Method for Implementing Subsurface Solid Derived Concentration Guideline Levels (DCGL) – 12331

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ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC) and other federal agencies currently approve the Multi-Agency Radiation Site Survey and Investigation Manual (MARSSIM) as guidance for licensees who are conducting final radiological status surveys in support of decommissioning. MARSSIM provides a method to demonstrate compliance with the applicable regulation by comparing residual radioactivity in surface soils with derived concentration guideline levels (DCGLs), but specifically discounts its applicability to subsurface soils. Many sites and facilities undergoing decommissioning contain subsurface soils that are potentially impacted by radiological constituents. In the absence of specific guidance designed to address the derivation of subsurface soil DCGLs and compliance demonstration, decommissioning facilities have attempted to apply DCGLs and final status survey techniques designed specifically for surface soils to subsurface soils. The decision to apply surface soil limits and surface soil compliance metrics to subsurface soils typically results in significant over-excavation with associated cost escalation.

MACTEC, Inc. has developed the overarching concepts and principles found in recent NRC decommissioning guidance in NUREG 1757 to establish a functional method to derive dose-based subsurface soil DCGLs. The subsurface soil method developed by MACTEC also establishes a rigorous set of criterion-based data evaluation metrics (with analogs to the MARSSIM methodology) that can be used to demonstrate compliance with the developed subsurface soil DCGLs. The method establishes a continuum of volume factors that relate the size and depth of a volume of subsurface soil having elevated concentrations of residual radioactivity with its ability to produce dose. The method integrates the subsurface soil sampling regime with the derivation of the subsurface soil DCGL such that a self-regulating optimization is naturally sought by both the responsible party and regulator.

This paper describes the concepts and basis used by MACTEC to develop the dose-based subsurface soil DCGL method. The paper will show how MACTEC's method can be used to demonstrate that higher concentrations of residual radioactivity in subsurface soils (as compared with surface soils) can meet the NRC's dose-based regulations. MACTEC's method has been used successfully to obtain the NRC's radiological release at a site with known radiological impacts to subsurface soils exceeding the surface soil DCGL, saving both time and cost.

INTRODUCTION

Current NRC guidance for conducting final radiological status surveys at nuclear materials sites and facilities in the decommissioning phase is contained in the MARSSIM (3) and in NUREG-1757, Consolidated NMSS Decommissioning Guidance (4). MARSSIM specifically addresses measurement and averaging criteria for "surface" radioactivity of both land areas and buildings but does not speak to the acceptable criteria or averaging methods for demonstrating that residual radioactivity in subsurface soils is within the approved guideline limits. While less specific than the guidance contained in MARSSIM, NUREG 1757, Vol. 2, Appendix G does outline a conceptual framework for demonstrating compliance with the NRC's decommissioning criteria (2) when residual radioactivity is present in subsurface soils. However, it lacks the detail necessary to make direct application at any particular site. It further encourages the licensee to consult with the NRC in the development of subsurface soil DCGLs and compliance measurement plans, especially where locally elevated concentrations of radioactivity in subsurface soil may be present. To take advantage of the prospect for less restrictive subsurface soil DCGLs, it is necessary to develop a technically competent method by which subsurface soil DCGLs can be derived using site-specific data and by which compliance can be assessed.

Regulatory standards governing site decommissioning and radiological release are dose-based and are written in such a way that the licensee carries the burden of demonstrating with acceptable confidence that the standard has been achieved. Dose assessments are, therefore, an integral component of the process used to demonstrate compliance with the decommissioning standard. Conventional pathway analysis concludes that the dose from radioactivity in subsurface soils at depths greater than approximately 0.3 to 0.5 meters below the ground surface (depending upon the isotopes present) is essentially zero (except dose that might arise from radioactivity in subsurface soil migrating downward and impacting the groundwater). This phenomenon is common to most environmental pollutants and derives from the fact that human contact with contaminants in subsurface soils is isolated by the surface soil layer. Even penetrating gamma radiation is subject to increasing attenuation as the contaminant layer gets deeper and the overburden soil layer gets thicker.

On this basis alone, one might conclude that there should be no bound on the concentration of residual radioactivity that might be left in subsurface soils deeper than 0.3 to 0.5 meters below the ground surface (the depth below which self-attenuation is practically complete). However, this conclusion assumes that residual radioactivity in subsurface soil will remain at depth over the period considered in the analysis. Depending upon site-specific conditions, it may not be reasonable to assume that subsurface soil will remain undisturbed for a 1,000-year period, the evaluation period considered in determining whether a site has met the criteria for decommissioning. Therefore, in considering the potential impact that residual radioactivity in subsurface soils might have on future exposures at the site, it is reasonable to consider the possibility that future human intrusion (e.g., excavation) could result in subsurface soil being brought to the surface where human exposure is a plausible consequence. The evaluation of such a scenario must take into account: 1) the volume of the soil that might reasonably be expected to be excavated, 2) the depth of the excavation, 3) the potential presence of overburden soils, and 4) the dose consequences of the contaminated soil in the post-excavation geometry.

REGULATORY GUIDANCE

In addressing the derivation of subsurface soil DCGLs and in consideration of the potential for future human intrusion, NRC guidance from NUREG-1757 establishes three guiding principles:

- "The [subsurface soil] DCGL may be based on the assumption the residual radioactivity [in the subsurface] may be excavated some day" and brought to the surface where exposure occurs.
- "…mixing of the residual radioactivity [in subsurface soil layers with overburden layers] will occur during excavation."
- Subsurface soil "DCGLs and mixing volumes should be based on an acceptable site-specific dose assessment."

With few exceptions, future land use scenarios at a given site could reasonably involve excavation in one form or another. The NRC guidance clearly calls for due consideration of the potential for future excavations to bring subsurface soils to the surface where exposure may occur. At the same time, it is acknowledged that the mixing of subsurface soils with overburdening soils will inevitably occur in such a scenario, and should be accounted for in the subsurface soil DCGL derivation process. Finally, subsurface soil DCGLs must be derived in consideration of the underlying dose-based regulations governing radiological decommissioning and license termination.

The NRC's guidance (NUREG-1757) on the design of surveys to assess the presence and significance of residual radioactivity in subsurface soils is also relatively general in nature (as compared with surface soil guidance contained in MARSSIM (3)), but does provide the basic framework for the design and for making compliance decisions. Guidance specifies core-sampling methods and offers the following design considerations:

- "The number of cores to be taken is initially the number (N) required for the [Wilcoxon Rank Sum] (WRS) or Sign test, as appropriate."
- "Core samples should be homogenized over a soil thickness that is consistent with the assumptions made in the dose assessment, typically not exceeding 1 meter in depth. It is not acceptable to average radionuclide concentrations over an arbitrary soil thickness."
- "Adjustment of the grid spacing is more complicated than for surface soils because scanning is not applicable."

The requirement that there be a sufficient number of cores (samples) to satisfy the WRS or Sign test indicates that the survey-unit-wide estimate of central tendency is expected to be included as a compliance metric. The minimum number of data points (cores) required to satisfy the statistical tests can be determined in exactly the same manner as that described in MARSSIM for application to surface soils.

Arbitrary blending or segmentation of core samples is inappropriate. While not expounded upon or explained in the NUREG, blending or averaging of radionuclide concentrations over an arbitrary soil thickness could mask the presence of significantly elevated concentrations of residual radioactivity in a discreet stratum. Cores should, therefore, be appropriately segmented into samples that are representative of the radiological consequences of the site-specific stratigraphy and typically not exceeding 1 meter in depth.

Because subsurface soil DCGLs are dependent on the volume of soil that is potentially involved in a future excavation scenario, it is imperative that the survey design place corehole locations on a systematic grid over the survey unit (as opposed to a purely random distribution). Because scanning of subterranean soils is not possible in the same way that scanning is conceived in MARSSIM, adjustment of the coring grid density to achieve a desired or achievable scanning detection limit is not applicable. Again, no specific guidance is offered in the NUREG on how to determine whether the grid spacing that results from the minimum sample size needed to satisfy the statistical test is sufficient or how to adjust the grid spacing when necessary. Nonetheless, basic statistical concepts akin to those described in MARSSIM can be employed to evaluate the need to adjust the grid density such that there is reasonable confidence that significant volumes of subsurface soils having important quantities of residual radioactivity do not go undetected.

Each of these guiding principles is integrated within the method described in this paper.

DERIVING SUBSURFACE SOIL DCGLs

The magnitude of a subsurface soil DCGL depends upon the volume of subsurface soil having elevated concentrations of residual radioactivity and the vertical position of the subsurface soil within the soil column, relative to the ground surface at final grade. This leads to the development of volume factors and mixing factors that, when combined, yield a scaling factor by which the surface soil DCGL is modified to arrive at a subsurface soil DCGL. The basic concept and precepts of the method rely upon a site-specific, comparative dose assessment of the potential future dose to a receptor. The dose assessment is comparative in that it relies on the existence of a site-specific surface soil dose assessment from which a surface soil DCGL is derived.

The site-specific surface soil dose model is run iteratively such that a measure of the dose consequence relative to the source term volume is the derived. The comparative dose assessment technique used here is analogous to the process described in MARSSIM to arrive at area factors for surface soil DCGLs. Intrusive activities that could bring subsurface soil to the surface might range from soil coring (e.g., well installation) to utility trenching to large-scale soil excavations such as those associated with the placement of the foundation for a house or a commercial building. Reasonably, excavation volumes could range from relatively small to significantly large. Volume factors arise from the geometry transformation associated with an excavation scenario and account for the variability in dose response with respect to the volume of subsurface soil excavated and brought to the surface. They are independent of the depth to which a subsurface excavation has been advanced, the geometry of a hypothetical excavation, and the location of a hypothetical excavation on the site (or within a survey unit).

The dose to a hypothetical receptor is calculated assuming that the surface soil at the site is uniformly contaminated with residual radioactivity at the approved surface soil activity limit and over what is in effect an infinite area[a]. This calculated potential dose serves as the baseline for comparison with the exposure potential to the receptor from a variety of scenarios in which subsurface radioactivity is brought to the surface. As the volume of subsurface radioactivity brought to the surface decreases, the areal size impacted by such actions also decreases; thus, the potential dose consequence is correspondingly reduced. By calculating the potential future dose resulting from a wide range of potential excavation volumes in which varying amounts of subsurface soils having residual radioactivity are brought to the surface, and then comparing these with the baseline dose from an infinite "slab" of surface soils, volume factors are derived.

Having performed the comparative dose modeling as described above, a set of dose response curves relating the maximum annual dose to the volume of contaminated subsurface soil can be derived. When graphed, a curve emerges relating the dose response relationship in terms of the volume factor. Dose is typically inversely proportional to the volume of the source term and logarithmically approaches an asymptotic limit corresponding to the infinite source term geometry of the baseline case as the hypothesized excavation volume increases.

Using the derived relative dose-producing capability of each isotope for varying source sizes, a "volume factor" can be calculated. The volume factor is simply the ratio of the dose produced by the baseline case source term to the dose produced by a smaller volume source (Equation 1).

$$VF = \frac{DR_{Baseline}}{DR_{Volume}} \quad \text{(Eq. 1)}$$

While it is possible to calculate a discrete volume factor value for any single specific source volume under consideration, it is far more useful to derive the function of the curve that relates dose response and volume to the volume factor. In this way, any series of hypothetical excavation volumes can rapidly be assessed and volume factors derived. The discreet volume factor data are subjected to complex regression analysis (multivariate ratio fit analysis) using statistical analysis software (1). The best-fit model is selected and fit to the data, yielding a function that mathematically represents the volume factor curve and from which a volume factor can be readily calculated without additional dose modeling. The function is used to produce the best-fit curve (Figure 1) and to calculate the volume factor for any hypothesized excavation volume. An example curve is plotted vs. discretely calculated values derived from the RESRAD modeling (7).

As described above, volume factors account for the variability in dose response with respect to the volume of soil excavated and brought to the surface, but they are independent of the depth to which the excavation was advanced. Consequently, volume factors cannot account for the mixing of subsurface and surface soil strata as they are excavated and spread out on the ground surface. The concept of mixing volumes is used to derive factors that account for the mixing of residual radioactivity in subsurface soils with overburden soils in an excavation scenario. "Mixing factors" describe the variability in dose-response with respect to the vertical position of a subsurface soil strata (relative to the post-remediation ground surface at final grade) potentially involved in an excavation scenario. Mixing factors are independent of the actual volume of subsurface soil material that could conceivably be excavated and spread out on the surface and are independent of the isotope(s) involved.

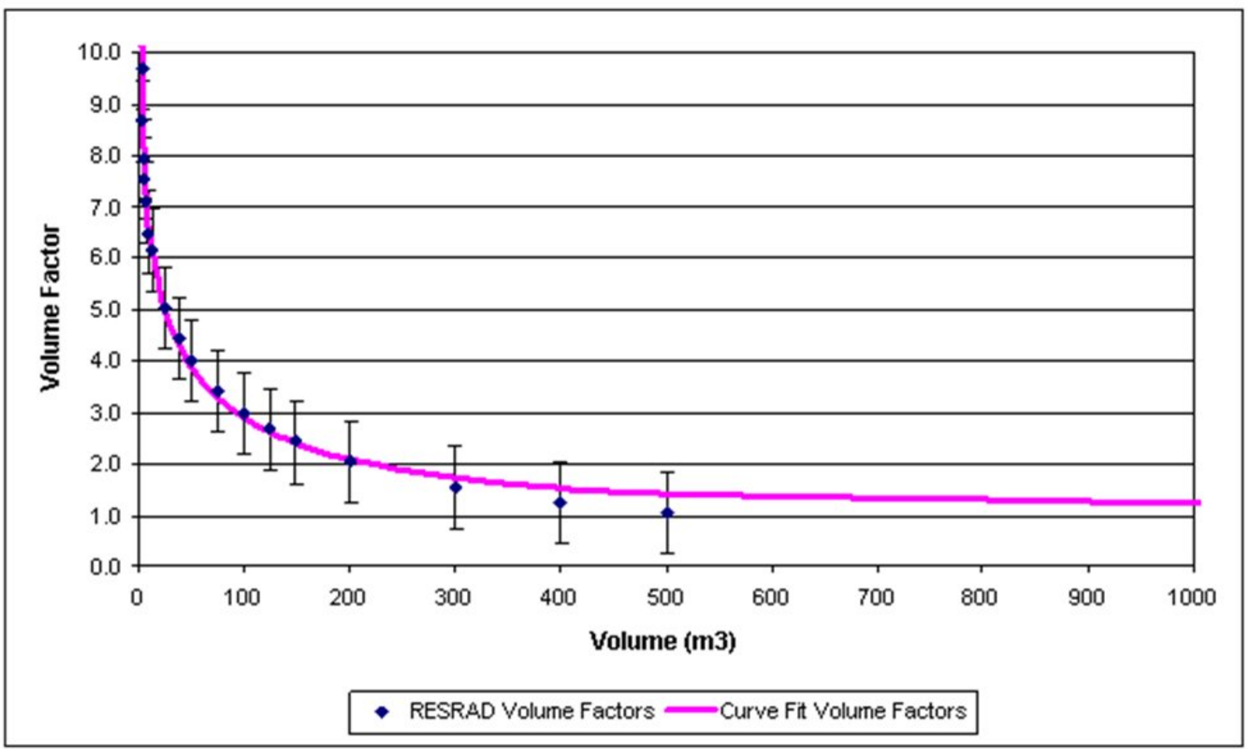


Figure 1 Best-Fit Volume Factor Curve

Conceptually, the mixing factor is very easy to understand and to calculate. The mixing factor is simply the ratio of the total thickness of the soil column (from ground surface to the bottom of the subsurface soil stratum under consideration) to the thickness of the same subsurface soil stratum (Figure 2). The result is a discrete mixing factor for each individual subsurface soil stratum defined.

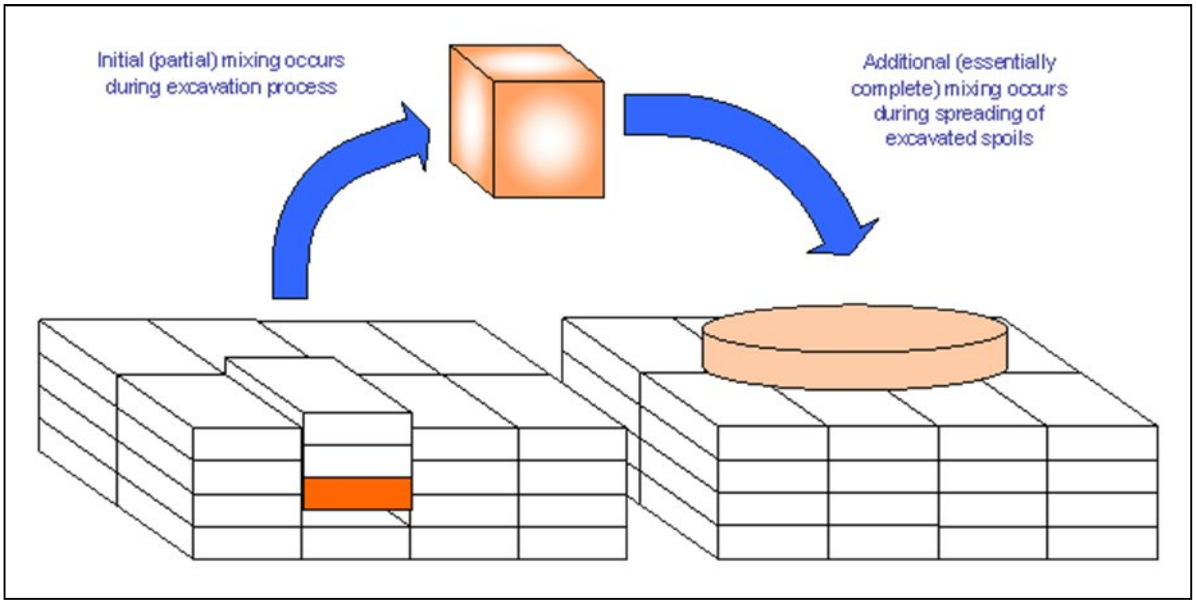


Figure 2 Conceptual Mixing Volume Model

It is important to understand that the vertical demarcation of soil strata in a particular survey unit being surveyed for compliance with the approved final radiological status cannot be arbitrarily assigned. NRC guidance in NUREG-1757 (4) specifies, "Core samples [used to measure residual concentrations of radioactivity in subsurface soils and demonstrate compliance] should be homogenized over a soil thickness that is consistent with the assumptions made in the dose assessment, typically not exceeding 1 meter in depth." It further adds, "It is not acceptable to average radionuclide concentrations over an arbitrary soil thickness." In demarcating subsurface soil strata, one must consider both the assumptions used in site-specific dose modeling as well as the natural, site-specific, geologic divisions that may be present in the soil column and potentially influence the presence of residual radioactivity.

To calculate values for mixing factors, it is necessary to identify the number of vertical strata and the thickness of each stratum within a survey unit. It is possible that a different set of subsurface soil strata would be defined for different survey units, depending upon their predominant geologic composition.

All of the modeling and calculations performed to this point have been undertaken with the objective of arriving at factors by which the approved surface soil DCGLs might be modified to account for the lesser capability of residual radioactivity in subsurface soils to produce dose to an exposed individual. Two distinct factors by which surface soil DCGLs might be modified have emerged: 1) volume factors, and 2) mixing factors.

Combining these two variable factors produces a single factor by which surface soil DCGLs can be scaled to yield equally protective values of DCGL for subsurface soils (Equation 2).

$$k_{Scaling} = \left(k_{Vol}\right) * \left(k_{Mix}\right) \quad \text{(Eq. 2)}$$

The appropriate subsurface soil DCGL for any given volume of subsurface soil in any vertical position relative to the ground surface at finished grade is then given by the following relationship (Equation 3).

$$DCGL_{Subsurface} = \left(k_{Scaling}\right) * \left(DCGL_{Surface}\right) \quad \text{(Eq. 3)}$$

It is recognized that subsurface residual radioactivity contained closer to the surface, say 0-1 meter, may deliver dose without being excavated. This exposure may occur from: 1) direct gamma radiation from in-situ radioactivity close to the surface, 2) the root uptake pathway down to about the first meter, and 3) the uncovering of contaminated surfaces through grading during construction and surface erosion over time, which could then cause dose through surface exposure pathways. However, the excavation scenarios considered yield more conservative estimates of the dose response (and, thus, subsurface soil DCGLs) than would in-situ radioactivity in near surface soils 0-1 meter below the surface because in the excavation scenarios, soil is presumed to be spread over a larger area on the immediate surface after excavation. Therefore, the excavation scenario is used to determine conservative subsurface soil limits for the top 0-1 meter layer as well as for deeper subsurface layers. This conservatism is appropriate due to the uncertainty associated with potential exposure pathways for near-surface residual radioactivity in soil.

SUBSURFACE SOIL SURVEY DESIGN

After the “volume factors” and “mixing volume factors” have been determined, a survey design for assessing the residual concentrations of radioactivity in subsurface soil is developed. The survey design needs to address the general guidance for subsurface soil sampling provided in NUREG-1757 (4) while accounting for the potential lateral and vertical variability in concentrations of residual radioactivity in the subsurface soils.

A survey to assess residual radioactivity in subsurface soils must be designed to ensure that the number and location of samples are sufficient to:

- Satisfy the appropriate statistical test for the survey unit (wide area) criterion, the $DCGL_W$,
- Demonstrate, with reasonable confidence, that a significant volume of subsurface soil having important quantities of residual radioactivity is identified by at least one sample, and

- Demonstrate that the average residual radioactivity concentration in the identified volume would not result in a significant dose if it were excavated and brought to the surface where intimate contact and human exposure is possible.

Laterally, survey units are demarcated using the same concepts and criteria described in MARSSIM (3). What is unique to subsurface soil assessment is the vertical demarcation of the survey unit into depth strata. Stratigraphic logs of the potentially impacted soil column (such as those generated in a typical well installation) are useful in discerning the presence of a subsurface stratum that might influence the presence of residual radioactivity[b].

The vertical demarcation of soil column has two bounding considerations. The smallest thickness of a defined vertical soil layer is limited to the thickness used to derive the volume factor curves. This represents the smallest significant thickness to be considered in the compliance assessment and is thus consistent with the site-specific dose modeling used to derive the subsurface soil DCGLs. The largest thickness for a defined vertical soil layer is nominally limited to a thickness of 1-meter, as suggested in the applicable guidance.

The survey method for assessing the residual radioactivity in subsurface soils involves the physical collection of soil samples from corings advanced to depth in each defined survey unit in which it is known or suspected that substantial quantities of radioactivity exist in the subsurface soils. The coreholes from which volumetric samples are obtained are placed using a systematic square sample grid[c].

Two data needs compete to determine the minimum corehole density expected to be needed in order to satisfy the survey's data quality objectives. The first data need is to demonstrate compliance with the survey unit wide area average ($DCGL_W$) statistical test. The second data need is to demonstrate compliance with the local area subsurface soil DCGLs derived using the scaling factors. The minimum number of data points required to satisfy the survey unit wide area statistical test can be determined in exactly the same manner as that described in MARSSIM (3) for application to surface soils. It is important to recognize that the sample size, N, estimated to be necessary to satisfy the statistical test for the survey-unit-wide area average is the number of coreholes advanced into the subsurface soil.

Once the minimum number of coreholes has been determined, they are distributed over the survey unit using a random start, systematic square grid. Having estimated the required sample size needed to satisfy the statistical test, there is need to determine the corehole density required to demonstrate compliance with the local area subsurface soil DCGLs calculated through the derived scaling factors. This process is conceptually analogous to the grid spacing adjustment described in MARSSIM for surface soils when it becomes necessary to compensate for inadequate scan detection sensitivity.

The first step in the process is to determine the volume of soil represented by each sample in each subsurface soil layer based upon the thickness of the layer and the corehole grid spacing. For example, assume that the minimum grid spacing necessary to satisfy the wide area average statistical test is 8m by 8m, and the thickness of each vertical layer of subsurface soil is 1m. In this case, each sample is shown to represent a soil volume of $64m^3$.

The next step is to access and compare historically available data and remediation control sample data with the permissible subsurface soil DCGL concentrations from the volume factor curves for each subsurface soil stratum. The concept involves estimating the reasonable maximum concentration expected in a given depth layer (e.g., the 90^{th} percentile estimate from among the existing data) and correlating that concentration with volume using the mixing factor adjusted volume factor curves.

For example, assume that the 90^{th} percentile estimate of the soil radioactivity concentration for depth layer #2 from among the existing data is 23 pCi/g. The reasonable maximum concentration (23 pCi/g) intersects the volume factor curve (adjusted for the mixing volume factor for layer #2) at a volume of approximately $22.5m^3$ (Figure 3). This local area volume represents the smallest significant volume of soil with the potential capacity to produce an annual dose in excess of the NRC's decommissioning dose standard should it be involved in a future excavation scenario as described above. Because the smallest local area soil volume is smaller than the $64m^3$ volume represented by each soil sample spaced on a grid designed to demonstrate compliance with the wide area DCGL, it is necessary to adjust the corehole grid such that each sample represents $22.5m^3$. This process is repeated for each depth layer and for each individual isotope with a site-specific soil DCGL.

Demonstration of compliance with the subsurface soil DCGLs is achieved through the collection and analysis of corehole samples. The derivation of subsurface soil DCGLs and, thus, the design of the compliance survey is based on the subdivision of the soil column of a survey unit into regularly sized and spaced "cubes" in the lateral and vertical directions. Soil cores penetrating each of the soil "cubes" are advanced to below the known depth of radiological impact or to refusal. The soil core is collected in such a way that a discreet soil sample is collected from each depth interval identified. Once segmented into individual cores corresponding to each depth layer, the core samples are homogenized over individual lifts and then appropriately packaged, labeled, and processed for subsequent analysis.

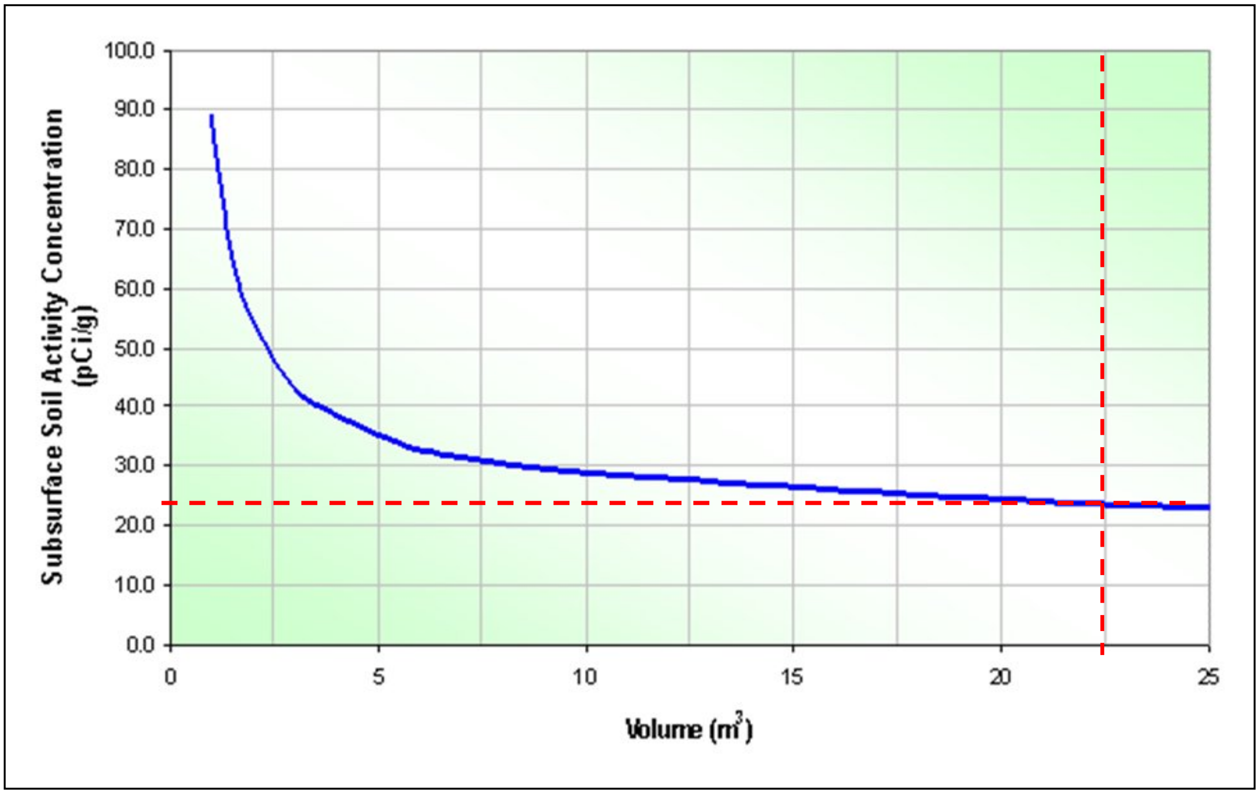


Figure 3 Example–Correlating Reasonable Maximum Concentration with Volume

CALCULATIONS TO DEMONSTRATE COMPLIANCE

Three different compliance metrics (DCGLs) must be satisfied in order to demonstrate that a survey unit with residual radioactivity in subsurface soil meets the dose-based release criteria. They are:

- $DCGL_W$—Survey unit wide-area composite average for each progressively deeper subsurface soil increment.
- $DCGL_{LAA}$—Local Area Averaging (LAA) compares combinations of nearest neighbor cells both laterally and vertically. Averaging in the lateral direction is limited to contiguous, nearest neighbor cells. Averaging in the vertical direction is not limited.
- $DCGL_{EMC}$—Individual sample comparisons with maximum concentration limits

Survey Unit Wide Area Average Compliance Metric: ($DCGL_W$)

The wide area average compliance metric is analogous to the $DCGL_W$ for surface soil. In fact, the average concentration of residual radioactivity for each progressively deeper subsurface soil layer in a survey unit must satisfy the $DCGL_W$ for surface soils. The survey unit wide-area average DCGL for subsurface soils is different from the simple surface soil $DCGL_W$ in that it extends that concept to progressively deeper layers. Still, the basic compliance hierarchy applicable to surface soil DCGLs is applicable also to subsurface soils.

When drawing conclusions from the data relative to the wide area DCGL, the data will sometimes clearly show that a survey unit meets or exceeds the release criterion, obviating the need to perform a statistical test of the data. Such is the case in which each individual data point is less than the $DCGL_W$.

Because there is a potential that the depth layers in a survey unit are not of equal thickness, it would not be appropriate to take the straight arithmetic average or to perform statistical tests of all samples when samples from multiple depth layers are included. Yet, samples from multiple depth layers (when they exist) must be considered when demonstrating compliance with the wide area average criterion. This situation is accommodated through the application of weighting factors used to calculate a volume-weighted average. Weighting factors are based on a single layer's relative contribution to the total soil volume under consideration[d].

For example, when the number of cores in a survey unit is 36, the number of samples (N) in each depth layer is 36, and:

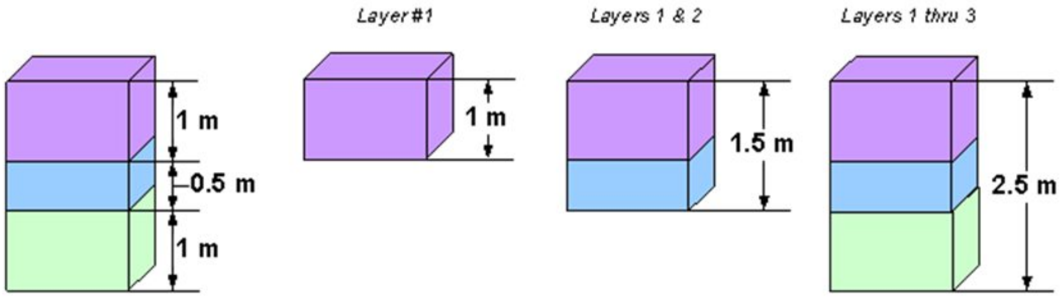
- The average of N=36 samples from layer #1 must be less than the $DCGL_W$,
- The sum of the weighted averages of samples from layers 1 and 2 must be less than the $DCGL_W$,
- The sum of the weighted averages of samples from layers 1, 2, and 3 must be less than the $DCGL_W$, and
- Etc.

Weighting factors are derived from the thicknesses of each layer using Equation 5. A sample calculation is presented in Figure 3.

$$w_i = \frac{t_i}{\sum_{l=1}^{n} t_l} \qquad \text{(Eq. 4)}$$

Where: w_i = weighting factor for layer 'i' when averaged over 'n' layers

n	=	number of layers considered in the average
l	=	the sequential layer identifier (e.g., layer 1, layer 2, etc.)
t_i	=	thickness of layer 'i'
t_l	=	thickness of layers 'i' through 'n'



$$w_i = \frac{t_i}{\sum_{l=1}^{n} t_l}$$

l Layer	t Thickness (Meters)	w_i Weighting Factors When Vertical Averaging includes Layers		
		1	1 & 2	1 thru 3
Layer #1	1.0	1.000	0.667	0.400
Layer #2	0.5		0.333	0.200
Layer #3	1.0			0.400

Figure 4 Example Weighting Factor Calculations

In demonstrating compliance with the wide area average criterion, it is necessary to calculate the individual layer averages. Then, a series of weighted averages, each considering the next progressively deeper layer of subsurface soil is calculated. Each of these weighted averages is then compared with the surface soil $DCGL_W$ to determine compliance.

If it becomes necessary to perform the statistical test to demonstrate compliance with the wide area average criterion, and the subsurface soil has been subdivided into strata of non-uniform thickness, weighting is again required. In this circumstance, the weighted averages of samples from a single column (corehole) and from progressively deeper strata are used in the selected statistical test. In this way, samples from a stratum that is only half as thick as another will not have more influence on the estimate of the central tendency value than is appropriate, avoiding a biasing effect on the statistical analysis.

The Local Area Average Compliance Metric: $DCGL_{LAA}$

The "local area average" metric is a hybrid of the wide area average compliance metric ($DCGL_W$) and the single sample comparison metric ($DCGL_{EMC}$). It is warranted as a distinct compliance metric ($DCGL_{LAA}$) in assessing whether a survey unit having residual radioactivity in subsurface soil meets the basic decommissioning dose standards published by the NRC (2). The subsurface soil $DCGL_{LAA}$ is designed to show that concentrations of residual radioactivity in varying volumes of soil potentially involved in some future excavation scenario will not likely result in exposures that exceed the decommissioning dose standards. The value of the subsurface soil $DCGL_{LAA}$ is scaled to the surface soil $DCGL_W$ and is proportional to both the volume of soil involved in a hypothetical excavation and the depth increment from which the subsurface soil was excavated. Compliance with the $DCGL_{LAA}$ is determined by calculating the averages of combinations of nearest neighbor cells for each defined depth increment. Averaging in the lateral direction is limited to four mutually contiguous cells. Averaging in the vertical direction is not limited.

The local area average concept is somewhat complex because each cell in a given layer (except those on the boundary of a survey unit) can be evaluated as one of four mutually contiguous blocks of cells in four different combinations. Laterally, each combination of the four "nearest neighbor" samples in a given layer needs to be evaluated. Volumes greater than that represented by four contiguous cells can and must be evaluated but are necessarily limited laterally to the area circumscribing four cells.

In addition to the areal averaging described above, a vertical averaging criterion is also defined. These averaging criteria are intended to identify significant volumes of residual radioactivity in contiguous volumes in the vertical, as opposed to the horizontal (lateral) direction. The vertical (columnar) average is calculated for each contiguous combination of samples in a single vertical column starting with the ground surface.

The Single Sample Comparison Compliance Metric: $DCGL_{EMC}$

The $DCGL_{EMC}$ is simply an individual sample comparison with a maximum concentration limit. The maximum concentration limit is, in reality, simply an extension of the local area average concept. It is the concentration derived from the dose response curves and mixing volume factors corresponding to the volume of a single cell in a given layer. Recall that the sample grid used to perform the survey is adjusted (if necessary) to limit the soil volume of any single cell such that the presence of the reasonable maximum concentration expected could not, in and of itself, result in a future annual dose greater than the approved decommissioning limit.

It should be noted at this point that the presence of a single sample in excess of the maximum concentration limit does not necessarily and automatically fail the survey unit, but it is a flag or trigger for further investigation. One may, for example, determine that additional samples in a suspect cell would likely show that the average concentration of residual radioactivity in that cell is actually below the maximum concentration limit. This process is analogous to that described in MARSSIM for surface soils. Of course, all such exceedances must be resolved before a decision can be made as to the final radiological status of a survey unit under consideration for release from radiological controls.

CONCLUSIONS

Having considered the current NRC guidance for consideration of residual radioactivity in subsurface soils during decommissioning (4), MACTEC has developed a technically based approach to the derivation of and demonstration of compliance with subsurface soil DCGLs for radionuclides. In fact, the process uses the already accepted concepts and metrics approved for surface soils as the foundation for deriving scaling factors used to calculate subsurface soil DCGLs that are at least equally protective of the decommissioning annual dose standard. Each of the elements identified for consideration in the current NRC guidance (4) is addressed in this proposed method. Additionally, there is considerable conservatism built into the assumptions and techniques used to arrive at subsurface soil scaling factors and DCGLs. The degree of conservatism embodied in the approach used is such that risk managers and decision makers approving and using subsurface soil DCGLs derived in accordance with this method can be confident that the future exposures will be well below permissible and safe levels.

The technical basis for the method can be applied to a broad variety of sites with residual radioactivity in subsurface soils. Given the costly nature of soil surveys, excavation, and disposal of soils as low-level radioactive waste, MACTEC's method for deriving and demonstrating compliance with subsurface soil DCGLs offers the possibility of significant cost savings over the traditional approach of applying surface soil DCGLs to subsurface soils. Furthermore, while yet untested, MACTEC believes that the concepts and methods embodied in this approach could readily be applied to other types of contamination found in subsurface soils.

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7 Yu, C., et. al., 2001. Users Manual For RESRAD Version 6.0, ANL/EAD-4, Argonne National Laboratory, Environmental Assessment Division, Argonne, IL., July 2001.

FOOTNOTES

a. This represents the worst-case hypothetical condition that might exist and still satisfy the approved surface soil concentration guidelines (DCGLs) using the methods and technologies described in MARSSIM (NUREG-1575, 3).

b. The mere presence of a distinguishable subsurface soil stratum does not in itself necessitate its demarcation as a discreet soil layer from which samples are specifically collected. However, when the geo-chemical properties of a distinguishable stratum differ significantly from the overlying or underlying strata such that it potentially influences the presence of residual radioactivity, it should be discriminated and defined as a distinct layer.

c. A triangular systematic grid design is recognized as being slightly more efficient than square grid designs at locating local deposits of a contaminant (assuming circular geometry). However, a skewed grid, such as that associated with a triangular grid system, introduces significant (and unnecessary) complexity in the nearest neighbor averaging calculations (introduced later in this section).

d. The wide-area weighted average concept is the mathematical equivalent of the residual radioactivity concentration that would be expected to result if the entire volume of soil in a specific survey unit (from the ground surface down to specific depth layer) were to be blended together. It is noteworthy to consider that the NRC staff recently considered the appropriateness of actually allowing the intentional mixing of soil for a number of reasons (5). The staff concluded that the use of intentional mixing of contaminated soil (in limited circumstances and on a case-by-case basis) to meet the license termination rule (LTR) was appropriate. The Commission approved the staff recommendation (6).