**DOCUMENT RELEASE AND CHANGE FORM**

Prepared For the U.S. Department of Energy, Assistant Secretary for Environmental Management
By Washington River Protection Solutions, LLC., PO Box 850, Richland, WA 99352
Contractor For U.S. Department of Energy, Office of River Protection, under Contract DE-AC27-08RV14800

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1. **Doc No:** RPP-53865  **Rev.** 03

2. **Title:**
   TECHNICAL BASIS DOCUMENT: DETECTION CAPABILITY FOR RADIOLOGICAL FIELD INSTRUMENTS

3. **Project Number:** ☒ N/A

4. **Design Verification Required:** ☒ Yes  ☐ No

5. **USQ Number:** ☒ N/A
   RPP-27195

6. **PrHA Number**
   **Rev.**  ☒ N/A

7. **Approvals**

<table>
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<th>Signature</th>
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<td>BENSEN, MATT J</td>
<td>BENSEN, MATT J</td>
<td>05/30/2017</td>
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<td>RAYMER, JULIA R</td>
<td>RAYMER, JULIA R</td>
<td>06/29/2017</td>
</tr>
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<td>Document Control Approval</td>
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<td>06/29/2017</td>
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<td>06/26/2017</td>
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</table>

8. **Description of Change and Justification**
   Correction of Errors in Tables

9. **TBDs or Holds**
   ☒ N/A

10. **Related Structures, Systems, and Components**

   a. **Related Building/Facilities**  ☒ N/A
   b. **Related Systems**  ☒ N/A
   c. **Related Equipment ID Nos. (EIN)**  ☒ N/A

11. **Impacted Documents – Engineering**

<table>
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<th>Document Number</th>
<th>Rev.</th>
<th>Title</th>
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<td>06</td>
<td>TOC Technical Basis for the Clearance (Release) of Material and Equipment (M&amp;E)</td>
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12. **Impacted Documents (Outside SPF):**

   TF-RC series of procedures

13. **Related Documents**

<table>
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<th>Rev.</th>
<th>Title</th>
</tr>
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| ☒ N/A

14. **Distribution**

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<td>LIGHTFOOT, ROY L</td>
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<tr>
<td>SWALLOW, KORI R</td>
<td>BASE OPS TANK FARM SUPPORT</td>
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TECHNICAL BASIS DOCUMENT: DETECTION CAPABILITY FOR RADIological FIELD INSTRUMENTS

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC27-08RV14800

P.O. Box 850
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Approved for Public Release;
Further Dissemination Unlimited
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J. E. Kurtz
Washington River Protection Solutions

Date Published
June 2017

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Printed in the United States of America
Executive Summary

This document provides equations for evaluating and establishing the radioactivity detection capability of radiological instruments used by the Tank Operations Contractor (TOC) Radiological Control (RadCon) organization for radiological contamination monitoring. These equations may be used when new instruments are being procured or when other adequate technical basis information, such as empirical studies or acceptable vendor supplied information, is not available for the instrument. This document supersedes TFC-1009-FACT-0144, “Technical Basis Document: Counting Statistics for Tank Farms Radiological Control.”

Evaluation results for the Ludlum Model 2360 ratemeter/scaler/data logger with the Ludlum Model 43-93 Alpha Beta Scintillation Detector 100 cm² probe are included in this document. These results provide a basis for the use of the 2360/43-93 instrument and are an application example that can serve as benchmark calculations for subsequent instrument calculations based on the methods provided within this document.
Table of Contents

LIST OF TABLES ......................................................................................................................... 3
LIST OF TERMS ............................................................................................................................ 4
1.0 INTRODUCTION .................................................................................................................. 5
2.0 DIRECT CONTAMINATION SURVEYS ............................................................................ 5
2.1 Instrument Selection and Detection Limits ........................................................................ 5
2.2 Typical High and Low Background Count Rate Survey Applications ........................... 6
2.3 Survey Parameter Selection ............................................................................................... 6
2.3.1 Direct Surveys .................................................................................................................. 6
2.3.2 Removable Surveys ....................................................................................................... 6
2.3.3 Survey Confidence Level ............................................................................................... 7
2.3.4 Index of Sensitivity ......................................................................................................... 8
2.3.5 Surveyor Efficiency ....................................................................................................... 8
2.3.6 Surface Efficiency ......................................................................................................... 8
2.4 Beta-Gamma Count Rate Surveys Equations .................................................................. 9
2.4.1 Beta-Gamma Scan Survey MDA Equation ................................................................... 11
2.4.2 Beta-Gamma Static Survey MDA Equation .................................................................. 11
2.4.3 Beta-Gamma Removable Survey MDA Equation ......................................................... 12
2.5 Alpha Surveys (Background 0 to 3 cpm) ......................................................................... 12
2.5.1 Alpha Scan Survey Equation (Background 0 to 3 cpm) .............................................. 14
2.5.2 Alpha Static Survey Equation (Background 0 to 3 cpm) .............................................. 15
2.5.3 Alpha Removable Survey Equation (Background 0 to 3 cpm) .................................... 16
2.6 Alpha Surveys (Background 3 to 10 cpm) ....................................................................... 16
2.6.1 Alpha Scan Survey Equation (Background 3 to 10 cpm) ............................................ 18
2.6.2 Alpha Static Survey Equation (Background 3 to 10 cpm) ............................................ 18
2.6.3 Alpha Removable Survey Equation (Background 3 to 10 cpm) ................................ 19
3.0 SCALER COUNTING ......................................................................................................... 19
3.1 Minimum Detectable Net Signal/Decision Level ............................................................. 20
3.2 Minimum Detectable Net Signal/Minimum Detectable Activity (MDA) ....................... 21
4.0 LUDLUM 2360/43-93 DETECTION CAPABILITY TECHNICAL BASIS .................... 23
4.1 Ludlum 2360/43-93 Beta Scan/Static/Removable Surveys ............................................ 24
4.2 Ludlum 2360/43-93 Alpha Scan/Static/Removable Surveys .......................................... 24
5.0 EBERLINE E140 SERIES AND LUDLUM MODEL 3 SERIES WITH GEIGER-MULLER (GM) PANCAKE PROBES DETECTION CAPABILITY TECHNICAL BASIS ... 25
6.0 PORTABLE ALPHA METER (PAM) RADIATION SURVEY INSTRUMENT DETECTION CAPABILITY TECHNICAL BASIS .................................................. 25
7.0 EXCEPTIONS AND UNPREDICTABLE CONDITIONS .............................................. 26
8.0 CALCULATIONAL INSTRUMENT SPECIFICATIONS .............................................. 26
9.0 REFERENCES ................................................................................................................... 27
ATTACHMENT A- LUDLUM 2360/43-93 DETECTION CAPABILITY ............................... 1
ATTACHMENT B – EBERLINE E140 SERIES AND LUDLUM MODEL 3 SERIES WITH GEIGER-MULLER PANCAKE PROBES DETECTION CAPABILITY ....................... 1
ATTACHMENT C – PORTABLE ALPHA METER (PAM) RADIATION SURVEY INSTRUMENT DETECTION CAPABILITY 1

2
LIST OF TABLES

Table 1: Index of Sensitivity ($d'$) for Contamination Survey Calculations ........................................ 8
Table 2: Minimum 4 Pi Instrument Efficiencies ..................................................................................... 26
Table 3: Probe Physical Dimensions ................................................................................................... 26
Table 4: Values of $d'$ for Selected True Positive and False Positive Proportions (MARRSIM interpolated values) ...................................................................................................................... 27
Table A-1: Ludlum 2360/43-93 Beta Scan Survey Parameters ................................................................. 1
Table A-2: Ludlum 2360/43-93 Beta Static/Removable Survey Parameters ............................................ 1
Table A-3: Ludlum 2360/43-93 Alpha Scan Survey Parameters ................................................................. 1
Table A-4: Ludlum 2360/43-93 Alpha Static/Removable Survey Parameters ........................................... 1
Table B-1: GM Scanning Surveys at a 95% Confidence Level (5,000 dpm/100 cm$^2$) ....................... 1
Table B-2: GM Scanning Surveys at a 67% Confidence Level (5,000 dpm/100 cm$^2$) ......................... 1
Table B-3: GM Static Surveys at a 67% or 95% Confidence Level (5,000 dpm/100cm$^2$) ................. 2
Table B-4: GM Scanning Surveys at a 67% Confidence Level (1,000 dpm/100cm$^2$) ......................... 2
Table B-5: GM Technical Smear Counting at 67% or 95% Confidence Level for 1,000 dpm/100cm$^2$ ................................................... 2
Table C-1: PAM Scanning Surveys at a 95% Confidence Level ................................................................. 1
Table C-2: PAM Scanning Surveys at a 67% Confidence Level ................................................................. 2
Table C-3: PAM Static Surveys at a 95% Confidence Level ..................................................................... 3
Table C-4: PAM Static Surveys at 67% Confidence Level ....................................................................... 3
Table C-5: PAM Smear Counting Techniques to Achieve 20 dpm Sensitivity at 67% ......................... 4
Table C-6: PAM Smear Counting Techniques to Achieve 70 dpm Sensitivity at 67% ......................... 4
Table C-7: PAM Smear Counting Techniques to Achieve 20 dpm Sensitivity at 95% Confidence ............................................................................................................................................... 4
Table C-8: PAM Smear Counting Techniques to Achieve 70 dpm Sensitivity at 95% Confidence ............................................................................................................................................... 5
LIST OF TERMS

Terms

Confidence Level. The statistical certainty that a specific objective is reached using a given set of parameters.

Decision Level. The minimum measured value of the instrument signal required to give confidence that a positive (nonzero) amount of contamination is present.

Minimum Detectable Concentration. The minimum detectable radioactivity per unit area derived from the detection limit (counts) multiplied by an appropriate conversion factor to give units consistent with an existing site guideline, typically in units of dpm/100 cm$^2$.

Minimum Detectable Count Rate. The minimum detectable source count rate for a surveyor during a particular source activity observation interval, in units of cpm.

Minimum Detectable Activity. The minimum detectable value of the amount of radioactivity in a sample. Same definition as the minimum detectable concentration for direct surveys, but related to the quantity (activity) of a radionuclide rather than the concentration of a radionuclide for other types of measurements.

Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
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<tr>
<td>DL</td>
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<td>MDA</td>
<td>Minimum Detectable Activity</td>
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<td>MDC</td>
<td>Minimum Detectable Concentration</td>
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<td>MDCR</td>
<td>Minimum Detectable Count Rate</td>
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<tr>
<td>DOE</td>
<td>Department of Energy</td>
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<td>Department of Energy Richland Operations Office</td>
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<td>MARLAP</td>
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Units

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<td>centimeter</td>
</tr>
<tr>
<td>cpm</td>
<td>counts per minute</td>
</tr>
<tr>
<td>dpm</td>
<td>disintegrations per minute</td>
</tr>
<tr>
<td>s</td>
<td>second</td>
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1.0 INTRODUCTION

This document provides equations that may be used to evaluate and establish radiological field instrument radioactive contamination detection capabilities when other adequate technical basis information, such as empirical studies or acceptable vendor supplied information, is not available for the instrument. This document assumes familiarity with statistics and does not discuss derivation of the equations, instead focusing on applications.

Equations for use in evaluating and establishing direct contamination survey capabilities (detection capabilities for scans and static measurements as performed by Tank Operations Contractor (TOC) Radiological Control (RadCon) personnel) are discussed, derived and provided in Section 2.0. The basis for these equations is the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), NUREG-1575/ EPA 402-R-97-016/ DOE/EH-0624, Rev. 1. MARSSIM provides a nationally consistent consensus approach to conducting radiation surveys and investigations at potentially contaminated sites.

Equations for use in evaluating and establishing fixed geometry/scaler counting capabilities are discussed, derived and provided in Section 3.0. The basis for these equations is the Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP), NUREG-1576 EPA 402-B-04-001A. MARLAP is intended to provide a nationally consistent approach to producing laboratory data that meet a project’s or program’s data requirements.

Calculation results for the Ludlum Model 2360 ratemeter/scaler/data logger with the Ludlum Model 43-93 Alpha/Beta Scintillation Detector 100 cm² probe are provided. These results serve as an example for the methods provided in this document. Results also provide a basis for the field use of the 2360/43-93 instrument.

2.0 DIRECT CONTAMINATION SURVEYS

2.1 INSTRUMENT SELECTION AND DETECTION LIMITS

Direct measurement techniques (e.g. scans and static counts) must be capable of measuring levels equal to or below the established release or survey contamination control limits. In order to determine an instrument’s usefulness for a particular application, its detection capability for the application must be evaluated and established.

Detection capability is subject to variation from measurement to measurement, instrument to instrument, operator to operator, and procedure to procedure. This variation depends on geometry; background; instrument calibration; abundance, type and energy of the radiations being measured; counting time; operator training; operator experience; self-absorption in the medium being measured; and interferences from radionuclides or other materials present in the medium. The detection capability that is achievable in practice must not exceed the release or survey limit.
2.2 TYPICAL HIGH AND LOW BACKGROUND COUNT RATE SURVEY APPLICATIONS

For TOC RadCon, high count rate surveys are typically performed when monitoring for beta-gamma emitters or uranium. Low count rate or near-zero surveys are typically performed to monitor for other alpha emitters (such as Pu-239 or Am-241).

2.3 SURVEY PARAMETER SELECTION

2.3.1 DIRECT SURVEYS

The basis for the direct contamination survey equations used by TOC RadCon is contained in MARSSIM (NRC 2000).

A direct contamination survey as described in this document is equivalent to the scan survey described in MARSSIM Chapter 6, Section 6.4, Scanning Surveys, and consists of two parts: (1) scan surveys and (2) static (or pause) measurements/counts.

During scan, there is a brief look at potential sources beneath the probe that is determined by the scan speed. The instrument’s audible response is near real time during the scan and is the basis for triggering a surveyor to stop and perform static measurements/counts to validate the possible presence of contamination beneath the probe. For low background surveys, such as alpha surveys, a single audible event (click) is considered a positive response and triggers a static measurement/count for validation. For high count rate surveys, such as beta surveys, a subjective, perceived increase in the audible count rate by the surveyor is considered a positive response and triggers a static measurement/count for validation.

Static (or pause) measurements/counts are performed when a positive response is observed/perceived during the scan. This response is marked by the surveyor interrupting the scan and holding the probe stationary for a period of time, while comparing the instrument response during that time to the background counting rate. For low background surveys, such as alpha surveys, a single audible event (click) indicates that activity above background may have been detected at the desired confidence level. For high count rate surveys, such as beta surveys, a subjective perceived increase in the audible count rate by the surveyor indicates that activity above background may have been detected at the desired confidence level.

2.3.1.1 Probe Area Conversions – Detectable Contamination

Large Area Uniform Contamination:

When monitoring an area with uniform contamination, correct readings taken using the 50 cm$^2$ PAM probe to units of dpm/100 cm$^2$, by multiplying the dpm/probe-area by a factor of 2 or a GM by factor of 6.

For example, a uniform reading of 50 cpm over a large area (100 cm$^2$ or greater) can be converted
to dpm/100 cm$^2$ as follows:

$$50 \text{ cpm} \times 7 \text{ dpm/cpm} = 350 \text{ dpm} \times 2 = 700 \text{ dpm/100 cm}^2.$$  

**Non-Uniform Contamination:**

To convert readings taken with a 50 cm$^2$ PAM probe to units of dpm/100 cm$^2$, add two adjacent dpm/probe readings together or with GM by adding 6 adjacent dpm/probe readings.

### 2.3.2 Removable Surveys

Each of the removable counting methods below rely on the same basic process. The background is evaluated by performing a one-minute count and establishing the background count rate for the instrument. The background must be less than the maximum value identified for the selected method. Performing the one minute background count daily is sufficient but the value should be verified periodically during use throughout the day. The result of the background count should be posted or marked on the instrument.

**Removable contamination survey:** A technical smear, collected by swiping an area of 100 cm$^2$, is placed beneath the probe and the measurement result in dpm (MDA in the absence of contamination) is divided by the sampled area of 100 cm$^2$ to achieve the desired units of dpm/100 cm$^2$. In this case, probe area does not impact measurement sensitivity because the probe’s active area completely covers the technical smear.

**Transferable contamination survey:** The soil transferability survey is performed in accordance with TFC-ESHQ-RP_MON-C-20 Survey Methods for Contaminated Soil, Wildlife, and Vegetation. In this case, the sample is collected over a large area on a shoe cover or canvas/cotton cloth $\geq$ 100 cm$^2$ in area. This sample is then counted using appropriate direct survey method above, over a 100 cm$^2$ area of the sample, to meet required 67% MDA for the measurement.

### 2.3.3 Survey Confidence Level

Confidence levels express the statistical certainty that a specific objective is reached using a given set of parameters. Confidence levels range from 0% to 100%.

The 67% confidence level is used for general monitoring of personnel, posting and control activities.

Confidence levels for material release are based on guidance from the Department of Energy Richland Operations Office (DOE/RL) (DOE/RL 1995). When contamination is likely, surveys need to have at least a 95% confidence level for detecting contamination at or below a specified limit. When contamination is not likely, surveys need to have at least a 67% confidence level for detecting contamination at or below a specified limit.
2.3.4 Index of Sensitivity

For direct contamination surveys, the index of sensitivity \( d' \) takes into account decision errors (i.e., correct detection and false positive probabilities). Values of \( d' \) are identified in MARSSIM Table 6.5, “Values of \( d' \) for Selected True Positive and False Positive Proportions”. The interpolated values of \( d' \) selected for standard use by TOC RadCon are shown in Table 1.

<table>
<thead>
<tr>
<th>Survey Confidence</th>
<th>Scanning</th>
<th>Static</th>
<th>Removable - Portable</th>
<th>Removable – Scaler</th>
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<td>95% (40% false positive)</td>
<td>1.90</td>
<td>2.48 (20% false positive)</td>
<td>2.48 (20% false positive)</td>
<td>3.28 (5% false positive)</td>
</tr>
<tr>
<td>67% (40% false positive)</td>
<td>0.70</td>
<td>1.28 (20% false positive)</td>
<td>1.28 (20% false positive)</td>
<td>2.08 (5% false positive)</td>
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</table>

2.3.5 Surveyor Efficiency

Laboratory studies using simulated sources and backgrounds have been performed to assess the detection capabilities of surveyors under controlled conditions during decommissioning. The methodology and analysis of results for these studies are described in the NUREG-1507 draft (NRC 1995). The surveyor’s actual performance as compared with that which is ideally possible (using the ideal observer construct) provides an indication of the efficiency of the surveyors. This applies in surveys of real property where large areas are surveyed during which maintenance of distances and speeds by the surveyor tends to degrade over time. TOC will assume a surveyor efficiency of 1.0, which simplifies the calculations.

2.3.6 Surface Efficiency

The idea of surface efficiency was introduced in ISO-7503 and incorporated into MARSSIM as a method to alleviate the effects of various surface effects on efficiency such as back-scatter, etc. differences from calibration. The use of this parameter is based on 2 pi surface emission rates efficiency with a surface efficiency factored in to make up the 4 pi efficiency for the measurement. The Hanford Site Services Contractor uses the source 4 pi activity to determine an instrument efficiency. The use of this parameter using 4 pi efficiencies will not be used.
2.4 BETA-GAMMA COUNT RATE SURVEYS EQUATIONS

The following equations are used to derive and establish beta-gamma count rate survey Minimum Detectable Activities (MDAs). See MARSSIM (2000), Chapter 6, for discussion regarding these equations. These equations were modified to remove the surface and surveyor efficiency parameters (See 2.3.5 and 2.3.6)

\[
Scan\ Survey\ MDC = \frac{MDCR}{E \times \frac{PA}{100cm^2}}
\]

(MARSSIM 2000, Ch. 6, Equation 6-10)

Where:

- \(MDC\) is the minimum detectable concentration (dpm/100cm\(^2\))
- \(MDCR\) is the minimum detectable count rate (cpm)
- \(E\) is the instrument efficiency (4 pi)
- \(PA\) is the physical detector/probe area (cm\(^2\))

\[
MDCR = s_i \left(\frac{60}{i}\right)
\]

(MARSSIM 2000, Ch. 6, Equation 6-9)

Where:

- \(s_i\) is the minimum detectable number of source counts in the time interval
- \(i\) is the observation time interval (seconds); the time the source activity spends under the probe. The time interval can be calculated for scanning surveys by dividing the effective probe width (in the direction of travel) by the scan speed. Please note that units must be consistent for probe width and scan speed (e.g., cm and cm/s).
\[ i = \frac{w}{v} \]

Where:

- \( w \) is the detector width in direction of scan (cm)
- \( v \) is the scan speed (cm/s)

\[ s_i = d' \sqrt{b_i} \]

(MARSSIM 2000, Ch. 6, Equation 6-8)

Where:

- \( d' \) is the index of sensitivity; a factor corresponding to the required true positive and false positive probabilities from Tables 1 or 4
- \( b_i \) is the number of background counts in the time interval \( i \).

\[ b_i = \frac{bkgd \times i}{60} \]

Where:

- \( bkgd \) is the background count rate in cpm

When the probe is held in a stationary position during a static measurement/count, the static count time is the observation time interval (seconds) or the time the source activity spends under the probe.

\[ T = i \]

Where:

- \( i \) is the observation time interval (s); the time the source activity spends under the probe.
- \( T \) is the static measurement count time (s)

The equations in this section are combined to arrive at equation forms presented in Section 2.4.1 and 2.4.2.
2.4.1 Beta-Gamma Scan Survey MDA Equation

\[
Scan
\text{ Copy:}
\text{ MD}
\text{ Area } (dpm/100\text{cm}^2) = \frac{d'}{\sqrt{\frac{bw}{60v}}}, \frac{60v}{w} \frac{E}{PA} \frac{100}{100}
\]

Where:

\(d'\) is the Index of Sensitivity from Tables 1 or 4
\(bkgd\) is the background count rate in cpm
\(w\) is the detector width in direction of scan (cm)
\(v\) is the scan speed (cm/s)
\(E\) is the instrument efficiency (4 pi)
\(PA\) is the physical detector/probe area (cm^2)

2.4.2 Beta-Gamma Static Survey MDA Equation

\[
\text{Static Copy:}
\text{ MD}
\text{ Area } (dpm/100\text{cm}^2) = \frac{d'}{\sqrt{\frac{bkgd * T}{60}}}, \frac{60}{T} \frac{E}{PA} \frac{100}{100}
\]

Where:

\(bkgd\) is the background count rate in cpm
\(d'\) is the Index of Sensitivity from Tables 1 or 4
\(E\) is the instrument efficiency (4 pi)
\(PA\) is the value of the physical detector/probe area (cm^2) for measurements of surfaces equal to or greater than the physical detector/probe area, or a value of 100 if the item (surface/sample/smear, etc.) is smaller than the physical detector/probe area.
\(T\) is the static count time; interval the source/activity spends under the probe (s)

When using static measurements to evaluate or count items with areas that are smaller than the physical detector/probe area (such as smears, air samples, etc.), the probe area correction factor (PA/100) is removed from consideration by setting it to a value of one (1) with PA =100.
2.4.3 Beta-Gamma Removable Survey MDA Equation

Counting technical smears to evaluate beta-gamma removable contamination levels is performed using either field instrumentation or low-level background counting systems. The smear is counted for sufficient time to ensure detection criteria are achieved.

The equation is derived from the static MDA in section 2.4.2 and merely removes the area parameter as the area is assumed to be 100 cm$^2$.

\[
\text{Removable Survey MDA (dpm/100cm2)} = \frac{d' \sqrt{bkgd \times T}}{60 \frac{60}{T^2}} E
\]

Where:

- $bkgd$ is the background count rate in cpm
- $d'$ is the Index of Sensitivity from Tables 1 or 4
- $E$ is the instrument efficiency (4 pi)
- $T$ is the static count time; interval the source/activity spends under the probe (s)

2.5 ALPHA SURVEYS (BACKGROUND 0 TO 3 CPM)

See MARSSIM, Appendix J for a description of the derivation of the equations in this section.

The following equations are used for determining low count rate survey parameters (valid for background from 0 to 3 cpm):

\[
P_{(n=1)} = 1 - P_{(n=0)}
\]

(MARSSIM 2000, Appendix J, Equation J-4)

\[
P_{(n=1)} = 1 - e^{-\frac{GEw}{60B}}
\]

(MARSSIM 2000, Ch. 6, Equation 6-12, Appendix J, Equation J-5)
Where:

\[ P_{(n \geq 1)} \] is the probability of observing one or more counts

\[ G \] is the contamination activity level beneath the probe (dpm)

\[ E \] is the instrument efficiency (cpm/dpm) (4 \pi)

\[ w \] is the detector width in direction of scan (cm)

\[ v \] is scan speed (cm/s)

The above equation assumes that the background count rate is equal to zero but provided acceptable results up to 3 cpm.

The contamination activity level beneath a probe can be calculated as follows:

\[ G = \frac{C(PA)}{100} \]


Where:

\[ C \] is the value of the contamination level criterion (dpm/100 cm\(^2\))

\[ PA \] is the value of the physical detector/probe area (cm\(^2\)) for measurements of surfaces equal to or greater than the physical detector/probe area, or a value of 100 if the item (surface/sample/smear, etc.) is smaller than the physical detector/probe area

When using static measurements to evaluate or count items with areas that are smaller than the physical detector/probe area (such as smears, air samples, etc.), the probe area correction factor (PA/100) is removed from consideration by setting it to a value of one (1) with A =100. In such cases, \( G = C \).

The dwell time, or observation time interval, of the probe over the contamination beneath it, is either a function of scan speed and physical detector/probe width in the direction of the scan, or the count duration for a static measurement/count. This relationship can be expressed as follows:
\[ i = \frac{w}{v} = T \]

Where:

- \( i \) is the observation time interval (s); the time the source (contamination) spends beneath the probe.
- \( w \) is the detector width in the direction of scan (cm)
- \( v \) is the scan speed (cm/s) for scan surveys
- \( T \) is the static measurement/count time (s) for static surveys

The equations in this section are combined to arrive at the equation forms in Section 2.5.1 and 2.5.2.

### 2.5.1 Alpha Scan Survey Equation (Background 0 to 3 cpm)

\[
P_{(n \geq 1)} = 1 - e^{-(\frac{(C)(PA)(E)(w)}{100})}.
\]

Where:

- \( P_{(n \geq 1)} \) is the probability of observing one or more counts
- \( C \) is the value of the contamination level criterion (dpm/100 cm²)
- \( PA \) is the value of the physical detector/probe area (cm²)
- \( E \) is the instrument efficiency (4 pi)
- \( w \) is the detector width in direction of scan (cm)
- \( v \) is scan speed (cm/s)

The solution to this equation provides the probability of detecting one or more counts \( P_{(n \geq 1)} \) during scan for a given scan velocity (\( v \)), when all other variables (background count rate, detector width in the direction of scan, physical detector/probe area, contamination criterion and instrument efficiency as described in Section 2.5) are known and constant.

The equation can also be solved algebraically to determine a maximum scan velocity (\( v \)) that can be used to achieve a given probability of detecting one or more counts \( P_{(n \geq 1)} \), when all other variables (background count rate, detector width in the direction of scan, physical detector/probe area, contamination criterion and instrument efficiency as described in Section 2.5) are known and constant.
area, contamination criterion and instrument efficiency as described in Section 2.4) are known and constant.

The equation is applicable where surfaces being surveyed are relatively clean, dry and smooth with little to no self-absorption.

### 2.5.2 Alpha Static Survey Equation (Background 0 to 3 cpm)

\[
P_{(n \geq 1)} = 1 - e^{-\frac{C(\text{PA})}{100}(E)(T)}
\]

Where:

- \( P_{(n \geq 1)} \) is the probability of observing one or more counts
- \( C \) is the value of the contamination level criterion (dpm/100 cm\(^2\))
- \( \text{PA} \) is the value of the physical detector/probe area (cm\(^2\)) for measurements of surfaces greater than or equal to the detector/probe area, or a value of 100 if the item (surface/sample/smear, etc.) is smaller than the physical detector/probe area
- \( E \) is the instrument efficiency (cpm/dpm) (4 pi)
- \( T \) is the static measurement/count time (s) for static surveys

When using static measurements to evaluate or count items with areas that are smaller than the physical detector/probe area (such as smears, air samples, etc.), the probe area correction factor (A/100) is removed from consideration by setting it to a value of one (1) with A =100.

The solution to this equation provides the probability of detecting one or more counts \( P_{(n \geq 1)} \) for a given static measurement/count time \( T \), that can be used during a static measurement/count (pause) when all other variables (background count rate, physical detector probe area, contamination criterion and instrument efficiency as described in Section 2.5) are known and constant.

The equation can also be solved algebraically to determine a minimum static measurement/count time \( T \) that can be used during a static measurement/count (pause) to achieve a given probability of detecting one or more counts, \( P_{(n \geq 1)} \), when all other variables (background count rate, physical detector/probe area, contamination criterion and instrument efficiency as described in Section 2.5) are known and constant.
The equation is applicable where surfaces being surveyed are relatively clean, dry and smooth with little to no self-absorption.

2.5.3 Alpha Removable Survey Equation (Background 0 to 3 cpm)

\[ P_{(n\geq1)} = 1 - e^{-\frac{(C)(E)(T)}{60}} \]

Where:
- \( P_{(n\geq1)} \) is the probability of observing one or more counts.
- \( C \) is the value of the contamination level criterion (dpm/100 cm\(^2\)).
- \( E \) is the instrument efficiency (cpm/dpm) (4 pi).
- \( T \) is the measurement/count time (s) for static surveys.

2.6 ALPHA SURVEYS (BACKGROUND 3 TO 10 CPM)

See MARSSIM, Appendix J for a description of the derivation of the equations in this section.

The following equations are used for determining low count rate survey parameters in areas with an elevated background count rate (valid for background from > 3 to 10 cpm):

\[ P_{(n\geq2)} = 1 - P_{(n=0)} - P_{(n=1)} \]

\[ P_{(n\geq2)} = 1 - \left( 1 + \frac{(GE + B)T}{60} \right) e^{-\frac{(GE+B)T}{60}} \]

(MARSSIM 2000, Ch. 6, Equation 6-14, Appendix J, Equation J-7)

Where:
- \( P_{(n\geq2)} \) is the probability of two or more counts during the time interval.
- \( G \) is the contamination activity level beneath the probe (dpm).
- \( E \) is the instrument efficiency (cpm/dpm) (4 pi).
- \( B \) is the background count rate (cpm).
- \( T \) is the time interval (s) the source spends under the probe.
The contamination activity level beneath a probe is calculated as follows:

\[ G = \frac{C(PA)}{100} \]


Where:

- \( C \) is the contamination level criterion (dpm/100 cm\(^2\))
- \( PA \) is the physical detector/probe area (cm\(^2\)) for measurements of surfaces equal to or greater than the detector/probe area, or a value of 100 if the item (surface/sample/smear, etc.) is smaller than the physical detector/probe area

When using static measurements to evaluate or count items with areas that are smaller than the physical detector/probe area (such as smears, air samples, etc.), the probe area correction factor (A/100) is removed from consideration by setting it to a value of one (1) with A =100.

The dwell time, or observation time interval, of the probe over the contamination activity beneath it, is either a function of scan speed and physical detector/probe width in the direction of the scan, or the count duration for a static measurement/count. This relationship can be expressed as follows:

\[ T = \frac{w}{v} = i \]

Where:

- \( i \) is the observation time interval (s); the time the source spends under the probe.
- \( w \) is the detector width in direction of scan (cm)
- \( v \) is the scan speed (cm/s) for scan surveys
- \( T \) is the static count time (s) for static surveys

The equations in this section are combined to arrive at the equation forms in Section 2.6.1 and 2.6.2.
2.6.1 Alpha Scan Survey Equation (Background 3 to 10 cpm)

\[ P_{(n\geq2)} = 1 - \left( 1 + \frac{(C(PA)E + B)w}{60v} \right) e^{-\frac{(C(PA)E+B)w}{60v}} \]

Where:

- \( P_{(n\geq2)} \) is the probability of observing two or more counts
- \( C \) is the value of contamination criterion (dpm/100 cm\(^2\))
- \( PA \) is the value of physical detector/probe area (cm\(^2\))
- \( B \) is the background count rate (cpm)
- \( E \) is the instrument efficiency (cpm/dpm)
- \( w \) is the width of detector in direction of scan (cm)
- \( v \) is scan speed (cm/s)

The solution to this equation provides the probability of detecting two or more counts \( P_{(n\geq2)} \) during scan for a given scan velocity \( v \), when all other variables (background count rate, detector/probe width in the direction of scan, physical detector/probe area, contamination criteria and instrument efficiency as described in Section 2.6) are known and constant.

The equation is applicable where surfaces being surveyed are relatively clean, dry and smooth with little to no self-absorption.

2.6.2 Alpha Static Survey Equation (Background 3 to 10 cpm)

\[ P_{(n\geq2)} = 1 - \left( 1 + \frac{(C(PA)E + B)T}{60} \right) e^{-\frac{(C(PA)E+B)T}{60}} \]

Where:

- \( P_{(n\geq2)} \) is the probability of observing two or more counts
- \( C \) is the contamination criterion (dpm/100 cm\(^2\))
- \( PA \) is the physical detector/probe area (cm\(^2\)) for measurements of surfaces equal to or greater than the detector/probe area, or a value of 100
if the item (surface/sample/smear, etc.) is smaller than the physical detector/probe area

\[ B \] is the background count rate (cpm)

\[ E \] is the instrument efficiency (cpm/dpm) (4 pi)

\[ T \] is the static count time (s) for static surveys

When using static measurements to evaluate or count items with areas that are smaller than the physical detector/probe area (such as smears, air samples, etc.), the probe area correction factor \((A/100)\) is removed from consideration by setting it to a value of one (1) with \(A = 100\).

The solution to this equation provides the probability of detecting two or more counts \(P_{(n \geq 2)}\) for a given static count time \(T\), that can be used during a static measurement/count (pause) when all other variables (background count rate, physical detector/probe area, contamination criteria and instrument efficiency as described in Section 2.6) are known and constant.

The equation is applicable where surfaces being surveyed are relatively clean, dry and smooth with little to no self-absorption.

### 2.6.3 Alpha Removable Survey Equation (Background 3 to 10 cpm)

\[
P_{(n \geq 2)} = 1 - \left(1 + \frac{(CE + B)T}{60}\right) \left(1 - \frac{(CE+B)T}{60}\right)
\]

Where:

\[ P_{(n \geq 2)} \] is the probability of observing two or more counts

\[ C \] is the contamination criterion (dpm/100 cm\(^2\))

\[ B \] is the background count rate (cpm)

\[ E \] is the instrument efficiency (cpm/dpm) (4 pi)

\[ T \] is the static count time (s) for static surveys

### 3.0 SCALER COUNTING

Fixed geometry counting involves counting samples (for example, surfaces, smears, air samples) for specified periods of time, and typically involves the use of scaler instruments with detectors very close to the size of the sample. Use of the scaler function on a portable instrument should follow the statistics in section 2.0.
The equations in this section may be used with industry standard bench top instruments to establish instrument detection capabilities for the measurement of radioactivity in samples, or on surfaces, at levels that are consistent with applicable control requirements.

These equations would be appropriate for use when counting samples with bench top scalers, such as the Ludlum 2929 (or equivalent), for air sample, smear, and lapel counting.

The basis for the detection capability equations used by TOC RadCon is contained in the MARLAP (2004).

3.1 MINIMUM DETECTABLE NET SIGNAL/DECISION LEVEL

Following standard Poisson-normal counting statistics the critical level, \( S_C \), can be determined using the following formula:

\[
S_C (\text{net counts}) = z_{1-\alpha} \left( \frac{t_S}{t_B} \right) \left[ \frac{N_B}{t_B} \right] \left[ 1 + \frac{t_S}{t_B} \right]
\]

(MARLAP (2004), Vol. III, Ch. 20, Equation 20.11)

Where:

- \( S_C \) is the critical signal (net counts)
- \( z_{1-\alpha} \) is the quantile of the standard normal distribution (See MARLAP (2004), Appendix G, Table G-1)
- \( \alpha \) is the Type I error, or ‘false positive’ rate
- \( N_B \) is the number of background counts in the background count interval \( t_B \)
- \( t_S \) is the sample count time
- \( t_B \) is the background count time

\( S_C \) is essentially analogous to the term “decision level” in definition (activity above background has been detected) except that Decision Level (DL) is typically given in net cpm, whereas \( S_C \) is given in net counts for the sample count time. \( S_C \) can be converted to DL in units of cpm by simply dividing through by the sample count time (\( t_S \)).

\[
DL \ (\text{cpm}) = \frac{z_{1-\alpha} \sqrt{\left( \frac{N_B}{t_B} \right) \left[ \frac{t_S}{t_B} \right] \left[ 1 + \frac{t_S}{t_B} \right]}}{t_S}
\]
Where:

\[ z_{1-\alpha} \] is the quantile of the standard normal distribution (See MARLAP (2004), Appendix G, Table G-1)
\[ \alpha \] is the Type I error, or ‘false positive’ rate
\[ N_B \] is the number of background counts in the background count interval \( t_B \)
\[ t_S \] is the sample count time
\[ t_B \] is the background count time

When the Type I (\( \alpha \)) error rate is set to 5% (95% confidence level), \( z_{1-\alpha} \) equals 1.645. Substituting \( z_{1-\alpha} = 1.645 \) into the equation for \( S_C \), and then dividing through by the sample count time (\( t_S \)) to convert net count to net count rate, results in the recognizable standard form of the equation for Decision Level (\( DL \)):

\[
DL(cpm) = 1.645 \sqrt{\frac{1}{R_b} \left( \frac{1}{T_b} + \frac{1}{T_g} \right)}
\]

Where:

\( DL \) is the Decision Level
\( R_b \) is the count rate of the background
\( T_b \) is the background count time
\( T_g \) is the sample count time

This is the form of the equation currently used in TF-RC-021, Analyzing Air and Smear Samples for Alpha and Beta Emissions, Attachment A, Equation A.2.

It should be noted that the form of the equation provided above does not specifically take into account sample self-absorption considerations, or sample collection efficiencies or surface efficiency effects that may be present in the field. Such modifying factors, if used, would be appropriately included in the denominator in the above equation.

### 3.2 Minimum Detectable Net Signal/Minimum Detectable Activity (MDA)

The minimum detectable net signal, \( S_D \), in counts, can be determined using the following formula:
\[
S_D = S_C + \frac{z_{1-\beta}^2}{2} + z_{1-\beta} \sqrt{\frac{z_{1-\beta}^2}{4} + S_C + R_B t_S \left[ 1 + \frac{t_S}{t_B} \right]}
\]

(MARLAP (2004), Vol. III, Ch. 20, Equation 20.28)

Where:

- \(S_C\) is the critical signal
- \(z_{1-\alpha}\) is the statistical quantile of the standard normal distribution (See MARLAP (2004), Appendix G, Table G-1)
- \(z_{1-\beta}\) is the statistical quantile of the standard normal distribution (See MARLAP (2004), Appendix G, Table G-1)
- \(\alpha\) is the Type 1 error, or ‘false positive’ rate (set at 5% for 95%-confidence)
- \(\beta\) is the Type 2 error, or ‘false negative’ rate (set at 33% for 67%-confidence or 5% for 95%-confidence)
- \(N_B\) is the number of background counts in the listed interval
- \(t_S\) is the sample count time
- \(t_B\) is the background count time
- \(R_B\) is the count rate of the background

The minimum detectable activity is the smallest amount of radioactivity in a sample that can be detected with a given probability of erroneously detecting radioactivity, when in fact none was present (Type I, or \(\alpha\), error) and also, a probability of not detecting radioactivity, when in fact it is present (Type II, or \(\beta\), error).

The minimum detectable activity (MDA) is determined using the MARLAP equations above, and applying the efficiency of the instrument and the sample counting time as follows:

\[
MDA \ (dpm) = \frac{S_C + \frac{z_{1-\beta}^2}{2} + z_{1-\beta} \sqrt{\frac{z_{1-\beta}^2}{4} + S_C + R_B t_S \left[ 1 + \frac{t_S}{t_B} \right]}}{E \cdot t_S}
\]

Where:

- \(S_C\) is the critical signal
- \(z_{1-\alpha}\) is the statistical quantile of the standard normal distribution
- \(z_{1-\beta}\) is the statistical quantile of the standard normal distribution
- \(\alpha\) is the Type 1 error, or ‘false positive’ rate (set at 5% for 95%-confidence)
\( \beta \) is the Type 2 error, or ‘false negative’ rate (set at 33\% for 67\%-confidence or 5\% for 95\%-confidence)

\( N_B \) is the number of background counts in the listed interval

\( t_s \) is the sample count time

\( t_B \) is the background count time

\( R_B \) is the count rate of the background

\( E \) is the efficiency of the counting system

When the Type I (\( \alpha \)) and Type II (\( \beta \)) error rate is set to 5\% (95\% confidence level), \( z_{1-\alpha} \) and \( z_{1-\beta} \) equal 1.645. Substituting \( z_{1-\beta} \) and \( z_{1-\alpha} = 1.645 \) into the above equation for MDA, results in the well-known standard form of the equation for Minimum Detectable Activity (MDA):

\[
MDA \ (dpm) = 2.71 + 3.29 \sqrt{\frac{R_B T_g \left( 1 + \frac{T_g}{T_b} \right)}{E_c T_g}}
\]

Where:

- \( MDA \) is the Minimum Detectable Activity
- \( R_B \) is the count rate of the background
- \( T_b \) is the background count time
- \( E_c \) is the instrument efficiency
- \( T_g \) is the sample count time

This is the form of the equation currently used in TF-RC-021, *Analyzing Air and Smear Samples for Alpha and Beta Emissions*, Attachment A, Equation A.3.

It should be noted that the form of the equation provided above does not specifically take into account sample self-absorption considerations, or sample collection efficiencies or surface efficiency effects that may be present in the field. Such modifying factors, if used, would be appropriately included in the denominator in the above equation.

### 4.0 LUDLUM 2360/43-93 DETECTION CAPABILITY TECHNICAL BASIS

Calculation results for the Ludlum Model 2360 ratemeter/scaler/data logger with the Ludlum Model 43-93 Alpha Beta Scintillation Detector 100 cm\(^2\) probe are provided. These results serve as a practical example for the methods provided in this document. Results also provide a basis for field use of the 2360/43-93 instrument.
4.1 **LUDLUM 2360/43-93 BETA SCAN/STATIC/REMOVABLE SURVEYS**

The equation in Section 2.4.1 is used to establish beta scan survey detection capability for the 2360/43-93 at the 67% and 95% survey confidence levels. Standard and typical scan speeds ($v$) of 2 in/s (5 cm/s) and 1 in/s (2.5 cm/s) were used. Indexes of Sensitivity ($d'$) used are as listed in Tables 1 or 4 for the associated confidence level. A beta background count rate ($R_b$) of 500 cpm was used and will be controlled for field use through procedure specification as a maximum allowed beta background count rate. Instrument efficiency ($E$) of 15% was used, and will be controlled for field use through procedure specification as a minimum Cs-137 efficiency calibration value. The 43-93 probe has a physical detector/probe area ($PA$) of 100 cm$^2$ and is 2.73 inches (6.93 cm) wide ($w$) in the narrowest direction of scanning, and these values are used. The detection capability ($MDA$) for the instrument was calculated for these above identified conditions. Results are tabulated in Attachment A, Table A-1, *Ludlum 2360/43-93 Beta Scan Survey Parameters*.

The equation in Section 2.4.2 is used to establish beta static (pause) survey detection capability for the 2360/43-93 at the 67% and 95% survey confidence level. Standard static (pause) count times ($T$) of 5 s and 10 s were used. Indexes of Sensitivity ($d'$) used are as listed in Tables 1 or 4 for the associated confidence level. A beta background count rate ($R_b$) of 500 cpm was used and will be controlled for field use through procedure specification as a maximum allowed beta background count rate. Instrument efficiency ($E$) of 15% was used, and will be controlled for field use through procedure specification as a minimum Cs-137 efficiency calibration value. The 43-93 probe has a physical detector/probe area ($PA$) of 100 cm$^2$, and this value was used in the calculation. The detection capability ($MDA$) for the instrument was calculated for these conditions. Results are tabulated in Attachment A, Table A-2, *Ludlum 2360/43-93 Beta Static/Removable Survey Parameters*.

The equation in section 2.4.3 is used to establish beta removable survey detection capability for the 2360/43-93 at the 67% and 95% survey confidence level. Count times ($T$) of 5 s and 15 s were used. Indexes of Sensitivity ($d'$) used are as listed in Tables 1 or 4 for the associated confidence level. A beta background count rate ($R_b$) of 500 cpm was used and will be controlled for field use through procedure specification as a maximum allowed beta background count rate. Instrument efficiency ($E$) of 15% was used, and will be controlled for field use through procedure specification as a minimum Cs-137 efficiency calibration value. The detection capability ($MDA$) for the instrument was calculated for these conditions. Results are tabulated in Attachment A, Table A-2, *Ludlum 2360/43-93 Beta Static/Removable Survey Parameters*.

4.2 **LUDLUM 2360/43-93 ALPHA SCAN/STATIC/REMOVABLE SURVEYS**

The equation in Section 2.5.1 is used to establish alpha scan survey detection capability for the 2360/43-93 at the 67% and 95% survey confidence level. Standard contamination criteria ($C$) were selected to correspond with routinely desired $MDAs$. The 43-93 probe has a physical detector/probe area ($A$) of 100 cm$^2$ and is 2.73 inches (6.93 cm) wide ($d$) in the narrowest direction of scanning, and these values are used in the calculation. The maximum allowable background is 3 cpm and will be controlled though procedure specification. Instrument efficiency ($E$) of 14% was used, and will be controlled for field use through procedure specification as a minimum Pu-
239 efficiency calibration value. Scan speeds (v) were determined that met the desired detection capability (MDA) for the instrument. The detection capability (MDA) for the instrument was calculated for these conditions. Results are tabulated in Attachment A, Table A-3, *Ludlum 2360/43-93 Alpha Scan Survey Parameters*.

The equation in Section 2.5.2 is used to establish alpha static (pause) survey detection capability for the 2360/43-93 at the 67% and 95% survey confidence level. Standard contamination criteria (C) were selected to correspond with the routinely desired MDAs. The 43-93 probe has a physical detector/probe area (A) of 100 cm², and this value is used in the calculation. The maximum allowable background is 3 cpm and will be controlled though procedure specification. Instrument efficiency (E) of 14% was used, and will be controlled for field use through procedure specification as a minimum Pu-239 efficiency calibration value. Static count times (T) were determined that met the desired detection capability (MDA) for the instrument, and were conservatively rounded for ease of use. Results are tabulated in Attachment A, Table A-4. *Ludlum 2360/43-93 Alpha Static/Removable Survey Parameters*.

The equation of 2.5.3 is used to establish alpha removable survey detection capability for the 2360/43-93 at the 67% and 95% survey confidence level. Standard contamination criteria (C) were selected to correspond with the routinely desired MDAs. The maximum allowable background is 3 cpm and will be controlled though procedure specification. Instrument efficiency (E) of 14% was used, and will be controlled for field use through procedure specification as a minimum Pu-239 efficiency calibration value. Count times (T) were determined that met the desired detection capability (MDA) for the instrument, and were conservatively rounded for ease of use. Results are tabulated in Attachment A, Table A-4. *Ludlum 2360/43-93 Alpha Static/Removable Survey Parameters*.

### 5.0 EBERLINE E140 SERIES AND LUDLUM MODEL 3 SERIES WITH GEIGER-MULLER (GM) PANCAKE PROBES DETECTION CAPABILITY
#### TECHNICAL BASIS

The GM is used to evaluate surfaces for beta contamination. Methods to perform surface contamination measurements for a few applications can be found in Attachment B. The calculation results are based on equations in section 2.5.

### 6.0 PORTABLE ALPHA METER (PAM) RADIATION SURVEY INSTRUMENT DETECTION CAPABILITY
#### TECHNICAL BASIS

The PAM is used to survey material and personnel for alpha contamination by direct frisk or evaluating technical smears for removable alpha activity. Methods to perform alpha contamination measurements for a few applications can be found in Attachment C. The limits given in the tables within Attachment C are typical of contamination limits set forth in 10 CFR 835, Appendix D, for posting and conditional release surveys. The limits for unconditional release surveys were taken from U.S. Department of Energy (DOE) Order 5400.5 Figure IV-1 as approved by DOE O 458.1 and modified with the Nuclear Regulatory Commission (NRC) Regulatory Guide 1.86 as appropriate for unconditional release surveys.
7.0 EXCEPTIONS AND UNPREDICTABLE CONDITIONS

When conditions exist where the general survey procedure described within this document cannot be used for alpha or beta-gamma surveys, a site-specific radiological survey plan may be developed to aid the Radiological Control Technicians in performing the survey. Such conditions may include, but are not necessarily limited to:

1. Source term contamination present on the surface/sample that is not bounded by a minimum efficiencies of Table 2;
2. Background conditions that exceed 500 cpm beta or 3 cpm alpha.
3. Surface/sample conditions that deviate from the assumption of a reasonably clean, dry and smooth surface with little to no self-absorption.

8.0 CALCULATIONAL INSTRUMENT SPECIFICATIONS

Table 2: Minimum 4 Pi Instrument Efficiencies

<table>
<thead>
<tr>
<th>Detector</th>
<th>Physical Width</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(w) (inches)</td>
</tr>
<tr>
<td>GM</td>
<td>1.75</td>
</tr>
<tr>
<td>43-93</td>
<td>2.73</td>
</tr>
<tr>
<td>GM</td>
<td>1.75</td>
</tr>
</tbody>
</table>

Table 2: Minimum 4 Pi Instrument Efficiencies

<table>
<thead>
<tr>
<th>Detector</th>
<th>Minimum 4 Pi Instrument Efficiencies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>90Sr/90Y</td>
</tr>
<tr>
<td></td>
<td>¼”</td>
</tr>
<tr>
<td>GM</td>
<td>0.21</td>
</tr>
<tr>
<td>43-93</td>
<td>0.20</td>
</tr>
<tr>
<td>PAM–50 cm2</td>
<td>--</td>
</tr>
<tr>
<td>PAM–100 cm2</td>
<td>--</td>
</tr>
</tbody>
</table>

a Assume a typical Hanford mixture with >90% of the total activity as 90Sr/90Y and 137Cs.
b Assume a typical Hanford mixture with >90% of the total activity as 90Sr/90Y and 137Cs plus HTDs.
c Based on MSA calibration parameter minimums.

Table 3: Probe Physical Dimensions

<table>
<thead>
<tr>
<th>Detector</th>
<th>Physical Width (w) (inches)</th>
<th>Physical Probe Area (PA) (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 cm² PAM</td>
<td>1.8</td>
<td>54</td>
</tr>
<tr>
<td>100 cm² PAM</td>
<td>3.1</td>
<td>100</td>
</tr>
<tr>
<td>43-93</td>
<td>2.73</td>
<td>100</td>
</tr>
<tr>
<td>GM</td>
<td>1.75</td>
<td>15.5</td>
</tr>
</tbody>
</table>
Table 4: Values of $d'$ for Selected True Positive and False Positive Proportions 
(MARRSIM interpolated values)

<table>
<thead>
<tr>
<th>False Positive Proportion</th>
<th>True Positive Proportion</th>
<th>0.67</th>
<th>0.95</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td></td>
<td>2.08</td>
<td>3.28</td>
</tr>
<tr>
<td>0.10</td>
<td></td>
<td>1.72</td>
<td>2.92</td>
</tr>
<tr>
<td>0.15</td>
<td></td>
<td>1.48</td>
<td>2.68</td>
</tr>
<tr>
<td>0.20</td>
<td></td>
<td>1.28</td>
<td>2.48</td>
</tr>
<tr>
<td>0.25</td>
<td></td>
<td>1.12</td>
<td>2.32</td>
</tr>
<tr>
<td>0.30</td>
<td></td>
<td>0.97</td>
<td>2.16</td>
</tr>
<tr>
<td>0.35</td>
<td></td>
<td>0.83</td>
<td>2.02</td>
</tr>
<tr>
<td>0.40</td>
<td></td>
<td>0.70</td>
<td>1.90</td>
</tr>
<tr>
<td>0.45</td>
<td></td>
<td>0.58</td>
<td>1.77</td>
</tr>
<tr>
<td>0.50</td>
<td></td>
<td>0.44</td>
<td>1.64</td>
</tr>
</tbody>
</table>

9.0 REFERENCES


ATTACHMENT A- LUDLUM 2360/43-93 DETECTION CAPABILITY

Table A-1: Ludlum 2360/43-93 Beta Scan Survey Parameters

<table>
<thead>
<tr>
<th>Confidence Level</th>
<th>Scan Speed</th>
<th>MDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>67%</td>
<td>≤ 2 in/sec (5 cm/sec)</td>
<td>≤ 692 dpm</td>
</tr>
<tr>
<td></td>
<td>≤ 1 in/sec (2.5 cm/sec)</td>
<td>≤ 489 dpm</td>
</tr>
<tr>
<td>95%</td>
<td>≤ 2 in/sec (5 cm/sec)</td>
<td>≤ 1878 dpm</td>
</tr>
<tr>
<td></td>
<td>≤ 1 in/sec (2.5 cm/sec)</td>
<td>≤ 1328 dpm</td>
</tr>
</tbody>
</table>

Table A-2: Ludlum 2360/43-93 Beta Static/Removable Survey Parameters

<table>
<thead>
<tr>
<th>Confidence Level</th>
<th>Count Time</th>
<th>MDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>67%</td>
<td>≥ 5 sec</td>
<td>≤ 661 dpm</td>
</tr>
<tr>
<td></td>
<td>≥ 10 sec</td>
<td>≤ 467 dpm</td>
</tr>
<tr>
<td>95%</td>
<td>≥ 5 sec</td>
<td>≤ 1281 dpm</td>
</tr>
<tr>
<td></td>
<td>≥ 10 sec</td>
<td>≤ 906 dpm</td>
</tr>
</tbody>
</table>

Table A-3: Ludlum 2360/43-93 Alpha Scan Survey Parameters

Due to low limits with alpha emitting isotopes, continuous scans at this speed (≤ 0.75 inches/sec.) are often not possible with any accuracy. When calculated scanning speeds ≤ 0.75 inches/sec are necessary, alternative methods should be derived, such as contiguous short-duration static measurements. Contiguous static counts at 1/4” should be required for alpha detection in lieu of scanning surveys.

<table>
<thead>
<tr>
<th>Confidence Level</th>
<th>Scan Speed</th>
<th>MDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>67%</td>
<td>≤ 2 in/sec (5 cm/sec)</td>
<td>≤ 500 dpm</td>
</tr>
<tr>
<td></td>
<td>≤ 1 in/sec (2.5 cm/sec)</td>
<td>≤ 300 dpm</td>
</tr>
<tr>
<td></td>
<td>≤ 0.5 in/sec (1.3 cm/sec)</td>
<td>≤ 100 dpm</td>
</tr>
<tr>
<td>95%</td>
<td>≤ 1 in/sec (2.5 cm/sec)</td>
<td>≤ 500 dpm</td>
</tr>
<tr>
<td></td>
<td>≤ 0.5 in/sec (1.3 cm/sec)</td>
<td>≤ 300 dpm</td>
</tr>
<tr>
<td></td>
<td>≤ 0.2 in/sec (0.5 cm/sec)</td>
<td>≤ 100 dpm</td>
</tr>
</tbody>
</table>

Table A-4: Ludlum 2360/43-93 Alpha Static/Removable Survey Parameters

<table>
<thead>
<tr>
<th>Confidence Level</th>
<th>Count Time</th>
<th>MDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>67%</td>
<td>≥ 5 sec</td>
<td>≤ 100 dpm</td>
</tr>
<tr>
<td></td>
<td>≥ 10 sec</td>
<td>≤ 70 dpm</td>
</tr>
<tr>
<td></td>
<td>≥ 20 sec</td>
<td>≤ 30 dpm</td>
</tr>
<tr>
<td></td>
<td>≥ 25 sec</td>
<td>≤ 20 dpm</td>
</tr>
<tr>
<td>95%</td>
<td>≥ 15 sec</td>
<td>≤ 100 dpm</td>
</tr>
<tr>
<td></td>
<td>≥ 20 sec</td>
<td>≤ 70 dpm</td>
</tr>
<tr>
<td></td>
<td>≥ 65 sec</td>
<td>≤ 20 dpm</td>
</tr>
</tbody>
</table>
ATTACHMENT B – EBERLINE E140 SERIES AND LUDLUM MODEL 3 SERIES WITH GEIGER-MULLER PANCAKE PROBES DETECTION CAPABILITY

Table B-1: GM Scanning Surveys at a 95% Confidence Level (5,000 dpm/100 cm²)

These levels are based upon listening to the audible output count rate. Contamination is detected when the measurement is perceived to be above background. The maximum background is limited to 150 cpm, the efficiency 13.8%, and the detector being ≤ ¼” above the surface.

Due to small probe size with GM pancake probes, continuous scans at this speed (≤ 0.75 inches/sec.) are often not possible with any accuracy. When calculated scanning speeds ≤ 0.75 inches/sec are necessary, alternative methods should be derived, such as contiguous short-duration static measurements. Contiguous static counts of a minimum of 5 seconds (at 1/4”) should be required for beta detection in lieu of scanning surveys. This will ensure the minimum detectable of 5,000 dpm/100 cm² is met.

<table>
<thead>
<tr>
<th>Radiation Type</th>
<th>Maximum Scan Speed</th>
<th>MDA (dpm/100cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta/Gamma</td>
<td>0.6 in/s (use statics)</td>
<td>4,934</td>
</tr>
</tbody>
</table>

Methods to perform scanning surveys to **three times** the total contamination limits at a 95% Confidence Level are:

<table>
<thead>
<tr>
<th>Radiation Type</th>
<th>Maximum Scan Speed</th>
<th>MDA (dpm/100cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta/Gamma</td>
<td>2 in/s</td>
<td>9,009</td>
</tr>
</tbody>
</table>

Table B-2: GM Scanning Surveys at a 67% Confidence Level (5,000 dpm/100 cm²)

These levels are based upon listening to the audible output count rate. Contamination is detected when the measurement is perceived to be above background. The maximum background is limited to 150 cpm, efficiency 13.8%, and the detector being ≤ ¼” above the surface.

<table>
<thead>
<tr>
<th>Radiation Type</th>
<th>Maximum Scan Speed</th>
<th>MDA (dpm/100cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta/Gamma</td>
<td>2 in/s</td>
<td>3,319</td>
</tr>
</tbody>
</table>
Methods to perform scanning surveys to **three times** the total contamination limits (15,000) at a 67% Confidence Level are:

<table>
<thead>
<tr>
<th>Radiation Type</th>
<th>Maximum Scan Speed</th>
<th>MDA (dpm/100cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta/Gamma</td>
<td>4 in/s</td>
<td>4694</td>
</tr>
</tbody>
</table>

**Table B-3: GM Static Surveys at a 67% or 95% Confidence Level (5,000 dpm/100cm$^2$)**

These levels are based upon listening to the audible output count rate at $\leq \frac{1}{4}$” distance for 5 seconds. Contamination is detected when the measurement is perceived to be above background. When contamination is detected, the activity per 100 cm$^2$ is measured as the sum of six adjacent pancake probe measurements using the meter to quantify the activity. Background is limited to $\leq 150$ cpm and efficiency to $\geq 13.8\%$.

<table>
<thead>
<tr>
<th>Radiation Type</th>
<th>Minimum Count Time</th>
<th>MDA (dpm/100cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta/Gamma</td>
<td>5 sec</td>
<td>2539/4,919</td>
</tr>
</tbody>
</table>

**Table B-4: GM Scanning Surveys at a 67% Confidence Level (1,000 dpm/100cm$^2$)**

Not Possible

**Table B-5: GM Technical Smear Counting at 67% or 95% Confidence Level for 1,000 dpm/100cm$^2$**

These levels are based upon listening to the audible output count rate for 5 seconds. Contamination is detected when the measurement is perceived to be above background. The following methods provide 67% or 95% confidence level to the measurement.

Background is limited to $\leq 150$ cpm and efficiency to $\geq 13.8\%$, with the probe at a distance $\leq \frac{1}{4}$” of swipe.

The scaler function of the Ludlum Model 3 is helpful when performing static surveys, especially at lower count rates.

<table>
<thead>
<tr>
<th>Radiation Type</th>
<th>MDA (dpm/100cm$^2$)</th>
<th>Minimum Count Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta/Gamma</td>
<td>394/762</td>
<td>5 Sec</td>
</tr>
</tbody>
</table>
ATTACHMENT C – PORTABLE ALPHA METER (PAM) RADIATION SURVEY INSTRUMENT DETECTION CAPABILITY

Table C-1: PAM Scanning Surveys at a 95% Confidence Level

These levels are based upon listening to the audible output count rate. When a count is detected, the RCT should stop and evaluate the suspected area for minimum of 5 seconds then scan approximately 13 cm (5 in.) of the previous path at a reduced scan speed. If no additional counts are detected, the survey is continued; otherwise, the area is considered contaminated. The background is assumed to be a maximum of 3 cpm. The probe is maintained within 6 mm (1/4 in) or less of the surface.

Due to low limits with alpha emitting isotopes, continuous scans at this speed (≤ 0.75 inches/sec.) are often not possible with any accuracy. When calculated scanning speeds ≤ 0.75 inches/sec are necessary, alternative methods should be derived, such as contiguous short-duration static measurements. Contiguous static counts, from Table C-3, should be required for alpha detection in lieu of scanning surveys ensuring the minimum detectable activity of the measurement is met. If elevated activity is indicated, a longer duration static measurement is taken at that position to confirm the total average contamination criteria are not exceeded.

Methods to perform 95% confident scanning surveys to the total contamination limits (100/500 dpm/100 cm²) are:

<table>
<thead>
<tr>
<th>Radiation Type</th>
<th>Instrument</th>
<th>Maximum Scan Speed</th>
<th>MDA (dpm/100cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α:100</td>
<td>50 cm² Probe</td>
<td>Not possible</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>100 cm² Probe</td>
<td>Not Possible</td>
<td>NA</td>
</tr>
<tr>
<td>α:500</td>
<td>50 cm² Probe</td>
<td>0.4 in/s</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>100 cm² Probe</td>
<td>1 in/s</td>
<td>390</td>
</tr>
</tbody>
</table>

Methods to perform 95% confident scanning surveys to three times the total contamination limits (300/1,500) are:

<table>
<thead>
<tr>
<th>Radiation Type</th>
<th>Instrument</th>
<th>Maximum Scan Speed</th>
<th>MDA (dpm/100cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α :300</td>
<td>50 cm² Probe</td>
<td>Not Possible</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>100 cm² Probe</td>
<td>0.75 in/s</td>
<td>290</td>
</tr>
<tr>
<td>α:1,500</td>
<td>50 cm² Probe</td>
<td>1 in/s</td>
<td>1200</td>
</tr>
<tr>
<td></td>
<td>100 cm² Probe</td>
<td>3 in/s</td>
<td>1200</td>
</tr>
</tbody>
</table>
Table C-2: PAM Scanning Surveys at a 67% Confidence Level

Conditional release surveys of material and equipment, posting surveys, and personnel frisking require a 67% confident survey. The following methods provide 67% confidence level to the measurement.

These levels are based upon listening to the audible output count rate. When a count is detected, the RCT should stop and evaluate the suspected area for 5 seconds then scan approximately 13 cm (5 in.) of the previous path at a reduced scan speed. If no additional counts are detected, the survey is continued; otherwise, the area is considered contaminated. The background is assumed to be a maximum of 3 cpm. The probe is maintained within 6 mm (¼ in.) or less of the surface.

Due to low limits with alpha emitting isotopes, continuous scans at this speed (≤ 0.75 inches/sec.) are often not possible with any accuracy. When calculated scanning speeds ≤ 0.75 inches/sec are necessary, alternative methods should be derived, such as contiguous short-duration static measurements. Contiguous static counts, from Table C-4, should be required for alpha detection in lieu of scanning surveys ensuring the minimum detectable activity of the measurement is met. If elevated activity is indicated, a longer duration static measurement is taken at that position to confirm the total average contamination criteria are not exceeded.

Methods to perform 67% confident scanning surveys to the total contamination limits (100/500 dpm/100 cm²) are:

<table>
<thead>
<tr>
<th>Limit (dpm/100cm²)</th>
<th>Instrument</th>
<th>Maximum Scan Speed</th>
<th>MDA (dpm/100cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α: 100</td>
<td>50 cm² Probe</td>
<td>Not Possible</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>100 cm² Probe</td>
<td>Not Possible</td>
<td>NA</td>
</tr>
<tr>
<td>α: 500</td>
<td>50 cm² Probe</td>
<td>1 in/s</td>
<td>430</td>
</tr>
<tr>
<td></td>
<td>100 cm² Probe</td>
<td>2 in/s</td>
<td>290</td>
</tr>
</tbody>
</table>

Methods to perform 67% confident scanning surveys to three times the total contamination limits are:

<table>
<thead>
<tr>
<th>Three Times Limit (dpm/100cm²)</th>
<th>Instrument</th>
<th>Maximum Scan Speed</th>
<th>MDA (dpm/100cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α: 300</td>
<td>50 cm² Probe</td>
<td>0.7 in/s (use statics)</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>100 cm² Probe</td>
<td>2 in/s</td>
<td>290</td>
</tr>
<tr>
<td>Three Times Limit (dpm/100cm²)</td>
<td>Instrument</td>
<td>Maximum Scan Speed</td>
<td>MDA (dpm/100cm²)</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------------</td>
<td>--------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>α: 1,500</td>
<td>50 cm² Probe</td>
<td>3 in/s</td>
<td>1300</td>
</tr>
<tr>
<td></td>
<td>100 cm² Probe</td>
<td>6 in/s</td>
<td>860</td>
</tr>
</tbody>
</table>

**Table C-3: PAM Static Surveys at a 95% Confidence Level**

These levels are based upon listening to the audible output count rate for the time period specified. When a count is detected, the RCT should reevaluate the suspected area for an additional time period, as specified for the measurement. If no additional counts are detected, the survey is continued. Otherwise, the area is considered contaminated. The background is a maximum of 3 cpm. The probe is placed at ≤ ¼” of the surface during the survey.

<table>
<thead>
<tr>
<th>Limit (dpm/100cm²)</th>
<th>Instrument</th>
<th>Count Time</th>
<th>MDA (dpm/100cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α: 100</td>
<td>50 cm² Probe</td>
<td>30 s</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>100 cm² Probe</td>
<td>20 s</td>
<td>60</td>
</tr>
<tr>
<td>α: 300</td>
<td>50 cm² Probe</td>
<td>10 s</td>
<td>210</td>
</tr>
<tr>
<td></td>
<td>100 cm² Probe</td>
<td>5 s</td>
<td>250</td>
</tr>
</tbody>
</table>

**Table C-4: PAM Static Surveys at 67% Confidence Level**

These levels are based upon listening to the audible output count rate for the time period specified. When a count is detected, the RCT should reevaluate the suspected area for an additional time period, as specified for the measurement. If no additional counts are detected, the survey is continued. Distance is ≤ ¼”.

Otherwise, the area is considered contaminated. The background is assumed to be a maximum of 3 cpm.

<table>
<thead>
<tr>
<th>Limit (dpm/100cm²)</th>
<th>Instrument</th>
<th>Count Time</th>
<th>MDA (dpm/100cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α: 100</td>
<td>50 cm² Probe</td>
<td>10 s</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>100 cm² Probe</td>
<td>5 s</td>
<td>88</td>
</tr>
<tr>
<td>α: 300</td>
<td>50 cm² Probe</td>
<td>5 s</td>
<td>155</td>
</tr>
<tr>
<td>Limit (dpm/100cm$^2$)</td>
<td>Instrument</td>
<td>Count Time</td>
<td>MDA (dpm/100cm$^2$)</td>
</tr>
<tr>
<td>-----------------------</td>
<td>--------------</td>
<td>------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>100 cm$^2$ Probe</td>
<td>5 s</td>
<td>88</td>
<td></td>
</tr>
</tbody>
</table>

**Table C-5: PAM Smear Counting Techniques to Achieve 20 dpm Sensitivity at 67%**

67% PAM Smear Counting Techniques to Achieve 20 dpm Sensitivity when Background is a maximum of 3 cpm and distance is ≤ ¼”.

<table>
<thead>
<tr>
<th>Limit (dpm/100cm$^2$)</th>
<th>Instrument</th>
<th>Count Time</th>
<th>MDA (dpm/100cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α: 20</td>
<td>50 cm$^2$ Probe</td>
<td>30 s</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>100 cm$^2$ Probe</td>
<td>30 s</td>
<td>15</td>
</tr>
</tbody>
</table>

**Table C-6: PAM Smear Counting Techniques to Achieve 70 dpm Sensitivity at 67%**

67% PAM Smear Counting Techniques to Achieve 70 dpm Sensitivity when background is a maximum of 3 cpm and distance is ≤ ¼”.

<table>
<thead>
<tr>
<th>Limit (dpm/100cm$^2$)</th>
<th>Instrument</th>
<th>Count Time</th>
<th>MDA (dpm/100cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α: 70</td>
<td>50 cm$^2$ Probe</td>
<td>10 s</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>100 cm$^2$ Probe</td>
<td>10 s</td>
<td>44</td>
</tr>
</tbody>
</table>

**Table C-7: PAM Smear Counting Techniques to Achieve 20 dpm Sensitivity at 95% Confidence**

95% PAM Smear Counting Techniques to Achieve 20 dpm sensitivity when background is a maximum of 3 cpm and distance is ≤ ¼”.

<table>
<thead>
<tr>
<th>Limit (dpm/100cm$^2$)</th>
<th>Instrument</th>
<th>Count Time</th>
<th>MDA (dpm/100cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α: 20</td>
<td>50 cm$^2$ Probe</td>
<td>60 s</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>100 cm$^2$ Probe</td>
<td>60 s</td>
<td>20</td>
</tr>
</tbody>
</table>
Table C–8: PAM Smear Counting Techniques to Achieve 70 dpm Sensitivity at 95% Confidence

¼", 95% PAM Smear Counting Techniques to Achieve 70 dpm Sensitivity when Background is a maximum of 3 cpm

<table>
<thead>
<tr>
<th>Limit (dpm/100cm²)</th>
<th>Instrument</th>
<th>Count Time</th>
<th>MDA (dpm/100cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α: 70</td>
<td>50 cm² Probe</td>
<td>20 s</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>100 cm² Probe</td>
<td>20 s</td>
<td>60</td>
</tr>
</tbody>
</table>