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Mr. James A. Mills, P.E.
U.S. Army Corps of Engineers, St. Louis District
Contracting Officer's Representative
CEMVS-ED-C
1222 Spruce Street
St. Louis, MO 63103

SUBJECT: Contract DACW43-00-D-0515, Task Order 0004
Transmittal of the Final *Sample Protocol for the Release of Overburden Material*

Dear Mr. Mills:

Please find enclosed a copy of Final *Sample Protocol for the Release of Overburden Material* for your files. This document was prepared at the request of Mr. Dennis Chambers to provide the technical basis for releasing overburden or other material in lieu of disposal. Comments on the draft version of this protocol from Mr. Chambers and Mr. Brian Harcek have been incorporated as appropriate. It is intended that this protocol will be incorporated into each of the three FUSRAP Final Status Survey Plans during their next scheduled revision.

Additional copies of this document are being distributed to the individuals identified below. If you have any questions or need additional information, please call Sherry Gibson at (314) 581-7767 or me at (314) 770-3000.

Sincerely,

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SAMPLE PROTOCOL FOR THE RELEASE OF OVERBURDEN MATERIAL

1.0 INTRODUCTION

This survey and sampling protocol outlines the theory, methodology, and decision making process necessary to determine the final disposition of suspected clean overburden soil and other suspected clean materials associated with the St. Louis Formally Utilized Sites Remedial Action Program (FUSRAP) Sites. This protocol pertains to soil, soil-like and other unconsolidated materials that have a very low potential for radioactivity levels above the chosen comparison criterion (e.g., background, DCGL, other appropriate DCGLs, etc.). [For the purposes of this protocol, unconsolidated materials are defined as any natural materials that are less than 10 inches in all dimensions.]

This protocol uses the methods and assumptions discussed in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM). MARSSIM guidance focuses on the demonstration of compliance during the final status survey; however, environmental parameters and assumptions are not significantly different for the release of overburden material.

This protocol will be incorporated into the existing St. Louis FUSRAP SLDS, SLAPS, and SLAPS VP Final Status Survey Plans during their next scheduled revisions. This document shall serve as the Field Change Notice (FCN) to these documents until such time that they have been formally incorporated during the document revision process.

2.0 METHODOLOGY

The process of planning the survey/sampling and evaluating the survey data is discussed in this section. The goal of this section is to present the major steps in determining a statistically-based sampling strategy to determine with confidence the level of radioactivity of the subject material. MARSSIM provides guidance on developing appropriate sampling designs using the Data Quality Objectives (DQO) process to ensure that the survey/sampling results are of sufficient quality and quantity to support the compliance demonstration. The compliance demonstration is simply a decision as to whether or not the material sampled meets that established release criteria.

This protocol is designed to allow for comparison of overburden and other material sample data sets with the appropriate criterion. To maintain consistency with MARSSIM, the chosen release criteria will be referred to as the derived concentration guideline level (DCGL). The DCGL is the value that will be compared with the average radionuclide concentration of the sampled material. For this protocol, the DCGL may be background radioactivity level(s), the soil cleanup level established in the EE/CA or ROD (including or not including background), or other criteria, as appropriate. Additionally, an upper bound limit for each radionuclide of concern is set at the 95% UCL for the sample population. This value is established to account for the statistical uncertainty of data points at or near the DCGL to prevent failing the overburden if a single data point is above the DCGL but within the statistical certainty of the sample population.

If the imposed DCGL is background or includes background, comparison with reference area values is not appropriate. Data in this category will be evaluated using the Sign Test following the guidance provided in Section 8.3 of MARSSIM. If the imposed DCGL is "above background", comparison with a reference area sample population is required. Evaluation of "above background" data will be conducted using the WRS test following the guidance provided in Section 8.4 of MARSSIM.

2.1 Sample/Survey Planning

This process begins with the development of DQOs. On the basis of these objectives and the known or anticipated radiological conditions of the overburden or other material, the numbers and locations of sampling points used to demonstrate compliance with the chosen criterion are determined. Many applicable DQOs pertaining to statistical based MARSSIM sampling have been developed and are documented in the St. Louis FUSRAP Final Status Survey Plans. However, additional objectives specific to a particular area, material, and criteria may need to be established to provide the basis for demonstrating compliance. These additional DQOs will be reviewed and approved by the USACE prior to implementing the associated sampling protocol.

2.2 Survey Design

A minimum amount of information is needed from preliminary evaluations and/or surveys to develop an effective sample design. This includes:

- sufficient information to justify classification and specification of the limitations of the overburden to be surveyed and
- an estimate of the variability of the radioactivity in the overburden or other material slated for release.

For the release of overburden or other material, it is likely that an estimate of σ_s can be determined form earlier scoping or characterization data. If not, conservative assumptions need to be made based on site knowledge. An estimate of σ_r is necessary when the WRS test will be used to evaluate the data.

Figure 2 in the MARSSIM Roadmap presents the major steps in the development of a survey design that integrates scanning surveys with direct measurements and sampling. Most of the steps are easy to understand; however, several are important enough to justify additional discussion in this guide. These steps are:

- Classify Areas by Contamination Potential
- Group/Separate Areas into Survey Units
- Determine the Number of Data Points
- Evaluate and Modify Design Results

2.2.1 Classify Areas by Contamination Potential

Classification is a critical step in survey design because it determines the level of effort based on the potential for elevated radioactivity. Overestimating the potential for elevated radioactivity results in an unnecessary increase in the level of survey/sample effort. Underestimating the potential for elevated radioactivity greatly increases the probability of failing to demonstrate compliance based on the survey/sample results. There are two key decisions made when classifying areas: 1) is the radioactivity in the area likely to exceed the relevant criteria and 2) is the radioactivity present in small areas of elevated activity or is it distributed relatively homogeneously across the area? By limiting the scope of this protocol to overburden or other material intended for release, it is assumed that the subject materials are not likely to exceed the DCGL and that the radioactivity is homogeneous throughout the material to be sampled.

MARSSIM addresses the likelihood of radioactivity exceeding the DCGL and thus the sample design requirements by dividing the area to be evaluated into three classes. Class 1 areas/material are those that, prior to remediation, are likely to have residual radioactivity above the DCGL. Class 2 areas/material are those that are not expected to have residual radioactivity above the chosen DCGL; whereas, Class 3 areas/material are those that have a low probability of containing elevated radioactivity.

2.2.2 Group/Separate Areas into Survey Units

Information obtained from preliminary surveys or site knowledge is crucial for classifying overburden areas. For the purpose of this protocol, overburden material intended for release will not be considered a Class 1 area since this implies that residual radioactivity is known to be present above the DCGL. Generally, overburden material separated from potentially contaminated material by a liner or other physical barrier will be designated as a Class 3 area. Overburden material that may be in direct contact with potentially contaminated material will generally be designated as a Class 2 area. Overburden areas/material will be limited in size based on classification and site-specific conditions. The following DQO for survey unit area and volume limitations has been established for this protocol:

Survey Unit Designation	Max. Survey Unit Area	Max. Survey Unit Volume
Class 2	10,000 m^2	1,500 m^3 or ~ 2,000 yd^3
Class 3	50,000 m^2	7,500 m^3 or ~ 10,000 yd^3

Maximum survey unit volumes are based on an evaluation depth interval of 0.15 meters (6 inches) across a survey unit area.

2.2.3 Determine the Number of Data Points

The first step in determining the number of data points is to specify the acceptable decision error. There are two type of decision error: Type I (α) and Type II (β). The probability of making decision errors can be controlled by adopting an approach called hypothesis testing. The null hypothesis (H_O) is treated like a baseline condition and is defined by MARSSIM as:

H_O = residual radioactivity in the survey unit exceeds the release criterion meaning the area is assumed to be above the chosen criteria until proven otherwise.

Based on this null hypothesis, the Type I error pertains to the probability of elevated radioactivity being inappropriately released. The lower the Type I error, the less chance that overburden material above the chosen DCGL will unknowingly be released. The Type II error relates to the chance of erroneously disposing of material that is below the criterion. The lower the Type II error, the lower the chance of material suitable for release being shipped offsite as contaminated. Both α and β are typically set at 0.05, but the final values differ depending on the DQOs. As the Type I error relates to increased risk/dose it is not appropriate to increase this typical value. The Type II error is more a function of disposal costs and not public or environment protection; therefore, a range of 0.05 to 0.25 is considered acceptable for the release of overburden material.

The next step is to estimate the variability of the radionuclide concentration, σ. The standard deviation of the radionuclides of concern may be determined from preliminary sampling results. If the area/material is being compared to "above background" criteria, the variability of the overburden (σ_s) and the variability of an appropriate reference area population (σ_r) must be used. If the chosen DCGL is or includes background, it is appropriate to use the one-sample statistical test (Sign Test) for data evaluation; therefore σ_r is not needed for determining sample point requirements.

Underestimating σ can underestimate the number of measurements needed to demonstrate compliance, which increases the probability that the survey unit will fail the statistical test. Overestimating σ can result in collecting more data points than is necessary to demonstrate compliance. When preliminary data is not obtained and a σ cannot be determined, MARSSIM suggests using a coefficient of variation of 30% of the *expected* mean survey unit concentration. As with all parameters, site-specific data should always be used when available.

The third step in determining the number of sample points is to calculate the relative shift, Δ/σ. The Δ/σ is an expression of the resolution of the measurement in units of measurement uncertainty. The shift, Δ, is equal to the width of the gray region. The upper bound of the gray region is defined by MARSSIM as the DCGL. The lower bound of the gray region (LBGR) is a project specific parameter, adjusted to provide a value of Δ/σ between one and three. Δ/σ can be adjusted using the following steps:

- Initially select the LBGR to equal one half the DCGL. Calculate Δ/σ.
- If Δ/σ is less than one, select a lower value for the LBGR. Continue to select lower values for the LBGR until Δ/σ is greater than or equal to one, or until the LBGR equals zero.
- If Δ/σ is greater than three, select a higher value for LBGR. Continue to select higher values for LBGR until Δ/σ is less than or equal to three.
- If Δ/σ is between one and three, continue with the fourth step.

The fourth step in determining the number of data points is to use the α, β, and Δ/σ to obtain that appropriate number of sample points necessary to satisfy the requirements. Table 5.5 in MARSSIM contains the number or samples (N) necessary for a given α, β, and Δ/σ when the DCGL is or includes background. Table 5.3 in MARSSIM contains the number of samples (N) necessary for a given α, β, and Δ/σ when the area/material is being compared to "above background" criteria. The N values in each of these tables contain a 20% increase to account for lost or unusable samples.

If there are multiple radionuclides of concern in the overburden material being evaluated, the σ and DCGL for each isotope is used to determine individual radionuclide sample point values. The largest value for the number of sample points is used to determine the sample layout. Using the largest of the individual sample point values is more conservative than calculating a combined, weighted value, and also provides a greater level of confidence in the compliance demonstration.

2.2.4 Determine Sample Layout

Class 2 areas/material are generally sampled using a random-start systematic grid pattern. The grid spacing is determined one of two ways depending on the shape of the grid chosen. If a triangular grid is used (preferred), the grid spacing is estimated as follows:

$$L=\sqrt{\frac{A}{0.866\,x\,N}} \qquad \text{(Equation 1)}$$

where: A = the surface area in the survey unit and
N = the largest number of samples calculated for the above survey design

If the square grid is used, the spacing is estimated as follows:

$$L=\sqrt{\frac{A}{N}} \qquad \text{(Equation 2)}$$

Class 3 areas are generally sampled at random locations. These locations are determined by randomly generating sample coordinate locations within an area. Factors such as material accessibility, overburden depth, ex situ pile configuration etc. may affect the sample location layout (e.g., number of 6" evaluation layers). In these situations, it may be necessary to combine a random start systematic sample location layout with randomly generated sample depths to provide adequate coverage of Class 2 and Class 3 overburden. To ensure consistent implementation of this method of combining sample scheme layouts, the following DQOs have been established for this overburden sampling protocol:

- The minimum number of systematic sample borehole locations shall be no less than 50% of the required number of samples.

- The maximum number of systematic sample borehole locations shall be no more than 100% of the required number of samples to be collected for the compliance demonstration.
- The number of sample borehole locations shall be adjusted between 50% and 100% of the required number of samples to provide at least 3 times the distinct sample intervals as the number of samples required for the compliance demonstration. This will ensure an adequate number of samples intervals are available to randomly generate sample depths.

To illustrate implementation of these DQOs, consider an ex situ overburden pile requiring 16 samples to show compliance with the chosen DCGL. In this situation, the DQOs of this protocol dictate the number of systematic sample borehole locations to be between 8 and 16 to create at least 48 distinct sample intervals for randomly generating sample depths. It is not intended that this approach provide for collecting at least one sample from each borehole as this would result in sample bias, which is not consistent with the MARSSIM approach.

(Note: All sample scheme layouts for each specific overburden area/material to be evaluated shall be submitted to the USACE for concurrence.)

2.3 Survey Design Evaluation and Modification

After the number and layout of the samples per evaluation area have been calculated, it is then determined if that number is reasonable. It is possible, using this protocol that there are not enough samples proposed to produce the desired level of comfort or there are too many samples points, which may make the effort, cost prohibitive. It is the responsibility of the site managers and health physicists to evaluate whether the number of samples is reasonable. If it is determined that the number of samples is inadequate or excessive, the sample DQOs should be reevaluated.

3.0 RADIOLOGICAL GAMMA SCANS

With the ability to field-detect radioactivity using hand-held instrumentation, MARSSIM recommends that some level of scanning be performed in an attempt to identify areas that exceed the chosen DCGL or other specified investigation level.

Surface scans for gross gamma radiation will be performed to confirm the absence of areas of elevated activity in the overburden material slated for release. Gamma scans will be performed on accessible areas/material except those when posing undue harm to the survey crews (e.g., large piles with severe slopes, etc.). For these situations, innovative techniques such as reach poles may be used to accomplish the required scanning.

Surface scan coverage for Class 2 overburden areas/material will be, to the extent possible, at least 20% of the surface of the area or material to be released. Coverage for Class 3 surface scans will be at least 10%. For piles and in situ areas consisting of more than one 6 inch evaluation layer, consideration should be given to performing gamma scans of subsurface layers as the material is being excavated and/or dispositioned. At a minimum surface gamma scans will be conducted on the surface of the overburden material prior to sampling.

Gamma scans will be biased by the surveyor supervisor and when feasible will concentrate on areas that have the highest potential for contamination. The surveyor will advance at a speed of approximately 2 ft/s (0.5 m/s) while passing the detector over the surface in a serpentine pattern. Audible response of the instrument will be monitored, and locations of elevated audible response will be noted. The ambient background for an area will be determined at the start of the survey and a scanning response which is detectable above the background level (e.g., 2,000 cpm above background) will be set as the investigation level, indicating potential elevated radioactivity. Gamma scan data may be recorded in real time, using position and data recording methods.

Gamma scans will be conducted to verify that there are no significant gamma radiation level differences which would indicate a non-homogenous radioactivity distribution in the overburden material. It is possible for overburden areas above contaminated soils to exceed the investigation level due to the presence of gamma emitting nuclides in the soils beneath the overburden. Each area that exceeds the investigation shall be investigated by sampling or other means to prove that the increased gamma radiation is due to the contaminated soil beneath the overburden area and not due to overburden layer itself.

Table 2 lists the radiological field survey instruments that will be used (functional and performance equivalents may be used, as determined by a Certified Health Physicist). Detection sensitivities have been determined following the guidance of NUREG-1507, using nominal literature values for background, response, and site conditions. Derivations of these values are documented in each of the St. Louis Final Status Survey Plans. Refinements to these detection sensitivity estimates may be made on the basis of actual instrument response and background data gathered during site survey activities.

All instrumentation will have current calibration (within the past 12 months, or more frequently if recommended by the manufacturer). Daily field performance checks will be conducted in accordance with individual instrument use procedures. These performance checks will be performed prior to and following daily field activities and at any time the instrument response appears questionable. Only data obtained using instruments that satisfy the performance requirements will be accepted for use in the evaluation.

Table 2 -Typical Gamma Scan Instruments

Description	Application	Approximate Detection Sensitivity (pCi/g)
Ludlum Model 44-10; 2-inch × 2-inch NaI gamma scintillation detector	Gamma scans of all surfaces	Th-230, 2120; Ra-226, 2.8; and U-238, 39
Ludlum Model 2221; Scaler/ratemeter (with earphones)	Readout instrument for gamma scintillation detector	N/A

4.0 PRACTICAL APPLICATION

This section illustrates the use of this protocol for in situ and ex situ (i.e., pile) scenarios.

4.1 Example 1 – In Situ Overburden

For the purpose of this example, an area approximately 50 meters by 75 meters (3,750 m^2) contains suspected clean overburden to a depth of 0.6 meters (2 feet). This area is separated by a liner from soil contaminated with Ra-226, Th-230, and U-238. Site history suggests little potential for elevated residual radioactivity to exist in the upper 0.6 meter region and preliminary sampling of the overburden indicates it is in the range of background.

The DCGLs chosen for this evaluation are the mean radionuclide concentrations from the population of 37 North County surface soil background samples. Summary statistics of this background data set are provided in Table 3 below:

Table 3 – NC Background Surface Soil Summary Statistics

Statistic	Th-230 (pCi/g)	Ra-226 (pCi/g)	U-238 (pCi/g)
Mean	1.49	0.96	1.08
UCL-95	1.59	1.01	1.17
St. Dev	0.32	0.19	0.28
No. Samples	37	37	37

The protocol limits the evaluation to 0.15 m (6 inch) intervals; therefore, in a 0.6 meter region there are 4 evaluation intervals each with an area of 3,750 m^2 for a total are to be evaluated of 15,000 m^2. This equates to a volume of in situ overburden of about 2,250 m^3 (2,960 yd^3). Since the overburden material has a very low probability of elevated radioactivity; the material is separated from the potentially contaminated area by a liner; and the total area/volume is less than 50,000 m^2/7,500 m^3 the overburden is classified as one Class 3 survey unit. In addition, since the DCGL is background, the overburden will be evaluated using the one-sample statistical test (Sign Test).

The DQO process for this case has established the Type I and Type II errors to both be 0.05. Since multiple radionuclides are present, the relative shift, Δ/σ, is calculated for each of the three. The results of this calculation are provided in Table 4:

Table 4 – Example 1 Δ/σ Calculation

Parameter	Th-230	Ra-226	U-238
Mean or DCGL	1.49	0.96	1.08
St. Dev (σ)	0.32	0.19	0.28
LBGR (1/2 of DCGL)	0.74	0.48	0.54
Shift (Δ = DCGL – LBGR)	0.75	0.48	0.54
Δ/σ,	2.3	2.5	1.9

This calculation shows that U-238 yields the most restrictive relative shift value at 1.9. Since the relative shift is between the suggested range of 1 to 3, no adjustment of the LBGR is needed. From Table 5.5 in MARSSIM, the number of sample points needed for the Sign Test is determined to be 16 for an Δ/σ of 1.9 and an α and β of 0.05.

The protocol establishes that samples will be collected in 6 inch (0.15 meter) intervals. Sampling to a depth of 2 feet (0.6 meters) will require samples at the 0-6 inch, 6-12 inch, 12-18 inch, and 18-24 inch intervals. To provide an equal chance for one of the 16 samples to fall into each of the four, 6 inch intervals, 16 sample locations will be placed across the area of the overburden material using a random start systematic triangular pattern. The triangular sampling pattern spacing is calculated using Equation 1 at 16.5 meters [$L = (3750\ m^2/0.866*16)^{1/2}$].

All sample location will be split into four sample intervals each uniquely identified creating a total of 64 distinct samples. Random number generation will be used to select 16 samples from the 64 uniquely identified samples. Samples will be collected at the specified location and depth.

4.2 Example 2 – Ex Situ Pile of Overburden

This example addresses excavated overburden or other material staged in a pile awaiting disposition. This example will use the same contaminants of concern (Ra-226, Th-230, and U-238) as Example 1. The pile is 1.8 meters high (6 feet) and 24 meters (80 feet) in diameter equating to a volume of approximately 450 m^3 (600 yd^3). The pile is not in contact with potentially contaminated material and site history and preliminary sampling indicate very little potential for elevated radioactivity. This leads to the conclusion that this pile may be designated as a Class 3 material in accordance with the protocol.

The DCGL chosen for this example will be the surface soil clean up criteria of 5 pCi/g for each radionuclide of concern and will include background. In other words, no provisions will be made for considering the background of the overburden material. Since the DCGL includes background the appropriate statistical test for evaluation is the Sign Test.

For the purposes of this example the DQO process has established the Type I and Type II errors to both be 0.05. The variability of the contaminants of concern for this pile is unknown so a coefficient of variation of 30% of the expected mean will be used as an estimate for σ. This results in a maximum estimate of σ at 1.5 pCi/g (30%*5 pCi/g). With a DCGL of 5 pCi/g, an LBGR of 2.5 pCi/g and a σ of 1.5 pCi/g a relative shift value of 1.7 is calculated. Since the relative shift is between the suggested range of 1 to 3, no adjustments of the LBGR is needed.

From Table 5.5 in MARSSIM, the number of sample points needed for the Sign Test is determined to be 17.

An alternative approach to sample layout must be considered since the overburden material exists as an ex situ pile. Following the DQOs presented in Section 2.2.4 of this protocol, a systematic pattern of at least 9 samples is required over the "footprint" of the overburden pile. The area of the pile "footprint" is approximately 452 m^2 [$A=\Pi r^2$] resulting in triangular sample spacing of 7.6 meters [$L = (452\ m^2/0.866*9)^{1/2}$].

For purposes of this example, it is assumed that the 9 boreholes are distributed resulting in 2 boreholes 6 feet in depth, 3 boreholes 4 feet in depth, 2 boreholes 2 feet in depth and 2 boreholes 1 foot in depth. This produces 60 available sample intervals which exceeds the minimum number of 51 (e.g., 3 x 17 = 51) required by the DQO. No adjustments to the number of systematic sample locations are necessary to meet the DQOs. Random number generation will be used to select 17 samples from the 60 uniquely identified samples. Samples will be collected at the specified location and depth.

5.0 DATA EVALUATION

This protocol stipulates that the average concentration of each radionuclide of concern will be compared to the chosen DCGL(s). For this protocol, the DCGL may be background radioactivity level(s), the soil cleanup level established in the EE/CA or ROD (including or not including background), or other criteria, as appropriate. Additionally, no individual samples will exceed an upper bound limit set at the 95% UCL for the population of the survey unit samples.

If the DCGL is or includes background, the data for each radionuclide of concern will be evaluated using Sign Test following the procedures in Section 8.3 of MARSSIM. If the overburden or other material is to be compared against "above background" criteria, the data for each radionuclide of concern will be evaluated using the WRS test following the procedures in Section 8.4 of MARSSIM.

The initial step for evaluating the data will include a general review of the data to determine if the established DQOs have been met and if enough useable data exists for performing the evaluation. Once it has been determined the data is of sufficient quality and quantity the data assessment may proceed.

Each data set will be plotted using posting plots or bar charts for visual comparison of the distribution and the population mean, standard deviation, and 95% UCL values will be calculated. For each survey unit, the individual data values for each of the individual radionuclides will be compared with the DCGL and the 95% UCL.

- If all the values for all the radionuclides of concern in the survey unit are less than the DCGL, the survey unit satisfies the established criterion; no further data evaluation is required. The overburden under evaluation may be released.
- If the survey unit mean for any of the radionuclides of concern is greater than the DCGL, the overburden under evaluation does not satisfy the established criterion. Further

evaluation of the data and use of an alternative DCGL may be considered to determine whether the overburden is suitable for other applications besides unrestricted release (e.g., excavation backfill, etc.).

- If the survey unit mean for all radionuclides of concern is less than the DCGL but some individual data are greater than the DCGL (but less than the 95% UCL for the population), testing of the data using the appropriate statistical test (Sign or WRS) is conducted.
- If individual data exceed the calculated 95% UCL for the population, the sample population does not meet the established DQOs. Removal of the overburden area (and representing data) may be considered allowing for re-evaluation of the new area.

5.1 Sign Test

The Sign Test is completed as shown in Section 8.3.2 of MARSSIM as follows:

- List each of the survey unit measurements.
- Subtract each measurement from the DCGL.
- Discard all differences which are "0"; determine a revised sample size.
- Count the number of positive differences; this value is the test statistic, S+.
- Compare the value of S+ to the critical value in MARSSIM Table I.3 for the appropriate sample size and decision level.

If S+ is greater that the critical value, the overburden material meets the established criteria. If S+ is smaller than the critical value, the overburden material does not meet the established criteria.

5.2 WRS Test

The WRS Test is completed as shown in Section 8.4.2 of MARSSIM as follows:

- Obtain adjusted reference area measurements by adding the DCGL to each measurement.
- Pool and rank the adjusted reference area measurements and sample measurements in order of increasing size starting at 1.
- If several measurements are tied (i.e., have the same value), they are assigned the average rank of that group of tied measurements.
- If there are "less than" values (t), they are all given the average of the ranks from 1 to t. Therefore, they are all assigned the rank $t(t+1)/(2t)=(t+1)/2$, which is the average of the first t integers. If there is more than one detection limit, all observations below the largest detection limit should be treated as "less than" values.
- Sum the ranks of the adjusted reference area measurement; this value is the test statistic, W_r.
- Compare the value of W_r to the critical value given in Table I.4 for the appropriate values of the reference are size, sample population size, and Type I error.

If W_r is greater than the critical value, the overburden material meets the established criteria. If W_r is less than the critical value, the overburden material does not meet the established criteria.

6.0 REFERENCES

DoD 2000. *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM),* NUREG-1575, Rev. 1, EPA 402-R-97-016, Rev. 1, August.

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