

IMPLEMENTATION OF BENCHMARK DOSE APPROACH AT FUSRAP SITES

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ABSTRACT

All cleanup actions at sites being remediated under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), as amended must be protective of human health and the environment and must comply with applicable or relevant and appropriate requirements (ARARs). Cleanup levels at CERCLA sites are developed based on ARARs or, when no ARARs are available, site-specific risk assessments. The determination of whether a requirement is an ARAR must be made on a site-specific basis.

On April 12, 1999, the U.S. Nuclear Regulatory Commission (NRC) amended 10 CFR 40 by adding requirements to Criterion 6(6) of Appendix A (64 FR 17506), *Radiological Criteria for License Termination of Uranium Recovery Facilities* [Criterion 6(6) rule]. The amendment addresses the lack of remedial standards for contaminated building surfaces and for soil contamination from radionuclides other than radium. To comply with the Criterion 6(6) rule, an NRC licensee must calculate the potential total effective dose equivalent to the average member of the critical group for that site that would result from the radium standard [0.19 Bq/g (5 pCi/g) surface and 0.56 Bq/g (15 pCi/g) subsurface] within 1000 years, based upon site-specific parameters (radon dose excluded). This dose is termed the benchmark dose. Licensees are then to remediate the site such that the residual radionuclides remaining on the site that are distinguishable from background, would not result in a dose greater than the benchmark dose.

The U.S. Army Corps of Engineers (USACE) is managing the Formerly Utilized Sites Remedial Action Program (FUSRAP) pursuant to its CERCLA authority. Many sites within FUSRAP are contaminated with uranium and thorium processing residuals containing the same radionuclides (e.g., radium-226, radium-228, thorium-230, thorium-232, uranium-234 and/or uranium-238) as found at NRC uranium recovery facilities and thorium mills. USACE has determined that the Criterion 6(6) rule is relevant and appropriate at some FUSRAP sites.

This paper describes the use of the Criterion 6(6) rule for the derivation of cleanup levels at several FUSRAP sites. USACE experience implementing the Criterion 6(6) requirements has revealed areas where uncertainties exist and guidance is not currently available. Some examples include the use of the benchmark dose approach at former thorium processing sites, the use of cover in subsurface modeling, proper inclusion of exposure pathways, and ALARA considerations. Lessons learned dealing with these ambiguities will be presented.

INTRODUCTION

The U.S. Army Corps of Engineers (USACE) is required by Congress to comply with the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), 42 USC 9601 et seq. and the National Contingency Plan (NCP), 40 CFR 300, in conducting cleanup work at sites within the Formerly Utilized Sites Remedial Action Program (FUSRAP). The process for developing cleanup levels under CERCLA applies to the remediation of radioactive contamination at FUSRAP sites and any other hazardous substances, pollutants, or contaminants that are also present and require cleanup as part of the program. Cleanup levels at CERCLA sites are developed based on applicable or relevant and appropriate requirements (ARARs). The determination of whether a requirement is an ARAR must be made on a site-specific basis. Risk-based cleanup levels will be established if ARARs are either not available or do not adequately address the risk due to the presence of multiple contaminants and/or multiple exposure pathways. Risk-based cleanup levels should be based upon the likely future land use at the site.

The U.S. Nuclear Regulatory Commission (NRC) regulations for active licensed uranium recovery (UR) facilities [i.e., conventional uranium mills and uranium extraction processes such as in situ leach (ISL) facilities] and thorium mills are codified at 10 CFR 40. NRC amended 10 CFR 40 on April 12, 1999 by adding requirements to Criterion 6(6) of Appendix A (64 FR 17506). The amendment, *Radiological Criteria for License Termination of Uranium Recovery Facilities* [Criterion 6(6) rule], addresses the lack of remedial standards for contaminated building surfaces and for soil contamination from radionuclides other than radium.

Under FUSRAP, USACE identifies, investigates, and takes appropriate cleanup action at sites with radioactive contamination from the early atomic weapons program. FUSRAP sites are contaminated with uranium and thorium processing residuals containing the same radionuclides (e.g., radium-226, radium-228, thorium-230, thorium-232, uranium-234 and/or uranium-238) as found at active NRC licensed UR facilities and thorium mills. USACE has determined that the Criterion 6(6) rule is relevant and appropriate at some FUSRAP sites.

This paper first describes the Criterion 6(6) rule as well as accompanying NRC guidance. It discusses a U.S. Environmental Protection Agency (EPA) directive which covers the Criterion 6(6) rule. It also discusses, and provides an example, of the required sum of the ratios calculation. This paper then details the derivation of surface and subsurface soil cleanup levels for radionuclides other than radium at a former uranium processing site and a former thorium processing site.

USACE experience implementing the Criterion 6(6) requirements has exposed areas where uncertainties exist and guidance is either not currently available or is conflicting. Some example areas include the use of the benchmark dose approach at former thorium processing sites, the use of cover in subsurface modeling, proper

inclusion of exposure pathways, and ALARA considerations. USACE lessons learned dealing with these ambiguities will be presented.

CRITERION 6(6) RULE

NRC's 10 CFR 40, Appendix A, applies to UR facilities and thorium mills that produce byproduct material. The UR facilities and thorium mills are exempt from the decommissioning criteria in 10 CFR 20 Subpart E, as specified in Section 20.1401(a). Decommissioning of mills and ISLs is similar in that the type of soil and building contamination is the same, consisting mainly of residual radium (Ra-226) and natural uranium (U-nat). The applicable cleanup standards for soil radium in Criterion 6(6) of Appendix A address the main contaminant at uranium mills in the large areas (hundreds of acres) where windblown contamination from the tailings pile has occurred, and at ISLs in holding/settling ponds and process solution spills. However, in other mill and ISL site areas, NRC has determined that uranium would be the radionuclide of concern. These areas include under the mill or process building or in a yellowcake (U_3O_8 with impurities) storage area. Thorium-230 (Th-230, the parent of Ra-226) would be the radionuclide of concern at some mill raffinate evaporation ponds.

Because Part 40, Appendix A, provides only decommissioning soil radium and ground-water protection criteria, Criterion 6(6) was amended to address criteria for residual radionuclides, other than radium in soil, for decommissioning of lands and remaining structures. The final Criterion 6(6) rule (effective June 11, 1999) added a paragraph after the radium in soil criteria in Criterion 6(6), to read:

By product material containing concentrations of radionuclides other than radium in soil, and surface activity on remaining structures, must not result in a total effective dose equivalent (TEDE) exceeding the dose from cleanup of radium contaminated soil to the above standard (benchmark dose), and must be at levels which are as low as is reasonably achievable. If more than one residual radionuclide is present in the same 100-square-meter area, the sum of the ratios for each radionuclide, of concentration present to the concentration limit, will not exceed "1" (unity). A calculation of the potential peak annual TEDE within 1000 years to the average member of the critical group that would result from applying the radium standard (not including radon) on the site must be submitted for approval. The use of decommissioning plans with benchmark doses which exceed 100 mrem/yr, before application of ALARA, requires the approval of the Commission after consideration of the recommendation of the NRC staff. This requirement for dose criteria does not apply to sites that have decommissioning plans for soil and structures approved before June 11, 1999.

The benchmark dose applies to surface cleanup [buildings or the top 15 cm (6 inches) of soil] of radionuclides other than radium and it is the estimated dose resulting from cleanup of areas to 0.19 Bq/g (5 pCi/g) Ra-226 at that site. For areas requiring the use of the radium subsurface soil standard, the estimated dose resulting from 0.56 Bq/g

(15 pCi/g) Ra-226 at that site and for those areas, would be used.^a The same concept of regulation (using a Ra-228 benchmark dose) would be applicable to thorium mills.

GUIDANCE

US Nuclear Regulatory Commission

The NRC published for comment draft guidance, to be incorporated into the NRC final Standard Review Plan, on modeling and implementation of the radium benchmark dose approach (64 FR 17690). Specifically, the draft guidance included information describing acceptable dose modeling codes and calculations. The draft guidance also included considerations for some input parameter values such as scenarios for the critical group, exposure pathways, source term, the use of cover, external gamma modeling (e.g., shielding factor and time fractions), and modeling ingestion. Following a sixty day comment period, NRC responses to the public comments were prepared and published. The revised guidance has been incorporated into the *Standard Review Plan for the Review of a Reclamation Plan for Mill Tailings Sites Under Title II of the Uranium Mill Tailings Radiation Control Act* (1).

Chapter 5 of NUREG-1620 contains the general requirements for a decommissioning plan and the remediation and verification of soil Ra-226 contamination cleanup. Appendix H of NUREG-1620 discusses the evaluation of the radium benchmark dose approach, specifically dose modeling.

US Environmental Protection Agency

EPA guidance on Criterion 6(6) is contained in Directive no. 9200.4-35P, *Remediation Goals for Radioactively Contaminated CERCLA Sites Using the Benchmark Dose Cleanup Criteria in 10 CFR Part 40 Appendix A, I, Criterion 6(6)* (2). This document addresses the use of the Criterion 6(6) rule when setting remediation goals at CERCLA sites with Ra-226, Ra-228, Th-230, Th-232, or U-234, and/or U-238 as contaminants of concern. It clarifies the relationship between the soil standards in EPA's 40 CFR 192 and the Criterion 6(6) rule. However, several recommendations in the directive will limit the situations where Criterion 6(6) is used at CERCLA sites. The directive refers to previous EPA guidance to recommend that Criterion 6(6) not be used if the calculated benchmark dose from the radium standard is above 15 mrem/yr (3). This limit on the benchmark dose is significantly less than the 100 mrem/yr limit in the Criterion 6(6) rule. The directive also recommends that the Th-230 and Th-232 soil concentrations be summed and compared to the radium standard of 5 pCi/g independently of the concentration limits for those radionuclides calculated using the benchmark dose. Also incorporated from previous guidance, this directive recommends that the subsurface benchmark dose be calculated using the surface radium standard of 5 pCi/g not the 15 pCi/g subsurface soil standard (4). For sites where Th-230 is the primary contaminant of concern, these recommendations could lead to a significant increase in the amount of soil requiring remedial action. The directive also recommends that an additional assessment be performed to ensure that the risk from residual radionuclides (and, if present, other

chemicals) is within the 10^{-4} to 10^{-6} range. This recommendation ostensibly requires that a risk-based cleanup be performed even though the Criterion 6(6) ARAR addresses all radionuclides and all pathways at the site. The directive acknowledges that this recommendation is specific to this ARAR.

There are several other recommendations that may pose dose modeling and release survey problems. The recommendation that the benchmark dose be met for the sum of exposures from soil and structures may only be appropriate under certain site-specific scenarios. Also, the guidance recommends that the dose from volumetric contamination in structures be considered, but it does not recommend how this be accomplished. The recommendation that a subsurface benchmark dose be estimated for each 15 cm increment to the depth of contamination could result in a different set of cleanup criteria for each layer of subsurface soil.

SUM OF THE RATIOS CALCULATION

The benchmark dose approach ensures that the dose to an average member of the critical group will not exceed that from the radium standard. The sum of the ratios (SOR) calculation is required when more than one radionuclide is present. When using the SOR, the cleanup criterion, which is expressed as the derived concentration guideline level (DCGL), is set equal to unity. Therefore, any significant concentration of other radionuclides will reduce the allowable concentration of radium that can remain. The following example illustrates the effect of the SOR on residual concentrations at a uranium recovery facility with Th-230 and U-nat contamination:

$$DCGL_{Surface} = \frac{C_{Ra226}}{Limit_{Ra226}} + \frac{C_{Th230}}{Limit_{Th230}} + \frac{C_{Unat}}{Limit_{Unat}} \leq 1 \quad (\text{Eq. 1})$$

If the benchmark dose approach is used to derive surface concentration limits for Th-230 and U-nat of 14 pCi/g and 150 pCi/g respectively, then the SOR equation becomes:

$$DCGL_{Surface} = \frac{C_{Ra226}}{5 \text{ pCi/g}} + \frac{C_{Th230}}{14 \text{ pCi/g}} + \frac{C_{Unat}}{150 \text{ pCi/g}} \leq 1 \quad (\text{Eq. 2})$$

If the residual concentrations of Th-230 (5 pCi/g) and U-nat (50 pCi/g) in a 100-square meter area are determined and placed into the equation it becomes:

$$DCGL_{Surface} = \frac{C_{Ra226}}{5 \text{ pCi/g}} + \frac{5 \text{ pCi/g}}{14 \text{ pCi/g}} + \frac{50 \text{ pCi/g}}{150 \text{ pCi/g}} \leq 1 \quad (\text{Eq. 3})$$

$$DCGL_{Surface} = \frac{C_{Ra226}}{5 \text{ pCi/g}} + 0.36 + 0.33 \leq 1 \quad (\text{Eq. 4})$$

Solving for the concentration of Ra-226:

$$DCGL_{Surface} = 1.55 \text{ pCi/g} \geq C_{Ra226} \quad (\text{Eq. 5})$$

This example demonstrates that for this area of the site to meet the Criterion 6(6) SOR requirement the residual Ra-226 concentration would have to be significantly lower than the 5 pCi/g surface standard.

DERIVATION OF CLEANUP LEVELS AT FUSRAP SITES

USACE has used the Criterion 6(6) rule to derive cleanup levels at several FUSRAP sites. Through this experience, USACE has recognized that derivation of cleanup levels using the benchmark dose approach at a former thorium processing site, as opposed to a former uranium processing site, presents unique challenges. Examples of each are given below.

Former Uranium Processing Site

The Linde FUSRAP site in Tonawanda, NY is a former uranium processing site. The reasonably probable future land use at this site is commercial/industrial. The critical groups were identified as the industrial worker and the construction worker. However, the radium benchmark dose is based on the industrial worker scenario. Surface and subsurface soil Th-230 and U-total cleanup levels were derived via the RESRAD code (version 5.82). Input parameters were selected based on site-specific information, where available. Exposure pathways modeled were direct gamma, inhalation, and soil ingestion.

The industrial worker was assumed to work at the site in an office building or light industrial facility constructed at some time in the future. The expected condition for the site is that at least 15 cm (6 inches) of asphalt or soil will be maintained over most areas to provide for vehicular traffic or to support vegetative growth. This cover, if maintained, will reduce external gamma radiation levels and will preclude the ingestion of contaminated soil and inhalation of contaminated dust particles. However, as required, no cover was modeled when deriving the surface benchmark dose in order to evaluate the unlikely, but plausible, worst case exposure conditions. The subsurface benchmark dose was calculated assuming 15 cm of cover.

Table I provides the benchmark dose; that is, the potential peak annual TEDE within 1000 years to the industrial worker that would result from applying the radium standard.

Table I. Linde Benchmark Dose (Industrial Worker Scenario)

	<i>Ra-226 Concentration (pCi/g)</i>	<i>Benchmark Dose (mrem/yr)</i>
Surface	5	8.8
Subsurface	15	4.1

Table I data was used to derive cleanup levels for Th-230 and U-total. These cleanup levels are given in Table II.

Table II. Linde Cleanup Levels for All Radionuclides of Concern

<i>Radionuclide</i>	<i>8.8 mrem/yr (Surface)</i>	<i>4.1 mrem/yr (Subsurface)</i>
Ra-226	5 pCi/g	15 pCi/g
Th-230	14 pCi/g	44 pCi/g
U-total	554 pCi/g	3,021 pCi/g

The cleanup levels in Table II are present in the Record of Decision (ROD) signed in March 2000 (5). Remedial action addressed in this ROD was initiated in April 2000.

Former Thorium Processing Site

The W.R. Grace FUSRAP site in Curtis Bay, MD is a former thorium processing site. Hence, the W.R. Grace site is contaminated with both Ra-228 and Ra-226. The reasonably probable future land use at this site is commercial/industrial. The critical groups have been identified as the industrial worker and the maintenance/construction worker. The radium benchmark dose is based on the maintenance/construction worker scenario. Surface and subsurface soil U-234, U-238, and Th-232 cleanup levels were derived via the RESRAD code (version 5.95). It was assumed that the worker would be on site for 130 days per year for 25 years conducting activities associated with construction of new facilities and ongoing upkeep of utilities associated with an industrial facility. Exposure pathways modeled were direct gamma, inhalation, soil ingestion, and ingestion of aquatic foods.

A draft benchmark dose for surface soil was calculated using 5 pCi/g Ra-226. A second draft benchmark dose for surface soil was calculated using 5 pCi/g Ra-228. Both assumed a cover depth of zero. Draft benchmark doses were also determined for 15 pCi/g Ra-226 and for 15 pCi/g Ra-228 at the subsurface, assuming a cover depth of 15 cm in each case. The most conservative surface and subsurface draft benchmark doses were selected to derive the cleanup levels for the other radionuclides of concern.

Table III. W.R. Grace Draft Benchmark Dose (Maintenance/Construction Worker)

	<i>Ra-228 Concentration (pCi/g)</i>	<i>Benchmark Dose (mrem/yr)</i>
Surface	5	5
	<i>Ra-226 Concentration (pCi/g)</i>	<i>Benchmark Dose (mrem/yr)</i>
Subsurface	15	7.8

Table I data was used to derive draft cleanup levels for U-234, U-238, and Th-232. These cleanup levels are given in Table II.

Table IV. W.R. Grace Draft Cleanup Levels for All Radionuclides of Concern
Utilizing Most Conservative Benchmark Radium Dose

<i>Radionuclide</i>	<i>5 mrem/yr (Surface)</i>	<i>7.8 mrem/yr (Subsurface)</i>
Ra-226	5 pCi/g	15 pCi/g
Ra-228	5 pCi/g	15 pCi/g
U-234	1,492 pCi/g	6,219 pCi/g
U-238	288 pCi/g	1,346 pCi/g
Th-232	3 pCi/g	4.8 pCi/g

To date, these draft cleanup levels still require finalization. It is anticipated that the cleanup level development will be documented in an appendix of the site Feasibility Study and finalized in the Record of Decision.

IMPLEMENTATION UNCERTAINTIES

USACE experience implementing the Criterion 6(6) requirements has exposed areas where uncertainties exist and federal policy and/or guidance is not currently available. Some examples follow.

Thorium Processing Sites

NRC guidance (NUREG-1620) only addresses UR facilities because there are no currently licensed or planned thorium mills.

Though the guidance states that the same concept of regulation would be applicable at thorium mills, it does not address how NRC would regulate an ore processing site with both Ra-228 and Ra-226 at above background levels. It is clear that the total radium concentration will be limited to 5 pCi/g; however, it is not evident how the benchmark dose should be calculated and used to derive concentration limits for other radionuclides such as Th-232, Th-230, and U-238.

As demonstrated in the W.R. Grace example, one approach is to calculate two benchmark doses; one utilizing Ra-226 and one utilizing Ra-228. Cleanup levels for other radionuclides are based upon the more conservative benchmark dose.

Another approach may be to derive a benchmark dose for the sum of the radium (Ra-226 plus Ra-228). This may be possible if the ratio of Ra-226 to Ra-228 is known for a site.

The modeling of Ra-228 contamination within subsurface soils has identified several concerns with the benchmark dose approach. The half-life of Ra-228 is 5.75 years. This relatively short half-life causes the radionuclide concentration and its associated dose to decrease significantly from time zero to time 40 years. If the erosion

rate associated with the 15 cm cover is set at 0.001 meters/year, the entire cover material will have eroded after 150 years. These phenomena cause the subsurface benchmark dose to be one half the surface benchmark dose due to the fact that all the Ra-228 has decayed away prior to the cover material eroding. This would cause the subsurface Th-232 guideline to be one half the surface guideline. One suggestion, to combat this predicament, is to derive the subsurface Ra-228 benchmark dose assuming Ra-228 is in equilibrium with its Th-232 parent.

Cover in Subsurface Modeling

The use of cover in subsurface modeling is discussed in Appendix H of NUREG-1620. The following text appears on page H-5:

"A cover depth of zero is used in the surface contamination model and a depth of at least 15 cm (6 inches) for the subsurface model. The values for area and depth of contamination are derived from site characterization data. The erosion rate value for the contaminated zone is less than the RESRAD default value because in regions drier than normal, the erosion rate is less . . . and the value is justified."

Although information is provided regarding contamination zone erosion rate, information is not given regarding the erosion rate for cover with subsurface contamination. Further, it is not specified whether it is assumed the cover will be maintained for the 1000 year modeling period.

At the Linde FUSRAP site, it was assumed during derivation of the subsurface soil benchmark dose that 15 cm of cover would remain for the 1000 year modeling period and that no erosion of the contaminated zone would occur (i.e., both cover erosion rate and contamination zone erosion rate were set at zero). Justification for these assumptions was twofold. First, it was assumed that the asphalt cover would not erode. Second, due to the depth of contamination, in some locations greater than 1.2 m (4 feet) of backfill will be required to bring the excavation up to grade post-remediation. Consequently, subsurface material would not be subject to erosion over the 1000 year modeling period.

Exposure Pathways

In accordance with NUREG-1620, Appendix H, the scenarios chosen to model the potential dose to the average member of the critical group from residual radionuclides at the site must reflect reasonably probable future land use. NRC expects UR facilities seeking license termination to consider ranching, mining, home-based business, light industry, and residential farmer scenarios when performing dose modeling. Such scenarios are appropriate for UR facilities located in sparsely populated areas of the western United States. Some of these scenarios are not appropriate for FUSRAP sites located in eastern United States.

It is also questioned how to project future land use for 200 years. Further, it is unclear whether NRC has additional policy or guidance for determination of reasonably

probable future land use and, if so, how NRC policy or guidance compares to EPA guidance.

Interestingly, the approach to reasonably probable future land use differed slightly during derivation of cleanup levels at the Linde FUSRAP site versus the W.R. Grace FUSRAP site. At Linde, the benchmark dose was based on potential TEDE to the industrial worker. Whereas at Grace, currently two plausible critical groups have been identified and the draft benchmark dose is based on the potential TEDE to the maintenance/construction worker which is lower than that of the industrial worker. Note, per NUREG-1620, an overly conservative dose estimate is not acceptable, as it would result in higher allowable levels of uranium or thorium which would not be ALARA.

ALARA Considerations

In conjunction with the benchmark dose, the ALARA principle is considered in setting cleanup levels per the Criterion 6(6) rule. In practice at uranium mill sites, the ALARA principle is implemented by removing approximately 5 cm more of soil than is estimated to be necessary to achieve the radium standard. It is generally less expensive at such mills to remove more soil than to do sampling and testing that may indicate failure and require additional soil removal plus additional testing.

This same method (overexcavation of 5 cm) would not likely be ALARA at a FUSRAP site where contaminated soils are to be excavated and disposed off-site. The cost of off-site disposal is greater than the cost of on-site burial in a tailings impoundment. Therefore, ALARA implementation at FUSRAP sites, versus uranium mill sites, will be dissimilar.

Additionally, the method of contaminant deposition may not be similar. At older mills, large areas are covered with windblown radioactive material. Little subsurface contamination is present. The depth of contamination is shallow (usually less than 6 cm) and it is ALARA to remove all soils to a specified depth. Cleanup to near background levels has proven less costly for UR facilities than compared to more extensive soil sampling and analysis. At FUSRAP sites, however, significant subsurface contamination may be found. Once again, the ALARA approach will be divergent.

CONCLUSIONS

The development of site-specific cleanup levels and selection of a remedial action at a site, in compliance with the nine remedy selection criteria in CERCLA, is a fundamental part of the CERCLA process. From the start of work at a site, investigations should focus upon these outcomes. Reports should document assumptions and facts used in the risk assessment and ARAR identification process, justify the results, and ensure that they meet the standards of CERCLA and the NCP. If this is done, the site-specific decision on cleanup levels and remedy selection must be, and will be, defensible on the administrative record to the public, to interested regulatory agencies, and in any contested legal forum.

Derivation of cleanup levels at FUSRAP sites must be performed in accordance with CERCLA and the NCP. Often, 10 CFR 40, Appendix A, Criterion 6(6), *Radiological Criteria for License Termination of Uranium Recovery Facilities*, is identified as an ARAR and implementation of the benchmark dose approach has, consequently, occurred at FUSRAP sites.

As discussed in this paper, USACE has encountered uncertainties implementing the benchmark dose approach. Specific examples have been described and discussed. USACE lessons learned and alternatives for dealing with these ambiguities have been presented. However, much perplexity still remains and, as a result, consistent application of the benchmark dose approach from FUSRAP site to FUSRAP site is improbable.

Consistency will likely increase with experience and the emergence of additional policy, guidance, and/or direction. In the interim, USACE will continue to hold discussions with appropriate regulatory agencies regarding application of the benchmark dose approach on a site-specific (i.e., case-by-case) basis.

Within FUSRAP, the cost implications associated with off-site disposal of more waste material than is necessary are too great to arbitrarily choose cleanup levels. FUSRAP programmatic goals must be considered during project design and during development and implementation of cleanup levels. With proper planning and sound technical practices, the overarching objective of closing out FUSRAP sites can be accomplished in a manner that meets applicable regulations, poses no unacceptable risk to human health or the environment, and achieves Congressional expectations of cost and schedule efficiencies.

FOOTNOTES

^a In this paper, an attempt has been made to use SI units where logical. However, it is not possible to use SI units exclusively and still yield a coherent document. This is due to the fact that the radium standard in 10 CFR 40 is not in SI units, the amendment to 10 CFR 40, Appendix A, Criterion 6(6) is not in SI units, and neither NRC nor EPA guidance is primarily in SI units. Further, providing site-specific examples in SI units for comparison to a regulation that is in traditional units was determined to be too cumbersome for the reader.

REFERENCES

1. *Standard Review Plan for the Review of a Reclamation Plan for Mill Tailings Sites Under Title II of the Uranium Mill Tailings Radiation Control Act*, NUREG -1620, (2000).
2. *Remediation Goals for Radioactively Contaminated CERCLA Sites Using the Benchmark Dose Cleanup Criteria in 10 CFR Part 40 Appendix A, I, Criterion 6(6)*, EPA, Directive no. 9200.4-35P, (April 2000)

3. *Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination*, EPA, Directive no. 9200.4-18, (August 1997)
4. *Use of Soil Cleanup Criteria in 40 CFR 192 as Remediation Goals for CERCLA sites*, EPA, Directive no. 9200.4-25, (February 1998)
5. *Record of Decision for the Linde Site, Tonawanda, NY*, USACE, (2000)