PNL-SA--18646

DE91 008827

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February 1991

Presented at Waste Management '91
Tucson, Arizona
February 24-28, 1991

Work Supported by
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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Washington, D.C.

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ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC) regulates the release of slightly radioactive property for unrestricted use. On July 3, 1990, the NRC published a Policy Statement concerning slightly radioactive materials that are below regulatory concern (BRC). The BRC Policy Statement "establishes the framework within which the Commission will formulate rules or make licensing decisions to exempt from some or all regulatory controls certain practices involving small quantities of radioactive material." The heart of the NRC Policy Statement on BRC material is its individual and collective radiation dose limits. To ensure a uniform approach and consistent regulatory decisions, the NRC authorized the development of a comprehensive technical basis that considers the translation of residual contamination levels to annual dose. Radiation doses from residual contamination in buildings and soil are derived from a generic radiation exposure scenario analysis. This paper describes the development of the comprehensive technical basis for translating residual contamination levels to annual dose, provides the modeling details of an example scenario, and presents a comparison of results with existing guidance in Regulatory Guide 1.86.

INTRODUCTION

On July 3, 1990, the United States Nuclear Regulatory Commission (NRC) issued a Policy Statement on slightly radioactive property that is below regulatory concern (BRC). The Policy Statement provided a consistent basis for determining whether lands, structures, materials, equipment, and products having low levels of radioactivity could be found to merit deregulation. This Policy Statement was in response to a legislative directive from Congress and was based upon the best available knowledge from authoritative scientific organizations. The Policy Statement defines annual radiation doses that the NRC finds to be so low that the calculated, hypothetical increased risks of death from cancer from such doses may be justifiably considered below regulatory concern. The NRC Policy Statement on BRC is intended to establish a consistent risk framework for regulatory exemption decisions and ensure an adequate and consistent level of protection of the public.[1] The policy establishes individual dose criteria of 0.01 and 0.1 mSv/yr (1 and 10 mrem/yr, respectively) for individuals and 10 person-Sv/yr (1000 person-rem/yr) for populations. In viewing the uncertainties involved in risk assessment at low doses, the NRC found that an average dose to individuals in a critical group should be less than 0.1 mSv/yr (10 mrem/yr) for each exempted practice. However, they found that an interim dose criterion of 0.01 mSv/yr (1 mrem/yr) should be applied to those practices involving widespread distribution of radioactive material in such items as consumer products or recycled material

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[a] Work sponsored by the U.S. Nuclear Regulatory Commission through the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

and equipment. This interim policy is expected to apply until more experience is gained with the potential for individual exposures from multiple licensed and exempted practices. Only under unusual circumstances would exemptions be considered for practices that would cause continuing exposures exceeding a small fraction of 1 mSv/yr (100 mrem/yr). These circumstances may exist when the doses are shown to be as low as reasonably achievable (ALARA) and when additional regulatory control is not warranted by further reductions in individual and collective doses. The NRC selected the collective dose criterion of 10 person-Sv/yr (1000 person-rem/yr) because, at this level, the number of hypothetical radiation-induced cancers calculated for an exempted practice on an annual basis would be less than one. As a practical matter, the NRC policy is that consideration of dose rates in the 0.001 mSv/yr (0.1 mrem/yr) range introduces unnecessary complexity into the collective dose calculation and could impute an unrealistic sense of significance and certainty at such dose levels. Thus, the Policy Statement states that 0.001 mSv/yr (0.1 mrem/yr) is an appropriate truncation value to be applied to collective dose assessments.

TECHNICAL BASIS

The Policy Statement on BRC provides generic criteria for determining if more detailed cost-benefit analyses must be performed. All of over 22,000 NRC and NRC Agreement State licensees may use these generic screening criteria. To ensure a uniform approach and consistent regulatory decisions, the NRC authorized the development of a comprehensive technical basis that considers the translation of residual contamination levels to annual dose (NUREG/CR-5512).[2] The doses in the technical basis document are calculated in terms of the total effective dose equivalent (TEDE) to an average individual in an exposed population. The TEDE is the sum of the external dose equivalent and the internal committed effective dose equivalent from ingestion and inhalation. The data and parameter values used to describe the exposure conditions are selected to provide a prudently conservative estimate of the likely radiation dose to an average individual in a limited population. They are not selected to perform a worst-case analysis (maximally exposed individual). Still, the resulting annual TEDE factors, which probably overestimate the potential individual dose, should be useful in determining when more detailed site-specific assessments are required. Selection of a prudently conservative scenario requires a great deal of professional judgment and common sense. The intent is to account for the vast majority of potential uses of lands and structures and overestimate the most probable annual dose while discounting a small fraction of highly unlikely situations that would result in higher doses. The alternative was to use scenarios that would yield an upper limit on doses (i.e., bounding or worst case) and would unnecessarily limit the usefulness of the criteria without providing significantly increased benefits to the public health, the public safety, or the environment. Hence, the calculated annual doses in the technical basis document are judged to be higher than (i.e., overestimate) the most probable annual dose, but may be lower than (i.e., underestimate) the bounding annual dose.

There is flexibility in the application of the modeling contained in the technical basis report. For example, if the generic screening levels are too restrictive because the assumed modeling parameters are inappropriate for a specific site, then with adequate justification the generic parameters may be replaced with site-specific parameters. Within the modeling framework, such a substitution of parameters would lead to site-specific derived levels of annual dose. Upon adequate justification, the site-specific derived values may replace the generic screening values as exemption levels. A user-friendly, microcomputer-based program is being developed to facilitate such analyses. Beyond the modeling and scope of the technical basis report, it is possible that a licensee may find it necessary to provide site-specific modeling and optimization of radiation protection in accordance with the principles of ALARA for decommissioning or the termination of a license. The hierarchy of the values for residual radioactive contamination levels within the NRC policy framework is illustrated in Figure 1.

Radiation Exposure Scenarios

The scenarios used in the analyses for buildings and soils are summarized in Table 1.[2] For buildings, two scenarios are defined to generically describe potential contamination conditions accounting for: 1) subsurface or volume sources of contamination (the building renovation scenario) and 2) surface contamination (the building occupancy scenario). These scenarios are used to calculate unit concentration annual TEDE factors that translate the residual contamination level in a building to annual dose. For volume sources, the annual TEDE factors are in units of μSv per Bq/g (and mrem per pCi/g); for surface contamination, the annual TEDE factors are in units of μSv per Bq/100 cm^2 (and mrem per dpm/100 cm^2) for consistency with the units that currently appear in NRC Regulatory Guide 1.86.[3]

For soil, two scenarios are used to derive generic annual TEDE factors for surface soil contaminated to a depth of 15 cm and for the total inventory of material in soils or standing structures that may be buried onsite as rubble. The surface soil factors, which are provided in units of μSv per Bq/g (and mrem per pCi/g), are derived using the residential scenario and account for exposures to individuals who may live in a house on the site and raise garden crops. The inventory factors are in units of μSv per Bq (and mrem per pCi), and are derived using a scenario accounting for drinking contaminated ground water.

Radioactive Chain Decay Notation

Listings of the annual TEDE are provided in tables in NUREG/CR-5512 for each scenario considered for about 250 radionuclides or decay chain mixtures.[2] In these tables, all dose values are normalized to unit activity of the parent radionuclide. The radiations included in the dose factor for a parent are those associated with decay of the parent, plus radiations from progeny that are always in secular equilibrium. Radionuclide decay chain members with half-lives: 1) less than nine hours and 2) less than 10% of the listed parent half-life are included as implicit progeny. For inhalation and ingestion dose factors, the entries include radiations from all radionuclides contributing to internal dose following intake of the parent (within the 50-year dose commitment period). The inclusion of such contributions is defined precisely by the recommendations of ICRP and by the U.S. Environmental Protection Agency (EPA) in Federal Guidance Report No. 11[4] on committed effective dose significant half-life that reach secular equilibrium (constant ratio of activity as a function of time), an entry with "+C" notation is provided, giving dose factors for the entire chain. These decay chains have a long-lived parent with progeny of varying shorter half-lives such as found in the four actinide decay series (the neptunium, uranium, actinium, and thorium series). Entries are included for a decay chain member with a "+C" representation when all progeny of the chain member have half-lives less than 10% of the half-life of the listed member.

Example Pathway Analysis Details

As an example of the pathway analysis detail contained in NUREG/CR-5512, a detailed description of the building occupancy scenario is provided. The building occupancy scenario is defined to account for potential exposure to both fixed and removable thin layer or surface contamination sources. This scenario is used to derive surface activity annual TEDE factors.

This scenario considers chronic exposure to an individual for 2000 h/yr, which represents occupancy during a full work year (i.e., 50 wk at 40 h/wk) in a commercial facility. The exposure pathways considered include direct external exposure from surface sources, inhalation of resuspended removable contamination, and secondary ingestion of removable contamination. This scenario does not include consideration of indoor radon gas that may evolve from residual ^{226}Ra in the building. The air concentration during building occupancy is based on a resuspension analysis using a resuspension factor of 10^{-6} m^{-1}. The secondary ingestion doses use an assumed ingestion rate of 10^{-4} m^2 of loose surface activity ingested per hour of exposure. These assumptions and parameter values are used to modify the basic pathway dose rate conversion and committed effective dose rate conversion factors.

The contribution to the TEDE from external exposure is evaluated as follows:

$$DEXB_i = F_{TB} \, DFES_i \, S_{TBi} \qquad \text{(Eq. 1)}$$

where $DEXB_i$ = external dose from one year of building occupancy, μSv/yr per Bq/100 cm^2,

$DFES_i$ = external dose rate factor for exposure from contamination uniformly distributed on surfaces, μSv/h per Bq/100 cm^2,

S_{TBi} = time integral of radionuclide i activity over the exposure period TBP, Bq•h,
where TBP = length of the occupancy period (1 year), 8760 h,

F_{TB} = fraction of the time that exposure occurs during the one year building occupancy period (i.e., 2000 h/8760 h).

The time integral of unit activity, S_{TBi}, is evaluated as follows:

$$S_{TBi} = [1 - \exp(-\lambda_{ri}\ TBP)] / \lambda_{ri}\ (1\ Bq/100\ cm^2) \qquad \text{(Eq. 2)}$$

where λ_{ri} is the radiological decay constant for the parent radionuclide i (h^{-1}), and other terms are as previously defined.

Inhalation exposure is evaluated for inhalation of residual material resuspended from building surfaces. The inhalation committed effective dose equivalent is calculated as follows:

$$DHB_i = 100\ F_{TB}\ RF\ DFHS_i\ S_{TBi} \qquad \text{(Eq. 3)}$$

where DHB_i = inhalation committed effective dose equivalent from one year of building occupancy, μSv/yr per Bq/100 cm^2,

RF = resuspension factor, m^{-1},

$DFHS_i$ = inhalation committed effective dose rate factor for exposure to contaminated air in units of μSv/h per Bq/m^3,

100 = units conversion factor, Bq/m^2 per Bq/100 cm^2.

and other terms are as previously defined.

Ingestion dose is calculated for inadvertent ingestion of dust from building surfaces. The ingestion committed effective dose equivalent is estimated as follows:

$$DGB_i = 100\ F_{TB}\ \ GD\ DFGS_i\ S_{TBi} \qquad \text{(Eq. 4)}$$

where DGB_i = ingestion committed effective dose equivalent from one year of building occupancy, μSv/yr per Bq/100 cm^2,

GD = ingestion rate of removable surface activity for the building occupancy scenario, m^2/h,

$DFGS_i$ = ingestion committed effective dose rate factor for radionuclide i, μSv per Bq ingested,

100 = units conversion factor, μSv/m^2 per Bq/100 cm^2.

Again, the ingestion rate is based on the assumption that activity from 10^{-4} m^2 of surfaces is ingested per hour of occupancy.

The TEDE for the building occupancy scenario is evaluated as the sum of the contributions from the three exposure routes:

$$TEDEB_i = DEXB_i + DHB_i + DGB_i \quad \text{(Eq. 5)}$$

where $TEDEB_i$ = the annual TEDE for radionuclide i, μSv per year of building occupancy per Bq/100 cm^2, and the other terms are as previously defined.

Comparison with Regulatory Guide 1.86

The results of the building occupancy scenario for selected radionuclides are next used in a comparison with the historical NRC surface contamination values presented in Regulatory Guide 1.86.[3] This comparison is intended to illustrate the potential impact of the BRC policy when compared to the historical guidance used for license termination. In this comparison, the average surface contamination level from Regulatory Guide 1.86 is translated to TEDE for five radionuclides that include beta-gamma and alpha emitters. The results of this comparison are shown in Table 2. The doses from the building occupancy scenario at the average surface contamination levels from Regulatory Guide 1.86 all exceed the BRC individual dose criterion of 10 μSv per year. The estimated TEDE for ^{60}Co and ^{238}U are notably larger than the criterion. This result, although of interest, is not unexpected because Regulatory Guide 1.86 was based on judgement and practical considerations, not a scenario/pathway analysis.

SUMMARY

The NRC Policy Statement on BRC is designed to provide a consistent basis for license termination. The policy defines radiation doses to individuals and populations that produce justifiably low health risks. To ensure a uniform approach and consistent regulatory decisions, a comprehensive technical basis for translating contamination levels to annual dose has been developed. This technical basis will permit the development of generic screening levels and will allow the derivation of site-specific levels for sites that can justify simple differences in the scenario/pathway analysis. For more complex sites, more detailed site-specific modeling and an optimization (ALARA) analysis may be used if adequate justification for it can be developed.

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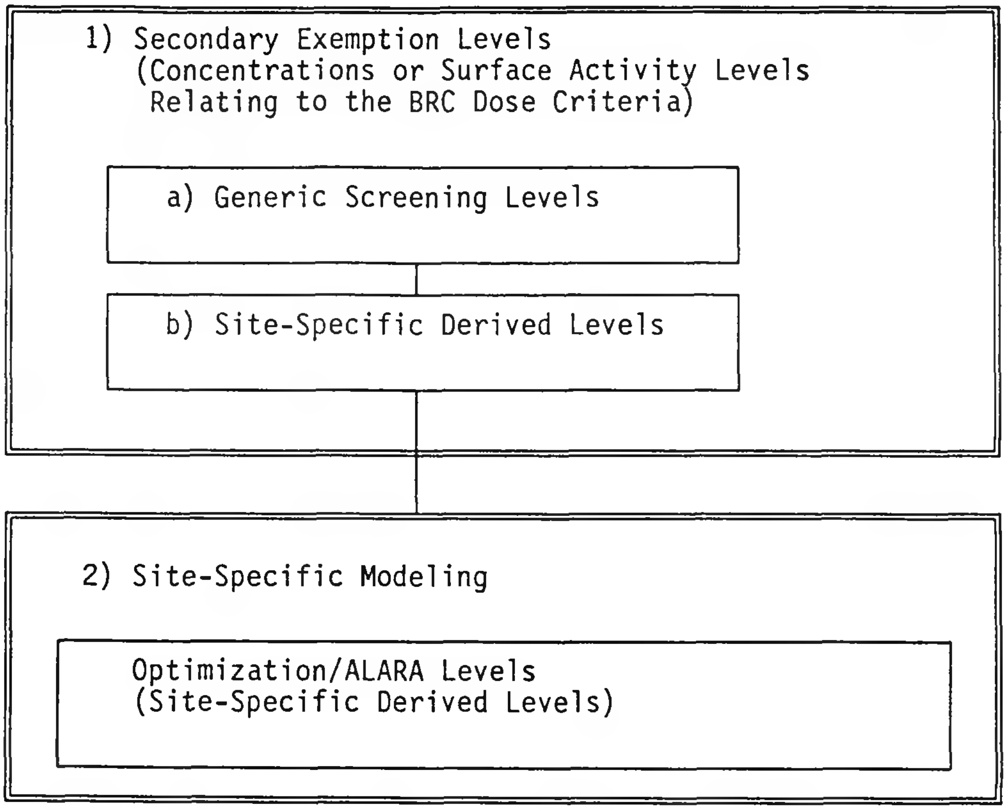

FIGURE 1. NUREG/CR-5512 Modeling

TABLE 1. Scenarios Considered in the Development of Annual Total Effective Dose Conversion Factors for Residual Radioactive Contamination

Source/Scenario	Exposure Pathways	Description
Building Sources		
Renovation	• External • Inhalation • Secondary Ingestion	Scenario to account for the presence of volume sources that may be disturbed during building renovation or demolition.
Building Occupancy	• External • Inhalation • Secondary Ingestion	Scenario to account for thin layers of surface contamination.
Surface Soil Sources		
Residential	• External • Inhalation • Food Ingestion	Scenario to account for residential use of property after decommissioning, including backyard gardening.
Total Inventory		
Drinking Water	• Ingestion of Ground Water	Scenario to account for potential contamination of ground water resources by residual inventories in soil or buildings that may be demolished and buried as rubble onsite.

TABLE 2. Comparison of Surface Contamination Values in Regulatory Guide 1.86, Translated to TEDE Using Results from the Building Occupancy Scenario of the Technical Basis Report

Radionuclide	R.G. 1.86 (dpm/100 cm^2)	Occupancy Scenario Dose (μSv/yr)*
^{60}Co	5000	140
^{90}Sr	1000	15
^{226}Ra	100	15
^{230}Th	100	33
^{238}U	5000	650

* For comparison with the BRC individual dose criterion of 100 μSv/yr.