APPENDIX D

ALARA ANALYSES

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In order to terminate a license, a licensee must demonstrate that the dose criteria in Subpart E of 10 CRR Part 20 have been met and must demonstrate whether it is feasible to further reduce the levels of residual radioactivity to levels below those necessary to meet the dose criteria (i.e., to levels that are “as low as is reasonably achievable” (ALARA). This Appendix describes methods acceptable to the Nuclear Regulatory Commission (NRC) staff for determining when it is feasible to further reduce the concentrations of residual radioactivity to below the concentrations necessary to meet the dose criteria. This appendix does not apply to, nor replace guidance for, operational ALARA programs. This guidance involves the same principle as the operational ALARA guidance:

> “Reasonably achievable” is judged by considering the state of technology and the economics of improvements in relation to all the benefits from these improvements. (However, a comprehensive consideration of risks and benefits will include risks from non-radiological hazards. An action taken to reduce radiation risks should not result in a significantly larger risk from other hazards.) NRC Regulatory Guide 8.8, Revision 3 (1978). [quotes in original]

In light of the conservatism in the building surface and surface soil generic screening levels developed by the NRC staff, the staff presumes, absent information to the contrary, that licensees or responsible parties that remediate building surfaces or soil to the generic screening levels do not need to demonstrate that these levels are ALARA. However, licensees or responsible parties should remediate their facility below these levels through practices such as good housekeeping. In addition, licensees or responsible parties should provide a description in the final status survey report of how these practices were employed to achieve the final activity levels.

In addition, if residual radioactivity cannot be detected, it may be assumed that it has been reduced to levels that are ALARA. Therefore, the licensee does not need to conduct an explicit analysis to meet the ALARA requirement.

Areas that have been released under then-existing requirements would not have to be reevaluated under 10 CFR 20.1401(c). According to 10 CFR 20.1401(c), the NRC would require additional clean-up following license termination only if it determines, based on new information, that the criteria of Subpart E were not met and that residual radioactivity remaining at the site could result in significant threat to public health and safety. Because ALARA represents an optimization technique below a dose criteria, it is not considered reasonable to reopen consideration of a previously released area, where radioactive materials were handled that meets the appropriate dose criterion.

In general, a method for determining whether levels of residual radioactivity are ALARA would have the following characteristics.

- **<u>The method is simple</u>**. The method for most licensee applications should be simple, because the effort needed for very sophisticated models cannot generally be justified.

In an ALARA analysis of a remediation action, the primary benefit (i.e., the collective radiation dose that will actually be averted in the future) is uncertain because future land uses, the number of people that will actually occupy a site, and the types of exposure scenarios are all uncertain. These uncertainties mean that the future collective dose cannot be known with precision. Because of the inherent limitation on the ability to precisely determine the future collective dose at a particular site, it is not useful to perform a complex analysis when a simple analysis can be appropriate. Licensees may use more complex or site-specific analyses if more appropriate for their specific situations (e.g., restricted release analyses, situations that include a number of unquantifiable benefits and costs).

- **The method is not biased and uses appropriate dose modeling to relate concentrations to dose**. The determination of ALARA should not be biased. This is different from demonstrating compliance with a dose limit. The analyses for dose assessments and surveys for compliance with the dose criteria described in this Standard Review Plan (SRP) include a reasonably conservative bias for demonstrating compliance. Unlike a demonstration of compliance, an ALARA analysis is an optimization technique that seeks the proper balance between costs and benefits below the dose limit. To achieve a proper balance, each factor in the ALARA analysis should be determined with as little bias as possible. If the ALARA analysis were intentionally biased, it would likely cause a misallocation of resources and could deprive society of the benefits from other uses of the resources. Thus, the ALARA analysis should provide an unbiased analysis of the remediation action, which can both avert future dose (a benefit to society) and cost money (a potential detriment because it can deprive future generations of the return on the investment of this money). Sections 1.1 and 1.2, respectively, discuss the methods that should be used in estimating benefits and detriments, or costs, including scenarios, models, and parameters for relating concentration to dose at a site. The Office of Management and Budget guidance to Federal agencies that implements the President's Executive Order 12866 "Regulatory Planning and Review," in Title 3 of the 1993 Compilation of the U.S. Code of Federal Regulations, January 1, 1994 (page 638), provides guidance on balancing benefits and detriments for analyzing the potential benefits of Federal regulations (Office of Management and Budget, "Economic Analysis of Federal Regulations under Executive Order 12866," January 11, 1996).

- **The method is usable as a planning tool for remediation**. Before starting a remediation action, the user should be able to determine generally what concentration of residual radioactivity would require a remediation action to meet the ALARA requirement. It would be inefficient if the user could not tell whether the area would pass the ALARA test until after the remediation. Establishing ALARA post-remediation would also likely result in it being less likely for a licensee to remediate below the dose limit(s) because of the additional manpower start-up costs associated with doing additional remediation.

- **As much as possible, the method uses the results of surveys conducted for other purposes**. The demonstration that the ALARA requirement has been met should not require surveys beyond those already performed for other purposes, such as the characterization survey and the final status survey. It would be inefficient (and unnecessary) to collect additional sets of measurements to demonstrate that remediation actions were taken wherever appropriate to meet the ALARA requirement if measurements undertaken for other purposes could be used.

1.0 ALARA Analyses

Subpart E of 10 CFR Part 20 contains specific requirements for a demonstration that residual radioactivity has been reduced to a level that is ALARA (10 CFR 20.1402, 20.1403(a), 20.1403(e), and 20.1404(a)(3)). A simplified method for demonstrating compliance with the ALARA requirement is described below. Licensees may use more complex or site-specific analyses if more appropriate for their specific situation. In general, more complex analyses will follow the general concepts presented herein. Evaluation of more complex analyses will be handled on a case-by-case basis and early involvement of the appropriate regulatory agencies and members of the public is suggested.

Sometimes it is very difficult or impossible to place a monetary value on an impact. A best effort should be made to assign a monetary value to the impact, because there may be no other way to compare benefits to costs. However, there may be situations for which a credible monetary value cannot be developed. In these situations, a qualitative treatment may be the most appropriate. Qualitative analyses will be evaluated on their merits on a case-by-case basis.

The simplified method presented here is to estimate when a remediation action is cost-effective using generalized estimates for the remedial action. If the desired beneficial effects ("benefits") from the remediation action are greater than the undesirable effects or "costs" of the action, the remediation action being evaluated is cost-effective and should be performed. Conversely, if the benefits are less than the costs, the levels of residual radioactivity are already ALARA without taking the remediation action. An example of various benefits and costs are listed in Table D1. Other than Collective Dose Averted, the additional benefits listed tend to only be important in comparisons between alternatives that address whether restricted release can be pursued by the licensee. The value of any benefit or cost can be negative in some cases.

Table D1. Possible Benefits and Costs Related to Decommissioning

Possible Benefits	Possible Costs
Collective Dose Averted Regulatory Costs Avoided Changes in Land Values Esthetics Reduction in Public Opposition	Remediation Costs Additional Occupational/Public Dose Occupational Non-radiological Risks Transportation Direct Costs and Implied Risks Environmental Impacts Loss of Economic Use of Site/Facility

In order to compare the benefits and costs of a remediation action, it is necessary to use a comparable unit of measure. The unit of measure used here is the dollar; all benefits and costs are given a monetary value, if possible. Benefits and costs are calculated as described in Sections 1.1 and 1.2 below.

The method should be applied during remediation planning, prior to the start of remediation, but after some or all of the characterization work is done. The method should be used only to determine whether and where particular remediation actions should be taken to meet the ALARA requirement.

If the licensee has already decided to perform a remediation action, there is no need to analyze whether the action was necessary to meet the ALARA requirement. The analysis described in this section is needed only to justify not taking a remediation action. For example, if a licensee plans to wash room surfaces (either to meet the dose limit or as a good practice procedure), there is no need to analyze whether the remediation action of washing is necessary to meet the ALARA requirement.

1.1 Calculation of Benefits

Collective Dose Averted

In the simplest form of the analysis, the only benefit estimated from a reduction in the level of residual radioactivity is the monetary value of the collective averted dose to future occupants of the site. For buildings, the collective averted dose from residual radioactivity should be based on some form of the building occupancy scenario. For land, the averted dose will generally be based on the resident farmer scenario. In general, the ALARA analysis should use the same critical group scenario that is used for the compliance calculation. Additional considerations related to groundwater contamination are discussed in Section 1.6.

The benefit from collective averted dose, B_{AD}, is calculated by determining the present worth of the future collective averted dose and multiplying it by a factor to convert the dose to monetary value:

$$B_{AD} = \$2000 \times PW(AD_{collective}) \qquad \textbf{(D1)}$$

where

B_{AD}	=	benefit from averted dose for a remediation action, in $
$2000	=	value in dollars of a person-rem averted (see NUREG/BR0058 “Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission,” Revision 2, November 1995)
$PW(AD_{collective})$	=	present worth of future collective averted dose

An acceptable value for collective dose is $2000 per person-rem averted, discounted for dose averted in the future (See Section 4.3.3 of “Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission,” NUREG/BR-0058, Revision 2, November 1995.). For doses averted within the first 100 years, a discount rate of 7percent should be used. For doses averted beyond 100 years, a 3 percent discount rate should be used.

The present worth of the future collective averted dose can be estimated from the equation below, for relatively simple situations:

$$PW(AD_{collective}) = P_D \times A \times 0.025 \times F \times \frac{Conc}{DCGL_W} \times \frac{1 - e^{-(r+\lambda)N}}{r+\lambda} \qquad \textbf{(D2)}$$

P_D	=	population density for the critical group scenario in people/m^2;
A	=	area being evaluated in square meters (m^2)
0.025	=	annual dose to an average member of the critical group from residual radioactivity at the Derived Concentration Guideline Level ($DCGL_W$) concentration in rems/yr;
F	=	fraction of the residual radioactivity removed by the remediation action. *F* may be considered to be the removable fraction for the remediation action being evaluated;
Conc	=	average concentration of residual radioactivity in the area being evaluated in units of activity per unit area for buildings or activity per unit volume for soils;
$DCGL_W$	=	derived concentration guideline equivalent to the average concentration of residual radioactivity that would give a dose of 0.25 mSv/yr (25 mrem/yr) to the average member of the critical group, in the same units as *"Conc"*
r	=	monetary discount rate in units of yr^{-1};
λ	=	radiological decay constant for the radionuclide in units of yr^{-1}; and
N	=	number of years over which the collective dose will be calculated.

The present worth of the benefit calculated by Equation 2, above, assumes that the peak dose occurs in the first year. This is almost always true for the building occupancy scenario, but not always true for the residential scenario where the peak dose can occur in later years. When the peak dose occurs in later years, Equation 2 would overestimate the benefit. The licensee may perform a more exact calculation that avoids this overestimation of the benefit of remediation by calculating the dose during each year of the evaluation period and then calculating the present worth of each year's dose. A detailed derivation of Equation 2 and some of the other equations are in the Annex to this Appendix.

The $DCGL_W$ used should be the same as the $DCGL_W$ used to show compliance with the 0.25 mSv/yr (25 mrem/yr) dose limit. The population density, P_D, should be based on the dose scenario used to demonstrate compliance with the dose limit. Thus, for buildings, the licensee should estimate P_D for the building occupancy scenario. For soil, the P_D should be based on the residential scenario. The factor at the far right of the equation, which includes the exponential terms, accounts for both the present worth of the monetary value and radiological decay.

If more than one radionuclide is present, the total benefit from collective averted dose, B_{AD}, is the sum of the collective averted dose for each radionuclide. When multiple radionuclides have a fixed concentration (i.e., secular equilibrium), residual radioactivity below the dose criteria is normally demonstrated by measuring one radionuclide and comparing its concentration to a $DCGL_W$ that has been calculated to account for the dose from the other radionuclides. In this case, the adjusted $DCGL_W$ may be used with the concentration of the radionuclide being measured. The other case is when the ratio of the radionuclide concentrations is not fixed and varies from location to location within a survey unit; this benefit is the sum of the collective averted dose from each.

Regulatory Costs Avoided

This benefit usually manifests in ALARA analyses of restricted release versus unrestricted release decommissioning goals. By releasing the site with no restrictions, the licensee will avoid the various costs associated with restricted release. These can include: (1) additional licensing fees to develop an Environmental Impact Statement, (2) financial assurance related to both the decommissioning fund [10 CFR 20.1403(c)] and the site restrictions [10 CFR 20.1403(d)(1)(ii)], (3) costs (including NRC-related) associated with public meetings or the community review committee [10 CFR 20.1403(d)(2)], and (4) future liability. When evaluating the ability of a licensee's proposal for restricted release according to 10 CFR 20.1403(a), avoiding these costs should be included in the benefits of the unrestricted release decommissioning alternative. These should not be included as costs related to the restricted release (see 1.2).

Changes in Land Values

The licensee should account for any expected change in the value of the site or facility caused by the different decommissioning options. This may be difficult to quantify.

Esthetics/Reduction in Public Opposition

These, too, can be very difficult to quantify. The licensee may wish to evaluate the effect of its decommissioning options with respect to the overall esthetics (including the decommissioning activities themselves) of the site and surrounding area. Another factor the licensee may wish to consider is the potential reduction in opposition, if there is any, to the decommissioning activities/goal the license is attempting to propose.

1.2 Calculation of Costs

The licensee should evaluate the costs of the remediation actions being evaluated. When doing a fairly simple evaluation, the costs generally include the monetary costs of: (1) the remediation action being evaluated, (2) transportation and disposal of the waste generated by the action, (3) workplace accidents that occur because of the remediation action, (4) traffic fatalities resulting from transporting the waste generated by the action, (5) doses received by workers performing the remediation action, and (6) doses to the public from excavation, transport, and disposal of the waste. Other costs that are appropriate for the specific case may also be included.

The total cost, $Cost_T$, which is balanced against the benefits, has several components.

$$Cost_T = Cost_R + Cost_{WD} + Cost_{ACC} + Cost_{TF} + Cost_{WDose} + Cost_{PDose} + Cost_{other} \quad \textbf{(D3)}$$

where $Cost_R$ = monetary cost of the remediation action (may include "mobilization" costs);
$Cost_{WD}$ = monetary cost for transport and disposal of the waste generated by the action;
$Cost_{ACC}$ = monetary cost of worker accidents during the remediation action;
$Cost_{TF}$ = monetary cost of traffic fatalities during transporting of the waste;
$Cost_{WDose}$ = monetary cost of dose received by workers performing the remediation action and transporting waste to the disposal facility;
$Cost_{PDose}$ = monetary cost of the dose to the public from excavation, transport, and disposal of the waste;
$Cost_{other}$ = other costs as appropriate for the particular situation.

All the costs described below do not necessarily have to be calculated. For example, if one or two of the costs can be shown to be in excess of the benefit, the remediation action has been shown to be unnecessary without calculating the other costs. Additionally, in some comparisons between alternate decommissioning options, some of these costs may in fact be negative (i.e., the alternative will cost less than the preferred option).

Remedial Action Costs

Calculation of the incremental remedial action costs include the standard manpower and mechanical costs. The licensee can account for any additional licensing fees from NRC (e.g., if the option to meet the ALARA goal requires another year of remediation). Lower concentrations may change sampling/survey requirements. Increased survey costs can be considered in the remedial action but note that this is the incremental costs of surveying below the dose limit. Survey costs related to evaluating compliance at the dose limit are not part of the ALARA analysis.

Transport and Disposal of the Waste

The cost of waste transport and disposal, $Cost_{WD}$, may be evaluated according to the following equation.

$$Cost_{WD} = V_A \text{ x } Cost_V \quad \textbf{(D4)}$$

Where V_A = volume of waste produced, remediated in units of m^3; and

$Cost_V$ = cost of waste disposal per unit volume, including transportation cost, in units of $/m^3

Non-Radiological Risks

The cost of nonradiological workplace accidents, $Cost_{ACC}$, may be evaluated using the equation below.

$$Cost_{ACC} = \$3{,}000{,}000 \, x F_W x T_A \qquad \textbf{(D5)}$$

where $3,000,000 = monetary value of a fatality equivalent to $2000/person-rem (see, pages 11-12 of "Reassessment of NRC's Dollar per Person-Rem Conversion Factor Policy," NUREG-1530, December 1995);
F_W = workplace fatality rate in fatalities/hour worked;
T_A = worker time required for remediation in units of worker-hours.

Transportation Risks

The cost of traffic fatalities incurred during the transportation of waste, $Cost_{TF}$, may be calculated similar to the equation below.

$$Cost_{TF} = \$3{,}000{,}000 \times \left(V_A \middle/ V_{SHIP} \right) \times F_T \times D_T \qquad \textbf{(D6)}$$

where V_A = volume of waste produced in units of m^3
F_T = fatality rate per truck-kilometer traveled in units of fatalities/truck-km
D_T = distance traveled in km
V_{SHIP} = volume of a truck shipment in m^3

The actual parameters should depend on the site's planned method of waste transport. Some facilities may consider a mix of trucking and rail transport to get the waste to the disposal site. In these cases, the cost would be equivalent to the total fatalities likely from the rail transport and the limited trucking, not just the trucking alone.

Worker Dose Estimates

The cost of the remediation worker dose, $Cost_{WDose}$, can be calculated as shown in the following equation:

$$Cost_{WDose} = \$2000 \times D_R \times T \qquad \textbf{(D7)}$$

where D_R = total effective dose equivalent rate to remediation workers in units of rems/hr;
T = time worked (site labor) to remediate the area in units of person-hour.

The cost of worker dose usually should not be discounted because the dose is all incurred close to the time of license termination.

Loss of Economic Use of Property

A cost in the "other" category could include the fair market rental value or economic use for the site during the time the additional remediation work is being performed. These costs are usually associated with locations such as laboratories, hospital rooms, and industrial sites, etc. This cost may be added to the costs in Equation 3.

Environmental Impacts

Another cost that could fall into the other category would be a remediation action that may damage an ecologically valuable area or cause some other adverse environmental impact. These impacts should be included as costs of the remediation action.

Default Parameters

For performing these calculations, acceptable values for some of the parameters are shown in Table D2.

Table D2. Acceptable Parameter Values for Use in ALARA Analyses.

Parameter	**Value**	**Reference and comments**
Workplace accident fatality rate, F_W	4.2×10^{-8}/hr	NUREG-1496 ("Final Generic Environmental Impact Statement in Support of Rulemaking on Radiological Criteria for License Termination of NRC-Licensed Nuclear Facilities," NUREG-1496, July 1997 Volume 2, Appendix B, Table A.1
Transportation fatal accident rate, F_T	Trucks: 3.8×10^{-8}/km	NUREG-1496, Volume 2, Appendix B, Table A.1
$/person-rem	$2000	NUREG/BR-0058
Monetary discount rate, *r*	0.07/yr for the first 100 years and 0.03/yr thereafter, or 0.07 for buildings and 0.03 for soil	NUREG/BR-0058
Number of years of exposure, *N*	Buildings: 70 yr soil: 1000 yr	NUREG-1496, Volume 2, Appendix B, Table A.1

Parameter	Value	Reference and comments
Population density, P_D	Building: 0.09 person/m^2 land: 0.0004 person/m^2	NUREG-1496, Volume 2, Appendix B, Table A.1
Excavation, monitoring, packaging, and handling soil	1.62 person-hours/m^3 of soil	NUREG-1496, Volume 2, Appendix B, Table A.1
Waste shipment volume, V_{SHIP}	truck: 13.6 m^3/shipment	NUREG-1496, Volume 2, Appendix B, Table A.1

1.3 Residual Radioactivity Levels that Are ALARA

The residual radioactivity level that is ALARA is the concentration, *Conc,* at which the benefit from removal equals the cost of removal. If the total cost, $Cost_{T,}$ is set equal to the present worth of the collective dose averted in Equation 2, the ratio of the concentration, *Conc,* to the $DCGL_W$ can be determined (derivation shown in the Annex to Appendix D).

$$\frac{Conc}{DCGL_W} = \frac{Cost_T}{\$2000 \times P_D \times 0.025 \times F \times A} \times \frac{r + \lambda}{1 - e^{-(r + \lambda)N}} \qquad \textbf{(D8)}$$

All the terms in Equation 8 are as defined previously.

If a licensee is considering restricting use of its site, it should refer to Section 1.7 of this appendix, which describes additional cost and benefit considerations that should be included. This derivation only explicitly considers the benefits related to reduction in collective dose. The numerical value of the other benefits (if not dose-related) could be subtracted from the total cost.

Since P_D, N, and r are constants that have generic values for all locations on the site, the licensee only needs to determine the total cost, $Cost_T$, and the effectiveness, F, for a specific remediation action. If the concentration at a location exceeds *Conc*, it will be cost effective to remediate the location by a method whose total cost is $Cost_T$. Note that the concentration, *Conc,* that is ALARA can be higher or lower (more or less stringent) than the $DCGL_W$, although licensees must meet the $DCGL_W$.

1.4 Examples of Calculations

Example 1: Washing Building Surfaces

This example considers a building with cesium-137 residual radioactivity (λ = 0.023/yr). The remediation action to be considered is washing a floor of 100 m^2 area. The licensee estimates that this will cost \$400 and will remove 20 percent (F = 0.2) of the residual radioactivity. For buildings, generic parameters are: P_D = 0.09 person/m^2, r = 0.07/yr, and N = 70 years. Using these values in Equation 8:

$$\frac{Conc}{DCGL_W} = \frac{\$400}{\$2000 \times 0.2 \times 0.025 \times 0.09 \times 100\ m^2} \times \frac{0.07 + 0.023}{1 - e^{-(0.07 + 0.023)70}} \qquad \textbf{(D9)}$$

$$\frac{Conc}{DCGL_W} = 0.41 \qquad \textbf{(D10)}$$

To meet the ALARA requirement, the floor should be washed if the average concentration exceeds about 41 percent of the $DCGL_W$. This is more stringent than the dose limit. This calculation shows that washing building surfaces is often necessary to meet the ALARA requirement. If the surfaces will be washed, there is no need for the licensee to perform the ALARA evaluation or to submit the evaluation to the NRC. If the licensee decided not to wash the building surfaces, the licensee could submit this evaluation and demonstrate in the final status survey that all surfaces have a concentration below 41 percent of the $DCGL_W$.

Example 2: Scabbling Concrete in a Building

This example is the same as above except that it evaluates use of a scabbling tool that removes the top 1/8 inch of concrete. The licensee estimates the total cost of the scabbling will be $5000 for the 100 m^2 floor and estimates that it will remove all the residual radioactivity so that F = 1. Using these values in Equation 8 gives:

$$\frac{Conc}{DCGL_W} = \frac{\$5000}{\$2000 \times 1 \times 0.025 \times 0.09 \times 100\ m^2} \times \frac{0.07 + 0.023}{1 - e^{-(0.07 + 0.023)70}} \qquad \textbf{(D11)}$$

$$\frac{Conc}{DCGL_W} = 0.97 \qquad \textbf{(D12)}$$

The licensee could decide to scabble depending on the concentrations present. In lieu of scabbling, the licensee could provide this analysis and demonstrate that the floor concentration is less than 0.97 $DCGL_W$.

Example 3: Removing Surface Soil

In this example, soil with an area of 1000 m^2 is found to contain radium-226 (λ = 0.000247/yr) residual radioactivity to a depth of 15 centimeters (cm). The licensee estimates that the cost of removing the soil (F = 1) will be $100,000. For soil, the generic parameters are P_D = 0.0004 person/m^2, r = 0.03/yr, and N = 1000 yr. Using these values in Equation 8 gives:

$$\frac{Conc}{DCGL_W} = \frac{\$100{,}000}{\$2000 \times 1 \times 0.025 \times 0.0004 \times 1000\ m^2} \times \frac{0.03 + 0.000247}{1 - e^{-(0.03 + 0.000247)1000}} \quad \textbf{(D13)}$$

$$\frac{Conc}{DCGL_W} = 151 \quad \textbf{(D14)}$$

Thus, meeting the dose limit would be limiting by a considerable margin. Based on these results, it would rarely be necessary to ship soil to a waste disposal facility to meet the ALARA requirement. The licensee could use this evaluation to justify not removing soil.

The advantage of the approach shown in these examples is that it allows the user to estimate a concentration at which a remediation action will be cost-effective prior to starting remediation and prior to planning the final status survey. Thus, it is a useful planning tool that lets the user determine which remediation actions will be needed to meet the ALARA requirement.

1.5 When Mathematical Analyses Are Not Necessary

In certain circumstances, the results of an ALARA analysis are known on a generic basis and an analysis is not necessary. For residual radioactivity in soil at sites that will have unrestricted release, generic analyses (see NUREG-1496, the examples in this appendix, and other similar examples) show that shipping soil to a low-level waste disposal facility is unlikely to be cost effective for unrestricted release, largely because of the high costs of waste disposal. Therefore shipping soil to a low-level waste disposal facility generally does not have to be evaluated for unrestricted release. In addition, licensees that have remediated surface soil and surfaces to the default screening criteria developed by NRC, have remediated soil such that it meets the unrestricted use criteria in 10 CFR 20.1402 or if no residual radioactivity distinguishable from background will be left at the site would not be required to demonstrate that these levels are ALARA.

Removal of loose residual radioactivity from buildings is almost always cost- effective except when very small quantities of radioactivity are involved. Therefore, loose residual radioactivity normally should be removed, and if it is removed, the analysis would not be needed.

1.6 Additional Considerations for Residual Radioactivity in Groundwater

The method described above is adequate for most situations and has minimal cost for analyses. However, other factors, as described below, should be included if the site will be released if it has residual radioactivity from site operations in groundwater.

If there is residual radioactivity from site operations in groundwater, it may be necessary to calculate the collective dose from consumption of the groundwater. Default or generic groundwater models typically assume that potable aquifers have small volumes and cannot supply large populations. When this is the case, dose calculations for the site critical group will adequately represent the collective dose from groundwater. However, when site-specific groundwater modeling is used, and the residual radioactivity is diluted in an aquifer of large volume and there is also an "existing population deriving its drinking water from a downstream supply using a downstream supply" (see page 39075 of "Radiological Criteria for License Termination," Final Rule, *Federal Register,* Volume 62, 62 FR 39058, July 21, 1997), the collective dose for that population should be included in the ALARA calculation. The possibility of reducing the collective dose by remediation should be one of the items evaluated as one of the benefits, even if remediation would not affect the critical group's doses significantly. Another consideration for groundwater residual radioactivity would be any potential costs incurred by other entities, such as a public water supply utility, to meet the requirements of the Safe Water Drinking Act, if the licensee's residual radioactivity levels would potentially lead to concentrations at the wellhead that would exceed the U.S. Environmental Protection Agency's Maximum Contaminant Levels.

2.0 Determination of "Net Public or Environmental Harm"

Subpart E, 10 CFR 20.1403(a) and 10 CFR 20.1403(e)(2)(I) address circumstances in which a licensee would be required to demonstrate that further remediation would cause net public or environmental harm. The calculation to demonstrate net public or environmental harm is a special case of the general ALARA calculation described above that compares the benefits in dose reduction to the cost of doses, injuries, and fatalities incurred. The calculation does not consider the monetary costs for performing further remediation, $Cost_{R,}$ or the costs of waste disposal, $Cost_{WD}$. Thus, if the benefit from averted dose B_{AD} is less than the sum of the costs of workplace accidents, $Cost_{ACC}$, the costs of transportation fatalities, $Cost_{TF}$, the costs of remediation worker dose, $Cost_{WDose}$, and the costs of any environmental degradation, $Cost_{ED}$, then there is net public or environmental harm. Thus, there is net public or environmental harm if:

$$Net\ harm\ if \quad B_{AD} < Cost_{ACC} + Cost_{TR} + Cost_{WDose} + Cost_{ED} \qquad \textbf{(D15)}$$

In some cases it will be very difficult to assign a credible monetary value to environmental degradation. For example, environmental harm could be caused by an action such as remediation of a wetlands area. There may be no way to assign a monetary value to this action. In these cases it is acceptable to use qualitative arguments, which will be evaluated on a case-by-case basis.

3.0 Demonstration of "Not Technically Achievable"

Subpart E, 10 CFR 20.1403(e)(2)(I) addresses circumstances in which a licensee would be required to demonstrate that further reductions in residual radioactivity are not technically achievable. Remediation of residual radioactivity is almost always technically achievable even if not economically feasible. This provision allows for special cases that may not be foreseeable; thus, specific guidance on this provision cannot be provided. Instead, NRC will evaluate licensee submittals on a case-by-case basis.

4.0 Demonstration of "Prohibitively Expensive"

Subpart E, 10 CFR 20.1403(e)(2) addresses circumstances in which a licensee would be required to demonstrate that further reductions in residual radioactivity would be prohibitively expensive. This can be demonstrated by an analysis like the ALARA analysis described above, but using a value of $20,000 per person-rem when calculating the value of the averted dose. This value reflects the NRC's statement in the final rule on radiological criteria for license termination that the NRC believes it is appropriate to consider that a remediation would be prohibitively expensive if the cost to avert dose were an order of magnitude more expensive than the cost recommended by the NRC for an ALARA analysis (see page 39071 of "Radiological Criteria for License Termination," Final Rule, *Federal Register,* Volume 62, 62 FR 39058, July 21, 1997). However, the NRC also stated that ". . . a lower factor may be appropriate in specific situations when the licensee could become financially incapable of carrying out decommissioning safely." Thus, values lower than $20,000 per person-rem may be used when remediation actions based on $20,000 per person-rem could cause the licensee to become financially incapable of carrying out the decommissioning safely.

Derivation of Equation 8 To Calculate the Concentration of Residual Radioactivity that Is ALARA

The ALARA analysis compares the monetary value of the desirable effects (benefits) of a remediation action (e.g., the monetary benefit of collective averted dose) with the monetary value of the undesirable effects (e.g., the costs of waste disposal). If the benefits of a remediation action would exceed the costs, the remediation action should be taken to meet the ALARA requirement.

$$\textit{If benefits} > \textit{costs}, \quad \textit{the remediation action should be taken} \tag{1}$$

The primary benefit from a remediation action is the collective dose averted in the future, i.e., the sum over time of the annual doses received by the exposed population. Assume:

1. A site has an area with residual radioactivity at concentration, *Conc*.
2. The concentration equivalent to 25 mrem (0.25 mSv)/yr ($DCGL_W$) for the site has been determined (for soil or for building surfaces, as appropriate).
3. The residual radioactivity at a site has been adequately characterized so that the effectiveness of a remediation action can be estimated in terms of the fraction F of the residual radioactivity that the action will remove.
4. The peak dose rate occurs at time 0 and decreases thereafter by radiological decay.

The derived concentration guideline ($DCGL_W$) is the concentration of residual radioactivity that would result in a total effective dose equivalent to an average member of the critical group of 0.25 mSv (25 mrem)/yr. Acceptable methods of calculating the $DCGL_W$ are discussed in Regulatory Position 1. Therefore, the annual dose D to the average member of the critical group from residual radioactivity at concentration *Conc* is:

$$D = 0.025 \ rem/yr \times \frac{Conc}{DCGL_W} \tag{2}$$

If a remediation action would remove a fraction, F, of the residual radioactivity present, the annual averted dose to the individual, $AD_{individual}$, is:

$$AD_{individual} \ (rem/yr/person) = F \times 0.025 \ rem/yr \times \frac{Conc}{DCGL_W} \tag{3}$$

The annual collective averted dose, $AD_{collective}$, can be calculated by multiplying the individual averted dose, $AD_{individual}$, by the number of people expected to occupy the area, A, containing the residual radioactivity. The number of people in the area containing the residual radioactivity is the area, A, times the population density, P_D, for the site.

Thus:

$$AD_{collective} = F \times 0.025 rem/yr \times \frac{Conc}{DCGL_W} \times A \times P_D \qquad (4)$$

The annual monetary benefit rate at time 0, B_0, from the averted collective dose in dollars per year can be calculated by multiplying the annual collective averted dose, $AD_{collective,}$ by \$2000/person-rem (\$200,000/person-sievert) (Reference A1):

$$B_0 = \$2000 \times F \times 0.025 \; rem/yr \; \frac{Conc}{DCGL_W} \times A \times P_D \qquad (5)$$

The total monetary benefit of averted doses can be calculated by integrating the annual benefit over the exposure time in years, considering both the present worth of future benefits and radiological decay. It is OMB and NRC policy to use the present worth of both benefits and costs that occur in the future (References A1 and A2).

The equation for the present worth, $PW_{B,}$ of a series of constant future annual benefits, B (in dollars per year), for N years at a monetary discount rate of r (per year) using continuous compounding is:

$$PW_B = B \times \frac{e^{rN} - 1}{r \; e^{rN}} \qquad (6)$$

The continuous compounding form of the present worth equation is used because it permits an easy formulation that includes radiological decay. If the annual benefit rate, $B,$ is not constant but is decreasing from an original rate, $B_{0,}$ because of radiological decay, the radiological decay rate acts like an additional discount rate that can be added to the monetary discount rate of decrease so that the present worth of the annual benefits PW_B becomes:

$$PW_B = B_0 \times \frac{e^{(r + \lambda)N} - 1}{(r + \lambda) \; e^{(r + \lambda)N}} \qquad (7)$$

Dividing the numerator and denominator of the right hand term by $e^{(r + \lambda)N}$ yields:

$$PW_B = B_0 \times \frac{1 - e^{-(r + \lambda)N}}{r + \lambda} \qquad (8)$$

As $N \rightarrow \infty$, Equation 8 has the limit:

$$PW_B = B_0 \times \frac{1}{r + \lambda} \qquad (9)$$

When the discount rate, *r,* is zero and the radiological decay rate is very small so that $r + \lambda \rightarrow 0$, and Equation 8 has the limit:

$$PW_B = B_0 \times N \qquad (10)$$

The total benefit from the collective averted dose, $B_{total,}$ is the present worth of the annual benefits. B_{total} can be calculated by combining Equations 6 and 8:

$$B_{total} = \$2000 \times F \times 0.025 \times \frac{Conc}{DCGL_W} \times A \times P_D \times \frac{1 - e^{-(r+\lambda)N}}{r+\lambda} \qquad (11)$$

Now consider the total cost of a remediation action, $Cost_T$. The costs included in $Cost_T$ are (1) the direct cost of the remediation action itself, $Cost_{RA}$, (2) the cost of waste disposal including its shipping cost, $Cost_{WD}$, (3), the monetary costs of workplace accidents during the remediation, $Cost_{ACC}$, (4) the monetary costs of transportation accidents during the shipping of waste, $Cost_{TF}$, (5) the monetary value of the dose that remediation workers receive, $Cost_{WDose}$, and (6) other costs as appropriate for the specific site, $Cost_{other}$. Thus,

$$Cost_T = Cost_R + Cost_{WD} + Cost_{ACC} + Cost_{TF} + Cost_{WDose} + Cost_{other} \qquad (12)$$

What is of interest in this derivation is the concentration, *Conc*, at which the benefit, $B_{total,}$ equals the total cost, $Cost_T$. Thus, in Equation 11, $Cost_T$ can be substituted for $B_{total,}$ and then Equation 11 can be solved for the concentration, *Conc,* relative to the $DCGL_W$ or $Conc/DCGL_W$ as in Equation 13.

$$\frac{Conc}{DCGL_W} = \frac{Cost_T}{\$2000 \times F \times 0.025 \times P_D \times A} \times \frac{r + \lambda}{1 - e^{-(r + \lambda)N}} \qquad (13)$$

Equation 13 can be used to determine the concentration in an area for which a remediation action should be taken to meet the ALARA criterion. The equation appears complicated, but can be solved in a few minutes with a hand-held calculator, and it only has to be done once for each type of remediation action at a site. P_D, *N*, and *r* are constants. Generic values for P_D and *N* are given in Reference A3 or may be determined on a site-specific basis. Values for *r* are given in References A1 and A2. The only site-specific information that the licensee needs is the total cost, $Cost_T$, and the effectiveness, *F,* for each remediation action being evaluated.

REFERENCES

1. NUREG/BR-0058, Revision 2, "Regulatory Analysis Guidelines of the U. S. Nuclear Regulatory Commission," November 1995.

2. Office of Management and Budget, “Economic Analysis of Federal Regulations under Executive Order 12866,” January 11, 1996 (Available on the web at http://www1.whitehouse.gov/WH/EOP/OMB/html/miscdoc/riaguide.html).

3. NUREG-1496, “Generic Environmental Impact Statement in Support of Rulemaking on Radiological Criteria for License Termination of NRC-Licensed Nuclear Facilities,” 1997.