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Standard Guide for Selection and Use of Portable Radiological Survey Instruments for Performing In Situ Radiological Assessments to Support Unrestricted Release from Further Regulatory Controls¹

This standard is issued under the fixed designation E 1893; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This standard provides recommendations on the selection and use of portable instrumentation that is responsive to levels of radiation that are close to natural background. These instruments are employed to detect the presence of residual radioactivity that is at, or below, the criteria for release from further regulatory control of a component to be salvaged or reused, or a surface remaining at the conclusion of decontamination and/or decommissioning.

1.2 The choice of these instruments, their operating characteristics and the protocols by which they are calibrated and used will provide adequate assurance that the measurements of the residual radioactivity meet the requirements established for release from further regulatory control.

1.3 This standard is applicable to the in situ measurement of radioactive emissions that include:

1.3.1 alpha

1.3.2 beta (electrons)

1.3.3 gamma

1.3.4 characteristic x-rays

1.3.5 The measurement of neutron emissions is not included as part of this standard.

1.4 This standard does not address instrumentation used to assess residual radioactivity levels contained in air samples, surface contamination smears, bulk material removals, or half/whole body personnel monitors.

1.5 This standard does not address records retention requirements for calibration, maintenance, etc. as these topics are considered in several of the referenced documents.

2. Referenced Documents

2.1 ASTM Standards:²

C 998 Practice for Sampling Surface Soil for Radionuclides
C 999 Practice for Soil Sample Preparation for the Determination of Radionuclides

C 1000 Test Method for Radiochemical Determination of Uranium Isotopes in Soil by Alpha Spectrometry

C 1133 Test Method for Nondestructive Assay of Special Nuclear Material in Low-Density Scrap and Waste by Segmented Passive Gamma-Ray Scanning

E 170 Terminology Relating to Radiation Measurements and Dosimetry

E 181 Test Methods for Detector Calibration and Analysis of Radionuclides

C 1215 Guide for Preparing and Interpreting Precision and Bias Statements in Test Method Standards Used in the Nuclear Industry

2.2 ANSI Standards:

ANSI N323B Radiation Protection Instrumentation Test and Calibration, Portable Survey Instrumentation for Near Background Operation³

ANSI N42.17A Performance Specifications for Health Physics Instrumentation-Portable Instrumentation for Use in Normal Environmental Conditions³

ANSI N42.17C Performance Specifications for Health Physics Instrumentation-Portable Instrumentation for Use in Extreme Environmental Conditions³

2.3 National Council on Radiation Protection and Measurements:

NCRP Report No. 57 Instrumentation and Monitoring

¹ This guide is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.03 on Radiological Protection for Decontamination and Decommissioning of Nuclear Facilities and Components.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036

Methods for Radiation Protection, National Council on Radiation Protection and Measurements, May 1978⁴

NCRP Report No. 58 A Handbook of Radioactivity Measurement Procedures, National Council on Radiation Protection and Measurements, 2nd Ed. February 1985⁴

NCRP Report No. 112 Calibration of Survey Instruments Used in Radiation Protection for the Assessment of Ionizing Radiation Fields and Radioactive Surface Contamination, National Council on Radiation Protection and Measurements, December 1991⁴

2.4 *International Organization for Standardization (ISO): ISO-4037-4* : 2004 X and Gamma Reference Radiations for Calibrating Dosimeters and Dose-rate Meters and for Determining their Response as a Function of Photon Energy, International Organization for Standardization, 1979⁵

ISO-6980-2 : 2005 Nuclear energy – Reference beta particle radiation - Part 2: Calibration fundamentals related to basic quantities characterizing the radiation field⁵

ISO-8769 Reference Sources for the Calibration of Surface Contamination Monitors – Beta Emitters (Maximum Beta Energy Greater than 0.15 MeV) and Alpha Emitters, International Organization for Standardization, 1988⁵

ISO 8769-2 : 1996 Reference sources for the calibration of surface contamination monitors-Part 2: Electrons of energy less than 0.15 MeV and photons of energy less than 1.5 MeV

ISO-7503-1 Evaluation of Surface Contamination - Part 1: Beta Emitters (Maximum Beta Energy Greater than 0.15 MeV) and Alpha Emitters, International Organization for Standardization, 1988⁵

ISO-7503-2 Evaluation of Surface Contamination - Part 2: Tritium Surface Contamination, International Organization for Standardization, 1988⁵

ISO-7503-3 : 2003 Evaluation of Surface Contamination - Part 3: Isomeric Transition and Electron Capture Emitters, Low Energy Beta Emitters ($E_{\beta\text{max}} < 0.15$ MeV), International Organization for Standardization, 1993 (draft)

2.5 *Department of Energy (DOE):*

DOE G441.1-1B Radiation Protection Programs Guide for Use with Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection, Chapter 9, Portable Monitoring Instrument Calibration, 3/1/2007

3. Terminology

3.1 *accuracy, n*—the degree of agreement of an individual measurement or average of measurements with an accepted reference value or level (ASTM E 170).

3.2 *calibration, v*—adjusting or determining the response or reading of an instrument relative to a series of conventionally true values for radiation sources (ANSI N323B).

3.3 *calibration source, n*—as used in this standard guide, see certified reference material.

3.4 *certified reference material, n*—a material that has been characterized by a recognized standard or testing laboratory for

some of its chemical or physical or radiological properties, and that is generally used for calibration of a measurement system or for development or evaluation of a measurement method (ASTM E 170).

3.5 *check source, n*—a radioactive source, not necessarily calibrated, which is used to confirm the continuing satisfactory operation of an instrument (ANSI N323B).

3.6 *control charts, n*—A plot of the results of a quality control action to record and demonstrate that control is being maintained within expected statistical variation or to indicate when control is or will be lost without intervention (DOE G441.1-B).

DISCUSSION—This provides a method for tracking an instrument's operation to demonstrate that data collected is within expected statistical variation and to ensure that potential failures and/or negative trends are identified early.

3.7 *functional check, n*—checks (often qualitative) to determine that an instrument is operational and capable of performing its intended function (ANSI N323B).

DISCUSSION—such checks may include, for example, battery check, high voltage check/adjustment, zero setting, audio settings, alarm settings, scale checks and check source and background response.

3.8 *hot spot, n*—localized areas of elevated activity that are less than 100 cm² in extent and exceed the applicable average guideline value by greater than a factor of three.

3.9 *lower limit of detection, n*—the smallest amount of a measured quantity that will produce a net signal above the system noise for a given measurement system or process that will result in an acceptable false positive rate if nothing is present and that will be correctly interpreted as “real” with a desired probability.

DISCUSSION—the usual acceptable error rates for in situ measurements are a false positive rate of 5% (Type I error) and a false negative rate of 5% (Type II error).

3.10 *minimum detectable activity (MDA), n*—see lower limit of detection (for purposes of this standard, MDA will be applied to the measurement of a point source or “hot spot” detection).

3.11 *minimum surface sensitivity (MSS), n*—see lower limit of detection (for purposes of this standard, MSS will be applied to measurements of distributed activity, which will incorporate the detector area to enable direct comparison to regulatory guidelines for surface activity).

3.12 *national standard, n*—an artifact, such as a well-characterized instrument or radiation source, that embodies the international definition of primary physical measurement standard for national use (ASTM E 170); see also certified reference material.

3.13 *precision, n*—the degree of mutual agreement among individual measurements (ASTM E 170).

DISCUSSION—Relative to a test method, precision is the degree of mutual agreement among individual measurements made under prescribed like conditions. The imprecision of a measurement may be characterized as the standard deviation of errors of measurement.

⁴ National Council on Radiation Protection and Measurement, 7910 Wodmont Ave., Bethesda, MD 20814

⁵ Available from ANSI Sales Department, 1430 Broadway, New York, NY 10018

3.14 *ratemeter, n*—an analog or digital electronic characteristic of a meter which provides the number of pulses per unit time.

3.15 *scaler, n*—a digital electronic characteristic of a meter which counts the distinct number of input pulses within a preset period of time.

3.16 *scan, n*—the process whereby the surveyor moves the probe over the area being surveyed in an attempt to locate areas with residual radioactivity.

DISCUSSION—the techniques of the scanning process will have significant affect on the MSS. Important parameters include scan speed, detector orientation, source-detector distance, scanned surface condition and the background response of the instrument.

3.17 *traceability, n*—the ability to demonstrate that a particular measurement instrument or artifact standard has been calibrated at acceptable time intervals against a national or international standard, or against a secondary standard which has been, in turn, calibrated against a national standard or transfer standard (ASTM E 170).

3.18 *transfer standard, n*—a physical measurement standard that is calibrated by direct or indirect comparison to a national standard and is typically a measurement instrument or radiation source (ASTM E 170).

3.19 *unrestricted release, n*—the release of a material or a surface area for use without further radiological controls.

DISCUSSION—This occurs after the material or area has been surveyed and the results of the survey show that residual radioactivity is below the applicable release criteria. All instrumentation and techniques used for this application must be capable of detecting radioactivity at levels below the release criteria.

4. Significance and Use

4.1 The purpose of this standard is to provide the user information and guidance for selecting and using instrumentation that will provide measurement results that can be compared to criteria for unrestricted use.

4.2 Use of this standard will provide greater assurance that the measurements obtained will be technically and administratively sufficient for making decisions regarding completion of decontamination and/or demolition/removal activities.

4.3 Use of this standard will provide greater assurance that the measurements obtained will be technically and administratively sufficient to meet all applicable regulatory requirements for unrestricted release of a component for recycle or reuse, or for unrestricted release of a remaining surface or area.

5. Instrument Selection

5.1 General:

5.1.1 Criteria for release of materials for recycling, re-use, or disposal, and of surfaces or areas remaining at the completion of decontamination or decommissioning activities, or both, are set by regulatory authorities. For surface contamination and selected volumetrically contaminated media, values provided by the Nuclear Regulatory Commission (NRC) have been generally applied to licensed facilities, both NRC and Agree-

ment State licenses (1).⁶ ANSI has published a standard for clearance of surfaces and materials that is based on pathway modeling and end-point exposures (2). The Department of Energy (DOE) applies standards that are essentially equivalent to those provided by the NRC (3). The Environmental Protection Agency (EPA) and NRC have developed criteria that are risk-based, resulting in radionuclide and pathway specific release values that will be applied to decommissioning activities.

5.1.2 *In situ* radioactive measurements related to unrestricted release to be treated in this standard include:

5.1.2.1 surface contamination measurements

5.1.2.2 measurements of radionuclide concentrations in media (gamma measurement only)

5.1.2.3 dose-rate measurements

5.2 General Selection Criteria:

5.2.1 The instrument to be utilized must provide an output signal that can be correlated to the appropriate release criteria applicable to the residual source characteristics; e.g., surface emission rate, specific or total activity, dose rate. NCRP Reports Nos. 57 and 58 describe instruments and protocols addressing these issues.

5.2.2 The characteristics and performance of the measuring instruments should be evaluated against the specifications described in ANSI N42.17A and ANSI N42.17C. This should include documentation that the instrument satisfies the calibration requirements described in ANSI N323B. NCRP 112 provides additional supplemental guidance on survey instrument calibration.

5.2.3 Documentation should be available that verifies that the applicable specification requirements described in ANSI N323B for the particular measurement conditions have been met for the instrument selected; e.g., minimum sensitivity, energy response, environmental response, etc.

5.3 Minimum Sensitivity (minimum detectable activity). The minimum sensitivity of the instrument selected should be ≤ 50 percent of the applicable release criteria to which the measurement results will be compared. (Appendix A provides further information for determining this.)

5.4 Energy Response. An instrument, selected for a particular residual radionuclide particle emission, should be calibrated for response to the energy of that emission. General guidance for determining this is found in ANSI N323B.

5.4.1 Photon Energy Response. In addition to the general provisions in ANSI N323B, descriptions of reference sources for making the photon energy response determination are found in ISO-4037-4.

5.4.2 Beta Energy Response. In addition to the general provisions in ANSI N323B, descriptions of reference sources for making the beta energy response determination are found in ISO-6980-2, ISO-8769 and ISO 8769-2.

5.5 Surface Contamination Detection. Residual surface contamination should be evaluated using either alpha or beta detectors. For performing “hot spot” location surveys, the detector shall be coupled to a ratemeter for performing

⁶ The boldface numbers in parentheses refer to a list of references at the end of this standard.

transient (scanning) surveys. For performing a residual activity (stationary) assessment, the probe may be coupled to either a ratemeter or a scaler (see Section 6.3.4).

5.5.1 When performing scan surveys, the alpha or beta probe window areas should be $\geq 100 \text{ cm}^2$.

NOTE 1—Smaller detector probes may be used to perform scan surveys where accessibility prevents utilization of larger probe sizes in accordance with scan requirements described in Section 6.4.1.

5.5.2 When performing stationary assessments, the probe window area should be $100 \text{ cm}^2 \pm 30\%$. Refer to Appendix X2 discussion on the effect of probe size on minimum detection.

NOTE 2—The probe area that is to be used in any measurement interpretation is the total window area, based on the window opening dimension, *not* the effective open window area, that includes protective screen effects.

5.5.2.1 Additional guidance for instrument selection to perform surface contamination measurements is provided for the following residual activities:

5.5.2.2 alpha and beta ($E > 0.15 \text{ MeV}$) emitters - ISO 7503-1

5.5.2.3 tritium - ISO 7503-2

5.5.2.4 beta ($E < 0.15 \text{ MeV}$), isometric transition, and electron capture emitters - ISO 7503-3.

5.6 *Specific Activity Measurements*—The *in situ* measurement of the residual activity distributed within a volumetric medium of interest shall be based on the photon emission rate from that medium. The results of the evaluations of this photon emission rate are normally expressed in units of picocuries per gram (pCi/gm) or becquerels per gram (Bq/gm). This evaluation will be dependent on the background response of the detector and on a conversion factor established for the medium of interest. Nonuniform distributed source geometries can result in large interpretation errors of *in situ* measurements; therefore, caution should be used with these evaluations.

5.6.1 *Background response*—The photon detector should have a response to background at the photon energy range of interest that will result in a minimum detectable activity that is $\leq 50\%$ of the applicable release criteria. Guidance on calibration and use of crystalline (germanium and sodium-iodide) detectors is provided in ASTM E 181.

5.6.2 *Background reduction*—The background response of the detector may be reduced by shielding or collimation. The shielding configuration should be selected to maximize response to the source configuration of interest, and may range from pin-hole collimation to selective shadow shielding.

5.6.3 *Conversion factor*—A conversion factor that will relate the *in situ* instrument response to the distributed source must be established. This may be done directly by sampling and analysis or by analytical modeling. The protocols for performing this determination are beyond the scope of this standard. Additional guidance for sampling and assessing residual activity in soil and low density scrap media are found in ASTM Standards C 998, C 999, C 1000, and C 1133.

6. Instrument Use

6.1 General Requirements:

6.1.1 Prior to using a particular instrument to assess the residual radioactivity, ensure that the instrument is appropriate

for the emissions and environmental conditions present by reviewing the criteria discussed in Section 5 and identified references.

6.1.2 Prior to using a particular instrument, ensure that documentation is available that indicates that the instrument has been calibrated in accordance with the requirements specified in ANSI N323B, and that the interval for recalibration has not been exceeded.

6.1.3 Prior to assessing the *in situ* measurements of the residual radioactivity, determine the natural radiological conditions for the site using one or more background reference areas. These areas shall be measured for:

6.1.3.1 radiological composition of media, such as air, water, soil, or structural material

6.1.3.2 amount of each primary radionuclide present

6.1.3.3 total terrestrial plus cosmic radiation dose rate

6.1.3.4 These areas are defined as having similar physical, chemical, biological, and geological characteristics as the areas to be assessed.

6.1.4 Determine the response of the instrument to the natural background and any background variations. The background response of the instrument shall be determined at a location representative of the area to be measured, but not affected by site operations. The NRC has drafted guidance for determining the background at a particular site (4).

6.2 Calibration:

6.2.1 General Criteria:

6.2.2 A calibration source will normally be used to establish the conversion factor used to convert the instrument response to an estimate of *in situ* residual radioactivity. The calibration shall be performed such that an *in situ* measurement can be accurately converted to the 4π (total) emission rate of the residual surface activity. Factors important to this conversion are discussed in Appendix X5. The calibration sources used for this determination shall, as a minimum, have the following characteristics:

6.2.2.1 have the same type of emissions (alpha, beta, or photon) as the residual radioactivity

6.2.2.2 have particle or photon energy that is within $\pm 10\%$ of the energy emitted from residual radioactivity. Alternately, calibration may be established from a curve generated from at least three sources with energies that bracket the energy of interest.

6.2.2.3 have a particle or photon emission rate that is no more than 50 times the applicable standard for unrestricted release

6.2.3 The calibration source should also have the following characteristics:

6.2.3.1 physical and/or chemical composition that produces similar backscatter characteristics as the residual *in situ* radioactive matrix, for example:

In situ medium	Source mount
iron/steel	steel
concrete	aluminum
wood/plaster	plastic
soil	aluminum

6.2.3.2 distribution (geometry) either within or on the surface that is similar to the residual radioactive matrix

6.2.4 *Special Criteria for Beta and Alpha Detectors:*

6.2.4.1 In addition to the criteria described in Section 6.2.1, the conversion factors for beta and alpha detectors should also consider the following:

6.2.4.2 the distance between the calibration source and the detector must be the same as the distance that will be used to quantify the in situ field activity.

6.2.4.3 for quantifying a point source, a “point source efficiency” should be used with the conversion factor.

6.2.4.4 for quantifying a distributed area source, a “surface source efficiency” should be used. The surface source used to determine the conversion factor should match the size and shape of the detector probe window area (see Section 5.5.2), but should not be smaller than 100 cm² regardless of probe window area.

6.3 *Source Checks:*

6.3.1 Each instrument used to perform residual radioactive measurements shall be tested (at least daily, or before each use if it is used less often than daily) using a suitable check source to verify operability within the allowable parameters.

6.3.2 Prior to using a particular instrument to assess the residual radioactivity, the mean reference response and reproducibility of the instrument, as defined in ASTM C 1215, shall be established following a specific protocol.

6.3.3 The daily verification, using the same protocol and check source, is compared to the mean response. If the daily check deviates from the mean by more than $\pm 20\%$, the instrument shall be removed from service for repair and/or recalibration (ANSI N323B).

NOTE 3—Control charts should be used to track the daily response against the mean to observe trends and take action before the instrument reaches a predetermined “failure” point.

6.3.4 The check source used to perform the protocol shall not decay by more than 25 % of the applicable response limits used with the control chart throughout the duration of the measurement task.

6.4 *Surface Contamination Measurements:*

6.4.1 Residual radioactivity on surfaces may be located by transient measurements (scanning) and quantified by stationary (fixed) measurements.

6.4.2 Scanning-Surface Activity. Surfaces are scanned to identify the presence of elevated radiation which might indicate residual radioactivity or hot spots in excess of the levels that would permit unrestricted release. Measurement protocols are described for performing scanning surveys in the federal interagency document, MARSSIM (5). The following requirements, as a minimum, should be followed when performing scan surveys for surface radioactivity:

6.4.2.1 Alpha and/or beta emissions should be measured, as applicable.

6.4.2.2 Large area detectors should be used for measuring flat surfaces; e.g., probe area ≥ 100 cm².

6.4.2.3 The detector response should be used with a rate-meter with a short electronic response time (time required to reach 90 % of steady state), preferably 2-4 s.

6.4.2.4 The distance between the detector and the surface should be maintained between 0.5 cm and 1.0 cm.

6.4.2.5 The scanning velocity should not exceed 1 detector width per second. This velocity should be reduced to as low as 1/5 detector width per second when the minimum response of the detector is near the unrestricted release guideline level. The effects of detector geometry, source geometry, and scanning velocity on detector response are shown in Appendix X2.

6.4.3 Scanning-Volumetric Activity: For residual radioactivity distributed within a matrix such that self-shielding effects significantly degrade or eliminate the alpha and beta emissions, residual activity must be identified using measurements of gamma emissions. The following requirements, as a minimum, should be followed when performing gamma scan surveys:

6.4.3.1 Crystalline or solid-state (e.g., sodium-iodide, germanium) detectors should be used with a ratemeter having a short electronic response time, preferably 2 - 4 s.

6.4.3.2 The distance between the detector and the survey area should not exceed 15 cm. Greater heights will reduce the sensitivity for detecting hot spots.

6.4.3.3 The scanning should be performed with the probe moved in a serpentine pattern approximately 1 m wide while advancing at a speed of approximately 0.5 meter per second.

6.4.4 Audio Response. Audio output from the ratemeter is recommended to augment observations of meter fluctuations in the ratemeter reading. The audio signal is independent of the electronic time constant of the meter and is a more sensitive indicator of elevated activity, particularly for time constants > 4 s.

NOTE 4—Experiments using hidden sources (Co-57) with signal-to-background ratios from 0.6-6 resulted in approximately 75 % being located based on ratemeter observation alone, compared to approximately 90 % for audio response (6).

6.4.5 Direct (fixed) Measurements. The estimate of the level of residual radioactivity is based on a measurement with the source-detector geometry fixed (stationary). When making these fixed measurements, the following requirements, as a minimum, should be complied with:

6.4.5.1 The detector should be coupled to a scaler for this measurement.

6.4.5.2 If a ratemeter is used with this measurement, a long response time should be used (> 20 sec). The detector shall be kept in position for at least three times the time constant of the ratemeter.

6.4.5.3 The effects of the concavity of the surfaces being measured on instrument efficiency shall be evaluated when the surface is not flat (examples are given in Appendix X5 for beta emissions).

6.4.5.4 For conditions where a visible layer of dirt, oxidation, or other coating cannot be removed, the effect on source-detector response shall be included for alpha and beta measurements (examples are given in Appendix X5 for beta emissions).

6.5 *Data Interpretation:*

6.5.1 *Alpha and Beta Emissions:*

6.5.2 The evaluation of surface activity for alpha or beta emissions (in dpm/100 cm²) is given by the expression (ISO-7503-1)

$$A_s = \frac{(n - n_B)}{\varepsilon_i \times \varepsilon_s \times \frac{W}{100}}$$

where:

- n = total count rate in cpm
- n_B = background count rate in cpm
- ε_i = instrument efficiency for alpha or beta radiation in cpm per dpm
- W = total physical window area of the detector in cm^2
- ε_s = source correction factor to account for differences between the calibration source and the residual activity, such as backscatter, self absorption, source protective coatings and/or surface coatings, geometry, etc. (unitless)

NOTE 5—The factor ε_i may be defined for either a point source or a surface source. The point source efficiency should be used to quantify hot spots. The surface source efficiency should be used to evaluate surfaces without hot spots.

NOTE 6—Further explanation of the factor ε_i and its relative magnitude are given in Appendix X5.

6.5.3 Gamma Emissions:

6.5.3.1 Gamma detection and subsequent interpretation is normally employed to evaluate the levels of residual activity that are distributed within a source matrix expressed as pCi/gm, Bq/kg, etc. For a uniformly distributed source, the volumetric source term is provided by the expression

$$S_v = \frac{n - n_B}{\varepsilon_\gamma}$$

where:

- S_v = volumetric source term in pCi/gm
- n = total count rate in cpm
- n_B = background count rate in cpm
- ε_γ = instrument efficiency for an uniformly distributed gamma source in cpm per pCi/gm.

NOTE 7—The gamma efficiency will normally be composed of two factors; a dose conversion in units of cpm/(mR/hr) measured with a known calibration source, and a source conversion factor in units of (mR/hr)/(pCi/gm) based on shielding theory. In general, the dose conversion factor for a particular detector is provided for a single photon energy, whereas, the source conversion factor includes scattered photons (buildup) which leads to an estimate of the gamma source strength that is conservative. The response of various NaI detector geometries as a function of photon energy is shown in Appendix X9.

APPENDIXES

(Nonmandatory Information)

X1. MINIMUM DETECTABLE ACTIVITY (MDA)

X1.1 When measuring residual radioactivity that must be within limits or guidelines that are very near to the levels that are present from natural background, the minimum amount of radioactivity that may be detected by a particular measurement system must be determined. With radiation measurement, the physical amount of the residual radiation source (pCi, dpm, Bq, etc.) is not directly measurable, but is observed as a measurement instrument response (digital counts, voltmeter deflection, etc.). Because radioactive decay follows statistical relationships, the statistics of detection and determination apply directly to the observed (or observable) signal (meter reading) and its associated random fluctuations. When measuring for the presence of low residual activity, one must distinguish between two fundamental aspects of the detection problem (6).

X1.2 Given a net signal that is greater in value than a similar signal that has been established as defining background, has a “real” activity above background been detected? (The “false positive” or Type I error)

X1.3 Given a completely specified measurement process, what is the minimum “real” activity that will produce an observed signal that will be detected? (The “false negative” or Type II error)

X1.4 The first aspect relates to making an *a posteriori* (after the fact) decision based upon the net signal(s) and a defined criterion for detection. This leads to the establishment of a

“critical level” (L_c) for which a signal exceeding this level will be interpreted as a residual activity with a probability α , when in fact it is only background, (error of the first kind). Conversely, the second aspect relates to making an *a priori* (before the fact) estimate of the detection capabilities of the measurement process that yields a signal exceeding the critical level that is in fact from a “real” residual source of activity. This “detection limit” (L_D) is the smallest value such that real residual radioactive material greater than L_D will be interpreted erroneously as background with a probability less than β . Mathematically these concepts are given as (7):

$$L_c = K_\alpha \sigma_0 + B_0 \quad (\text{X1.1})$$

$$L_D = L_c + K_\beta \sigma_0 \quad (\text{X1.2})$$

where:

- σ = standard deviation
- K = statistical constant based error probability for normally distributed events

The relationships between L_c and L_D are shown on Fig. X1.1.

X1.5 The quantity L_c is used to test an experimental result, whereas L_D refers to the capability of the measurement process itself (6). The concept of “detection limit” (L_D) has also been identified as “limit of detection” (8) and “minimum detectable activity” (MDA) (4). The term minimum detectable activity is

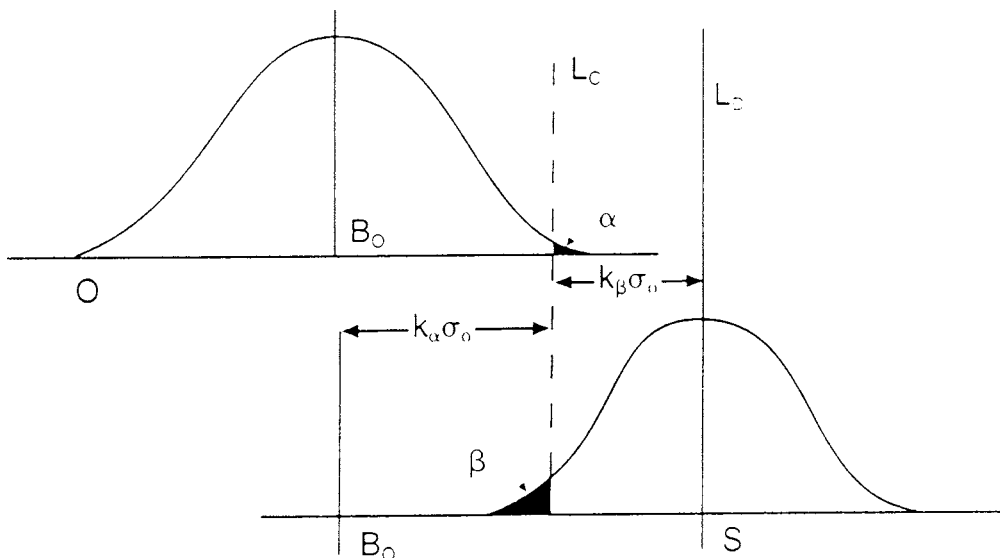


FIG. X1.1 Hypothesis Testing—Errors of the First and Second Kind

most commonly encountered in radiation measurement reports, and will be utilized here. The basic relationship for estimating the MDA at the 95% confidence level is (9):

$$MDA = C_o (3.0 + 4.65 \sigma_o) \quad (X1.3)$$

where:

C_o = proportionally constant relating the detector response to an activity

σ_o = standard deviation of the background

For purposes of this discussion, MDA will be defined in units of activity expressed as dpm or pCi. This mathematical relationship for MDA will be applied to point source or “hot spot” residual. The concept of detection limit for distributed activity will be expressed using the “minimum surface sensitivity” (MSS) of the detector, which will incorporate the detector area as a function that will allow values of minimum surface sensitivity to be compared directly to surface activity regulatory guidelines.

X1.6 For time integrated measurements using a scaler readout:

$$MSS = \frac{3.0 + 4.65 \sqrt{B_o * t}}{t \cdot \epsilon_o \cdot (A_d/100)} \quad (X1.4)$$

For measurements involving a ratemeter signal, the relationship is:

$$MSS = \frac{4.65 \sqrt{B_o/2\tau}}{\epsilon_o \cdot (A_d/100)} \quad (X1.5)$$

where:

B_o = background count rate (cpm)

A_d = window area of detector probe (cm²)

ϵ_o = detector efficiency in counts/disintegration (includes all source surface and self attenuation effects - see Appendix X5)

t = scaler count time (min)

τ = ratemeter time constant (min) = 0.438 θ

θ = time for meter to reach 90 % of steady state (X3.5)

X1.7 Typical minimum sensitivities for scalers and ratemeters using common detector types are shown in Table X1.1.

TABLE X1.1 Typical Minimum Surface Sensitivities – Stationary Surveys

Detector	Area (cm ²)	Background (cpm)	Efficiency (counts/dis)	Minimum Surface Sensitivity (dpm/100cm ²)	
				Scaler ^A	Ratemeter ^B (θ = 20 sec) ^C
Pancake GM	15.5	50	.30	760	1310
Large Area	128	300	.30	220	390
Floor Monitor	584	1000	.30	85	160
Alpha Scintillator	50	2	.15	120	160

^A Derived from Eq X1.4, [Appendix X1](#), for a 1 min count.

^B Derived from Eq X1.5, [Appendix X1](#)

^C This is typical of analog ratemeters on “slow” response setting”

X2. DETECTION OF LOW-LEVEL RESIDUAL ACTIVITY

X2.1 The ability to evaluate the existence and amount of low-level residual activity in the presence of natural radioactive background is dependent on both the electromechanical characteristics of the detector system and upon the protocols by which the detector system is employed. For assessing the residual radioactive condition of a surface to support an unrestricted release determination, the accepted protocol is to employ a detector, coupled to a scaler, to obtain measurements on a fixed set of grid locations. For this type of measurement, one must know the minimum sensitivity of the detector system for comparison to guidelines that must be met. However, this

technique is only representative for uniformly distributed activity. It will not be effective for “hot” spot activity, particularly beta or alpha. For example, five measurements using a 100 cm² probe to characterize a 1 m × 1 m area will cover 5 percent of the surface being assessed. Even when applied at predetermined systematic or biased locations, it will only detect hot spots in a hit or miss fashion. Scanning, using the detector coupled to a ratemeter is the most effective method for locating “hot” spot activity. This technique however, is limited by the transient response characteristics of the detector and the ratemeter.

X3. SCANNING EFFECTS - CONTAMINATION MONITORS

X3.1 The most common survey protocol utilized for surface release measurement is scanning for the presence of residual radioactivity. This is accomplished by moving the radiation detector over the surface of interest. For radioactive source levels very close to natural background levels, gamma monitors are not adequate for locating and assessing the presence of residual surface activity. Additionally, there are radionuclides of significance which decay by beta or alpha, with little or no gamma emissions. For this reason, surface measurements for residual activity are performed using either beta or alpha survey meters. While these types of detectors are sufficiently sensitive to differentiate activity levels close to background, they are also more sensitive to the measurement protocols employed. The most significant variable effecting source detection and interpretation during scanning is source-detector geometry. Geometry will be a function of detector probe velocity, source and detector dimensions, and source-detector distance.

X3.2 For measurements, where the detector probe is in transit with respect to a low activity source of small size, the minimum sensitivity is dependent on several additional parameters such as detector probe velocity, source sizes, meter time constant and detector/surface distance. Detection of activity above background depends on the skill and senses of the surveyor to recognize an increase in either of two signal output

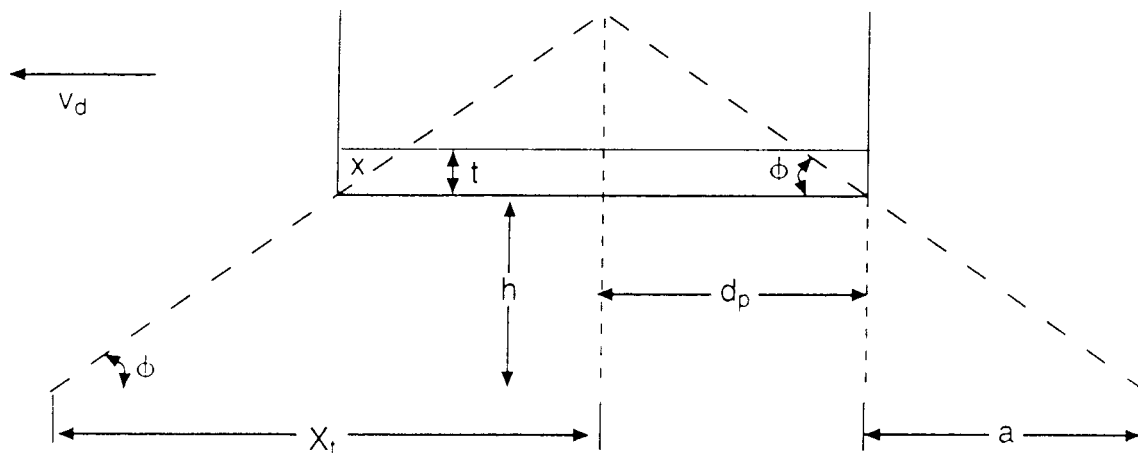
modes: (1) deflection of the needle (analog) or sudden increase in counts (digital) on the ratemeter, or (2) the audio output of the instrument.

X3.3 The response of a detector probe to beta or alpha surface contamination is produced by particle interaction within the probe volume to produce a response signal. This is dependent on the particle “seeing” the opening (window) into the interactive volume. [Fig. X3.1](#) illustrates the geometries involved.

X3.4 Consider this situation for a point source, as the detector probe passes over the surface. As the point source location moves off-center with respect to the probe window, the particle must travel further and penetrate a greater thickness of intervening material (e.g., detector window) until the response diminishes beyond the edge of the window or is shielded by the detector wall.

X3.5 The response of a ratemeter to an input signal from a detector probe moving in relationship to the source is dependent, not only on the time the detector “sees” the source, but also on the response time of the meter electro-mechanical components to a transient input signal. For analog instruments, this is directly related to the RC time constant (τ) of the meter by the relationship where time response (θ) is defined as the time for the meter to reach 90% of steady state response.

$$R(\theta) / R(0) = 1 - e^{-\theta/\tau} \tag{X3.1}$$



- h Distance from surface to probe
- t Apparent thickness of window, including screens
- d_p Length of probe window in direction of travel
- v_d Detector velocity

FIG. X3.1 Area of Detection

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where:

- $R(\theta)$ = transient response of the meter to a fixed source
- $R(0)$ = steady state response of the meter to a fixed source
- θ = response time of the meter, defined as the time to reach 90 % of steady state
- τ = electronic time constant of the meter

constant source/detector distance to account for the change in apparent detector efficiency as a function of probe velocity by the relationship.

$$\epsilon(v) = \epsilon_0 [1 - e^{-(d_p/v_d\tau)}] \quad (X3.3)$$

where:
 $\epsilon(v)$ = "apparent" detector efficiency for detector velocity (v)

- ϵ_0 = detector efficiency for steady state source response
- d_p = distance detector probe travels with source within effective detection area (length of window in direction of travel)
- v_d = scanning velocity of the detector probe
- τ = electronic time constant of the ratemeter

Equation Eq X1.5 would be modified for transient response as follows:

$$MSS = \frac{4.65 \sqrt{B_0/2\tau}}{\epsilon(v) \cdot (A_d/100)} \quad (X3.4)$$

X3.9 Fig. X3.2 illustrates the effects of different detector probe window sizes, and time responses on the transient response of the detector probe traveling at velocities up to 6-inches per second. Note that recommended practice is to scan at a probe velocity of 2-inches per second (5 cm/sec).

X3.10 When an audio output signal is used, experience has shown that a 25 % to 50 % increase may be easily identified at ambient background levels of several thousand counts per minute (typical of gamma scintillators), but at ambient levels of 1-2 counts per minute (typical of alpha meters) a two to

X3.6 For digital rate meters, input pulses are gated to a register for a fixed time period. At the end of this time period, a fixed fraction of the register content is subtracted from the total. This cycle of accumulation for time T and fixed fraction subtraction F is repeated continuously until an equilibrium is exponentially approached where the rate pulses are added to the register is equal to the rate they are subtracted. This equivalent time constant is given by (10).

$$\tau = TF \quad (X3.2)$$

Where:

- T = accumulation gating time
- F = fraction of pulses subtracted at each step

X3.7 Most ratemeters in current use have a switch that allows operation in "fast" or "slow" time response mode. The following are typical ratemeter response times:

- Fast: $\theta_f = 2$ sec; $\tau = 0.87$ sec (0.015 min)
- Slow: $\theta_s = 20$ sec; $\tau = 8.7$ sec (0.15 min)

X3.8 When ratemeter output is utilized, the minimum sensitivity may be derived for point source activity and

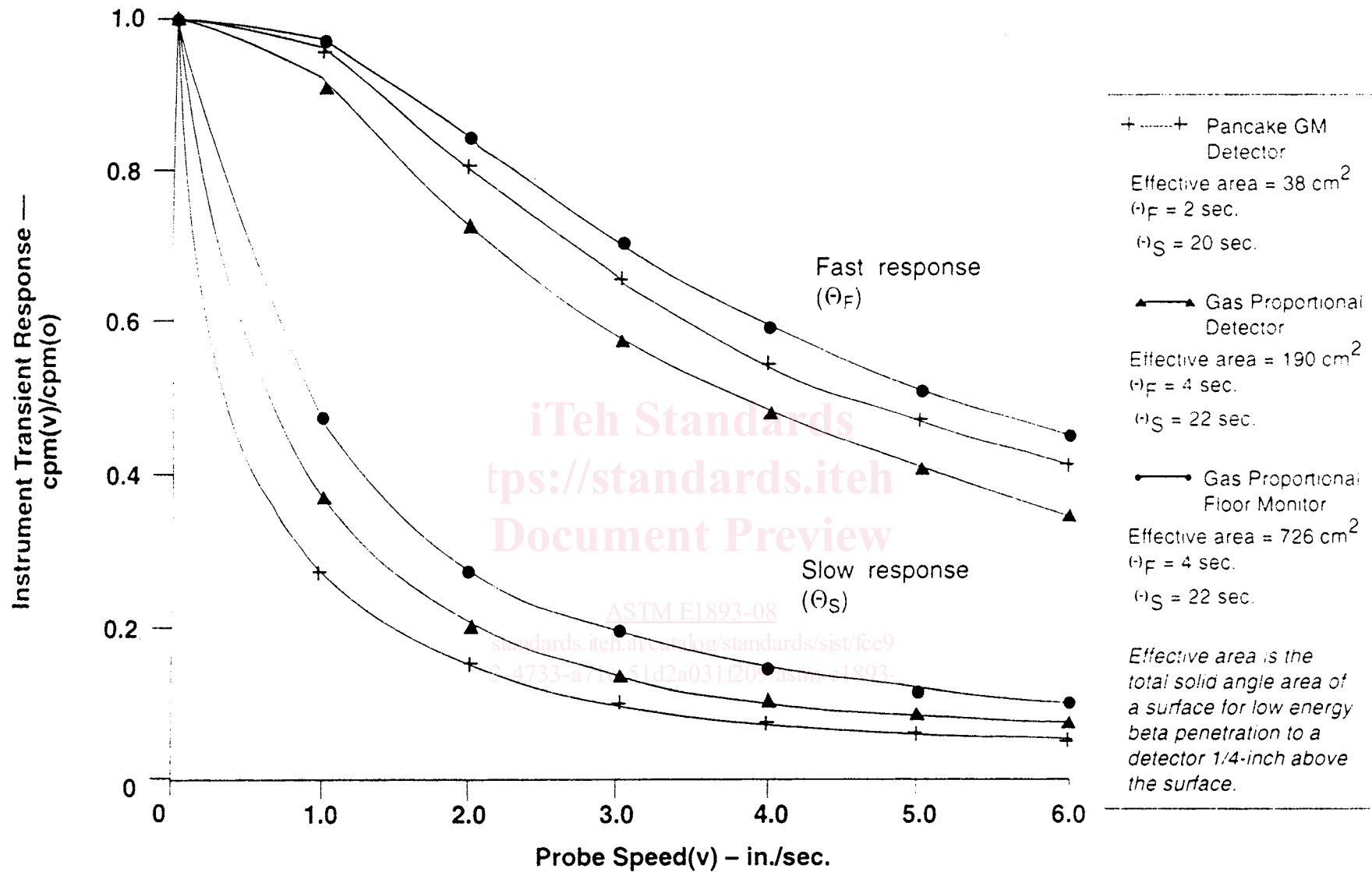


FIG. X3.2 Transient Response of Various Surface Contamination Detector Ratemeter Combinations