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ABSTRACT

This paper provides an overview of current and future decommissioning standards applicable in the United States. The standards promulgated by both the U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission (NRC), as well as standards proposed by the American National Standards Institute, are presented. A summary is presented of the recent NRC actions to produce revised residual radioactivity criteria. The NRC regulates the activities of licensees who own lands and structures that may be contaminated with radioactive materials and who wish to terminate their licenses. To acquire unrestricted release of their property, licensees must meet specific criteria and follow identified procedures that help the NRC staff determine that public health, safety, and the environment are protected. For license termination, existing standards are found in Regulatory Guide 1.86, "Termination of Operating Licenses for Nuclear Reactors" (AEC 1974). The standards are in terms of fixed, removable, and total surface- contamination levels for groups of radionuclides potentially present at licensed facilities. The standards in Regulatory Guide 1.86 have also been adopted by the DOE for decommissioning defense-related facilities. There are no widely accepted standards for release of soils or other bulk sources.

Since these standards were published in 1974, there have been revisions to the methods used for estimating radiation dose, changes in the underlying philosophy of radiation protection, and problems associated with applying surface-activity criteria to bulk-contamination cases. As a result, the NRC is in the process of revising its standards to provide a consistent basis for determining whether the use of lands, structures, materials, equipment, and products involving low levels of radioactivity could merit deregulation. For decommissioning, the NRC will set goals for limiting potential individual and collective doses and will define a procedure for measuring the value of returning lands and structures to unrestricted use by balancing the potential dose against potential benefits of license termination.

Recent work for the NRC has established a generic basis for translating contamination levels to annual dose. This basis uses modeling and radiation exposure pathway/scenario analyses to relate residual contamination levels in buildings and on land to individual dose. The NRC will use this work as the basis to develop generic screening criteria, in terms of surface- or bulk-contamination levels, related to their annual dose criteria.

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BACKGROUND

To aid in understanding the discussion of decontamination and decommissioning, the NRC provided the following standardized definitions (Oak et al. 1980):

- Decommissioning: Preparation of nuclear facilities for retirement from active service--a program to reduce or stabilize radioactive contamination and reduce potential health and safety impacts on the public.
- Decontamination: Those activities used to reduce the levels of radioactive contamination in or on property.
- Dismantlement: Immediate removal of radioactive material at time of site closure prior to license termination.
- Entombment: The encasement of radioactive materials in concrete or other material to assure long-lived retention of radioactive materials for decay.
- Safe Storage: Actions needed to place and maintain a nuclear facility in a condition to permit radioactive decay prior to final decommissioning.

The NRC currently has over 22,000 licensees, including commercial reactors, other uranium fuel cycle facilities, and facilities involved in the production and use of industrial and radiopharmaceutical sources. All of these facilities, and additional future facilities, will ultimately require license termination. There is a recognized need for a consistent and comprehensive approach for decommissioning that uses standardized criteria for the protection of public health and safety, and protection of the environment. The decommissioning options favored by the NRC are either immediate dismantlement after site closure or dismantlement after some period of safe storage to permit radioactive decay. The least-favored decommissioning option is entombment because it requires continued commitment of resources for security and monitoring, and regulatory actions for long periods of time. The following sections describe existing guidance for decommissioning provided by the NRC, DOE, and the American National Standards Institute (ANSI).

Regulatory Guide 1.86

In June of 1974, the Directorate of Regulatory Standards of the U.S. Atomic Energy Commission (AEC) issued Regulatory Guide 1.86 entitled "Termination of Operating Licenses for Nuclear Reactors" (AEC 1974). This Regulatory Guide contains descriptions of the methods and procedures considered acceptable for the termination of operating licenses for nuclear reactors. It has been used by both the NRC and DOE in evaluating, on a case-by-case basis, requests for license termination or decommissioning. The regulatory guide is intended to serve as the primary standard against which to evaluate the adequacy of decontamination efforts prior to unrestricted release. The standards are summarized in Table 1 in terms of acceptable surface contamination levels.

Table 1. Summary of the Acceptable Surface Contamination Levels from Regulatory Guide 1.86

Radionuclide	Limit (dpm/100 cm^2) Average[a][b]	Maximum[a][c]	Removable[a]
Natural U, ^{235}U, and associated decay products	5,000 α	15,000 α	1,000 α
Transuranics, ^{226}Ra, ^{228}Ra, ^{230}Th, ^{228}Th, ^{231}Pa, ^{227}Ac, ^{125}I, ^{129}I	100	300	20
Natural Th, ^{232}Th, ^{90}Sr, ^{223}Ra, ^{224}Ra, ^{232}U, ^{126}I, ^{131}I, ^{133}I	1,000	3,000	200
Beta-gamma emitters (radionuclides with decay modes other than alpha or spontaneous Fission) except ^{90}Sr and other noted above	5,000 β-γ	15,000β-γ	200 dpmβ-γ/100cm^2

(a) Corrected for background, efficiency, and geometry of the detector.
(b) Averaged over an area less than 1 m^2.
(c) For an area less than 100 cm^2.

Regulatory Guide 1.86 also describes possession-only license alternatives, surveillance, and security requirements necessary to achieve an unrestricted release for materials at nuclear reactors. This regulatory guide has been applied to a number of situations beyond nuclear reactors and remains the basic standard for achieving license termination.

Values were provided for average, maximum, and removable surface-contamination levels in units of dpm/100 cm^2. No bulk or volume activity values were provided. The average values were intended to represent the average value over an area of 1 m^2, or the entire area of objects smaller than 1 m^2. The maximum values were intended to apply to a surface area not to exceed 100 cm^2 and were a factor of three larger than the average value. The factor of three was intended to reflect a half-scale deflection of a log-based radiation detection instrument and was judged to be a level that could be observed under field conditions. The removable contamination level was intended to relate to the amount removed by wiping an area of 100 cm^2 with dry filter paper.

DOE Orders

The DOE has established policies and guidelines for the management, decontamination, and decommissioning of radioactively contaminated facilities and land under DOE ownership or control in DOE Order 5820.2A, Chapter V (DOE 1988). The policy of DOE is to ensure that contaminated facilities controlled by DOE are managed in a safe, cost-effective manner that complies with Federal and State requirements regarding exposures to radiation and other hazardous materials.

The basic radiation protection standards applied by the DOE are contained in DOE Order 5400.5 (DOE 1990). For residual radioactive materials, the basic standard (to be applied in addition to naturally occurring background exposures) is 1 mSv (100 mrem) effective dose equivalent; with the condition that exposures be maintained "as low as reasonably achievable" (ALARA). Under unusual circumstances, DOE may approve a temporary dose limit higher than 1 mSv (100 mrem), but not greater than 5 mSv (500 mrem) in a year. These unusual circumstances may include temporary conditions at a property scheduled for remedial action. The ALAPA requirement would apply for the selection of such a temporary dose limit.

For soil contamination, site-specific cleanup guidelines are to be calculated using the RESRAD software (DOE 1989). Residual concentrations of radioactive material in soil are those in excess of background concentrations, averaged over an area of 100 m^2. Soil concentrations of ^{226}Ra, ^{228}Ra, and ^{230}Th, are

- 5 pCi/g, averaged over the first 15 cm of subsurface soil, and
- 15 pCi/g averaged over 15-cm-thick layer of soil below a depth of 15 cm.

For external gamma radiation, buildings or habitable structures can not be released if the exposure rate exceeds 20 $\mu R/h$ above background, and they shall comply with the basic dose limit under an "appropriate use" scenario.

For surface contamination, DOE adopted the Regulatory Guide 1.86 values shown in Table 1, with the exception of the transuranic (TRU) radionuclide group. For the TRU grouping, DOE held in reserve the surface-contamination values, pending the development of standards more applicable to DOE facilities.

Draft ANSI Standard N13.12

In August 1988, ANSI published ANSI Standard N13.12, entitled "Draft American National Standard, Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use" (ANSI 1988). This draft standard was published for trial use and comment for a 12-month period, after which the standard would be revised and finalized. However, there has been no action to finalize the standard. The surface-contamination standard was developed by using the Maximum Permissible Concentration in air (MPC_a) or water (MPC_w) found in 10 CFR Part 20 (1975) to group radionuclides into three categories.

Table 2. Summary of Draft ANSI Standard N13.12 Primary Surface Contamination Limits

Group	Description[a]	Radionuclides	Limit (dpm/100 Cm^2) Removable	Total (fixed plus removable)
1	$MPC_a \leq 2 \times 10^{-13}$ Ci/m^3 or $MPC_w \leq 2 \times 10^{-7}$ Ci/m^3	^{227}Ac, ^{241}, ^{242m}, ^{243}Am, ^{249}, ^{250}, ^{251}, ^{252}Cf, ^{243}, ^{244}, ^{245}, ^{246}, ^{247} ^{248}Cm, ^{125}, ^{129}I, ^{237}Np, ^{231}Pa, ^{210}Pb, ^{238}, ^{239}, ^{240}, ^{242}, ^{244}Pu, ^{226}, ^{228}Ra, ^{228}, ^{230}Th	20	non-detectable[b]
2	Radionuclides not in Group 1 and with the $MPC_a \leq 1 \times 10^{-12}$ Ci/m^3 or $MPC_w \leq 1 \times 10^{-7}$ Ci/m^3	^{254}Es, ^{256}Fm, ^{126}, ^{131}, ^{133}I, ^{210}Po, ^{223}Ra, ^{90}Sr, ^{232}Th, ^{232}U	200	2,000α non-detectable β-γ[c]
3	Radionuclides not in Group 1 or Group 2	-----	1,000	5,000

(a) Non-occupational MPC_a and MPC_w listed in 10 CFR 20 (1975).
(b) With an instrument calibrated to measure at least 100 pCi distributed over 100 cm^2.
(c) With an instrument calibrated to measure 1 nCi spread over the detector area in an area with a background less than 100 counts per minute.

The standard states that property with contamination levels in excess of the table values shall be treated as radioactive material. In addition, the standard outlined the difference between fixed and removable contamination by defining the specific levels summarized in Table 3.

As the basis of ANSI N13.12, the limit for ^{90}Sr was arbitrarily taken to be 1000 dpm/100 cm^2 from background resulting from the atmospheric testing of nuclear weapons. For ingestion, the groupings were derived based on MPC_w with a bound of 5000 dpm/100 cm^2. For inhalation, the groupings were derived using a resuspension rate equation to determine the surface concentration needed to create the MPC_a expressed in dpm/100 cm^2.

Table 3. Summary of Draft ANSI Standard N13.12 Alternate Surface Contamination Limits

Contamination Contingencies[a]	Removable	Total (Fixed Plus Removable)
Unknown radionuclides; or alpha emitters other than natural U and decay products of natural Th are present; or if ^{227}Ac or ^{288}Ra are present	20	non-detectable[b]
All alpha emitters are from natural U and decay products or natural Th; and beta emitters do not include ^{227}Ac, ^{125}I, ^{226}Ra, and ^{228}Ra	200	2,000 α non-detectable β[c]
All alpha-emitters are from natural U and natural Th in equilibrium with progeny; beta emitters do not include ^{227}Ac, $^{125, 129, 131, 133}I$, ^{90}Sr, and $^{223, 228}Ra$	1,000	5,000

(a) Averaged over 1 m^2 with maximum activity in any 100 cm^2 to be less than three times value shown.
(b) With an instrument calibrated to measure 100 pCi or less over 100 cm^2.
(c) With an instrument calibrated to measure 1 nCi or less beta gamma over detector area with a background less than 100 counts per minute.

Problems with Existing Regulations

Several issues have been encountered that were beyond the scope of Regulatory Guide 1.86 and ANSI N13.12. These include the following:

- control of radioactive contamination that is dispersed within a material (bulk contamination)
- materials made radioactive by neutron activation
- contaminated soils
- contaminated clothing and personnel
- material for recycle (metals or equipment), and
- use of field instruments for materials with variable geometries contaminated with alpha-emitters.

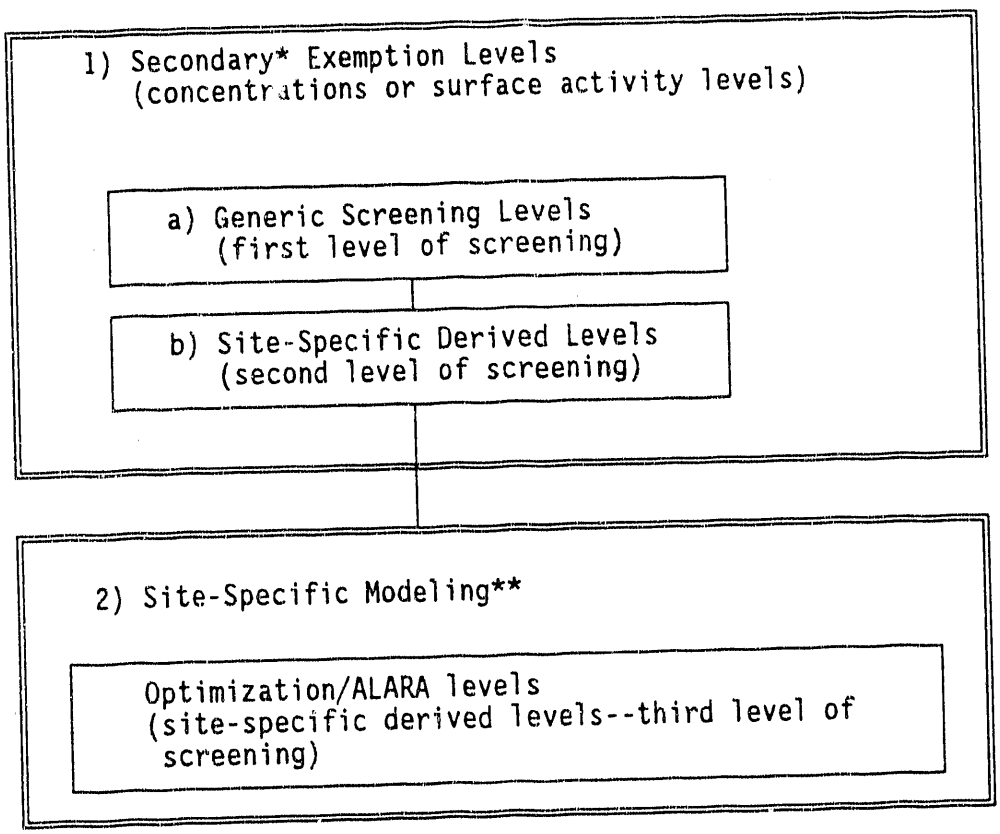
In addition, both methods rely on the use of the dosimetry methods found in the International Commission on Radiological Protection (ICRP) Publication 2 (1959) and the outdated listings of MPC_a and MPC_w. Each system was based on ingestion and inhalation without regard to the potential contribution from external irradiation. With the publication of the revised 10 CFR Part 20, the NRC adopted the dosimetry system outlined in ICRP Publications 26 (ICRP 1977) and 30 (ICRP 1979-1988). Because both Regulatory Guide 1.86 (AEC 1974) and draft ANSI Standard N13.12 (ANSI 1988) use the recommendations in ICRP Publication 2, both are inconsistent with other current standards and regulations. In recognition of these technical failings, and in an effort to improve their policy regarding decommissioning, the NRC is in the process of updating their decommissioning regulations and criteria.

DEVELOPMENT OF REVISED DECOMMISSIONING CRITERIA

During January 1990, the Office of Nuclear Regulatory Research of the NRC issued a draft report for public comment entitled "Residual Radioactive Contamination from Decommissioning: Technical Basis for Translating Contamination Levels to Annual Dose" (Kennedy and Peloquin 1990). The report was published to afford the benefit of comments from a broad spectrum of readers and potential users of the proposed methods. The report was intended to serve as the technical basis for upgrading the NRC's decommissioning policy, including replacing Regulatory Guide 1.86 for surface contamination. The scenarios and pathways outlined in the technical basis report are intended to model conditions in both buildings and contaminated soil areas so that a complete set of decommissioning criteria can be developed. For contaminated land, a special scenario was included to estimate the potential doses from residual contamination in soil resulting in contaminated ground water.

Since January 1990, over 250 comments of both a technical and editorial nature on the draft technical basis were received. Numerous additional comments were made on various aspects of the NRC policy on residual radioactivity. In response, the NRC clarified the intended purpose of the draft and final report. The NRC intends to use the modeling report as the basis for establishing a three-layered hierarchy for developing decommissioning criteria to be used to evaluate the release of property after decontamination and decommissioning. This hierarchy is summarized in Figure 1. The first level of screening is the application of generic criteria, derived from the modeling analysis using prudently conservative models and parameter values, to determine radiation doses from residual radioactive materials. The generic criteria are to be determined by dividing an annual total effective dose equivalent (TEDE) release criterion in mrem, consistent with the individual dose criterion specified by the NRC in the most recent version of 10 CFR 20 (56 FR 23360-23474). The second level of screening is derived using the same models as documented for the first level of screening, with parameter values selected to better represent the potential exposure conditions at a specific site. The third and final layer of evaluation relies on the use of technically-defensible, site-specific models and data to provide an even closer approximation of site-specific conditions.

Figure 1. NUREG/CR-5512 Modeling



* The primary exemption levels are defined in terms of annual dose. Exemption levels defined in terms of radioactivity and based on the primary exemption levels are defined as secondary exemption levels.

The development of models for screening to demonstrate compliance with environmental standards is the subject of Commentary No. 3 published by the National Council on Radiation Protection and Measurements (NCRP 1986). The NCRP presented three levels of criteria for determining compliance with the regulations of the Clean Air Act, 40 CFR Part 61, National Emission Standards for Hazardous Air Pollutants; Standards for Radionuclides (50 FR 5190). Screening level I in the NCRP method applies the simplest models and data including a high degree of conservatism with few user-defined parameter or data requirements. Levels II and III require additional site-specific data to reduce the modeling conservatism. If the user of the NCRP method shows compliance using the Level I models and data, then no further calculations are necessary. If the Level I results exceed the standards, the model user must apply the Level II and III models until compliance is determined. If the results fail at all levels, the NCRP recommends the use of professional assistance in radiological assessment to determine how to proceed (NCRP 1986).

The approach described by the NRC in determining residual radioactive contamination limits is quite similar to the NCRP screening method. The NRC approach will be documented in a three-volume set to finalize the initial January 1990 NUREG/CR-5512 report. Volume 1 contains the modeling mathematical formulations and the level of detail needed to develop microcomputer-based, user-friendly software under strict quality assurance procedures. Volume 1 is intended to be used as the major reference for the development of Volume 2 which contains the software description, including a user's manual, tables of generic unit-concentration TEDEs, example calculations developed to facilitate analyses, and the computer code listing. Volume 3 contains the results of a sensitivity analysis of parameter values used in the modeling and a comparison of the results with previously used guidance (e.g., Regulatory Guide 1.86).

The mathematical formulations in Volume 1 are intended to be used for the first two levels of screening. The first level of screening is intended to produce generic dose estimates that are unlikely to be exceeded at real sites. The degree of conservatism associated with the models and data at the first level of screening is difficult to determine. However, efforts have been made to select models and data that represent a variety of generic conditions and parameter values that lie within the distributions of reported or expected values (i.e., parameter values that are not at the extremes of the ranges). When this approach applies, the model and data selections are referred to as being "prudently conservative." The exceptions to this general approach are the model and data selections associated with the water-use model to account for potential ground-water contamination. For the water-use model, both the model and parameter selections have been made in an intentionally conservative manner and are so noted in the text.

For the first level of screening, portions of the modeling analysis are intentionally conservative. As a result, the annual TEDEs calculated using the default parameter values should provide an overestimate of the actual dose that individuals might receive. The second level of screening allows the use of site-specific data to reduce the conservatism of the result and produce a more realistic estimate of site-specific conditions. This approach should be useful in determining when more detailed site-specific assessments or modifications to the generic scenarios are required.

As with the NCRP screening models, the NRC will allow the application of a third level of evaluation to produce a more site-specific result. This third level would employ models and data that are carefully chosen to match the complex conditions at a specific site. When this third approach applies, licensees will need to defend the models, data, and results.

Use of Scenarios

The primary purpose of establishing generic radiation exposure scenarios for the first two levels of screening is not to assess or predict exact radiation exposures. Rather, the primary purpose of the scenarios is to establish four criteria to be used along with other information to make informed decisions about decontamination and decommissioning of sites with residual radioactive material. Four criteria are needed to create a complete and consistent basis for decision-making. The four criteria are 1) a surface contamination level for buildings and building materials (in Bq/100 cm^2 or dpm/100 cm^2), 2) volume (or bulk) criteria for volume sources in buildings (in Bq/g or pCi/g), 3) soil contamination criteria (in Bq/g or pCi/g of soil), and 4) a total site inventory criteria (in Bq or Ci). The other information used is likely to include direct measurement of the external dose rates. Although external exposure pathways are involved in the models for completeness, they are not intended to replace field measurements.

Scenarios for Contaminated Buildings

Two scenarios for residual radioactive materials in buildings are needed to adequately describe the potential contamination conditions found at actual facilities. These two scenarios account for 1) building renovation (subsurface or volume sources) and 2) normal building occupancy (exposure to surface-contamination sources). Estimates of the potential dose from a subsurface inventory in the building-renovation scenario are important to account for residual inventories of difficult-to-measure alpha-emitters or beta-emitters. The building occupancy scenario is intended to depict the situation where the residual inventory is present as a layer of surface contamination.

A number of potential exposure pathways can be identified during building renovation and building occupancy. Although the potential pathways may be quite numerous, some will produce greater radiation doses than others. The potential pathways considered in the NRC screening analysis are shown in the following list, with those selected for analysis shown in bold type:

- **external exposure to penetrating radiation from surface or volume sources**
- **inhalation of airborne radioactive dust**
- **inadvertent ingestion of "loose" surface contamination**
- external exposure from submersion in airborne radioactive dust
- internal contamination from puncture wounds during building renovation
- dermal absorption of radionuclides
- inhalation of the indoor radon aerosol.

The selection of these pathways, along with the selection of prudently conservative parameter values, provides a balanced analysis for 1) photon-emitters (through the external exposure pathway), 2) alpha-emitters (through the inhalation exposure pathway), and 3) beta-emitters (through inadvertent ingestion of "loose" surface contamination).

Scenarios for Contaminated Land

Two scenarios that rely on a generic water-use model are included for unrestricted use of land. The first scenario only considers drinking water from a ground-water source and accounts for the total radionuclide inventory at the site, in the soil, or in building materials that potentially may be demolished and disposed of onsite as buried rubble. The drinking-water scenario relates the annual TEDE in mrem per pCi (and μSv per Bq) of residual radioactive materials in soil. The second scenario considers residential use of land, including use of ground water for drinking and irrigation of farm products. The residential scenario relates the annual TEDE in units of mrem per pCi/g (and μSv per Bq/g) of soil. Because of the generic treatment of potentially complex ground-water systems, the water-use modeling is intentionally conservative and too simplistic to be considered a rigorous ground-water model. This means that the annual TEDE for the drinking water and residential scenarios may only indicate when additional site data or more sophisticated modeling are warranted. Again, modifications can be made to the scenarios for contaminated land to better account for site-specific soil contamination when conducting the level 2 or 3 screening analysis.

Several factors can influence the importance of the potential pathways that can be considered in the residential scenario. Among these factors are the nature and distribution of the contamination (i.e., surface or subsurface sources); the radionuclides (i.e., their chemical and physical properties); and the environmental setting (i.e., a humid or arid, warm or cold climate). The potential pathways considered for the residential scenario are shown in the following list, with those selected for analysis shown in bold type:

- **external exposure to penetrating radiation from volume soil sources while indoors and outdoors at the site**
- external exposure to soil tracked indoors as a surface source
- external exposure to penetrating radiation from submersion in airborne radioactive soil
- external exposure from swimming and shoreline activities associated with a contaminated surface-water source
- **inhalation of resuspended soil while outdoors or indoors**
- **inhalation of resuspended soil sources tracked indoors**
- inhalation of the radon aerosol while indoors or outdoors

- direct ingestion of soil
- inadvertent ingestion of soil tracked indoors
- ingestion of drinking water from a ground-water source
- ingestion of plant products grown in contaminated soil
- ingestion of plant products irrigated with contaminated ground water
- ingestion of animal products grown onsite (i.e., after the animals ingest contaminated drinking water, plant products, and soil)
- ingestion of drinking water from a contaminated surface-water source
- ingestion of fish from a contaminated surface-water source
- internal contamination from puncture wounds
- dermal absorption of radionuclides.

Again, the selection of these pathways, along with the selection of prudently conservative parameter values, provides a balanced analysis for 1) photon-emitters (through the external exposure pathway); 2) alpha-emitters (through the inhalation exposure pathway); and 3) beta-emitters (through ingestion of contaminated drinking water, agricultural crops, and fish).

SUMMARY

Unrestricted release of buildings or land after decommissioning is currently controlled by the NRC and DOE using Regulatory Guide 1.86 and DOE Orders that define residual radioactive contamination criteria. License termination or unrestricted release decisions have historically been made on a case-by-case basis using ALARA as a general guideline. Regulatory Guide 1.86 contains surface-contamination standards that were developed during the mid-1970s using the dosimetry system in ICRP Publication 2 (1959). Because of technical concerns regarding the basis of the existing standards, and in an effort to develop an improved risk-based system for determining standardized release criteria, the NRC is in the process of developing revised policy for license termination. The heart of this policy is the use of radiation exposure scenarios and pathways to establish a screening approach to derive residual radioactive contamination limits based on an individual dose criterion.

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