

RISK ASSESSMENT BASED ON CURRENT RELEASE STANDARDS
FOR RADIOACTIVE SURFACE CONTAMINATION

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ABSTRACT

Standards for uncontrolled releases of radioactive surface contamination have been in existence in the United States for about two decades. Such standards have been issued by various agencies, including the U.S. Department of Energy. This paper reviews the technical basis of published standards, identifies areas in need of revision, provides risk interpretations based on current technical knowledge and the regulatory environment, and offers suggestions for improvements.

INTRODUCTION

With the advance of the decontamination and decommissioning (D&D) activities associated with license termination of nuclear power plants and dismantling of the U.S. Department of Energy's (DOE's) nuclear weapons production facilities, it is of utmost importance that applicable release standards be developed and become available for D&D efforts. In the United States, specific release standards for bulk materials do not exist, but standards for the uncontrolled release of radioactive surface contamination have been in existence for about two decades. Such standards for surface contamination have been issued by the American National Standards Institute, Inc. (ANSI) (1), the U.S. Nuclear Regulatory Commission (NRC) (2), the U.S. Department of Transportation (DOT) (3), and DOE (4), (5), (6). The methods used to justify these standards were developed some 20 years ago and may not satisfy today's regulatory criteria. Recent advancements in conceptual and technical approaches allow an evaluation of the traditional method, which leads to a close examination of current surface release standards and the potential for related revisions.

EVALUATION OF CURRENT STANDARDS

Traditional Approach

Except for the standards issued by DOT (3) current standards for the uncontrolled release of radioactive surface contamination are very similar. The basis for these standards can be traced to the ANSI draft document, *Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use* (1). Appendix B of this document describes the approach that was used to derive the proposed release standards. The standards were derived on the basis of the maximum permissible concentrations for air (MPC_a) and water (MPC_w), which were developed under the old provisions of the Code of Federal Regulations, 10 CFR 20 (7).

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The approach and major assumptions used for deriving the standards included in the ANSI draft document (1) were as follows:

- Hazard evaluation, as well as instrumentation detection capabilities, was considered.
- The pathways considered for hazard evaluation included inhalation (of air) and ingestion (of water); no other pathways were considered.
- Except for some special radionuclides, the ingestion hazard was taken as being proportional to MPC_w ; the inhalation hazard was taken as being proportional to MPC_a .
- Suggested standards were based on either the ingestion pathway or inhalation pathway, whichever was more limiting.
- An upperbound of 5,000 dpm/100 cm² was established for all radionuclides.

The release standards were grouped by contamination level on the basis of the hazard evaluation. Subsequently, agencies other than ANSI modified these levels slightly and published their own release standards.

Current Regulatory Environment

Significant changes have taken place since the publication of surface contamination release standards in the 1970s. A more stringent regulatory environment has resulted in lower dose limits (e.g., 10 CFR 20 and DOE Orders 5400.5 and 5400.11), and newer dosimetric models, as described in publications of the International Commission on Radiological Protection (8), (9), (10), have been developed to obtain more accurate estimations of human doses and health risks. Updated methodologies and analytical tools, such as those presented for pathway analysis in NRC's *Residual Radioactive Contamination from Decommissioning* (NUREG/CR-5512) (11) and in *A Manual for Implementing Residual Radioactive Material Guidelines* (RESRAD) (12), have also been made available. Moreover, the trend of standard setting tends to be moving away from the traditional instrumentation-based approach (such as that used for the current standards) toward a risk-based approach (13).

Ramifications of Evaluation

The availability of this recent approach (e.g., NUREG/CR-5512 [11]) allows a close examination of current standards on a more justifiable basis (i.e., risk) than is possible with the traditional approach (i.e., instrumentation). Such examination would reveal the issue of consistency, as well as levels of conservatism (or nonconservatism), now contained in the existing standards. Findings from such efforts may serve as a basis for revising these standards.

RISK ASSESSMENT METHODOLOGY

Risks* based on current release standards are evaluated by using available risk methodologies and data. Risks are considered from three release scenarios for surface contamination: reuse, recycling, and disposal of the released materials. Individual exposures and the resulting health risks associated with these scenarios are calculated, with emphasis placed on the reuse scenario. The exposure pathways analyzed include inhalation, ingestion, external dose, and radon emanation. The latter two pathways were not considered in the derivation of current standards. The basic approach follows the "screening model" suggested by NUREG/CR-5512 (11), which estimates risks without site-specific information.

Reuse Scenario

Reuse of released materials usually follows surface decontamination. In this scenario, it is assumed that the shape, property, and function of the materials are retained. A variety of reuse scenarios can be postulated for facilities, equipment, and furniture. For analytical purposes, however, release of a building with widespread contamination is thought to be limiting (i.e., conservative) and is used here as a reference point for risk assessment. This assumption is in agreement with the basis for current standards. The analytical approach for assessing risks from such scenarios follows the building occupancy scenario described in NUREG/CR-5512 (11). Doses from inhalation and ingestion also follow the approach of NUREG/CR-5512. For external exposures, doses are calculated by using the SOILD methodology (14), which is being incorporated into the RESRAD-BUILD code (currently under development at Argonne National Laboratory) for building contamination scenarios. The external dose factors have been determined to be consistent with Federal Guidance Report No. 12 (15), which has recently been published by the U.S. Environmental Protection Agency. The dose contribution from radon and its decay products — a pathway not considered in NUREG/CR-5512 (11) — is also included.

Recycling Scenario

The recycling scenario includes such activities as scrap metal smelting and manufacturing of products out of the released materials. The exposure scenarios from recycling activities for surface-contaminated materials would be a subset of those considered for volume contamination. After smelting activities, all contamination would become volumetric because of mixing. Potential exposure to the public would essentially be via the external exposure pathway through the use of contaminated materials (and, to a certain extent, via ingestion). Exposure estimates based on the recycling scenario can be found in literature from the Commission of the European Communities (16). It was found that the potential dose from surface-contaminated materials is quite insignificant compared with those from volume-contaminated materials in the recycling scenario. Therefore, the latter are not analyzed separately here.

Disposal Scenario

The released materials in this scenario are assumed to be disposed of at a landfill. Doses to a future resident (who would reside on the landfill site) as the result of the released contamination are calculated by using the RESRAD code (12).

* Risks are defined here as dose, with the understanding that doses can be easily converted to health risks.

ASSUMPTIONS

The basic assumptions used for the analysis are described in this section.

Reuse Scenario

1. Doses from inhalation and ingestion of particulate follow NUREG/CR-5512 (11), which uses a static model to correlate the release to the surface contamination (in this case, a large area of contamination is assumed, and the room conditions are irrelevant). Specifically, a resuspension factor of $1 \times 10^{-6} \text{ m}^{-1}$ and an effective ingestion transfer factor of $1 \times 10^{-4} \text{ m}^2/\text{h}$ are assumed.
2. A single compartment model is used for the external and radon pathway, as well as for inhalation of volatile materials (e.g., iodines and tritium). A dimension of $5 \times 5 \times 3 \text{ m}$, with an air exchange rate of 1 per hour, is assumed for the room. As a conservative measure, the radon emanation factor from the wall surface is assumed to be 1. For the purpose of calculation, all iodines or tritium are assumed to be released to the room within 1 year.
3. Contamination conditions: Uniform surface contamination on the four walls of the compartment is assumed. Daughter ingrowth is considered for short-lived (less than 1-year half-life) nuclides, except as otherwise specified (such as for long chains of uranium-series nuclides).
4. Surface contamination levels are assumed to be the current release standards (e.g., the NRC Regulatory Guide 1.86 (2) and the DOE RADCON Manual (6)). Five groups of nuclides are considered: Group I - uranium nuclides; Group II - transuranics and others; Group III - thorium and others; Group - IV beta and gamma emitters; and Group V - tritium. For inhalation and ingestion pathways, the surface concentration limits for "removable" contamination are used; for the external exposure pathways, the "fixed + removable" limits are used. For radon pathways, both concentration limits are evaluated.

Recycle Scenario

The recycle scenario for materials with surface contamination is a subset of the overall recycle scenarios of contaminated materials (including volume contamination). As discussed earlier, the issues can be addressed more appropriately elsewhere; therefore, no further analysis is presented here.

Disposal Scenario

For the disposal scenario, the materials released are assumed to be uniformly mixed in a 1-m soil layer of a large landfill. Pathways to the hypothetical resident include the nine environmental pathways modeled in the RESRAD code (12).

RESULTS AND DISCUSSIONS

Risks (in terms of radiation doses) from the current surface release standards are assessed and expressed as total effective dose equivalent (TEDE), which is the sum of the committed effective dose

equivalent (CEDE) from internal exposures and the effective dose equivalent (EDE) from external exposures. Table I summarizes the results for the reuse scenario, and Table II lists the results for the disposal scenario.

Results indicate that doses from the disposal scenario, estimated to be at or below 1 mrem/yr, are consistently lower than those from the reuse scenario. However, reuse of materials carries significant economic benefits that are not within the scope of this paper. Further, disposal of contaminated materials in either landfills or licensed low-level disposal sites will increase the burden on the ever-scarce burial sites in the United States.

Further discussion of the results from the reuse scenario are discussed as follows:

1. The estimated doses are only a few millirem or less, except for a few nuclides, such as U-235, U-232, Th-228, and Th-232, listed in Groups I and II.
2. Doses based on the current standards exhibit a great deal of inconsistency in risk (e.g., from 4×10^{-4} mrem/yr for I-125 to 140 mrem/yr* for U-235 and its decay products).
3. The inhalation pathway is found to be dominant for most radionuclides. For this pathway, the surface resuspension factor appears to be the most sensitive parameter. The resuspension factor has been found to vary from 10^{-9} m^{-1} to 10^{-3} m^{-1} , with a probable range of 10^{-7} m^{-1} to 10^{-6} m^{-1} (11). This variance indicates a likely uncertainty by a factor of 10 or higher.
4. For Group I (uranium) nuclides, the uncertainties arise mainly from the ambiguity in interpreting the release standard itself. For U-238, for instance, control of the release (i.e., 1,000 dpm/100 cm^2) currently focuses on the alpha emitters. There are eight emissions per decay of U-238 nuclide in equilibrium with all its decay products. Therefore, the surface limit for U-238 itself becomes 125 dpm/100 cm^2 . However, of the eight alpha emitted, five are included in its Rn-222 and decay progeny. The emanation of radon into the room may render some alphas unaccounted for in the surface measurement procedure. Further, it can be assumed that the entire uranium decay chain is either in equilibrium (which can only occur in the undisturbed natural ore) or in partial equilibrium (at different uranium processing stages); such ambiguity also contributes to the uncertainty in the release limit.
5. Risk contributions from radon and its progeny (particularly Rn-220 for U-235) could be high. This would impact some nuclides in Groups I, II, and III. The release of radon from "fixed" versus "removable" surface contamination, together with the differing radon emanation power (generally in the range of 0.1 to 0.9), is a major factor of uncertainty.

* The method used in this calculation is for "screening" purposes only. The resulting estimated annual dose of 140 mrem does not mean the current standards exceed the annual limit of 100 mrem (5).

TABLE I

Summary of Surface Contamination Limits and Estimated Doses

Nuclide	Contamination Values (dpm/100 cm ²)		Doses (mrem/yr)				
	Removable	Fixed + Removable	Inhalation	Ingestion	External	Radon (a)	Total
<u>Group I (b)</u>							
U-natural + D	1,000α	5,000α	9	3	2 × 10 ⁻³	1 - 10	13 - 22
U-235 + D	1,000α	5,000α	110	30	0.06	-- (c)	140
U-238 + D	1,000α	5,000α	8	3	2 × 10 ⁻³	1 - 10	12 - 21
<u>Group II</u>							
Transuranics (d)	20	100	4	2	1 × 10 ⁻⁴	0.0	6
Ra-226	20	100	0.02	0.2	8 × 10 ⁻⁴	0.1 - 1	0.3 - 1
Ra-228 (e)	20	100	1 × 10 ⁻⁴	3 × 10 ⁻³	1 × 10 ⁻⁴	0.0	3 × 10 ⁻³
Th-230	20	100	0.7	0.1	1 × 10 ⁻⁴	0.0	0.8
Th-228 (e)	20	100	0.6	0.06	1 × 10 ⁻³	5 - 50	5 - 50
Pa-231	20	100	3	2	4 × 10 ⁻³	0.0	5
Ac-227	20	100	14	3	2 × 10 ⁻⁵	0.0	17
I-125	20	100	-- (d)	-- (d)	2 × 10 ⁻³	0.0	4 × 10 ⁻⁴
I-129	20	100	9 × 10 ⁻³	0.05	4 × 10 ⁻³	0.0	0.06
<u>Group III</u>							
Th-natural	200	1,000	35	5	2 × 10 ⁻⁴	0.0	40
Th-232	200	1,000	35	5	2 × 10 ⁻⁴	0.0	40
Sr-90	200	1,000	3 × 10 ⁻²	0.3	0.0	0.0	0.3
Ra-223 (e)	200	1,000	4 × 10 ⁻⁴	2 × 10 ⁻³	1 × 10 ⁻³	-- (c)	2 × 10 ⁻³
Ra-224 (e)	200	1,000	1 × 10 ⁻⁵	1 × 10 ⁻⁴	3 × 10 ⁻⁵	0.7 - 8	0.7 - 8
U-232	200	1,000	14	2	3 × 10 ⁻⁴	0.0	16
I-126	200	1,000	-- (c)	-- (c)	6 × 10 ⁻³	0.0	6 × 10 ⁻³
I-131	200	1,000	7 × 10 ⁻⁴	1 × 10 ⁻⁴	3 × 10 ⁻³	0.0	4 × 10 ⁻³
I-133	200	1,000	1 × 10 ⁻⁶	2 × 10 ⁻⁷	5 × 10 ⁻⁴	0.0	5 × 10 ⁻⁴

TABLE I

(Cont.)

Nuclide	Contamination Values (dpm/100 cm ²)		Doses (mrem/yr)				
	Removable	Fixed + Removable	Inhalation	Ingestion	External	Radon (a)	Total
<u>Group IV</u>							
Mn-54	1,000	5,000	3×10^{-4}	0.01	0.5	0.0	0.5
Co-60	1,000	5,000	0.02	0.2	3	0.0	3
Nb-94	1,000	5,000	0.04	0.06	2	0.0	2
Cs-134	1,000	5,000	4×10^{-3}	0.5	2	0.0	3
Cs-137	1,000	5,000	3×10^{-3}	0.4	0.7	0.0	1
Ce-144	1,000	5,000	0.02	0.08	0.04	0.0	0.1
Eu-154	1,000	5,000	0.03	0.08	2	0.0	2
<u>Group V</u>							
Tritium	10,000	10,000	0.05	6×10^{-3}	3×10^{-4} (f)	0.0	0.05

- (a) The uncertainty in radon doses results from the assumptions of radon release fraction and the building ventilation rate.
- (b) The radionuclide is assumed to be in equilibrium with all its decay products.
- (c) Dose conversion data are not available.
- (d) Transuranics are represented by Cm-248, which has a dose that is found to be limiting among the transuranic nuclides.
- (e) Includes all decay products with $T_{1/2}$ less than 1 yr.
- (f) The dose is estimated from the dermal pathway.

Sources of surface contamination limits: NRC Regulatory Guide 1.86 (2) and the DOE RADCON Manual (6).

TABLE II		
Estimated Individual Doses (a) from Disposal of Materials with Surface Contamination		
Radionuclide	Surface Release Limit (dpm/100 cm ²)	Annual Dose (mrem/yr)
Ac-227	500	1.5×10^{-2}
Am-241	500	5.5×10^{-3}
Co-60	5,000	5.5×10^{-1}
CS-137	5,000	2.6×10^{-1}
H-3	10,000	1.8×10^{-3}
I-129	500	1.2
Pu-238	500	4.5×10^{-3}
Pu-239	500	5.5×10^{-3}
Ra-226	500	1.8×10^{-1}
Ra-229	500	6.8×10^{-2}
Sr-90	5,000	2.0×10^{-1}
Tc-99	5,000	2.8×10^{-2}
Th-228	500	6.9×10^{-3}
Th-230	500	5.1×10^{-3}
Th-232	1,000	1.8×10^{-1}
U-232	1,000	1.7×10^{-1}
U-235	5,000	6.8×10^{-2}
U-238	5,000	2.2×10^{-2}

(a) Doses are estimated by the RESRAD code on the basis of a residential scenario for a landfill. Surface contaminated materials are assumed to be uniformly mixed with 1-m soil.

6. Uncertainties for Group IV (beta and gamma emitters) are relatively small (less than a factor of 2 to 3) because risks from external exposures are better characterized. Such doses are consistently found to be in the range of 1 to 3 mrem/yr.

CONCLUSIONS AND RECOMMENDATIONS

Results obtained from the current study reveal that risks based on current surface release standards are generally low (i.e., within a few millirem or lower per year, except for a few radionuclides). One major area of concern, however, is the large degree of inconsistency (i.e., variations seen in orders of magnitude) in the risk estimated. Some radionuclides such as U-235, U-232, Th-228, and Th-232, have estimated annual doses on the order of a few tens of millirem or higher per year. Such higher doses warrant further investigation. Also, contributions from radon and its progeny may be significant for some radionuclides. Thus, inclusion of radon in risk estimation cannot be ignored. In general, the approach suggested by NUREG/CR-5512 (11) appears to be on the conservative side; however, the resulting doses also exhibit large uncertainties.

On the basis of the study and the above conclusions, a few recommendations for improvement are made:

1. Future standards should be risk-based, with added considerations from other constraints (such as technology). Thus, an acceptable risk level must be carefully evaluated and recommended. The current International Atomic Energy Agency recommendation (13) suggests a level of 1 mrem/yr; this level is currently under review in the United States.
2. Radionuclide category and grouping may need to be redefined. Definition of the grouping may rely on the following considerations: risk level, type of radiation, or ease of detection. In addition, there seems little reason to list short-lived nuclides (such as I-133, with less than 1 day of half-life) in the standard table because of their rapid decay in time.
3. The adequacy of the "screening model" offered by NUREG/CR-5512 (11) may need further evaluation. This conclusion is in view of the situation where doses are found to be consistently dominated by the inhalation pathway, which is in turn controlled by a single, most important parameter (resuspension factor). Since this particular parameter is not related to the room conditions (e.g., such as room size or ventilation rate) or particle sizes (i.e., respirable fraction), the level of conservatism offered by the suggested resuspension factors is unclear. In addition, a great deal of inconsistency may exist in the level of conservatism introduced into various pathways.
4. Because of the large uncertainties (in most cases, conservatism) involved in the analysis, it is recommended that more advanced models be developed for a more accurate assessment. Such developments would include a dynamic model (as opposed to the static, screening model offered by NUREG/CR-5512 [11]) with more realistic measured data. For instance, the contaminant emission rate together with the room ventilation rate could be used in place of the resuspension factor for assessing the inhalation dose. Furthermore, it would also be appropriate to conduct the analysis by a probabilistic approach, rather than by the current deterministic method.

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