Instrument Efficiencies and ISO-7503 - 16525

Scott Hay, Michael S. Winters, and Michael S. Plonski
Cabrera Services Inc.

ABSTRACT

The *International Standard for the Evaluation of Surface Contamination* provides guidance on evaluating surface contamination, and is used to document clearance of buildings, materials, and equipment. A key component of the guidance is the determination of instrument efficiency based on the 2-pi emission rate of a traceable radiation source. Many projects implement portions of this guidance or apply the guidance incorrectly. These errors generally result in an overestimate of the instrument efficiency, resulting in an underestimate of the activity being measured and overly optimistic estimates of detectability.

A review of the recommendations for developing instrument efficiencies is provided, and the aspects of the guidance that are most often neglected are identified. The impact of failing to properly determine the instrument efficiency is demonstrated using experimental data. Data were collected using traceable alpha and beta radiation sources at multiple source-to-detector distances using gas-proportional and dual-phosphor detectors. The results of these measurements demonstrate the importance of proper implementation of the guidance for determining instrument efficiency and assist reviewers in identifying situations where the guidance was not properly implemented.

INTRODUCTION

The *International Standard for the Evaluation of Surface Contamination-Part 1: Beta-emitters (maximum beta energy greater than 0.15 MeV) and Alpha-emitters*, ISO-7503-1, was released in 1988. Over the past 28 years portions of this guidance have become standard practice when performing decommissioning surveys while other portions are often ignored. The requirements and recommendations for performing measurements of surface radioactivity are reviewed. Specific requirements and recommendations that may not be implemented fully or correctly for all decommissioning projects are identified. Measurements comparing ISO-7503-1 guidance with alternative common practices were performed. The results of these comparisons are provided to demonstrate potential impacts associated with implementing alternate approaches when performing measurements of surface radioactivity. Understanding the potential impacts associated with failure to implement the guidance in ISO-7503-1 assists survey planners in designing surveys that meet their survey objectives and allows reviewers to identify significant issues that may impact decisions concerning a project.

ISO-7503-1 REQUIREMENTS AND RECOMMENDATIONS

ISO-7503-1 guidance provides two main objectives for surface contamination measurements, along with requirements and recommendations for achieving these objectives.

1. Detection, determining the extent of surface contamination and controlling movement from areas of high contamination to areas of low contamination, and
2. Quantification, verifying permissible levels of surface contamination are not exceeded.

The procedures described in ISO-7503-1 for performing surface contamination measurements have become common practice for decommissioning projects. Moving a detector slowly over a surface while avoiding contact and listening to the audible response of the instrument, or scanning, to detect surface contamination is a familiar measurement technique. Other examples of commonly applied ISO-7503-1 guidance include measuring the background count rate at the place of measurement prior to making surface contamination measurements, and verifying instrument function and background count rates periodically during a project.

The ISO-7503-1 guidance associated with instrument efficiency and measurement geometry are not always implemented, and may be applied incorrectly. ISO-7503-1 states:

- Instrument efficiency values suitable for the radionuclides to be measured shall be available.
- Geometry conditions during a measurement should be as close as practicable to those used during instrument calibration.
- Instrument efficiency shall be determined under known geometrical conditions which shall be as close as practicable to the conditions for measurement.
- Reference sources shall have a known emission rate per unit area.
- Dimensions of the source should be sufficient to cover the window of the detector.
- Where sources are not available, sequential measurements with smaller sources of at least 100 square centimeters (cm^2) active area shall be carried out, and should cover the whole window area or at least representative fractions to provide an average reading.
- Because of the variation in instrument efficiency with energy extreme care shall be taken in the evaluation of mixed beta contamination.
- Where different radionuclides with different beta energies are present, it is practical to use the instrument efficiency for a single beta energy. The energy of the reference source should not be significantly greater than that of the lowest beta energy to be measured.

Observation and professional experience on multiple decommissioning projects over several years have identified three areas where ISO-7503-1 guidance has not been implemented or has been applied incorrectly. These areas represent a summary and should not be interpreted as a description of a single project or individual activity, or as a complete list of all potential deviations from ISO-7503-1 guidance.

1. Instrument efficiency determined under geometrical conditions different from those used for measuring surface contamination. Decommissioning surveys generally include scanning measurements with the detector suspended above the surface being measured combined with direct measurements with the detector in contact with the surface. Survey reports with a single instrument efficiency do not consider both sets of geometrical conditions.
2. Reference source active areas less than 100 cm^2 and less than the area of the detector window were used to determine instrument efficiencies. The majority of reference sources used to determine instrument efficiencies were observed to be 4.7 cm (2-inch) diameter (15.5 cm^2 active area) or 2.54 cm (1-inch) diameter (5 cm^2 active area) for detector windows of 100 cm^2 up to 821 cm^2.
3. Instrument efficiencies were determined without performing sequential measurements over the face of the detector to provide an average reading. Instrument efficiencies were often based on smaller reference sources using a single measurement, or multiple measurements at a single location on the detector.

EXPERIMENTAL METHOD

Instrument efficiencies were determined following the guidance provided in ISO-7503-1. Instrument efficiencies were also determined following observed common practices. The results were compared to determine the potential impact on data quality and decommissioning decisions made based on the surface contamination measurement results.

There are a large number of radiation detection instruments available for performing measurements of surface contamination. Three instruments were selected to provide a range of detector types and detector window areas for comparison. The detectors used during these experiments are listed in Table I.

TABLE I. Radiation Detection Instruments

Instrument Type	Detector Model	Meter Model	Detector Area
Scintillation	Ludlum 43-93	Ludlum 2224-1	100 cm^2
Gas Proportional	Ludlum 43-68	Ludlum 2360	126 cm^2
Gas Proportional	Ludlum 43-37	Ludlum 2360	583 cm^2

Reference sources were selected for both alpha and beta radiation, to provide a range of beta energies, and to provide a range of active areas. All of the reference sources used for these experiments are traceable to the National Institute of Standards and Technology (NIST). The reference sources used for these experiments are listed in Table II.

TABLE II. Reference Sources

Nuclide	Radiation (Energy)	Active Area	2-π Emission Rate	Activity
Thorium-230	Alpha (4.7 MeV)	150 cm^2	1080 s^{-1}	2210 Bq
Thorium-230	Alpha (4.7 MeV)	15.5 cm^2	350 s^{-1}	687 Bq
Technetium-99	Beta (294 keV)	150 cm^2	1830 s^{-1}	3790 Bq
Technetium-99	Beta (294 keV)	15.5 cm^2	187 s^{-1}	297 Bq
Chlorine-36	Beta (710 keV)	150 cm^2	2480 s^{-1}	3900 Bq
Strontium-90	Beta (2.28 MeV)	150 cm^2	4500 s^{-1}	3490 Bq
Strontium-90	Beta (2.28 MeV)	5 cm^2	43.8 s^{-1}	62.5 Bq

Strontium-90 is in secular equilibrium with Yttrium-90
Beta radiation energies are listed as end-point, or maximum, emission energies.
MeV = megaelectron volt
keV = kiloelectron volt
s^{-1} = inverse seconds
Bq = Becquerel, disintegrations per second

ISO-7503-1 compliant instrument efficiencies were determined for each detector using the one alpha (thorium-230 [Th-230]) and three beta technetium-99 [Tc-99], chlorine-36 [Cl-36], and strontium-90 [Sr-90]) 150 cm^2 reference sources. Reference standards were counted until at least 10,000 counts were recorded to minimize counting uncertainty. Assuming a Poisson distribution the counting uncertainty is equal to the square root of the counts, so the counting uncertainty for 10,000 counts would be 100 counts, or 1%. The 100 cm^2 detector and 126 cm^2 detector were centered on the reference standard for the entire count time. The 583 cm^2 detector is larger than any of the available sources, so sequential counts were performed. The reference source was placed at four locations equally spaced along the length of the 583 cm^2 detector. The source was counted for equal amounts of time at each location and the total number of counts used to provide an average reading across 100% of the face of the detector. Instrument efficiencies were determined for contact (detector in contact with the surface being measured) and with the detector suspended at heights of 1 cm and 2 cm above the surface being measured. The ISO-7503-1 compliant instrument efficiencies are provided in Table III.

TABLE III. ISO-7503-1 Compliant Instrument Efficiencies

Detector Area	Geometry	Th-230	Tc-99	Cl-36	Sr-90
100 cm^2	Contact	0.379	0.260	0.432	0.423
	+1 cm	0.094	0.217	0.377	0.358
	+2 cm	0.001	0.170	0.312	0.290
126 cm^2	Contact	0.344	0.385	0.298	0.278
	+1 cm	0.069	0.269	0.227	0.205
	+2 cm	0.001	0.196	0.173	0.154
583 cm^2	Contact	0.314	0.395	0.343	0.326
	+1 cm	0.234	0.360	0.330	0.306
	+2 cm	0.003	0.280	0.276	0.253

Instrument efficiencies were determined for the 100 cm^2 and 126 cm^2 detectors using sources with active areas less than 100 cm^2 at multiple locations. These sequential counts were performed at representative locations across the active window of the detector to provide an average value for the instrument efficiency. The 15.5 cm^2 reference sources for Th-230 and Tc-99 were counted at nine locations on a triangular grid that covered all except the corners of the detector window. The 5 cm^2 Sr-90 reference source was counted at 14 locations on a triangular grid and covered approximately 70% of the window for the 100 cm^2 detector and 55% of the window for the 126 cm^2 detector. The instrument efficiencies based on sequential measurements with reference sources less than 100 cm^2 at representative locations are provided in Table IV.

TABLE IV. Average Instrument Efficiencies Based on Sequential Counts

Detector Area	Geometry	Th-230	Tc-99	Sr-90
100 cm^2	Contact	0.373	0.205	0.420
	+1 cm	0.049	0.170	0.342
	+2 cm	---	---	---
126 cm^2	Contact	0.361	0.324	0.286
	+1 cm	0.128	0.227	---
	+2 cm	---	0.162	---

Contour plots of the measured instrument efficiency across the detector window were constructed for the 100 cm^2 and 126 cm^2 detectors. Figure 1 shows the instrument efficiency distribution for the 100 cm^2 detector for alpha radiation direct measurements on contact with the surface and for Sr-90 beta radiation direct measurements on contact with the surface being measured. A similar pattern was observed for instrument efficiencies for alpha radiation with the detector suspended 1 cm above the surface being measured. Similar patterns were observed for beta radiation with lower energy and with the detector suspended 1 cm above the surface. Figure 2 shows alpha instrument efficiencies for the 126 cm^2 detector on contact, and Sr-90 beta instrument efficiencies for the 126 cm^2 detector on contact. Similar patterns were observed for other nuclides and at 1 cm above the surface being measured. Note the efficiency values represented by the scales are different for each figure. Each color contour represents approximately 20% of the range of instrument efficiencies observed.

Instrument efficiencies based on a single count using a reference source smaller than the detector window were calculated for each of the three detectors. Summary statistics were calculated for the sequential measurements performed using the 100 cm^2 and 126 cm^2 detectors. A single count was performed using the 583 cm^2 detector. The 15.5 cm^2 reference sources for Th-230 and Tc-99 were placed at the center of the detector face. All counts were performed for measurements with the detector in contact with the surface being measured. The summary statistics and results for the single count instrument efficiencies are provided in Table V.

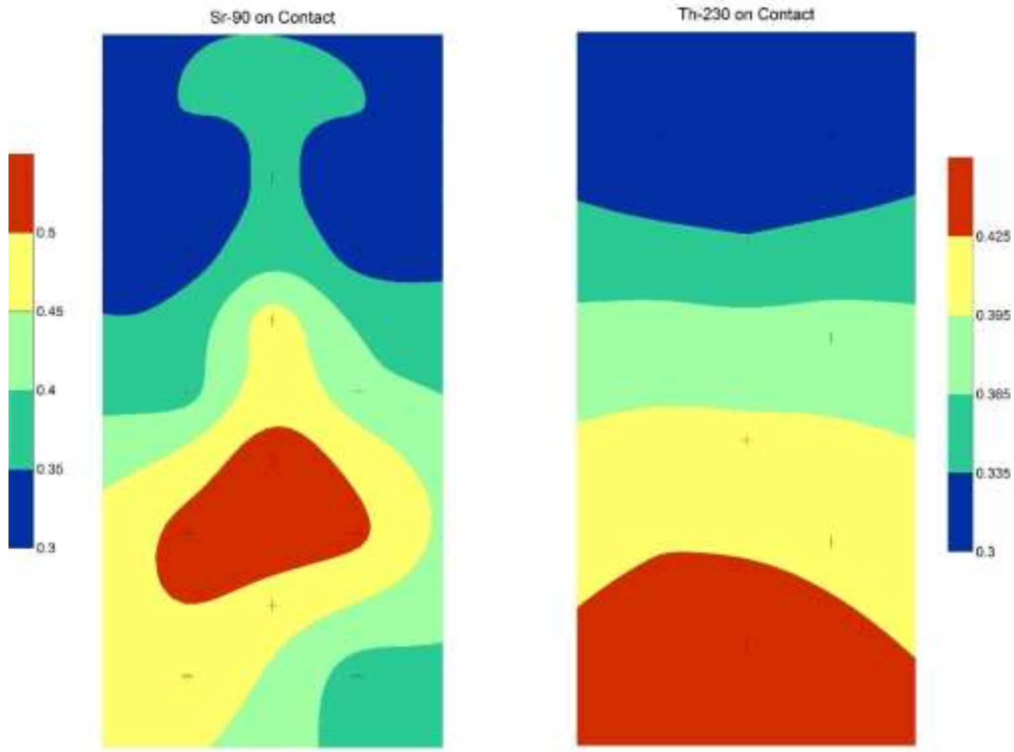

Fig. 1. 100 cm^2 Scintillation Detector Efficiency Contours

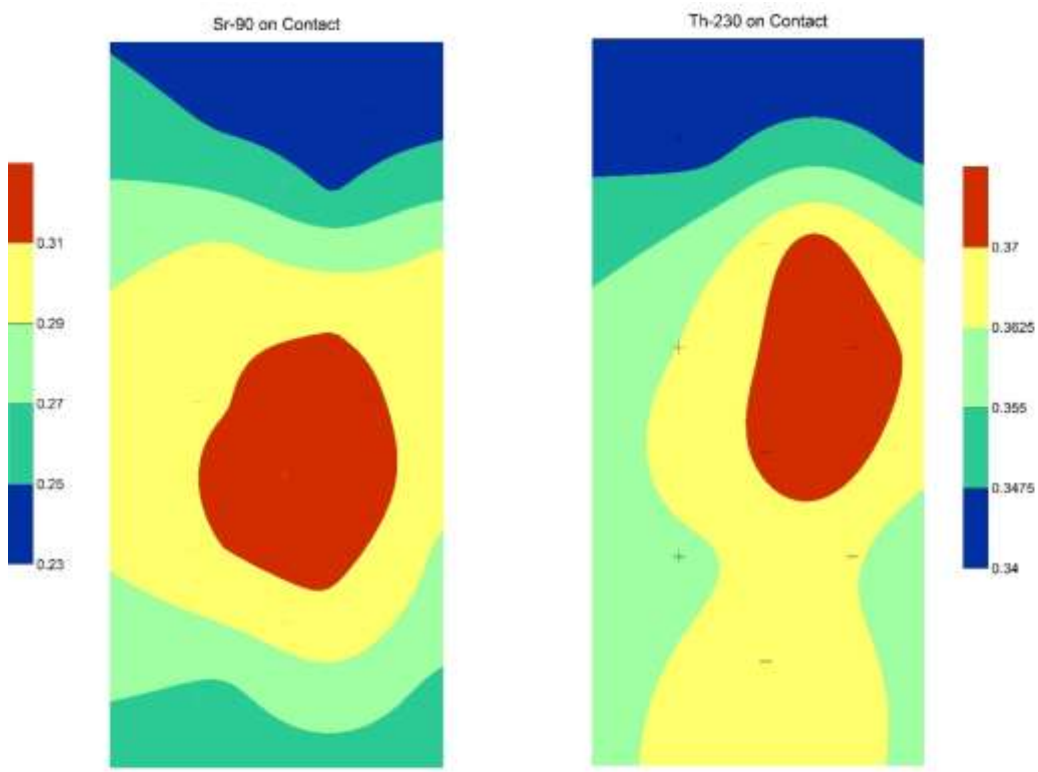

Fig. 2. 126 cm^2 Gas Proportional Detector Efficiency Contours

TABLE V. Instrument Efficiencies Based on Single Counts

Detector Area	Nuclide	Average	Standard Deviation	Minimum	Maximum
100 cm^2	Th-230	0.373	0.049	0.304	0.435
	Tc-99	0.205	0.050	0.143	0.270
	Sr-90	0.420	0.080	0.315	0.544
126 cm^2	Th-230	0.361	0.012	0.344	0.376
	Tc-99	0.324	0.016	0.303	0.340
	Sr-90	0.286	0.028	0.243	0.331
583 cm^2	Th-230	0.425*	---	---	---
	Tc-99	0.384*	---	---	---

* When only one measurement was performed the result is listed as the average.

DISCUSSION

The ISO-7503-1 compliant instrument efficiencies shown in Table III were calculated using either a single measurement or a short sequence of measurements. The large area of the reference sources allow shorter count times to collect sufficient data to minimize counting uncertainty while maintaining a low emission rate per unit area for the source. For detectors smaller than the active area of the source positioning the detector is less of an issue because the reference source provides a uniform emission rate over the entire detector window. The determination of instrument efficiencies as described in ISO-7503-1 is easy implemented and provides consistent and reproducible results.

Deviating from the guidance in ISO-7503-1 can have a significant impact on interpreting the results of surface contamination measurements. These impacts may lead to incorrect decisions regarding disposition of materials, equipment, or structures associated with the surfaces being measured. This is especially apparent for determining surface efficiencies where the geometry of the measurement is not consistent with the surface efficiency determination, or when there is a non-uniform response across the detector window.

Comparing instrument efficiency values from Table III and Table IV shows using a sequence of measurements representative of the entire detector window provides an average detector efficiency that is comparable to the ISO-7503-1 compliant measurement using a single count. The results for the 100 cm^2 scintillation detector and the 126 cm^2 gas proportional detector are consistent showing the two methods provide comparable results. These results demonstrate the requirement in ISO-7503-1 to use reference sources with active areas greater than 100 cm^2 may not be as important as the requirement to perform sequential measurements representing the entire detector window. However, the number of measurements required to provide a representative average instrument efficiency will be greater, especially for large area detectors like the 583 cm^2 gas proportional detector. The increased amount of data combined with documenting the results of the sequential measurements requires a significant increase in effort.

The instrument efficiencies based on sequential measurements also show there can be significant differences in instrument efficiency relative to where the activity is located. The scintillation detector provides a non-uniform response to radiation at different locations on the face of the detector. Table V shows the maximum value may be as much as two times the minimum value for the 100 cm^2 scintillation detector. The standard deviations for the 100 cm^2 results are also greater than the standard deviations from the gas proportional detector confirming the greater variability associated with the scintillation detector. Greater effort should be applied to ensuring sequential measurements are representative of the actual instrument efficiency for this type of detector.

The determination of instrument efficiency based on counts from a single location on the detector face can result in the most significant differences. If a single location is used to collect data and estimate the difference in the instrument efficiency can be as high as 0.12. This is more than 25% difference from the average instrument efficiency based on sequential measurements. In some cases the instrument efficiency is determined by selecting a position for the reference source that results in the highest instrument efficiency. This approach may underestimate the activity associated with a surface by as much as 25%.

The instrument efficiency results in Table III, Table IV and Table V all demonstrate the importance of geometry when developing instrument efficiencies. The distance between the detector window and the surface has a significant impact on the instrument efficiency, especially for alpha particles and lower energy beta particles. Even for higher energy beta particles the difference of 1 cm can change the instrument efficiency by 0.07, or approximately 15%. This supports the importance of developing separate instrument efficiencies for scanning at a specific height above a surface and performing direct measurements on contact with the surface.

A careful review of the instrument efficiencies for the gas proportional detectors points out one additional factor that may be significant when determining instrument efficiencies at different projects, at different elevations, or under different atmospheric conditions. Gas proportional detectors are sensitive to changes in temperature and pressure that can have a significant impact on instrument efficiency. Gas proportional detectors must be set up for the conditions that will be encountered at the location where measurements are performed. For projects that take more than a few weeks to complete, seasonal changes in temperature may impact instrument readings. Gas proportional detectors that are set up to operate at sea level will barely respond to a reference source in Denver. It may become necessary to determine instrument efficiencies for changing conditions. Performing periodic instrument function tests as described in ISO-7503-1 will identify when re-calibration of an instrument may be necessary.

CONCLUSIONS

The guidance in ISO-7503-1 provides a technically defensible and implementable process for performing measurements of surface contamination that are reproducible and consistent. Calculating instrument efficiencies correctly is one of the most important steps in performing surface contamination measurements, and is often not implemented or applied incorrectly. Failure to implement all of the guidance correctly may result in incorrect decisions regarding the levels of surface contamination.

There are three quick checks that can identify situations where ISO-7503-1 guidance has not been implemented or has been applied incorrectly.

1. Check for instrument efficiencies specific to scanning measurements and direct measurements, or a statement that the measurements were performed at a specified distance between the detector and the surface. A single instrument efficiency applied to all types of measurements may require additional consideration.
2. Review the reference source calibration certificates. Make sure the source calibration is recent and provides an active area larger than the detector window.
3. If the reference source is smaller than the detector window confirm a sequence of measurements were performed to provide a representative average surface efficiency.

REFERENCES

International Organization for Standardization, *Evaluation of Surface Contamination – Part 1: Beta-emitters (maximum beta energy greater than 0.15 MeV) and alpha emitters*, ISO 7503-1 (1988).