Considerations for Implementation of MARSSIM/MARSAME Surface Radioactivity Surveys within FUSRAP - 12330

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ABSTRACT

Surveys for residual surface radioactivity support the release of buildings under MARSSIM and the release of materials & equipment under MARSAME consensus guidance. There are a multitude of factors and conditions that must be assessed and addressed when developing a defensible survey design. ISO-7503 addresses the most basic survey considerations with consistent terminology and defensible calculation methodologies recommended for program-wide implementation by the authors. A key point of interest is the ISO-7503 approach to determining the total efficiency of the measurement system that is promoted by the authors for adoption throughout FUSRAP.

INTRODUCTION

The Formerly Utilized Sites Remedial Action Program (FUSRAP) identifies, investigates, and addresses sites that were part of the early atomic energy and weapons program for the United States. The U.S. Army Corps of Engineers was assigned management of FUSRAP in 1997.

The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) [1] provides guidance for designing, implementing, and assessing radiological surveys used to investigate and clean-up or control surface soils and building surfaces at FUSRAP sites. The Multi-Agency Radiation Survey and Assessment of Materials and Equipment supplement to MARSSIM (MARSAME) [2] provides guidance for designing, implementing, and assessing radiological surveys used to investigate and clean up or control materials and equipment at FUSRAP sites. Surface measurements supporting surveys based on MARSSIM and MARSAME guidance are routinely performed at sites within the FUSRAP program.

An essential component in the determination of surface radioactivity from surface measurements is the establishment of a defensible total efficiency for converting instrument recorded counts per minute to a concentration of radioactivity present over a predetermined surface area. As a result of individual experiences and professional background, contractors within FUSRAP often have dissimilar approaches to efficiency determinations. These inconsistencies are typically associated with determination of instrument efficiency, and techniques used to account for surface effects on survey measurements obtained. These differences are often at a level below what is typically specified in the final status survey or characterization work plan. Differences in technical approaches can create questions for stakeholders about the validity of results, especially in situations where a third-party contractor is performing verification surveys using their own independent survey methodology. ISO-7503-1 [3] provides a standard set of terminology and methodologies for the performance of surface surveys that may help promote greater consistency when addressing issues related to the translation of field instrument readings to levels of residual surface radioactivity.

DISCUSSION

Survey Guidance

MARSSIM and MARSAME provide technical guidance on planning, implementing, and assessing radiological surveys. The guidance provides a framework for radiological surveys that allows the user to optimize the survey based technical issues related to the site, project, contaminants, and other criteria.

MARSSIM describes a combination of direct measurements and scan measurements of building surfaces to demonstrate compliance with the release limit using a final status survey. Direct measurements provide an estimate of the median radionuclide concentration over the entire survey area. The minimum number of direct measurements is calculated to ensure the estimate of the median meets the survey objectives. Scan measurements identify small areas with levels of radioactivity significantly higher than the median. The space between direct measurements is calculated to ensure the minimum detectable activity for scan measurements meets the survey objectives. The sample spacing may increase the total number of direct measurements.

MARSAME provides the same survey guidance found in MARSSIM, but also allows alternative survey designs to account for differences in materials being surveyed. Scan-only surveys use scan measurements to measure radioactivity on materials and equipment and are characterized by a large number of short measurements where the material being measured moves relative to the detector. In situ surveys, on the other hand, are characterized by limited numbers of direct measurements with long count times where the material being measured and the detector are stationary.

A key decision for radiological surveys based on MARSSIM or MARSAME guidance is the selection of a measurement method combining an instrument and a measurement technique (i.e., scan or direct measurement). The selection of a measurement method should consider the survey objectives, radionuclides of concern, the physical characteristics of items to be surveyed, the performance characteristics of the instrument, and the differences in measurement techniques. All this information can be summarized as the total measurement uncertainty. The total measurement uncertainty of different measurement methods is then evaluated against project resources (i.e., cost and schedule) and availability.

Total measurement uncertainty should be evaluated by constructing an “uncertainty budget”. Major sources of uncertainty can be readily identified and a determination made on whether to try and reduce the uncertainty by changing the instrument, the measurement technique, or both. Experience has shown that efficiency is a major source of uncertainty for direct measurements on surfaces for FUSRAP projects.

Problems with Commonly Accepted Approaches to Instrument Selection

Historically measurement methods have been selected based on available instruments and professional judgment. Many hand-held instruments had similar efficiencies so the major source of uncertainty often came from the technician performing the measurements. For scan surveys the uncertainty of source-to-detector distances, field of view of the detectors, and scan speeds were directly related to the experience of the technician. All of these sources of uncertainty could be minimized by using direct measurements with the same instrument, but the time required to fully survey a room or a large piece of equipment using individual 100 cm^2 measurements was prohibitive.

Over the last two decades there have been improvements made to detectors, meters, and measurement systems that focus on reducing one or more sources of uncertainty associated with surface measurements. This means that a “one size fits all” or “rule of thumb” approach to instrument selection is not effective for ensuring a selected measurement method will be effective or efficient for meeting the survey objectives.

Many innovations make assumptions about the items being surveyed that impact preparations for survey. When all surveys were performed using small hand-held detectors the only preparation required was to make the surface clean and accessible. Newer measurement systems can reduce the total measurement uncertainty but only if the assumptions are known. Then the survey conditions can be adjusted to match the assumptions. For example, a mechanized system with a large detector can minimize variations in scan speed and source-to-detector distance, but only for large, flat surfaces. Items that will be measured need to be made to resemble large, flat surfaces in order to use this type of system. When the assumptions are violated the total measurement uncertainty becomes unknown and almost always increases.

Establishing Survey Measurement System Efficiency

In basic terms, the “efficiency” of a measurement system is essentially the expected instrument response (i.e., “counts” or “clicks”) to a level of radioactivity actually present of the surface. If one net “click” is heard on the instrument for every five particle emissions that actually occurred during the same time interval, the total efficiency would be twenty percent (20%). To add a layer of detail, the overall total system efficiency is comprised of “instrument efficiency” (i.e., the raw ability of an instrument to measure those radiations incident on the detector) and a “surface efficiency” (i.e., the ability of radiation emanating from the surface to actually reach the detector). It is these sub-elements where inconsistency in approaches is often discovered.

The most common and basic approach is to directly compare the instrument output during calibration to the reported total activity of a traceable source standard. This comparison establishes what is historically referred to as the “4-Pi Instrument Efficiency

($\varepsilon_{i,4\pi}$), used to convert instrument response, in units of counts per second (cps), to surface activity, in units of becquerels per square centimeter (Bq/cm^2) as follows:

$$(\quad / \quad) = \frac{}{{}_{,}\;(\qquad\qquad\qquad)} \qquad \text{(eq. 1)}$$

In real world situations, the actual surface conditions are seldom consistent with those of a typical commercial calibration source, especially when considering backscatter and self-absorption. When this disparity is addressed during survey design, it is often done by attempting to normalize the efficiency using source-to-surface correction factors based on graphs of the backscatter properties of selected elements and other arcane references. Efficiency values sometimes go uncorrected for surface characteristics which lead to greater overall measurement uncertainty. Lack of accounting for surface characteristics is most common in remedial support survey programs at sites undergoing active remediation where their survey programs are based on traditional radiation safety methods rather than a formalized MARSSIM/MARSAME-based approach.

ISO-7503-1 "Evaluation of surface contamination; Part 1: Beta-emitters (maximum beta energy greater than 0.15 MeV) and alpha-emitters" is an international consensus standard containing basic terms and methods associated with determining levels of residual radioactivity on surfaces. ISO-7503-1 establishes a consistent approach to be employed when converting physical survey instrument response, typically in counts per second (cps), into surface radioactivity levels in units of becquerels per square centimeter (Bq/cm^2).

As it pertains to this discussion, the key methodology presented in ISO-7503-1 is related to replacing the efficiency term ($\varepsilon_{i,\ 4\pi}$) in Eq. 1 with two independent terms: "Instrument Efficiency (ε_i)" and; "Surface Efficiency (ε_s)". The basic formula for determining activity from instrument output using the ISO-7503-1 methodology is presented as follows:

$$(\quad / \quad) = \frac{}{(\;)(\;)(\qquad\qquad\qquad)} \qquad \text{(eq. 2)}$$

The first of these terms is the "Instrument Efficiency (ε_i)" and is familiar to health physicists but often not in the manner presented in ISO-7503. In the ISO-7503 approach, the ε_i is based on the upper solid angle 2-Pi (2π) Surface Emission Rate of the calibration source rather than the typical 4-Pi (4π) source activity. Use of the ISO-7503 approach for determining ε_i ignores the various physical processes (e.g., self-absorption, backscatter, air absorption, geometry, etc.) that vary the number of particles incident on the detector during calibration. Instead, ε_i is based purely on the percentage of particles detected versus the expected surface emission rate of the traceable source used for calibration. The key benefit of this aforementioned approach to determination of ε_i is realized when the issue of surface efficiency (ε_s) is addressed as an independent parameter. Historically, health physicist would wring their hands over the best method to address the physical differences between the source(s) used for calibration and the surfaces undergoing survey. In fact, the determination of efficiency using the ISO-7503 approach renders all issues related to source physical properties essentially moot as the ε_s is based on the type and maximum particle emission energy of the residual radioactivity rather than the elemental properties of the underlying surface.

Another point to consider when assessing measurement system efficiency is the relationship between the particle energies used to develop ε_s and ε_i as they compare to the actual contaminant to be surveyed. This can be a complex process when a multiple nuclides are present. Health Physics evaluations of the source term, and expected decay progeny, should be performed to feed into efficiency determinations. ε_s is based on the maximum emission energy from the nuclides expected while ε_i is based on the average emission energy. It is then practical to develop weighted ratios based on expected isotopic abundances to yield ε_s and ε_i values applicable for gross activity measurements on surfaces. This logic can be applied during instrument calibration whereby multi sources are used to develop calibration curves covering the expected range of energies expected. When this approach is fully realized and a site-specific average emission energy is established, that value can be directly compared to the calibration curve to yield an more accurate $\varepsilon_{i.}$ This approach would inevitably be more defensible than the selection of a calibration source isotope which may or may not represent the true emission energy. This is especially true when dealing with beta sources of residual radioactivity and the options for routine commercial calibration are either Tc-99 or Sr/Y-90.

REFERENCES

1. Environmental Protection Agency (EPA). 2000*. Multi Agency Radiation Survey and Site Investigation Manual (MARSSIM)*. EPA-402-R-97-016, Rev. 1. United States Environmental Protection Agency.

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