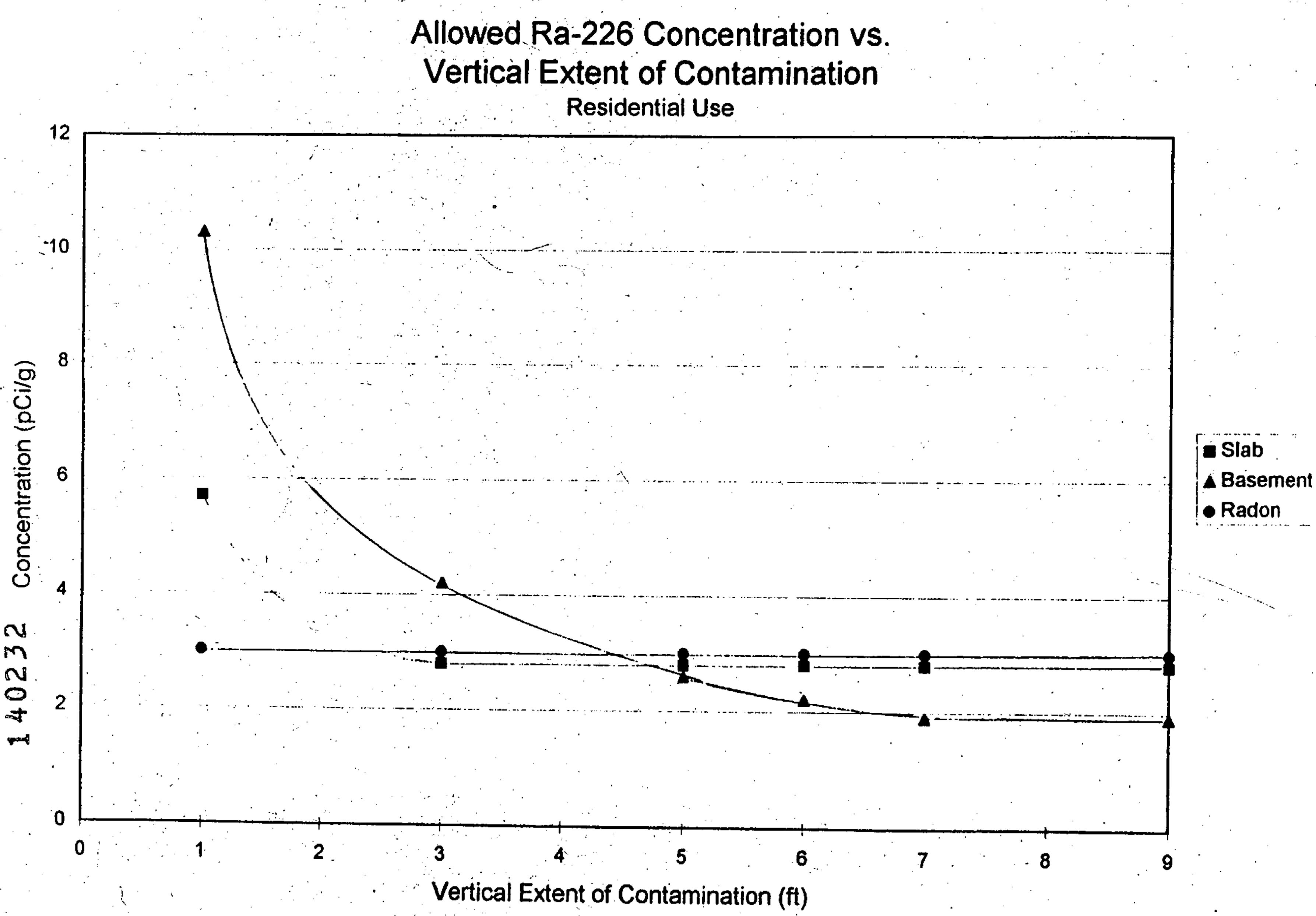

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Figure 4-3

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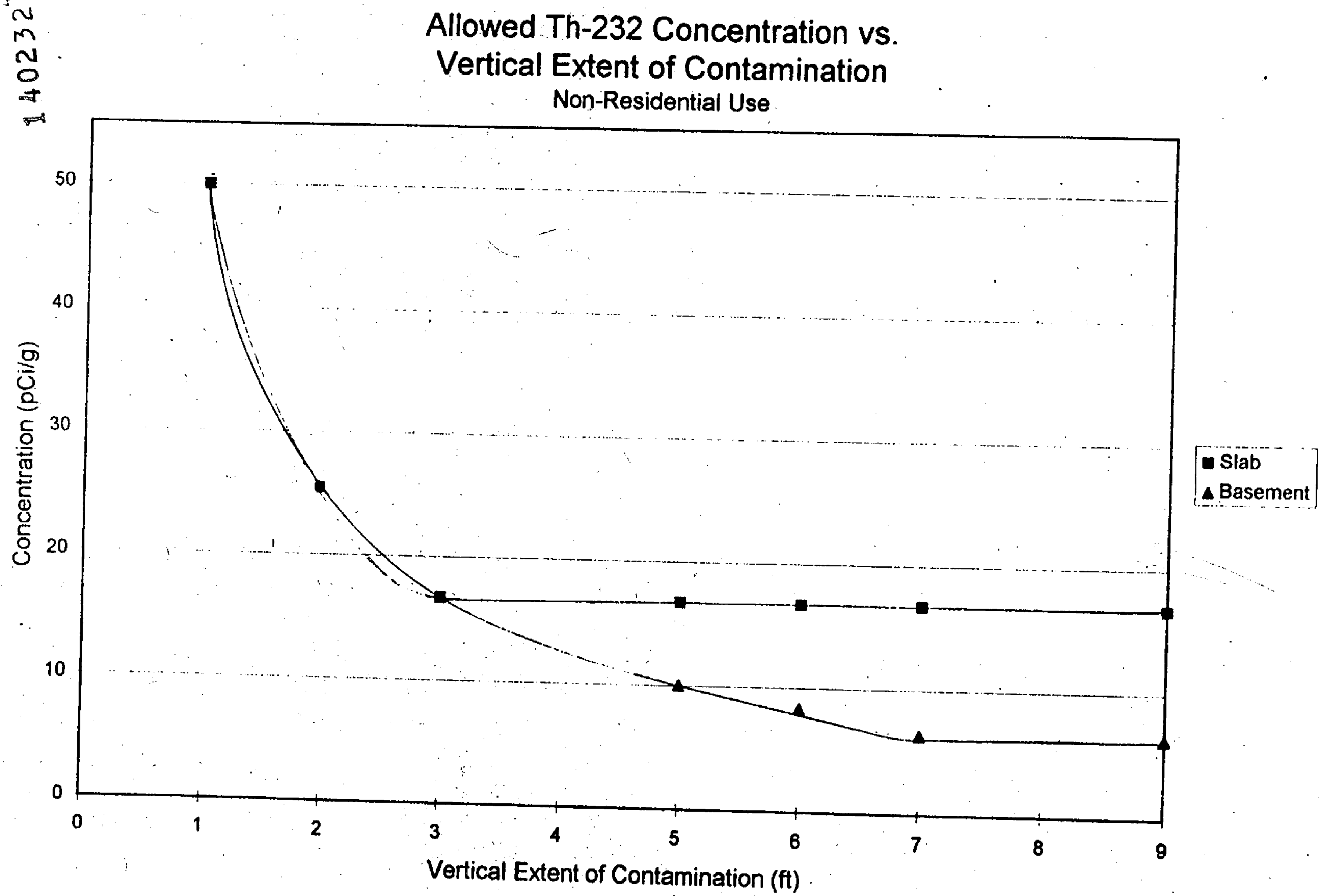

Figure 4-4

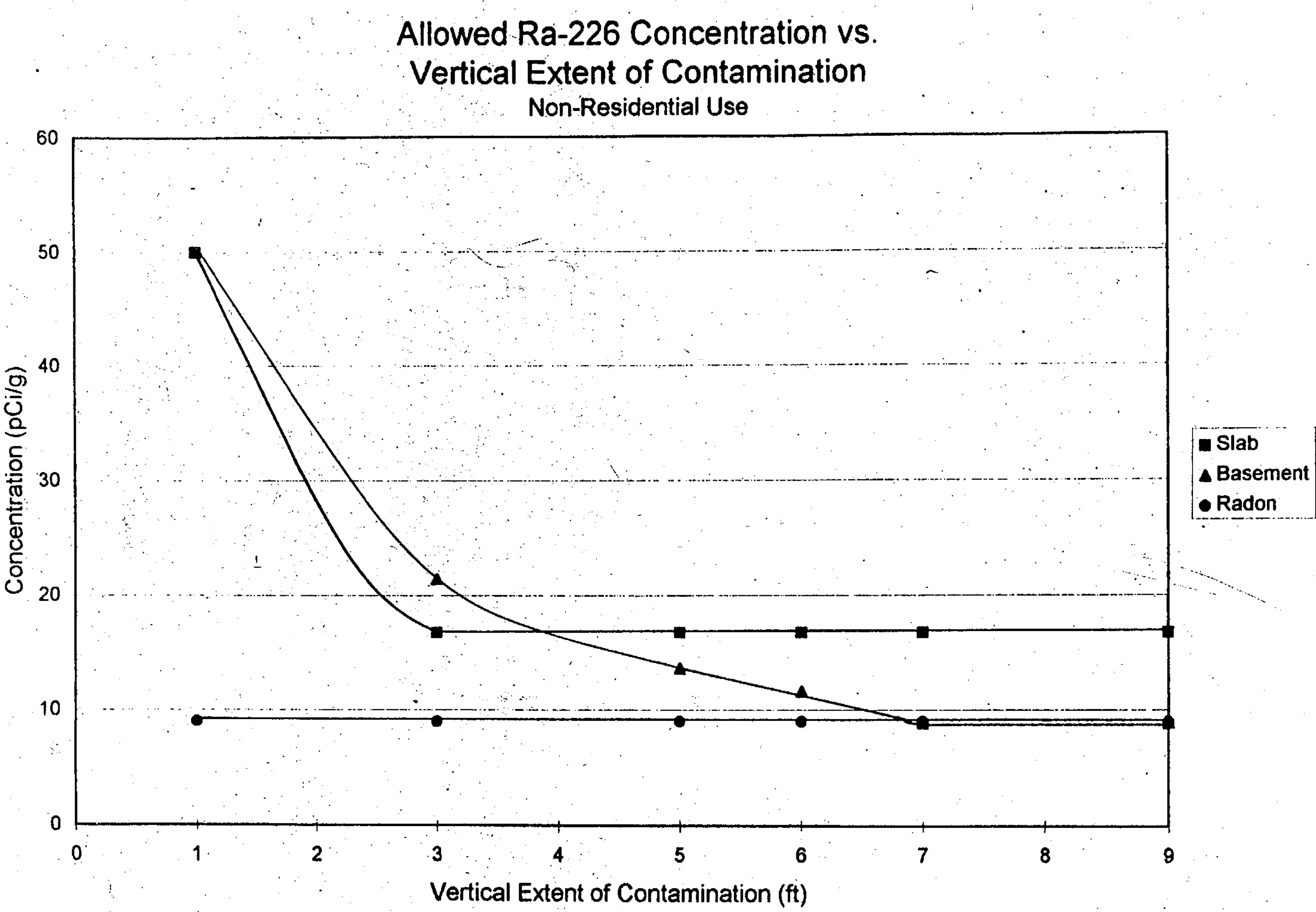

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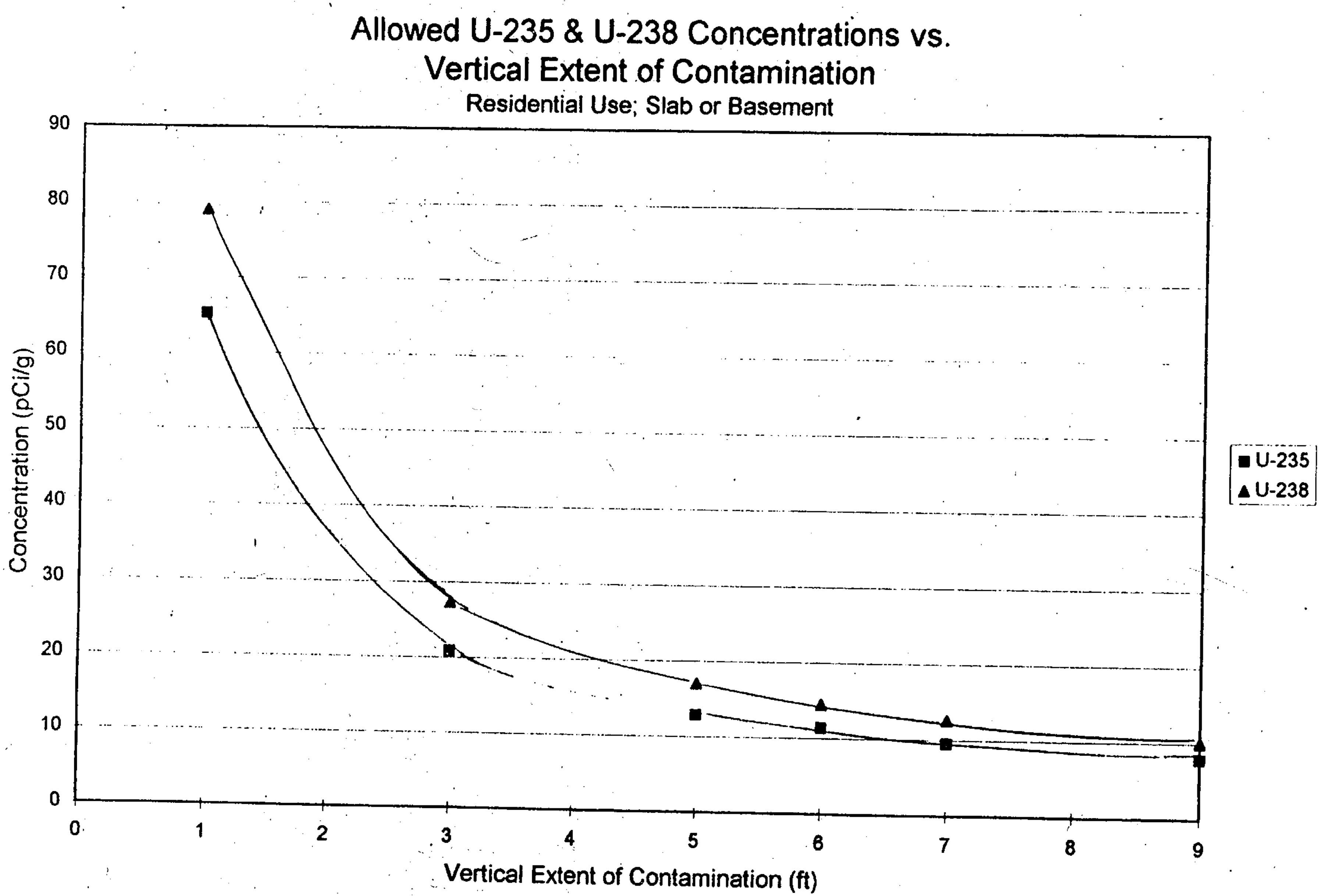
Figure 4-5



Allowed U-235 & U-238 Concentrations vs.
Vertical Extent of Contamination
Residential Use; Slab or Basement
Concentration (pCi/g)
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
Vertical Extent of Contamination (ft)
U-235
U-238

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APPENDIX A

ECONOMIC IMPACT

The economic impact of the proposed cleanup standards for radioactive materials will fall primarily on those agencies, businesses and individuals responsible for the discharge of such material onto the lands and into waters of the State. Because the approximately 35 known and/or suspected sites contaminated with radioactive materials generally involve large volumes of material and because options for remediation, other than full removal, have not previously been well defined, the remediation of these sites could be very costly. This rule creates several options for remediation that could significantly reduce those costs.

For example, by developing the proposed soil cleanup standards as a function of the vertical extent of the remaining contamination remediations can be achieved in many cases without full removal of all contaminated material from the site. Additionally, onsite dispersion is permitted as long as it achieves a desired combination on V and C as specified in Tables 1 or 2 of the rule.

To illustrate the potential cost savings for remediating radioactive contamination, six remediation scenarios are compared for non-residential use sites contaminated with thorium-232 (Table A-1) and radium-226 contaminated sites that are expected to be used for residential development (Table A-2). The remediation options evaluated range from full removal of all contamination to an off-site radioactive waste disposal facility to soil washing and backfilling with the resultant material. The Tables are presented by normalizing the cost of Option A to one and presenting the costs of the other options as a fraction of the cost of Option A.

To make these comparisons, several cost assumptions were made. Although the department reviewed numerous documents to ascertain the costs associated with previous remediations, it is cognizant that the figures used in this analysis may not, due to site specific characteristics and market conditions, reflect actual site remediation costs. The intent of this analysis is to illustrate how the standard setting methodology developed allows for options that may reduce overall remediation costs. The options contained herein may not represent all potential remediation options and are not intended to limit those planning remediations of contaminated sites.

Cost assumptions are based on reviews of "Generic Environmental Impact Statement in Support of Rulemaking on Radiological Criteria for Decommissioning of NRC Licensed Nuclear Facilities" (NUREG-1496), "Technical Background Information Report for the Soil Blending Program" (DEP, June 1987), contaminated site files, and, discussions with disposal facilities, DOE, and DEP Site Remediation personnel. Costs used in our analysis were estimated to be: $350/yd^3 for off-site disposal at a radioactive material disposal facility (including loading and transportation), $95/yd^3 for disposal at an ID-27 landfill, $180/yd^3 for excavation (which includes excavation, backfilling and grading), $190/yd^3 for soil washing, $145/yd^3 for soil blending, $120/yd^3 for soil dispersal and $3/yd^3 for clean soil to be used as backfill.

To compute the amount of soil requiring excavation to achieve the dose standard, the curves plotting the allowable radionuclide in soil concentration versus the vertical extent of contamination were utilized (Figures 4-1 through 4-5). In Figure 4-3, for example, for Th-232, if the soil radionuclide concentration for an 8 foot depth of contamination before remediation is less than 6 pCi/g, the incremental dose standard can be met without any soil excavation assuming at least 2 feet of clean cover is applied over the contaminated soil. If the soil radionuclide concentration prior to remediation is twice the soil concentration needed to meet the incremental dose standard without any excavation, (i.e. 12 pCi/g), then according to Figure 6, the vertical extent of the remaining contamination cannot exceed 4.3 feet. Therefore, the incremental dose standard can be met by removing about 3.7 feet of the contaminated material, or about 46%, thus resulting in a significant cost savings. A somewhat more complex relationship, due to the effects of the radon gas constraint shown in Figure 5, is also presented below for the residential scenario for Ra-226.

Row A of Tables A-1 and A-2 depicts the cost for removal of all contaminated soil to Envirocare in Utah as follows:

Excavation Cost	$	180.00/yd^3
Disposal	$	350.00/yd^3
Backfill	$	3.00/yd^3
Total	$	533.00/yd^3

The ratio across the top of the tables represents the radionuclide in soil concentrations before remediation relative to the allowed concentration for the preremediation depth of contamination. For example, column 2 indicates that soil concentrations are twice the standard, 4 indicates soil contamination concentrations are 4 times the standard etc.

For remediation scenarios B through F, cost savings as a fraction of the cost for total contaminated soil removal to an off-site disposal facility are presented. For the non-residential Th-232 scenario, the largest potential cost savings are realized if the minimum amount of soil is excavated and removed to either an ID-27 landfill or is dispersed on site, assuming enough clean soil exists on site. In both instances a cost savings greater than 50% is realized relative to the costs of full excavation of all contaminated soil and disposal off-site at a radioactive waste disposal facility. Excavation of the entire volume of contaminated soil and then blending with clean soil show minimal potential cost savings at fairly low radionuclide concentrations, but actually increases costs over total removal at higher concentrations (115% to 251%). No cost savings over total removal are expected for soil washing techniques.

The cost savings for the residential Ra-226 scenario, are similar to those for Th-232 for disposal in an ID-27 landfill or dispersal on site (≈50%). However, the use of partial removals is limited by the radon constraint at lower values of V (See Figure 4-2). Other remediation options appear to provide little cost savings over total excavation and off-site disposal.

While the actual costs may fluctuate, a strong case is made that the proposed cleanup standards provide remediation options that can result in significant cost reductions. Due to the large volumes of contaminated material on the sites expected to be encountered, these savings are likely to be on the order of tens of millions of dollars per site.

Economic Impact Calculations

Some sample economic impact calculations are presented below to allow the reader to review how the factors in Table A-1 and A-2 were derived.

Non-residential; Th-232

Option A. Full Removal of Volume to Utah

$ 180 yd^3	Excavation, Backfilling, Grading
$ 350 yd^3	Disposal at Envirocare
$ 3 yd^3	Clean Fill
$ 533 yd^3	

Option B. Excavation of Just Enough Material to Meet the Allowed Dose, With Disposal At Envirocare

R(Ratio of Pre- to Post Remediation Concentration)	Fraction of Material to be Removed
2	(8 - 4.3)/8 = .46
3	(8 - 2.7)/8 = .66
4	(8 - 2.1)/8 = .74
5	(8 - 1.8)/8 = .78
6	(8 - 1.5)/8 = .82
7	(8 - 1.2)/8 = .85
8	(8 - 1.05)/8= .87

C. Same as B, But Disposal at ID-27 Landfill

$ 180 yd^3	Excavation, Backfilling, Grading
$ 95 yd^3	Disposal at ID-27 Landfill
$ 3 yd^3	Clean Fill
$ 278 yd^3	

For the scenario when R=2 the cost of remediation is equal to 278 times the fraction of material that must be removed (.46 from Option B analysis). The cost relative to option A is then; (278 x .46)/533 = .24. Similar factors are derived for R=2,3,4 and so on.

Th-232 cont.

Option D. Excavation of Full Volume and Blending/ Backfilling

$ 180 yd^3	Excavating, Backfilling, Grading
$ 145 yd^3	Blending

For the scenario when R=2, the relative cost is;
(180 + (145 x 2))/533 = .88
For the scenario when R=3, the relative cost is;
(180 + (145 X 3))/533 = 1.15

The factors multiplying the $145 per yd^3 blending cost are derived by finding the volume of clean material necessary to blend down to the required concentrations, and adding that volume to the volume of contaminated soil. For example when R=2, 1 yd^3 of clean material must be blended with 1 yd^3 of contaminated material to reduce the concentration by one-half. Thus twice as much soil volume is processed, as compared to the contaminated volume.

Option E. Same as B, But Disperse Material On Site

$ 180 yd^3	Excavating, Backfilling, Grading
$ 120 yd^3	Spreading
300 yd^3	

For the scenario when R=2, the relative cost is;
((180 + 120) x .46)/533 = .26

Option F. Soil Washing and Backfilling

$ 180 yd^3	Excavation, Backfilling, Grading
$ 190 yd^3	Soil Washing with 40% of Volume Remaining
$ 350 yd^3	Disposal at Envirocare

For the scenario when R=2, the relative cost is;
(180 + 190 + (.40 X 350))/533 = .96

The same cost fraction is obtained for other values of R because in each case the full amount of contaminated material on site must be processed.

Economic Impact Calculations(cont)

Residential Ra-226

Option A. Full Removal of Volume to Utah

$	180 yd^3	Excavation, Backfilling, Grading
$	350 yd^3	Disposal at Envirocare
$	3 yd^3	Clean Fill
$	533 yd^3	

Option B. Excavation of Just Enough Material to Meet the Allowed Dose, With Disposal At Envirocare

R	Fraction of Material to be Remediated
2	(8 - 0)/8 = 1.0
3	(8 - 0)/8 = 1.0
4	(8 - 0)/8 = 1.0
5	(8 - 0)/8 = 1.0
6	(8 - 0)/8 = 1.0
7	(8 - 0)/8 = 1.0
8	(8 - 0)/8 = 1.0

In this case, i.e., residential Ra226, partial excavation can't be used for R equal or greater than two. From Figure 4-2, the required concentration for 8 feet of contamination is 1.9 pCi/g. Because of The limit on the allowed concentration of of 3 pCi/g at any value of vertical extent imposed by the radon background criteria, there is no value of vertical extent that can accept a ratio of R=2 or greater. Therefore Option B costs are identical to Option A costs.

Option C. Same as B, But Disposal at ID-27 Landfill

$	180 yd^3	Excavation, Backfilling, Grading
$	95 yd^3	Disposal at ID-27 Landfill
$	3 yd^3	Clean Fill
$	278	

For the scenarios when R=2 through 8, the cost ratio is; (277.9) /533 = .52. The factor is the same for all R again because partial excavation can't be used for R=2 or greater

Residential Ra-226 cont.

Option D. Excavation of Full Volume and Blending/ Backfilling

$ 180 yd^3 Excavating, Backfilling, Grading
$ 145 yd^3 Blending

For the scenario when R=2, the cost ratio is;
{180 + (2 X 145)}/533 = .88
For the scenario when R=3, the cost ratio is;
{180 + (3 x 145)}/533 =1.15

Option E. Same as B, But Disperse Material On Site

$ 180 yd^3 Excavating, Backfilling, Grading
$ 120 yd^3 Spreading
$ 300 yd^3

For the scenarios when R=2 through 8, the cost ratio is;
(180 + 120) /533 = .56

Option F. Soil Washing and Backfilling

$ 180 yd^3 Excavation, Backfilling, Grading
$ 190 yd^3 Soil Washing with 40% of Volume Remaining
$ 350 yd^3 Disposal at Envirocare

For the scenarios where R=2 through 8, the cost ratio is;
{180 + 190 + (.40 X 350)}/533 = .96

Table A-1

REMEDIATION COST AS A FRACTION OF REMEDIATION COST FOR FULL EXCAVATION AND DISPOSAL AT ENVIROCARE

NON-RESIDENTIAL -- Th-232

Remediation Scenarios	R = Ratio of the Pre-Remediation Concentration to the Post-Remediation Concentration Standard (C) from Table 4-4 <1							
	1	2	3	4	5	6	7	8
(A) Full removal of volume to Utah <2	—	1.0	1.0	1.0	1.0	1.0	1.0	1.0
(B) Excavation of just enough material to meet the allowed V, with disposal in Utah	—	.46	.66	.74	.78	.82	.85	.87
(C) Same as B but disposal in ID-27 landfill	—	.24	.34	.39	.41	.43	.44	.45
(D) Excavation of full volume and blending/backfill	—	.88	1.15	1.43	1.70	1.97	2.24	2.51
(E) Same as B but disperse material on-site	—	.26	.37	.42	.44	.46	.48	.50
(F) Soil Washing and Backfill	—	.96	.96	.96	.96	.96	.96	.96

Table A-2

REMEDIATION COST AS A FRACTION OF REMEDIATION COST FOR FULL EXCAVATION AND DISPOSAL AT ENVIROCARE

RESIDENTIAL -- Ra-226

Remediation Scenarios	R = Ratio of the Pre-Remediation Concentration to the Post-Remediation Concentration Standard (C) from Table 4-3 <1							
	1	2	3	4	5	6	7	8
(A) Full removal of volume to Utah <2	—	1.0	1.0	1.0	1.0	1.0	1.0	[illegible]
(B) Excavation of just enough material to meet the allowed V, with disposal in Utah	—	1.0	1.0	1.0	1.0	1.0	1.0	[illegible]
(C) Same as B but disposal in ID-27 landfill	—	.52	.52	.52	.52	.52	.52	[illegible]
(D) Excavation of full volume and blending/backfill	—	.88	1.15	1.43	1.70	1.97	2.24	[illegible]
(E) Same as B but disperse material on-site	—	.56	.56	.56	.56	.56	.56	[illegible]
(F) Soil Washing and Backfill	—	.96	.96	.96	.96	.96	.96	[illegible]

<1 For an 8 ft. Depth of contamination assumed in these examples

<2 Assumes cost of excavation, disposal, backfill = $533 per cubic yard