PNNL-14135-Rev. 1

U.S. DEPARTMENT OF ENERGY
Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Radiation Protection Instrument Manual PNL-MA-562

ML Johnson

August 2009

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Pacific Northwest National Laboratory
Richland, Washington 99352

Preface

This technical report contains Pacific Northwest National Laboratory's (PNNL) Radiation Protection Instrument Manual (PNL-MA-562) which was previously maintained by PNNL as a controlled manual.

The Hanford Instrument Evaluation Committee (HIEC) provides guidance on the content of PNL-MA-562 to ensure that it is a viable resource for each Hanford Site prime contractor. The HIEC includes a representative from each Hanford prime contractor who can address instrumentation needs and issues for their company, and one member each from the U.S. Department of Energy Richland Operations Office and Office of River Protection. The list of HIEC recommended radiation detection instruments and associated procedures were removed from PNL-MA-562 in 2009 and moved to a controlled document in PNL-MA-563, *Radiological Calibration Procedures*. This HIEC reviewed manual provides compliance with the U.S. Department of Energy (DOE) Radiological Control Standard (DOE-STD-1098-99) by recommending radiation detection instruments, which meet the operational needs of the Hanford Radiological Control Organizations, as standard instruments for use at Hanford.

This technical report was prepared by IS&T. Questions, comments, or requests for additional copies should be referred to the Radiological Calibration Laboratory Manager, IS&T, at (509) 376-5624.

Acknowledgments

This document is the compilation of the efforts of several staff members who have worked in the Radiological Calibration Laboratory over the past 20 years. Significant contributions were made by DM Fleming, JE Edmonds, TE Bratvold, LV Zuerner, VA Benton, RA Curd, AP Mileham, and RL Kathren.

Acronyms and Abbreviations

°	degree
α	alpha
β	beta
γ	gamma
AC	alternating current
ACS	alpha check source
ANSI	American National Standards Institute
APM	automated personnel monitor
ARA	airborne radioactivity area
ASP	alarm set point
BBCP	Bumble Bee CP
BNC	bayonet nut connector
BW	Black Widow
BWCP	Black Widow CP
C	celsius (°C) or capacitor (C)
CA	contamination area
CAM	continuous air monitor
cfm	cubic feet per minute
CFR	U.S. Code of Federal Regulations
cm	centimeter
CP	Cutie Pie (rate meter)
cpm	counts per minute
CRM	count rate meter
DAC	derived air concentration
DAC-hr	derived air concentration-hour
DIP (switch)	dual inline package
DMM	digital multi-meter
DOE	U.S. Department of Energy
dpm	disintegrations per minute
eV	electron volt
F	Fahrenheit

FIDLER	field instrument for detecting low-energy radiation
GCS	Gamma Calibration System
GM	Geiger-Müller
HCA	high contamination area
HEPA	high-efficiency particulate air
HFM	hand and foot monitor
HIEC	Hanford Instrument Evaluation Committee
hr	hours
HV	high voltage
ICCS	ion chamber check source
in	inches
IR	infrared
IS&T	Instrumentation Services and Technology
lb	pounds
LED	light-emitting diode
LO	"low"
lpm	liters per minute
Max.	maximum
MCA	multi-channel analyzer
MDA	minimum detectable activity
MDC	minimum detectable concentration
MeV	mega electron volt
MFP	mixed fission products
mg	milligram
MHV	mega high-voltage
MHz	megahertz
Min.	minimum
mm	millimeter
mR	millirad
NA	not applicable
nCi	nanocurie
NEDA	National Electronic Distributors Association

NIST	National Institute of Standards and Technology
NRC	U.S. Nuclear Regulatory Commission
NRD	neutron rem detector
NVRAM	nonvolatile random access memory
ORNL	Oak Ridge National Laboratory
ORP	Office of River Protection
PAM	portable alpha meter
PAS	portable alpha scaler
PCM	personnel contamination monitor
PIPS	passivated implanted planar silicon
PMT	photomultiplier tube
PNL	Pacific Northwest Laboratory
PNNL	Pacific Northwest National Laboratory
psig	pounds per square inch gauge
R	resistor
RAM	Random Access Memory
RBA	Radiological Buffer Area
RC	resistor/capacitor
RDA	reliably detectable activity
RH	relative humidity
RL	U.S. Department of Energy, Richland Operations Office
s	seconds
SENS	sensitivity
SF	Sigma Factor
V	Volts

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1.0 Introduction

1.1 Purpose

This document was prepared by the staff of the Pacific Northwest National Laboratory (PNNL) Instrumentation Services and Technology (IS&T) Group for use by radiological control organizations. It provides specific information for operating and using portable radiological monitoring instruments available for use on the Hanford Site.

Many of the more common portable instruments are available through a portable instrument pool maintained by IS&T. Other instruments are owned by the individual facilities and/or contractors.

1.2 Scope

Each section provides information on operating and using a particular instrument or instrument system. Each section provides not only the basic operational criteria but also data regarding response, such as energy and angular dependence. Additional information is provided to assist the knowledgeable user in proper interpretation of the text. Cautionary information is included to prevent misuse or misapplication of the instruments and thereby eliminate accidental or unnecessary radiation exposures to personnel.

1.3 Use of this Document

This document is available at calibration.pnl.gov. The document may be used as a reference guide for all questions regarding the operation or use of many of the portable radiological monitoring instruments available through the Hanford instrument pool.

Much of the information in this document was obtained from technical manuals prepared by the instrument manufacturers. A bibliography of technical manuals, which in many cases includes substantially more information than found in this manual, is available at the end of this manual.

Other information, primarily minimum detectable activities and environmental limitations, is from internally published letters, memos, and technical reports. A majority of these are not readily available to the public. In many cases, copies can be obtained by contacting the Radiological Calibration Laboratory Manager at (509) 376-5624.

Unfortunately, not all of the desired information can be included in this document. Out of necessity, certain data of limited interest or infrequent application have been excluded in the interest of readability, brevity, and cost effectiveness. Additional information and answers to questions regarding instrumentation or field measurements can be obtained from PNNL's Radiological Calibration Laboratory Manager at (509) 376-5624.

2.0 Approved Instrument List

2.1 Introduction

Historically, Section 2.0 of this document has listed instruments approved by the Hanford Instrument Evaluation Committee (HIEC) for use at the Hanford Site. This list is now maintained as a controlled document by the Hanford site calibration contractor. At the time this document was prepared, the Hanford site calibration contractor was Battelle, Pacific Northwest Division, and the calibration group was Instrumentation Services and Technology. Calibrations were performed at PNNL's Radiological Calibration Laboratory at Building 318, in the Hanford Site 300 Area. A current copy of the Approved Instrument List can be obtained by contacting the calibration laboratory Manager.

3.0 The Eberline RO-3B (CP) Radiation Survey Instrument

3.1 Instrument Description and Theory of Operation

The Eberline RO-3B, commonly called the Hanford Cutie Pie (CP), is a portable, pistol-shaped rate meter with an air-filled ionization chamber used to detect beta, gamma, and x-ray radiation (see Figures 3.1 and 3.2). The instrument is similar to the industry-standard Eberline RO-3, except that the switching order is reversed. The barrel of the instrument is the ionization chamber, which is a phenolic resin tube with a beta window consisting of a thin film of aluminized polycarbonate covering the front end. A removable beta shield of the same phenolic resin prevents most non-penetrating radiation from penetrating the beta window.

More detailed technical information can be obtained by contacting the PNNL calibration laboratory at (509) 376-5624.

3.1.1 Physical Description

The CP weighs 1.6 kg (3.5 lb). It measures 28 cm (11 in.) long by 25 cm (9.8 in.) high by 9.4 cm (3.7 in.) wide, including the handle. The ion chamber is a cylinder, 7.6 cm (3 in.) in diameter and 10 cm (4 in.) long, for a total volume of 465 cm^3 (28.4 $in.^3$). The chamber wall and beta shield density thickness are about 400 mg/cm^2. The beta window is made of one layer of aluminized polycarbonate and one layer of a clear, protective material. The total density thickness of the beta window is 7 mg/cm^2.

The CP has four linear ranges of operation, calibrated in units of exposure rate. 0 mR/hr to 5 mR/hr, 0 mR/hr to 50 mR/hr, 0 mR/hr to 500 mR/hr, and 0 mR/hr to 5,000 mR/hr.

Response time is relatively rapid—less than five seconds are required for the instrument to respond from 10% to 90% of the final reading on the two lower ranges, and less than three seconds are required on the two upper ranges.

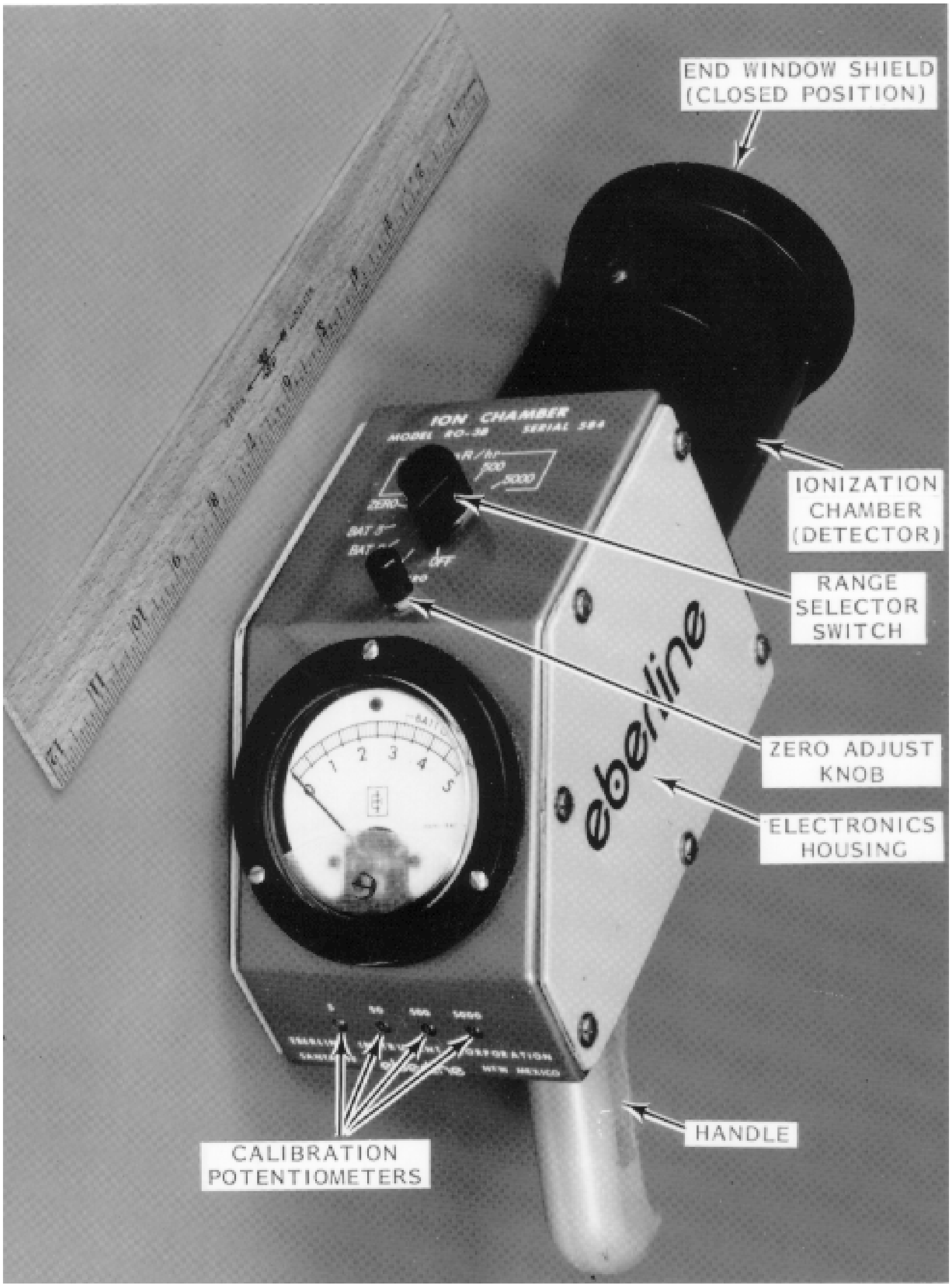

Figure 3.1. Hanford CP with End Window Shield in Closed Position

IONIZATION
CHAMBER
(detector)

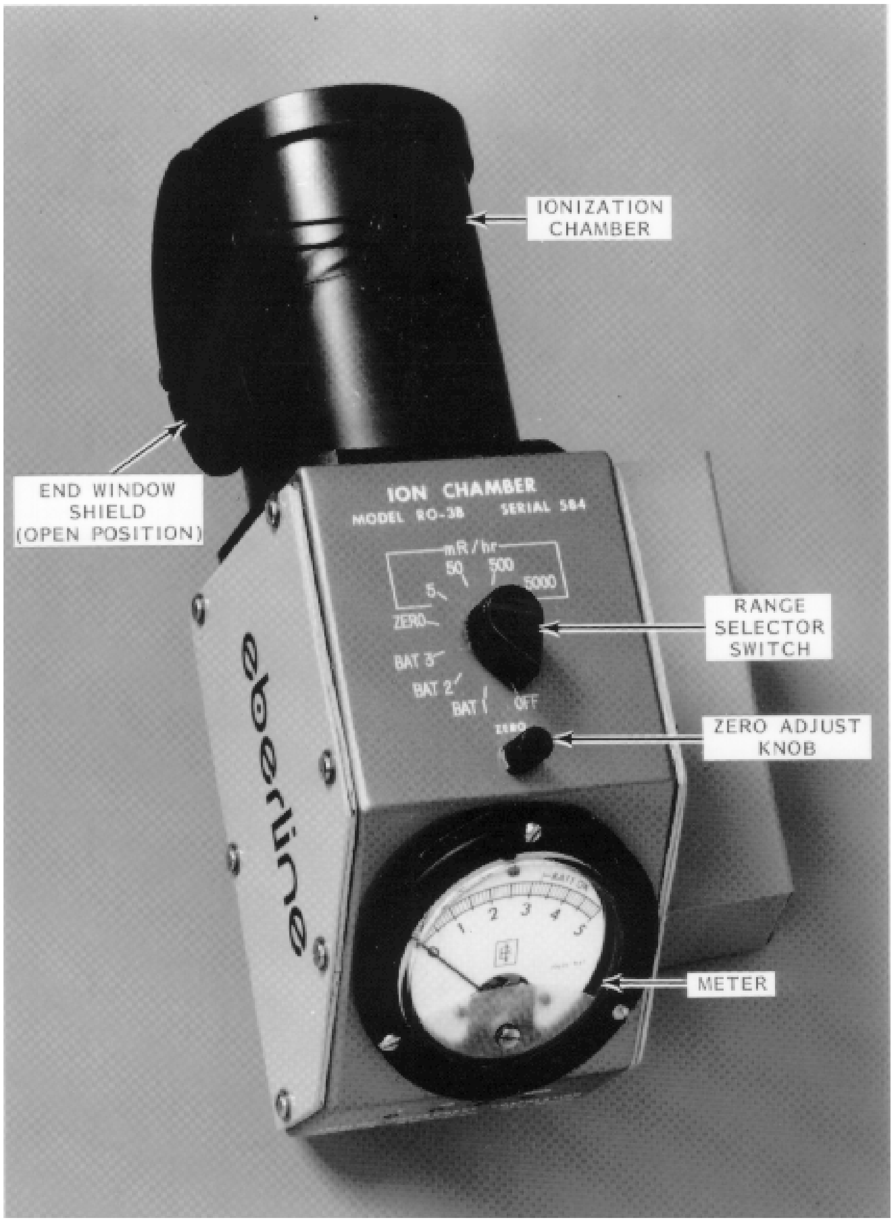

Figure 3.2. Hanford CP with End Window Shield in Open Position

3.1.2 Radiation and Energy Response

With the beta shield in place (window closed), the CP responds to photons with energies above about 10 keV, and beta particles with energies greater than 1 MeV (e.g., ^{90}SrY). The thin end window is too thick to admit alpha particles with energies less than 6 MeV, so for all practical purposes, the CP does not respond to alpha radiation. The CP also does not respond to neutrons.

3.1.3 Integral Sources

There are no radioactive sources attached to the CP.

3.2 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions in this section are provided as an example of acceptable methods.

3.2.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the instrument fails any of the operability checks, other than the battery test, fill out an Instrument Service Tag to identify the problem, attach it to the instrument, and return the instrument to the PNNL calibration laboratory for servicing.

- Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) on the expiration date on the calibration sticker.
- Ensure that the instrument source check is current. Source checks are generally valid for the day performed, and typically do not cover more than 24 hours.

NOTE: *Missing beta shields can be replaced in the field. Contact the Radiological Calibration Facility (the Calibration Lab) for a new beta shield.*

- Inspect the instrument for physical defects, such as broken meter glass, loose knobs, punctured windows, and broken handles.
- Turn the selector switch to BAT 1. The meter reading should be above the BATT cutoff line. Repeat this procedure for the BAT 2 and BAT 3 positions.
- Turn the selector switch to the ZERO position and, using the zero knob, set the instrument to zero.
- Check for erratic meter response (Turn the selector switch to the 5 mR/hr range and observe the meter needle for erratic behavior. Rotate the instrument from side to side and observe the meter needle).

3.2.2 Source Check

The CP may be source checked using a book source, linear beta source, or an ion chamber check source (ICCS) assembly. The initial source check is usually performed when the instrument is first received from the calibration laboratory. Source checks are performed daily, or before each use if the CP is used less often than daily.

3.2.2.1 Initial Source Check

Initial source checks should be performed immediately upon receiving a CP from the calibration laboratory. CPs should not be placed into storage until after performing the initial source check.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure that the values are reasonable. For the CP, the initial response is considered reasonable when the response is within*:

- *the acceptable ranges printed on a calibrated source assembly*
- *±20% of the mean instrument response for that source.*

NOTE: *As a reference, near contact measurements of a 47 mm 90SrY disk source with a CP resulted in a response of approximately 15.7 mR/h/kdpm. This was obtained with the source on a plane even with CP retaining ring.*[1]

Remove the beta shield from the window and center the CP window over the source position on the check source assembly. Move the source to the appropriate position for each range of the instrument and record the instrument's response on each range. Multiply the instrument's response by 0.8 and 1.2 to determine the acceptable range for that instrument.

3.2.2.2 Daily Source Check

NOTE: *The source used to perform the initial source check is used to perform the daily source check. To perform a daily source check with a source other than the one used for the initial source check, first perform the daily source check on the source used for the initial source check. If the instrument passes that daily source check, then perform a new initial source check using the new source to establish response limits for that source/CP combination.*

Remove the beta shield from the window and place the CP window over the source position on the check source assembly. Move the source to the appropriate position for each range of the instrument. The instrument response on each range should fall within the acceptable values determined during the initial source check. If the instrument fails, tag it with an Instrument Service Tag and return it to the calibration laboratory.

Source checks are generally valid for 24 hours after they are performed.

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[1] A Utter, PNNL data sheet, 11/10/1999

3.3 Operating Instructions

Before using the CP, perform the operability checks to make sure the instrument is in good working condition (see Section 3.3, Performance Test Instructions, for examples of typical operability checks). These checks should be performed each time the instrument is used.

To perform a radiation survey, turn the CP selector switch to the desired range and move the CP slowly while observing the meter response. When a measurement is to be performed at a particular location, allow at least one time constant (five seconds on lowest range) for the reading to stabilize on the final value.

NOTE: *When selecting the most sensitive range (5 mR/hr), switching noise may cause a temporary meter deflection. This can be avoided by first selecting a higher range, letting the needle settle, then switching to the 5 mR/hr range.*

In unknown fields, remove the beta shield to allow the CP to respond to both penetrating and non-penetrating radiations. Point the instrument toward possible sources of radiation. If the area is known to have only gamma radiation, the beta shield does not need to be removed.

Avoid contact between the instrument and other objects. Besides possible instrument contamination, pressure on the thin plastic window will cause false and erratic meter readings (from capacitive effects) and might puncture or rupture the window. If the metal case touches other metal objects, the reading may drop suddenly to zero (with recovery after a short delay).

The CP can be damaged by electrostatic discharge.[(2)] If damage is suspected while surveying (e.g., instrument is dropped or static discharge is observed/suspected), then perform an operational check and source check, or if an established field is available, assure the response is within ± 20% of the established value. An established value may be a previous reading or a well known, constant, non-zero field.

To ground the CP, in order to discharge static in a controlled manner and prevent instrument damage (e.g., before entering an ignition controlled area), turn instrument to the "OFF" or "ZERO" position, and then touch the metal case to any grounded metal surface. Under conditions where a high potential for static build-up (dry conditions) exists, the CP should be grounded frequently (approximately once every hour) and before making a measurement near (within one inch) a grounded object.

If necessary, multiply the CP reading by appropriate correction factors. Correction factors are required when measuring non-uniform fields (e.g., contact measurements or beaming radiation) and when the ambient temperature is less than 0°C (32°F). Correction factors are provided later in this section.

Calculate shallow and deep dose rates as follows:

$$\text{Deep Dose Rate} = \text{WC} \times \text{CF}_{\text{pen}} \times \text{CF}_{\text{temp}} \quad (3.1)$$

$$\text{Shallow Dose Rate} = [(\text{WO} - \text{WC})\text{CF}_{\text{non-pen}} + \text{WC} \times \text{CF}_{\text{pen}}] \times \text{CF}_{\text{temp}} \quad (3.2)$$

[1] Hanford Instrument Evaluation Committee Minutes, October 21, 1997, Attachment 4

where:

WC	=	instrument response with the window closed
WO	=	instrument response with the window open
$CF_{non\text{-}pen}$	=	non-penetrating (i.e., beta) correction factor
CF_{pen}	=	penetrating (i.e., gamma) correction factor
CF_{temp}	=	temperature correction factor

When the WC indication is less than one tenth of the WO indication (WC <0.1WO), then the calculation for shallow dose can be simplified as follows:

$$WO \times CF_{non\text{-}pen} \times CF_{temp} \quad (3.3)$$

3.3.1 Correction Factors

Small beam correction factors are used when the beam is too narrow to ionize the air in the chamber uniformly (i.e., beam diameter is less than 3 in.). Small beam correction factors are calculated as the ratio of the chamber cross-sectional area to the beam cross-sectional area. When measuring beams parallel to the chamber, the beam must be coaxial with the chamber. Though beams are not typically observed with non-penetrating radiation, the beam correction factors are applied to both penetrating and non-penetrating beam conditions.

To determine the beam correction factor, use the CP correction factor chart on the side of the instrument (Figure 3.3), except where $CF_{non\text{-}pen} < 3$. A minimum value of 3 for beam sources of nonpenetrating radiation should be used.

Geometry correction factors are used when the CP measurements are taken with the CP window less than 6 in. from the source. If the CP window is less than 1 in. from the source, use the correction factors provided in Table 3.1, and on the side of the CP. If the CP window is ≥1 in. and <6 in. from the source, then: $CF_{non\text{-}pen} = 3$ and $CF_{pen} = 1.5$. More detailed correction factors for specific geometries are shown in Figures 3.4, 3.5, and 3.6.

Table 3.1. CP Correction Factors to Obtain Exposure Rate at the Window

<table>
<tr><th rowspan="2">Diameter[(a)]
in.</th><th colspan="4">Disc</th><th colspan="3">Disc and Field</th></tr>
<tr><th>β @
Contact</th><th>γ @
Contact</th><th>β @
½ in.</th><th>γ @
½ in.</th><th>β @
≥1 in.</th><th>γ @
≥1 in.,
<6 in.</th><th>γ @
≥6 in.[(d)]</th></tr>
<tr><td><1/2 in.</td><td>100</td><td rowspan="2">40</td><td>10</td><td rowspan="3">4</td><td rowspan="8">3</td><td rowspan="8">1.5</td><td rowspan="8">1</td></tr>
<tr><td>½ in.</td><td>90</td><td>9</td></tr>
<tr><td>¾ in.</td><td>54</td><td>30</td><td>6</td></tr>
<tr><td>1 in.</td><td>35</td><td>23</td><td>5</td><td rowspan="2">3</td></tr>
<tr><td>1 ½ in.</td><td>17</td><td>13</td><td>4</td></tr>
<tr><td>2 in.</td><td>9</td><td>8</td><td rowspan="3">3</td><td rowspan="3">2</td></tr>
<tr><td>3 in.</td><td rowspan="2">4.5</td><td>4</td></tr>
<tr><td>>3 in.</td><td>2</td></tr>
</table>

<table>
<tr><th rowspan="2">Diameter
in.</th><th rowspan="2">Beam</th><th colspan="4">Cylinder[(b)]</th></tr>
<tr><th>β >3 in.[(c)]</th><th>γ 4 in.</th><th>γ
8 in.</th><th>γ 4 ft.</th></tr>
<tr><td><1/2 in.</td><td>144</td><td>47</td><td>26</td><td>20</td><td>8</td></tr>
<tr><td>½ in.</td><td>36</td><td>30</td><td>18</td><td>13</td><td>7</td></tr>
<tr><td>¾ in.</td><td>17</td><td>17</td><td>12</td><td>9</td><td>5</td></tr>
<tr><td>1 in.</td><td>9</td><td>10</td><td>9</td><td>7</td><td>4</td></tr>
<tr><td>1 ½ in.</td><td>4</td><td>7</td><td>6</td><td>5</td><td rowspan="2">3</td></tr>
<tr><td>2 in.</td><td>2</td><td>6</td><td>5</td><td>4</td></tr>
<tr><td>3 in.</td><td rowspan="2">1</td><td rowspan="2">5</td><td rowspan="2">4[(a)]</td><td rowspan="2">3[(a)]</td><td rowspan="2">2[(a)]</td></tr>
<tr><td>>3 in.</td></tr>
</table>

(a) γ correction for source diameter ≥18 in. = 1.0.
(b) Cylinder is on contact w/end of CP barrel; axis of cylinder is perpendicular to axis of CP chamber.
(c) Dimension is the cylinder length.
(d) For measurements at greater than 6 in., measure the distance between centerline of the instrument chamber and the source.

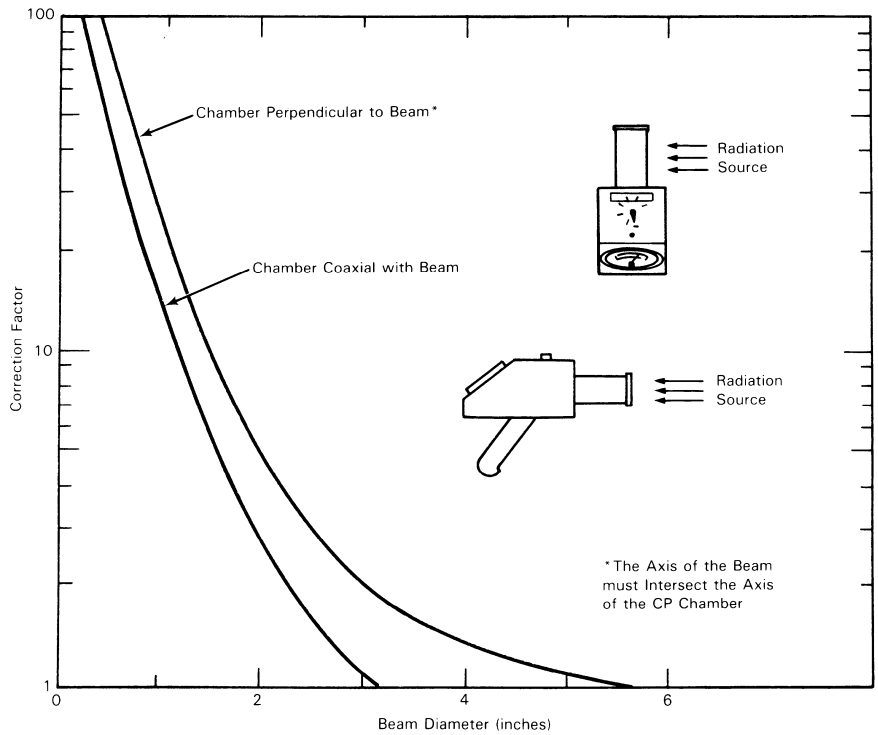

Figure 3.4. Small-Beam Correction Factors for the CP

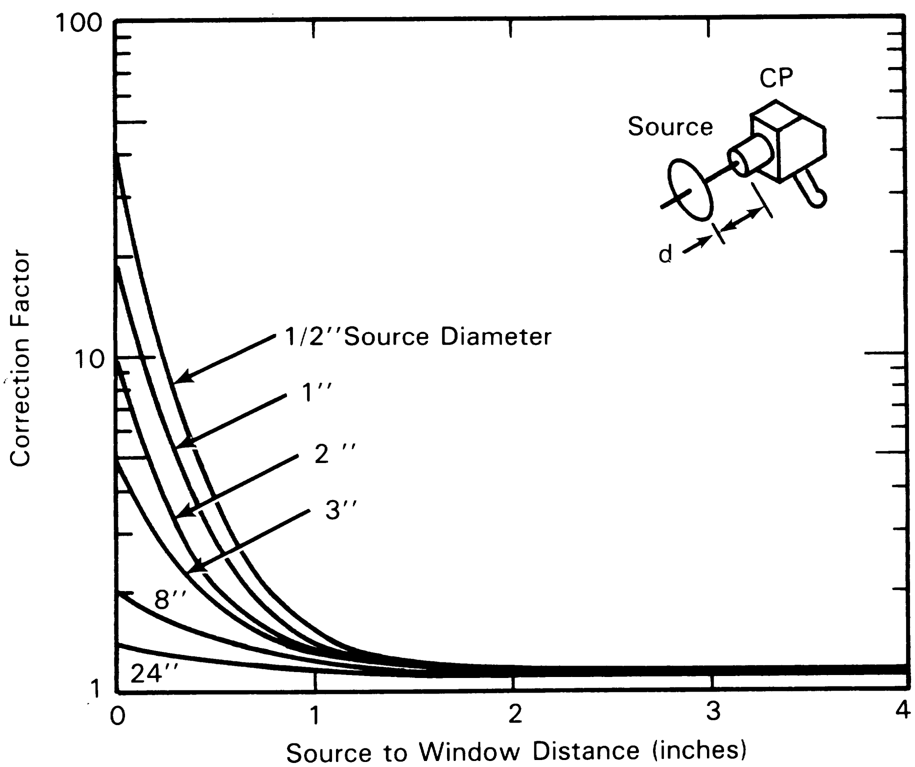

Figure 3.5. Penetrating Radiation Source Size and Distance Correction Factors for Disk Sources

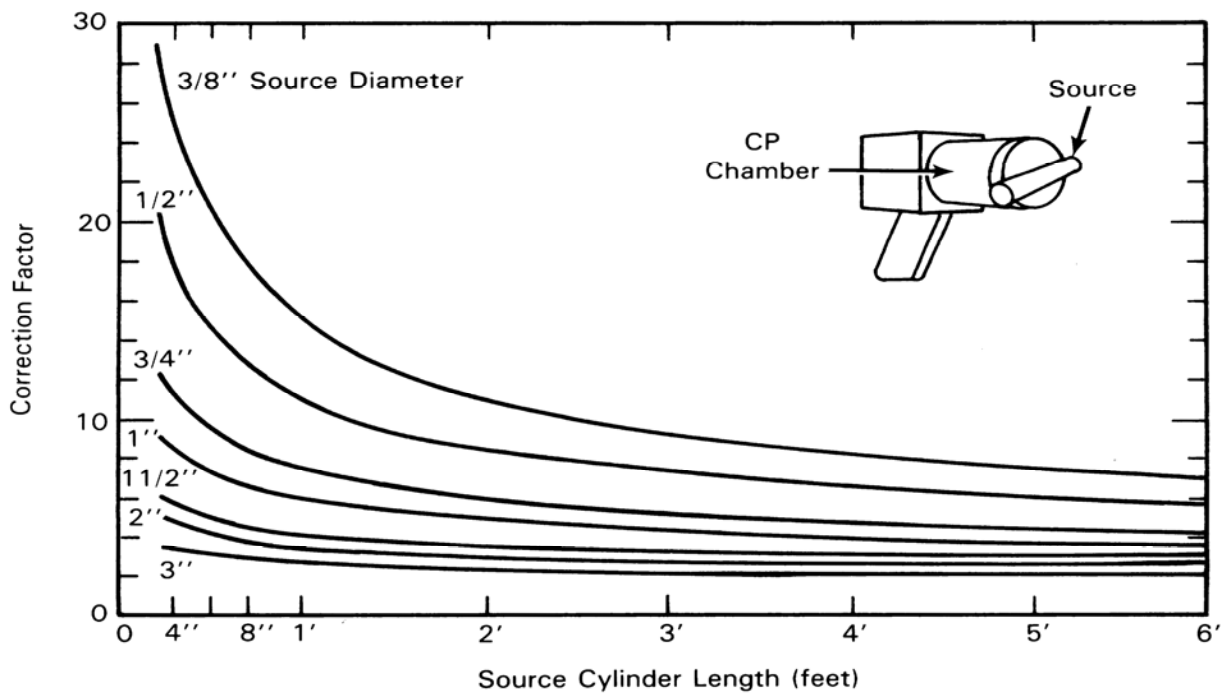

Figure 3.6. Correction Factors for Contact Dose Rates with Cylindrical Surface for Penetrating Radiation

Beta correction factors are used when non-penetrating radiation fields are measured. Multiply all non-penetrating exposure rate (WO - WC) CP readings by 3 ($CF_{non\text{-}pen} = 3$) unless the CP window is < 1 in. from the source. If the CP window is < 1 in. from the source, use the correction factors provided in Table 3.1 and on the side of the CP.

Temperature correction factors are used when the CP is used in an environment where the temperature is less than 0°C (32°F). The correction factors account for changes in air density with temperature. Correction factors are calculated in the following manner:

$$CF = \frac{273.15\text{ K} + \text{actual temperature}}{273.15\text{ K} + \text{reference temperature}}$$

where reference temperature is the temperature in Celsius at calibration, typically 22°C, and actual temperature is the temperature in Celsius of the operating environment. The correction factors are given in Table 3.2, Figure 3.7, and on a sticker on the instrument.

Photon energy correction factors are used when measuring photons energies below 100 keV. For these energies, use the appropriate correction factor from Figures 3.8 and 3.9. These correction factors can be used for the complete photon energy spectrum when the shield is in place or removed. With proper correction, the exposure rate from x-rays can also be measured if the effective energy is known.

Table 3.2. Temperature Correction Factors for Eberline RO-3B

If Temperature is	**Multiply Instrument Response by**
0°F to 32°F (-17°C to 0°C)	0.90
-20°F to 0°F (-29°C to -17°C)	0.85

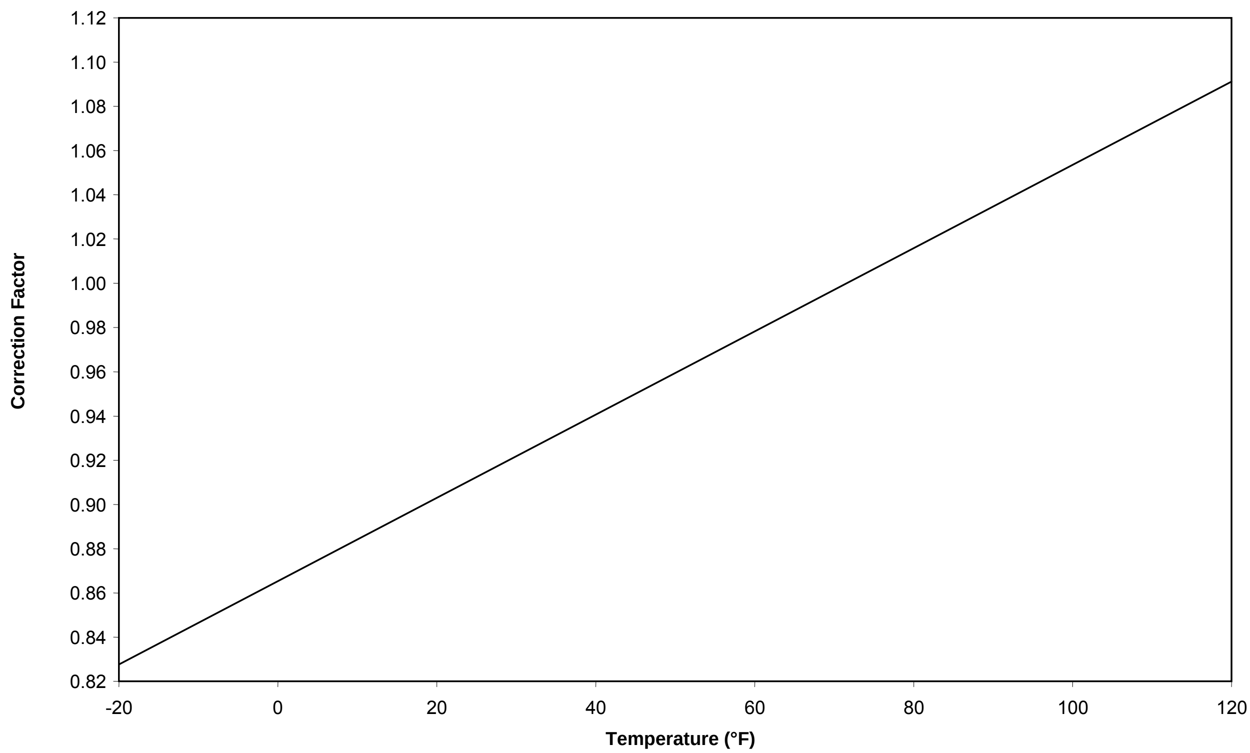

Figure 3.7. Temperature Correction Factors for the CP

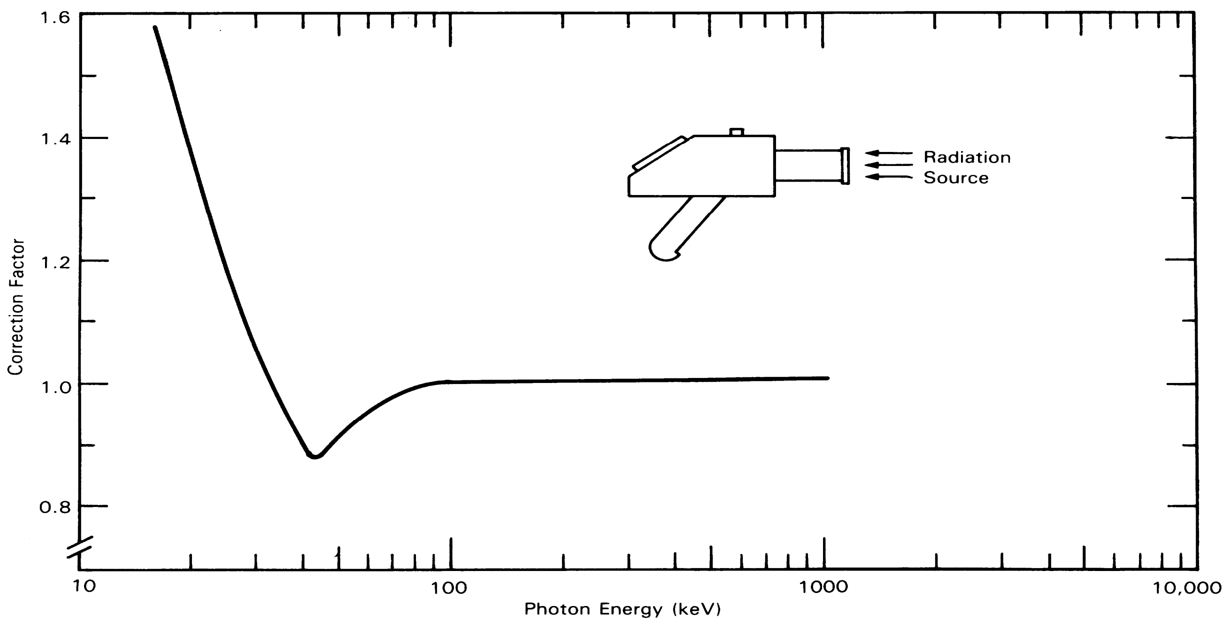

Figure 3.8. Energy Dependence of the CP Parallel Beam Energy Response (Shield On-Window Closed)

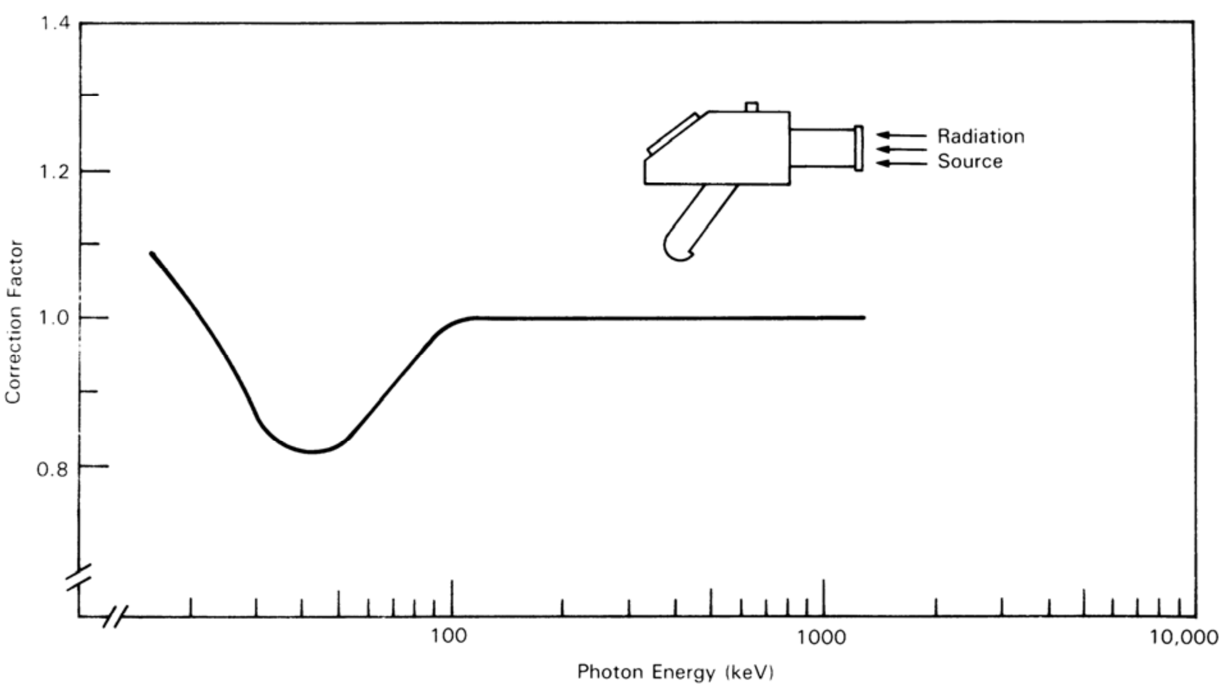

Figure 3.9. Energy Dependence of the CP Parallel Beam Energy Response (Shield Off-Window Open)

3.4 Calibration Instructions

The CP is calibrated at the PNNL calibration laboratory in the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff.

Before calibration, the instrument is inspected to make sure it is in good working order. The batteries are checked, the meter is checked for oscillations, and the instrument is inspected for physical damage. Damaged instruments are repaired before calibration. As-found readings at 40% and 80% of each range are also recorded before calibration. If the as-found readings are greater than ±20% out of tolerance, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

The instrument is calibrated in uniform ^{137}Cs photon fields at 21±2°C (70±3.6°F). The uniform fields are produced using source wells. Each range is calibrated at 80% of the full-scale readings. The response is then checked at 40% of the full-scale reading. As an example, the 5 mR/hr range is calibrated by placing the instrument in a 4 mR/hr field (80% of 5 mR/hr is 4 mR/hr) and adjusting the appropriate range potentiometer (located on the panel below the meter) to achieve the required reading (4 mR/hr ± 5%). The instrument is then placed in a 2 mR/h field (40% of 5 mR/hr). The instrument's response at both the 40% and 80% points has to be within ±5% of the actual exposure rate for the instrument to pass calibration. In addition, the CP is exposed to a radiation field that is at least twice the full-scale reading (or at least 10 R/hr) to make sure it properly indicates an off-scale condition. Instruments that do not off scale properly do not pass calibration.

The CP is calibrated annually and after any maintenance (other than battery changes) is performed. The calibration is valid through midnight on the expiration date listed on the calibration sticker.

For more detailed information on CP calibrations, refer to PNL-MA-563, Radiological Calibration Procedures, Section 3.2.1.

3.5 Maintenance Instructions

Routine maintenance on the CP is performed at the calibration laboratory. Routine maintenance includes checking the desiccant and, if it is turning pink, replacing the desiccant. Other maintenance commonly performed on the CP includes repairing the polycarbonate window and replacing batteries.

Common problems and causes are discussed below.

Erratic meter response: This may be caused by moisture in the chamber or cracks in the conductive coating (dag) on the interior surfaces of the chamber. Moisture in the chamber may be caused by a failure of the desiccant.

No response: This may be caused by a damaged integrated circuit on the chamber. This is commonly caused by a static discharge to the anode (inside the chamber). Therefore, avoid touching the anode inside the CP chamber or at any other point along the ionization chamber signal path.

Contaminated instruments: If the thin window of the CP must be removed because of contamination or if the window becomes torn, great care must be used to avoid touching the center electrode with the thin window. Touching the center electrode can result in severe damage to the CP electronics and must be avoided.

Low batteries: If a low battery condition is indicated, the batteries may be changed in the field (excluding any Contamination Area, High Contamination Area, or Airborne Radioactivity Area to prevent potential internal contamination). The CP uses four 9-V alkaline batteries (type National Electronic Distributors Association [NEDA] 1604), and no substitutions are allowed. When battery changes are performed in the field, the CP must be opened, which prominently exposes the signal path to damage from static discharge. Care should be taken to prevent damage to the instrument by using antistatic workstations and/or equipment (e.g., antistatic wrist bands). After batteries are changed, a daily source check must be performed before use.

Spent desiccant:. The calibration laboratory recommends sending instruments for fresh desiccant when the desiccant is becoming clear or pink. However, as long as the instrument functions correctly (as evidenced by successful completion of daily source checks), the instrument can be used in the field.

3.6 Instrument Specifications and Limitations

3.6.1 Temperature

The manufacturer specifies a usable temperature range of -40°C to 60°C (-40°F to 140°F) for the CP. Testing at PNNL confirms acceptable performance in the range -10°C to 50°C (14°F to 122°F); performance outside this range has not been evaluated.[3] Like all vented ion chamber instruments, the CP is temperature sensitive, as shown in Figure 3.7. At temperatures above freezing (0°C [32°F]), the temperature response is not significant. However, at temperatures below 0°C, the response should be corrected (see Section 3.2.1). A label with appropriate correction factors can be found on the CP.

3.6.2 Temperature Shock

The CP is sensitive to sudden changes in temperature (such as moving the instrument from indoors to outdoors on a cold day).[4] Allow the CP to equilibrate for at least an hour at the ambient temperature before making measurements.

3.6.3 Humidity and Pressure

The CP is insensitive to changes in ambient humidity. If used in areas of high humidity for an extended period, the desiccant may become saturated, and the instrument may develop an erratic response. In this case, return the CP to the calibration laboratory for maintenance.

The CP response is affected by changes in altitude because of the associated change in ambient pressure. Because the CP is calibrated on the Hanford Site at, essentially, the same altitude at which it is used, no corrections are required. The changes in ambient pressure caused by changing weather are minor and will not significantly affect the CP response.

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[3] Hanford Instrument Evaluation Committee Minutes (02/1994)
[4] Hanford Instrument Evaluation Committee Minutes (05/1995)

3.6.4 Electromagnetic Field Interference

The CP response can be affected by external magnetic fields.[5] In the presence of 10 gauss magnetic fields, the instrument response may decrease to near zero. This results from the external field causing the internal range switches (magnetic reed switches) to actuate, decreasing the indication as if the external range switch had been operated. Therefore, the CP should not be used in areas with high magnetic fields, e.g., near arc welders and particle accelerators.

3.6.5 Radio Frequency Interference

The CP is generally not affected by external non-ionizing radiation fields such as microwaves, portable radios, or cellular phones.[6]

High electromagnetic fields, such as from generators or ignition sources, may affect the CP response. Sources of these fields should be turned off before using the CP.

3.6.6 Electrostatic Interface

The CP can be damaged by electrostatic discharge.[7] Typical symptoms of damage from static discharge include a zero reading with no response to source check, an off "scale" high reading with no reduction when moved away from the source, or an on scale reading with the inability to zero the instrument.

3.6.7 Energies and Types of Radiation

The CP responds to gamma and beta radiation. The instrument will respond to high-energy beta radiation, such as ^{90}Sr(Y), when the window is closed. More information on using the CP in beta fields is in Section 3.7.

The CP response to low energy photons increases slightly at 40 keV and then drops off. The CP is usable (±15% response) for photon energies greater than 12 keV for open window readings and 30 keV for closed window readings. Measuring photon radiations with energies below these values is not recommended.

The energy correction factors charts shown in Figures 3.8, 3.9, and 3.10 are provided as general information regarding instrument response.

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[5] Hanford Instrument Evaluation Committee Minutes (05/1995)
[6] Hanford Instrument Evaluation Committee Minutes, May, 1995, Attachment 5
[7] Hanford Instrument Evaluation Committee Minutes, October 21, 1997 Attachment 4

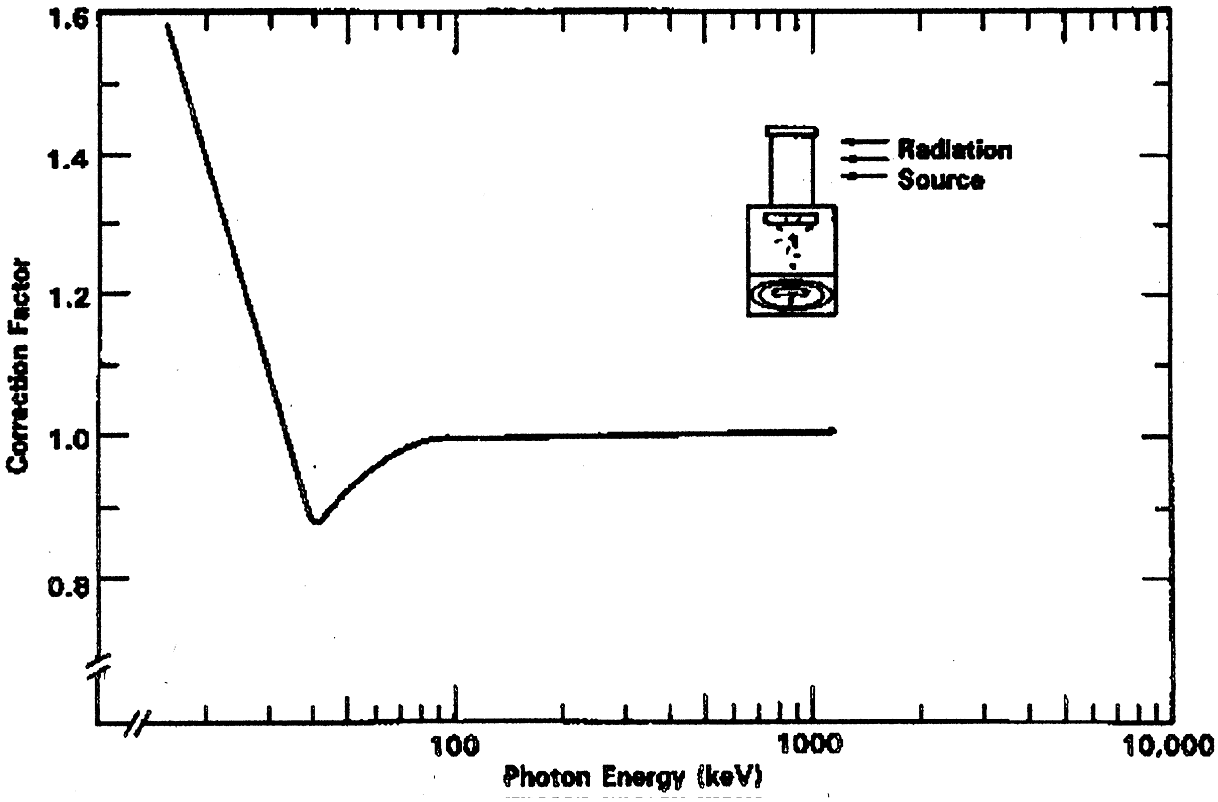

Figure 3.10. Eberline RO-3B Photon Energy Response 90-Degree Beam Energy Response (Shield On-Window Closed)

3.6.8 Interfering Ionizing Radiation Response

The CP is insensitive to alpha and neutron radiations.

3.6.9 Battery Life

The CP has a battery life of about 200 hours. When used in high-exposure rate areas, the battery life is shorter.

3.7 Applications

3.7.1 Dose Rate Measurements

The CP is used to establish beta and gamma personnel dose rates. When establishing beta dose rates, remove the shield from the end of the ionization chamber (as shown in Figure 3.2). Replace the shield to measure penetrating radiation.

Establishing the exposure rate in mixed ^{90}Sr(Y)/gamma fields is difficult because the CP does not adequately discriminate between ^{90}Sr(Y) beta and photon radiation. As a rule of thumb, if the open window reading is a factor of three higher than the closed-window reading, then shallow dose may be limiting.

3.7.2 Surface Contamination Measurements

When beta/gamma contamination values are greater than the range of the typical contamination monitoring instruments (e.g., pancake GM), a measurement using the CP is performed. The measurement is performed by placing the CP open window as close as possible to the source of contamination without touching it and recording the meter indication. The area of the contamination should also be recorded.

Typical CP response to specific sources are listed below::[8]

- 47 mm diameter ^{137}Cs source ~69,000 dpm/mR/hr
- Large area ^{137}Cs Source (10 cm x 10 cm) ~200,000 dpm/mR/hr

[8] Letter from ML Johnson, PNNL to D Cunningham, Westinghouse Hanford Company, "Eberline RO-3B Correction Factor for ^{137}Cs Activity," September 30, 1996.

4.0 The Bumble Bee and Black Widow CP Radiation Survey Instrument

4.1 Instrument Description and Theory of Operation

The Hanford Bumble Bee Cutie Pie (BBCP, Figure 4.1) and Black Widow CP (BWCP, Figure 4.2) are modified Eberline RO-3B ion chambers for special applications. These instruments are portable, pistol-shaped rate meters with air-filled ionization chambers that are used to detect alpha, beta, and photon radiations. The barrel of the instrument is the ionization chamber, which is a phenolic resin tube with a thin film covering the outer end. A shield of the same phenolic resin is provided as a non-penetrating radiation filter for the beta window. The beta window on these models is also removable. The beta window serves as an alpha shield. Removing the beta window allows alpha detection through the alpha window.

More detailed technical information can be obtained by contacting the PNNL calibration laboratory at (509) 376-5624.

4.1.1 Physical Description

The BBCP/BWCP weighs 1.6 kg (3.5 lb). They measure 28 cm (11 in.) long by 25 cm (9.8 in.) high by 9.4 cm (3.7 in.) wide, including the handle. The ion chamber is a cylinder 7.6 cm (3 in.) in diameter and 10 cm (4 in.) long, for a total volume of 465 cm^3 (28.4 $in.^3$). The chamber wall and beta shield density thickness are about 400 mg/cm^2. (The alpha window measures 0.85 mg/cm^2.) The beta window is made of one layer of aluminized polycarbonate with a density thickness of 6.20 mg/cm^2. The total density thickness of the beta window is 7.05 mg/cm^2.

The BBCP has four linear ranges of operation calibrated in units of exposure rate—0 mR/hr to 5 mR/hr, 0 mR/hr to 50 mR/hr, 0 mR/hr to 500 mR/hr, 0 mR/hr to 5000 mR/hr. Linearity is ±5% of full scale.

The BWCP has four linear ranges of operation calibrated in units of exposure rate—0 R/hr to 0.5 R/hr, 0 R/hr to 5 R/hr, 0 R/hr to 50 R/hr, and 0 R/hr to 500 R/hr. Linearity is ±10% of full scale.

Response time is relatively rapid—less than five seconds are required for the instrument to respond from 10% to 90% of the final reading on the two lower ranges, and less than three seconds are required on the two upper ranges.

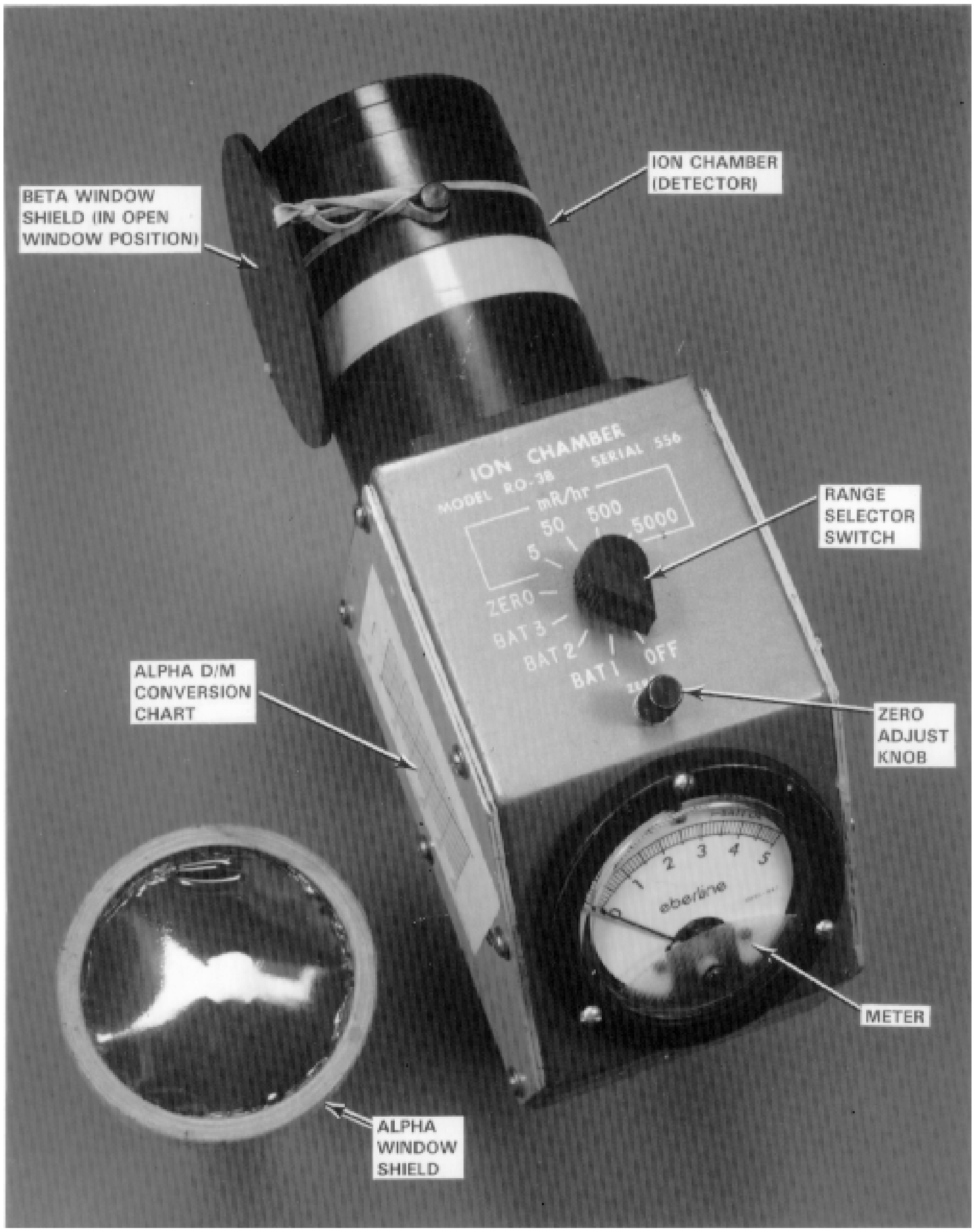

Figure 4.1. Bumble Bee Cutie Pie

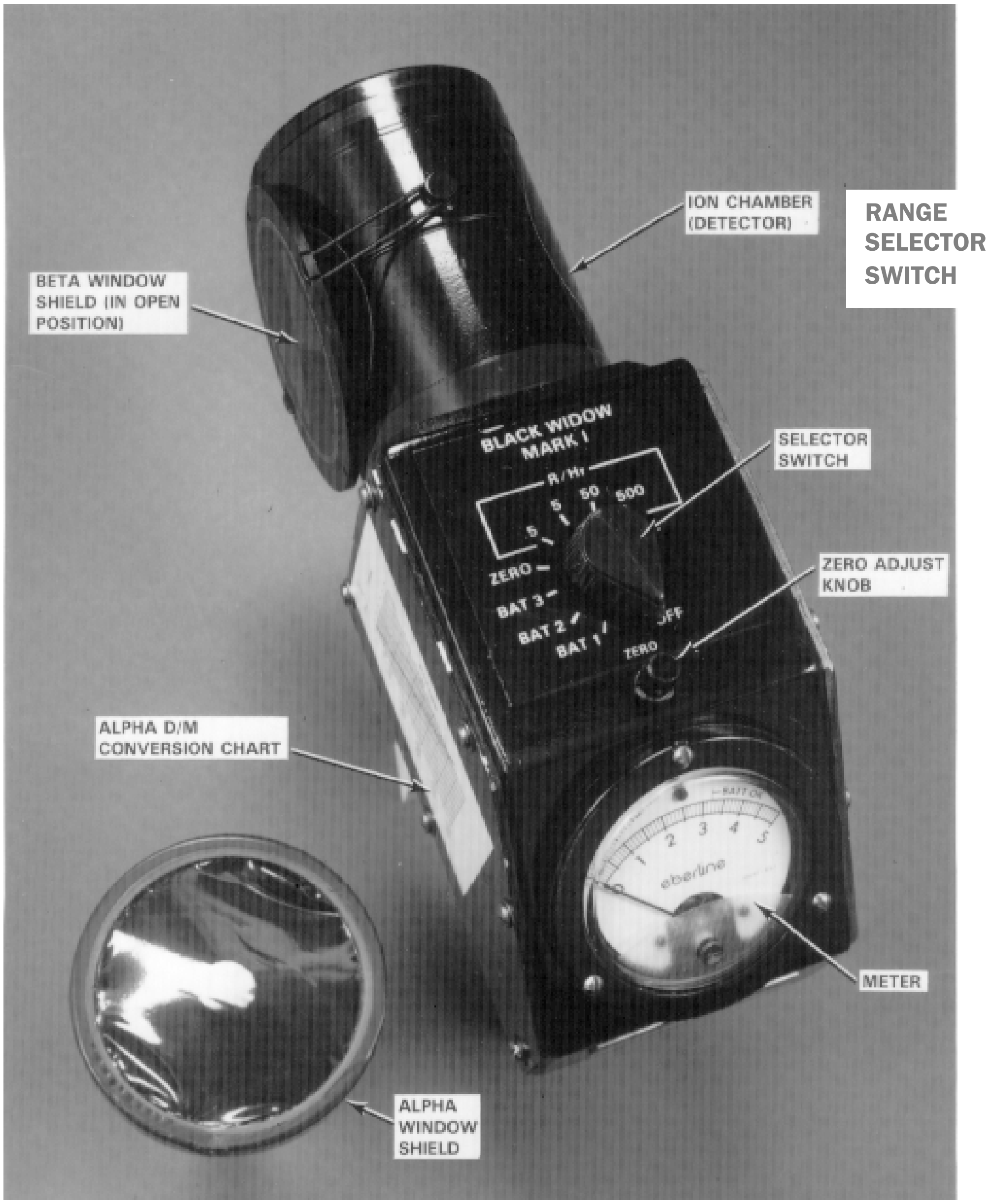

Figure 4.2. Black Widow Cutie Pie

4.1.2 Radiation and Energy Response

With the beta shield in place (window closed), the chamber responds to photons with energies above about 10 keV and beta particles with energies greater than 1 MeV (e.g., ^{90}SrY). However, photons with energies below 20 keV (e.g., plutonium and americium 14-keV x-rays) are significantly attenuated by the beta shield. With the beta shield removed (window open), the BW/BBCP responds to beta particles with energies greater than 65 keV (e.g., ^{57}Co) and photons with energies greater than a few keV. The thin (7 mg/cm^2) beta window is too thick to admit alpha particles with energies less than 6 MeV. With the beta window (alpha window shield) removed, the BW/BBCP responds to alpha radiation. The BW/BBCP does not respond to neutrons.

The BB/BWCP response to a given photon radiation energy is reasonably constant above 180 keV. Due to photoelectric emission from the chamber walls, the instrument shows an increase in sensitivity at energies below this point. This increase in sensitivity peaks at approximately 30 keV (beta filter removed), at which point wall absorption becomes an appreciable factor. The two effects balance at approximately 20 keV, with the absorption becoming dominant below these energies. See Figures 3.8 through 3.10 for energy response graphs of the BBCP and BWCP.

4.1.3 Integral Sources

There are no radioactive sources attached to, or inside, the BBCP and BWCP.

4.2 Operating Instructions

Before using the BB/BWCP, perform the operability checks to make sure the instrument is in good working condition (see Section 4.3, Performance Test Instructions, for examples of typical operability checks). These checks should be performed each time the instrument is used.

To perform a radiation survey, turn the selector switch to the desired range and move the instrument slowly while observing the meter response. When a measurement is to be performed at a particular location, allow at least one time constant (five seconds on lowest range) for the reading to stabilize on the final value.

NOTE: *When selecting the most sensitive range (e.g , 5 mR/hr on the BBCP), switching noise may cause a temporary meter deflection. This can be avoided by first selecting a higher range, letting the needle settle, and then switching to the most sensitive range.*

In unknown fields, remove the beta shield to allow the instrument to respond to both penetrating and non-penetrating radiation. Point the instrument toward possible sources of radiation. If the area is known to have only gamma radiation, the beta shield does not need to be removed.

When surveying for alpha radiation, remove the beta shield and beta window from the instrument. The BB/BWCP must then be pointed toward possible sources of alpha radiation. The instrument must be held in close proximity to the possible radiation source.

Avoid contact between the instrument and other objects. Besides possible instrument contamination, pressure on the thin plastic window will cause false and erratic meter readings (from capacitive effects), and might puncture or rupture the window. If the metal case touches other metal objects, the reading may drop suddenly to zero (with recovery after a short delay).

The BW/BBCP can be damaged by electrostatic discharge.[1] If damage is suspected while surveying (e.g., instrument is dropped or static discharge is observed/suspected), then perform an operational check and source check, or if an established field is available, assure the response is within ±20% of the established value. An established value may be a pervious reading or a well known, constant, non-zero field.

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[1]Hanford Instrument Evaluation Committee Minutes, October 21, 1997 Attachment A

To ground the CP, in order to discharge static in a controlled manner and prevent instrument damage (e.g., before entering an ignition controlled area), turn instrument to the OFF or ZERO position, and then touch the metal case to any grounded metal surface. Under conditions where a high potential for static build-up (dry conditions), the CP should be grounded frequently (approximately once every hour) and before making a measurement near (within one inch) a grounded object.

If necessary, multiply the instrument reading by appropriate correction factors. Correction factors are required when measuring non-uniform fields (e.g., contact measurements, beaming radiation) and when the ambient temperature is less than 0°C (32°F). Correction factors are provided later in this section.

Calculate shallow and deep dose rates as follows:

$$\text{Deep Dose Rate} = WC \times CF_{pen} \times CF_{temp} \quad (4.1)$$

$$\text{Shallow Dose Rate} = [(WO - WC)CF_{non-pen} + WC \times CF_{pen}] \times CF_{temp} \quad (4.2)$$

where:

WC	=	instrument response with the window closed
WO	=	instrument response with the window open
$CF_{non\text{-}pen}$	=	non-penetrating (i.e., beta) correction factor
CF_{pen}	=	penetrating (i.e., gamma) correction factor
CF_{temp}	=	temperature correction factor

When the WC indication is less than one tenth of the WO indication, (WC <0.1WO) then the calculation for shallow dose can be simplified as follows:

$$WO \times CF_{non\text{-}pen} \times CF_{temp} \quad (4.3)$$

4.2.1 Correction Factors

Small-beam correction factors are used when the beam is too narrow to ionize the air in the chamber uniformly (i.e., beam diameter is less than 3 in.). Small beam correction factors are calculated as the ratio of the chamber cross-sectional area to the beam cross-sectional area. When measuring beams parallel to the chamber, the beam must be coaxial with the chamber. Though beams are not typically observed with non-penetrating radiation, the beam correction factors are applied to both penetrating and non-penetrating beam conditions.

To determine the beam correction factor, use the BW/BBCP correction factor chart on the side of the instrument (Figure 3.3), except where $CF_{non\text{-}pen} < 3$. A minimum value of 3 for beam sources of non-penetrating radiation should be used.

Geometry corrections factors are used when BW/BBCP measurements are taken with the window within 6 in. of the source. If the window is within 1 in. of the source, use the correction factors provided in Figure 3.3 and on the side of the instrument. If the window is ≥ 1 in. and < 6 in. from the source, then $CF_{non\text{-}pen} = 3$ and $CF_{pen} = 1.5$. More detailed correction factors for specific geometries are shown in Figures 3.4, 3.5, and 3.6.

Beta correction factors are used when non-penetrating radiation fields are measured. Multiply all non-penetrating exposure rate (WO - WC) CP readings by 3 ($CF_{non\text{-}pen} = 3$), unless the BW/BBCP window is < 1 in. from the source. If the BW/BBCP window is < 1 in. from the source, use the correction factors provided in Figure 3.3 and on the side of the BW/BBCP.

Temperature correction factors are used when the BW/BBCP is used in an environment where the temperature is less than 0ºC (32ºF). The correction factors account for changes in air density with temperature. Correction factors are calculated in the following manner:

$$CF = \frac{273.15\text{ K} + \text{actual temperature}}{273.15\text{ K} + \text{reference temperature}}$$

Where reference temperature is the temperature in Celsius at calibration, typically 22ºC, and the actual temperature is the temperature in Celsius of the operating environment. The correction factors are given in Table 4.1, Figure 3.7, and on a sticker on the instrument.

Photon energy correction factors are used when measuring photon energies below 100 keV. For these energies, use the appropriate correction factor from Figures 3.8 through 3.10. These correction factors can be used for the complete photon energy spectrum when the shield is in place or removed. With proper correction, the exposure rate from x-rays can also be measured if the effective energy is known.

Alpha radiation correction factors are used to convert meter deflection to disintegrations per minute using the attached correction factor chart. The vertical axis of this chart is the BW/BBCP meter deflection. To convert from meter deflection to disintegrations-per-minute (dpm), locate the instrument response on the vertical axis and then follow that reading to the indicated line on the graph. Once the line is contacted, move down the graph to the horizontal axis to determine the corresponding dpm value for the reading (see Figure 4.3).

Table 4.1. Temperature Correction Factors for Eberline RO-3B (BW/BBCP)

If Temperature is	Multiply Instrument Response by
0°F to 32°F (-17°C to 0°C)	0.90
-20°F to 0°F (-29°C to -17°C)	0.85

Beta radiation correction factors are used to convert meter deflection to disintegrations per minute using the correction factor stated on the calibration sticker.

4.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions in this section are provided as an example of acceptable methods.

4.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

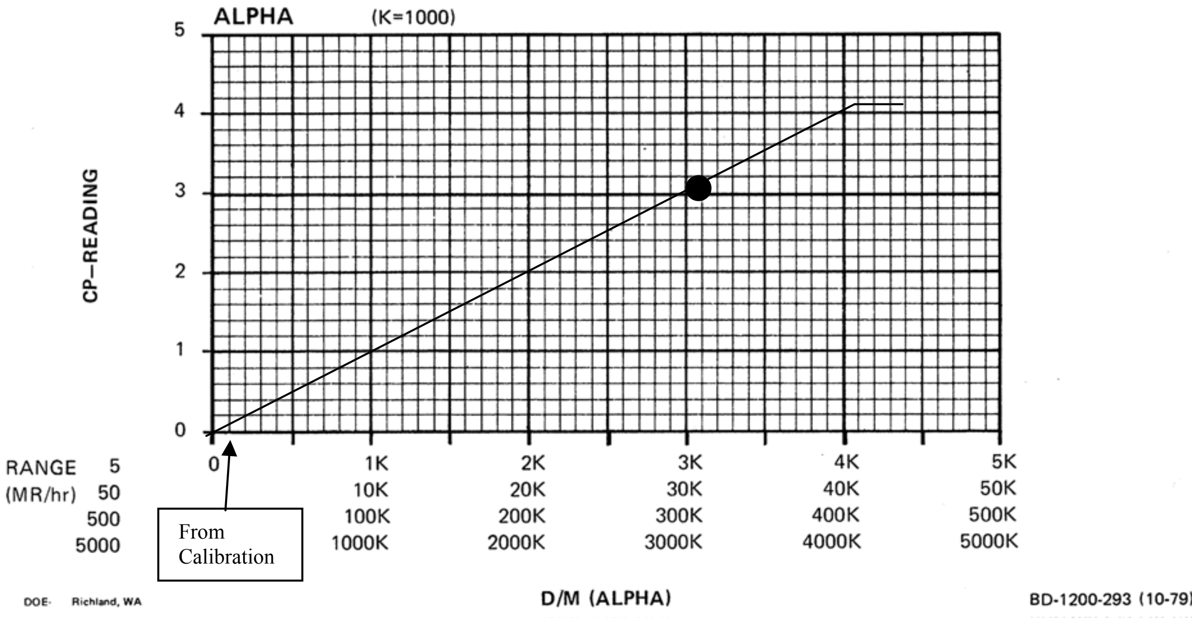

Figure 4.3. Example Alpha Activity Conversion Charts for BBCP and BWCP

(For more detailed information on BB/BWCP calibrations,
refer to PNNL-MA-563, Section 3.2.1 [BBCP] and 3.3.0 [BWCP]).

Check everything listed below. If the instrument fails any of the operability checks, other than the battery test, fill out an Instrument Service Tag to identify the problem, attach it to the instrument, and return the instrument to the PNNL calibration laboratory for servicing.

1. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) on the expiration date on the calibration sticker.
2. Ensure that the instrument source check is current. Source checks are generally valid for the day performed, and typically do not cover more than 24 hours.

NOTE: *Missing beta shields can be replaced in the field. Contact the calibration laboratory for a new beta shield.*

3. Inspect the instrument for physical defects, such as broken meter glass, loose knobs, punctured windows, or broken handles.
4. Turn the selector switch to BAT 1. The meter reading should be above the BATT cutoff line. Repeat this procedure for the BAT 2 and BAT 3 positions.
5. Turn the selector switch to the ZERO position and, using the zero knob, set the instrument to zero.

6. Check for erratic meter response. (Turn the selector switch to the lowest range and observe the meter needle for erratic behavior. Rotate the instrument from side to side and observe the meter needle.)

4.3.2 Source Check

The BBCP, and lower ranges of the BWCP, may be source checked using a book source, linear beta source, or an ICCS assembly. The initial source check should be performed when the instrument is first received from the calibration laboratory. Source checks are performed daily or before each use if the BW/BBCP is used less often than daily.

The upper ranges of the BWCP cannot typically be source checked in the field (because of the high radiation fields required). Therefore, these instruments are calibrated quarterly as a compensatory action in lieu of source checking the upper ranges.

4.3.2.1 Initial Source Check

Initial source checks should be performed upon receiving a BW/BBCP from the calibration laboratory. Instruments should not be placed into storage until after performing the initial source check.

NOTE*: Instrument response observed during the initial source check should be evaluated to ensure that the values are reasonable. For the BW/BBCP, the initial response is reasonable when the response is within:*

- *the acceptable ranges printed on a calibrated source assembly (BBCP)*
- *±20% of the mean instrument response for that source.*

Remove the beta shield from the window and center the window over the source position on the check source assembly. Move the source to the appropriate position for each range of the instrument and record the instrument response on each range. Multiply the instrument response by 0.8 and 1.2 to determine the acceptable range for that instrument.

4.3.2.2 Daily Source Check

NOTE: *The source used to perform the initial source check is used to perform the daily source check. To perform a daily source check with a source other than the one used for the initial source check, first perform the daily source check on the source used for the initial source check. If the instrument passes that daily source check, perform a new initial source check using the new source to establish response limits for that source/instrument combination.*

Remove the beta shield from the window and place the window over the source position on the check source assembly. Move the source to the appropriate position for each range of the instrument. The instrument response, on each range, should fall within the acceptable values determined during the initial source check. If the instrument fails, tag it with an Instrument Service Tag and return it to the the calibration laboratory.

Source checks are generally valid for 24 hours after they are performed.

4.4 Calibration Instructions

The BW/BBCP is calibrated at the PNNL calibration lab in the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff.

Before calibration, the instruments are inspected to make sure they are in good working order. The batteries are checked, the meter is checked for oscillations, and the instrument is inspected for physical damage. Damaged instruments are repaired before calibration. As-found readings at 40% and 80% of each range are also recorded before calibration. If the as-found readings are greater than ±20% out of tolerance, the calibration laboratory will contact the radiological control organization that last used the instrument to inform them of the problem.

The instruments are calibrated in uniform ^{137}Cs photon fields at 21 ±2°C (70 ±3.6°F). The upper range of the BWCP is calibrated using uniform ^{60}Co photon fields. The uniform fields are produced using source wells and/or the high-exposure facility. Each range is calibrated at 80% of the full-scale readings. The response is then checked at 40% of the full-scale reading. As an example, the 5 mR/hr range is calibrated by placing the instrument in a 4 mR/hr field (80% of 5 mR/hr is 4 mR/hr) and adjusting the appropriate range potentiometer (located on the panel below the meter) to achieve the required reading (4 mR/hr ± 5%). The instrument is then placed in a 2 mR/hr field (40% of 5 mR/hr). The instrument response at both the 40% and 80% points has to be within ±5% of the actual exposure rate for the instrument to pass calibration. In addition, the BW/BBCPs are exposed to a radiation field that is at least twice the full-scale reading (or at least 10 R/hr for BBCP and 1000 R/hr for BWCP) to make sure they properly indicates an off-scale condition. Instruments that do not off-scale properly do not pass calibration.

The BBCP is calibrated annually and after any maintenance is performed (other than battery changes). The calibration is valid through midnight of the expiration date listed on the calibration sticker. The BWCP is calibrated quarterly and after any maintenance is performed (other than battery changes).

The BW/BBCP response to alpha and beta radiation is also determined. A ^{230}Th alpha source is used to establish the instrument alpha response. This response is plotted on the alpha disintegrations per minute (dpm) conversion chart (Figure 4.3), attached to the side of the BW/BBCP. The BW/BBCP beta response is determined using a 50-mm beta-emitting ^{137}Cs source. Beta response is stated on the calibration sticker in units of dpm/mR/hr.

4.5 Maintenance Instructions

Routine maintenance on the BBCP is performed at the calibration laboratory and in the field. Maintenance of the BWCP must only be performed at the calibration laboratory because of potentially lethal high voltages internal to the instrument. Routine maintenance includes checking the desiccant and, if it is turning pink, replacing the desiccant. Another maintenance commonly performed on the BW/BBCP is repairing the windows.

Common problems and causes are discussed below.

Erratic meter response: This may be caused by moisture in the chamber or cracks in the conductive coating (dag) on the interior surfaces of the chamber. Moisture in the chamber may be caused by failure of the desiccant.

Spent desiccant: The calibration laboratory recommends sending instruments for fresh desiccant when the desiccant is becoming clear or pink. However, as long as the instrument functions correctly (as evidenced by successful completion of daily source checks), the instrument can be used in the field.

No response: This may be caused by a damaged integrated circuit on the chamber. This is commonly caused by a static discharge to the anode (inside the chamber). Therefore, avoid touching the anode inside the BW/BBCP chamber or other points along the ionization chamber signal path. The BWCP must only be serviced by the calibration laboratory due to potentially lethal high voltages.

Low battery: If the BBCP indicates a low battery condition, some of the batteries may be changed in the field (excluding any Contamination Area, High Contamination Area, or Airborne Radioactivity Area to prevent potential internal contamination). The BWCP must only be serviced by the calibration laboratory due to potentially lethal high voltages.

The BBCP uses four 9-V alkaline batteries (type NEDA 1604) and no substitutions are allowed. When battery changes are performed in the field, the BBCP must be opened, which prominently exposes the signal path to damage from static discharge. Care should be taken to prevent damage to the instrument by using antistatic work stations and/or equipment (e.g., antistatic wrist bands). After batteries are changed, a daily source check must be performed before use. If the facility does not have the capability to change batteries on the BBCP, the instrument may be returned to the calibration laboratory for a battery replacement. The Instrument Service Tag should show that a “battery change only” is required.

The BWCP uses one 67-V battery and one 45-V battery. In addition, it uses two 9-volt batteries. The batteries must only be replaced at the calibration laboratory due to potentially lethal high voltages.

4.6 Instrument Specifications and Limitations

4.6.1 Temperature

The manufacturer specifies a usable temperature range of -40ºC to 60ºC (-40ºF to 140ºF) for the BW/BBCP. PNNL testing confirms acceptable performance in the range -10ºC to 50ºC (14ºF to 122ºF); performance outside this range has not been evaluated.[2] Like all vented ion chamber instruments, the BW/BBCP is temperature sensitive (see Section 4.2.1). At temperatures above freezing (0ºC [32ºF]), the temperature response is not significant. However, at temperatures below 0ºC, the response should be corrected (see Section 3.2.1). A label with appropriate correction factors can be found on the BW/BBCP.

[2] Hanford Instrument Evaluation Committee Minutes, Attachment 2, February, 1994.

4.6.2 Temperature Shock

The BW/BBCP is sensitive to sudden changes in temperature (such as moving the instrument from indoors to outdoors on a cold day).[3] Allow the BW/BBCP to reach a thermal equilibrium at the ambient temperature for at least an hour before making measurements.

4.6.3 Humidity and Pressure

The BW/BBCP is normally insensitive to changes in ambient humidity. However, if used in areas of high humidity for an extended period, the desiccant may become saturated, and the instrument may develop an erratic response. In this case, return the BW/BBCP to the calibration laboratory for maintenance.

The BW/BBCP response is affected by changes in altitude because of the associated change in ambient pressure. Because the BW/BBCP is calibrated on the Hanford Site at, essentially, the same altitude at which it is used, no corrections are required. The changes in ambient pressure caused by changing weather are minor and will not significantly affect the BW/BBCP response.

4.6.4 Electromagnetic Field Interference

The BW/BBCP response can be affected by external magnetic fields.[4] In the presence of 10 gauss magnetic fields, the instrument response may decrease to near zero. This results from the external field causing the internal range switches (magnetic reed switches) to actuate, decreasing the indication as if the external range switch had been operated. Therefore, the BW/BBCP should not be used in areas with high magnetic fields, e.g., near arc welders and particle accelerators.

The instrument can be damaged by electrostatic discharge. Typical symptoms of damage from static discharge include a zero reading with no response to source check, an off-scale high reading with no reduction when moved away from source, or an on-scale reading with the inability to zero the instrument.

4.6.5 Radio Frequency Interference

The BW/BBCP is generally not affected by external non-ionizing radiation fields, such as microwaves, portable radios, or cellular phones.[5] High electromagnetic fields, such as from generators or ignition sources, may affect the BW/BBCP response. Sources of these fields should be turned off, shielded, or avoided when using the BW/BBCP.

4.6.6 Electrostatic Interface

The BW/BBCP can be damaged by electrostatic discharge.[6] Typical symptoms of damage from static discharge include a zero reading with no response to source check, an off-scale high reading with no

[3] Hanford Instrument Evaluation Committee Minutes, Attachment 5, May, 1995.
[4] Hanford Instrument Evaluation Committee Minutes, Attachment 5, May, 1995
[5] Hanford Instrument Evaluation Committee Minutes, Attachment 5, May, 1995.
[6] Hanford Instrument Evaluation Committee Minutes, Attachment 5, May, 1995

reduction when moved away from the source, or an on-scale reading with the inability to zero the instrument.

4.6.7 Energies and Types of Radiation

The BW/BBCP responds to alpha, beta, and gamma radiation. In the window closed position, the instrument responds to high-energy beta radiation (e.g., ^{90}Sr/Y). More information on using the BW/BBCP in beta fields is included in Section 4.7.

The BW/BBCP response to low-energy photons increases slightly at 40 keV and then drops off. The BW/BBCP is usable (±15% response) for photon energies greater than 12 keV for open window readings, and 30 keV for closed window readings. Measuring photon radiations with energies below these values is not recommended. The energy correction factors charts shown in Figures 3.8 through 3.10 are provided as general information regarding instrument response.

With only the beta shield removed, the end window is too thick (7 mg/cm^2) to admit alpha particles with energies less than 6 MeV. The BW/BBCP has a second removable window (alpha shield). With the alpha shield removed, the BW/BBCP responds to alpha radiation.

4.6.8 Interfering Ionizing Radiation Response

The BW/BBCP is insensitive to neutron radiations.

4.6.9 Battery Life

The BBCP uses four 9-V batteries and has a battery life of approximately 200 hours. When used in high exposure rate areas, the battery life is shorter.

The BWCP uses one 67-V battery and one 45-V battery that have battery lives of approximately 8,700 hours (1 year) each. In addition, it uses two 9-V batteries, which have a battery life of approximately 200 hours.

4.7 Applications

4.7.1 Dose Rate Measurements

The BW/BBCP is used to establish shallow and deep personnel dose rates. In order to determine shallow and deep dose rates, measurements of penetrating and non-penetrating exposure rates must be performed (see Section 4.2). When measuring non-penetrating radiation, remove the beta shield from the end of the ionization chamber. Replace the beta shield to measure penetrating radiation.

Establishing the dose rate in mixed ^{90}Sr(Y)/gamma fields is difficult because the BW/BBCP does not adequately discriminate between ^{90}Sr(Y) beta and photon radiation. The wall thickness of the BW/BBCP ionization chamber is approximately 400 mg/cm^2. As a rule of thumb, if the open window reading is a factor of three higher than the closed window reading, then shallow dose may be limiting.

4.7.2 Surface Contamination Measurements

When beta/gamma contamination values are greater than the range of the typical contamination monitoring instruments (e.g., pancake Geiger-Müller), a measurement using the BW/BBCP is performed. The measurement is taken by placing the BW/BBCP open window as close as possible to the source of contamination, without touching it, and recording the meter indication. The area of the contamination should also be recorded.

Typical CP responses to specific sources are listed below[7] and the exact beta response is listed on the calibration sticker for 47mm sources (e.g., technical smears).

- 47 mm diameter ^{137}Cs source ~69,000 dpm/mR/hr
- Large area ^{137}Cs Source (10 cm x 10 cm) ~200,000 dpm/mR/hr

When alpha contamination values are greater than the range of the typical alpha contamination monitoring instruments (e.g., portable alpha meter), a measurement using the BW/BBCP is performed. The measurement is performed by removing the beta and alpha shields and placing the BW/BBCP alpha window as close as possible to the source of contamination, without touching it, and recording the meter indication. The area of the contamination should also be recorded. A conversion chart on the side of the BW/BBCP is used to convert the instrument response to alpha activity.

[7] Letter from ML Johnson, PNNL, to D Cunningham, Westinghouse Hanford Company, "Eberline RO-3B Correction Factor for ^{137}Cs Activity," September 30, 1996.

5.0 Portable Alpha Meter

5.1 Instrument Description and Theory of Operation

The portable alpha meter (PAM) used at the Hanford Site consists of a count rate meter and an alpha scintillation detector. The count rate meter is the Bicron Surveyor X. The scintillation detector is manufactured at Hanford.

The Bicron Surveyor X may have a digital scaler built into the meter face. Surveyor X meters with scalers have a rubber booted, push button mounted on the front of the instrument for initiating the scaler. Scaler PAMs also have a red light emitting diode (LED) in the lower right corner of the meter face that indicates when the scaler is counting. The scaler may be set to 0.1 minutes, 1.0 minutes, or 10 minutes. During calibration, the scalers are set to a 1.0 minute count time.

5.1.1 Physical Description

The Bicron Surveyor X weighs about 1 kg (2.2 lb) and measures 20 cm (8 in.) long by 11 cm (4.3 in.) wide by 17 cm (6.8 in.) high, including a handle and probe clip. The instrument has an internal speaker, a mega high-voltage (MHV) connector or a bayonet nut connector (BNC) connector, and a high-voltage indication position on the selector switch. The instrument high voltage is adjustable and is set during calibration.

Two models of Surveyor X are available. The standard model (see Figure 5.1) meter scale indicates a count rate range of 0 cpm to 1,000 cpm. The Black Widow (BW) Surveyor X (see Figure 5.2) is also available with a count rate range from 0 cpm to 10,000 cpm. The BW meter has a red case to easily identify the higher range instrument. The upper count rate limit is 100,000 cpm for the standard meter, and 1,000,000 cpm for the BW. The standard count rate meter's linearity is ±5% of full scale over the entire range of the instrument. The BW meter linearity is ±5% for the X1 and X10 range and ±10% for the X100 range.

The meter response time is optimized for each range and is not adjustable by the user. The actual response time for each range is listed in Table 5.1. The response time is generally specified by the manufacturer as the time for the instrument reading to reach 90% of final value after a change in the radiation field. The resistor/capacitor (RC) time constant of the instrument can be calculated from the 0% to 90% response time by dividing the 0% to 90% response time by 2.3.

Table 5.1. Surveyor X Response Time

Response Time and Time Constant (RC) of Bicron Surveyor X		
Range	**Response Time (sec)**	**RC Time Constant (sec)**
X1	12	5.2
X10	5	2.2
X100	2	0.9

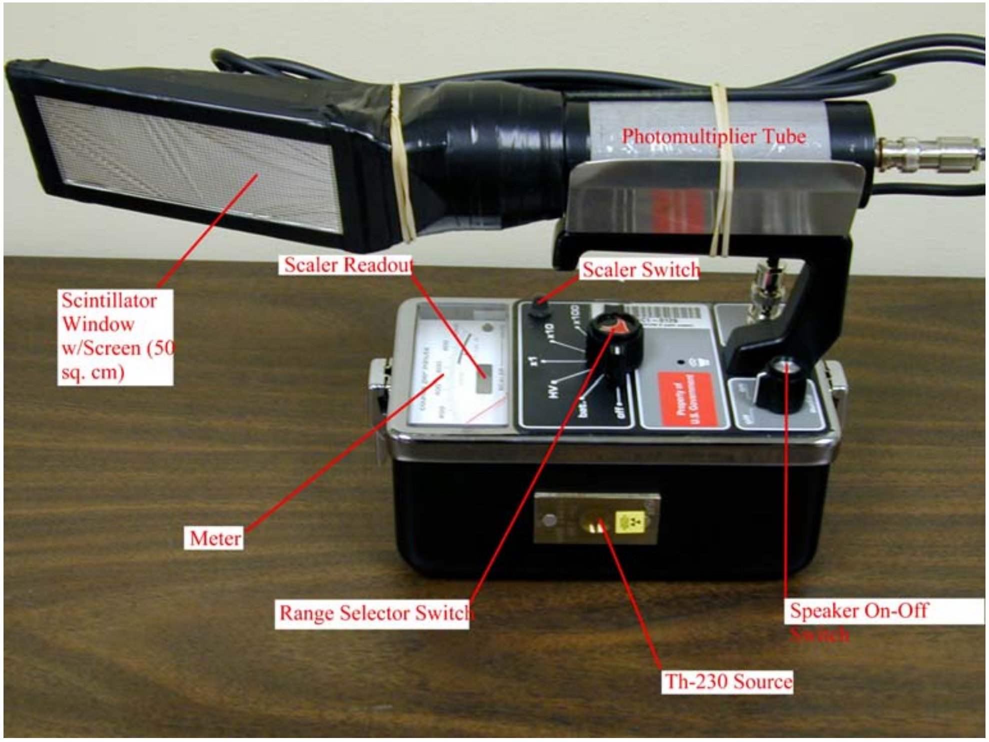

Figure 5.1. Bicron Model Surveyor X Count Rate Meter (PAM Configuration)

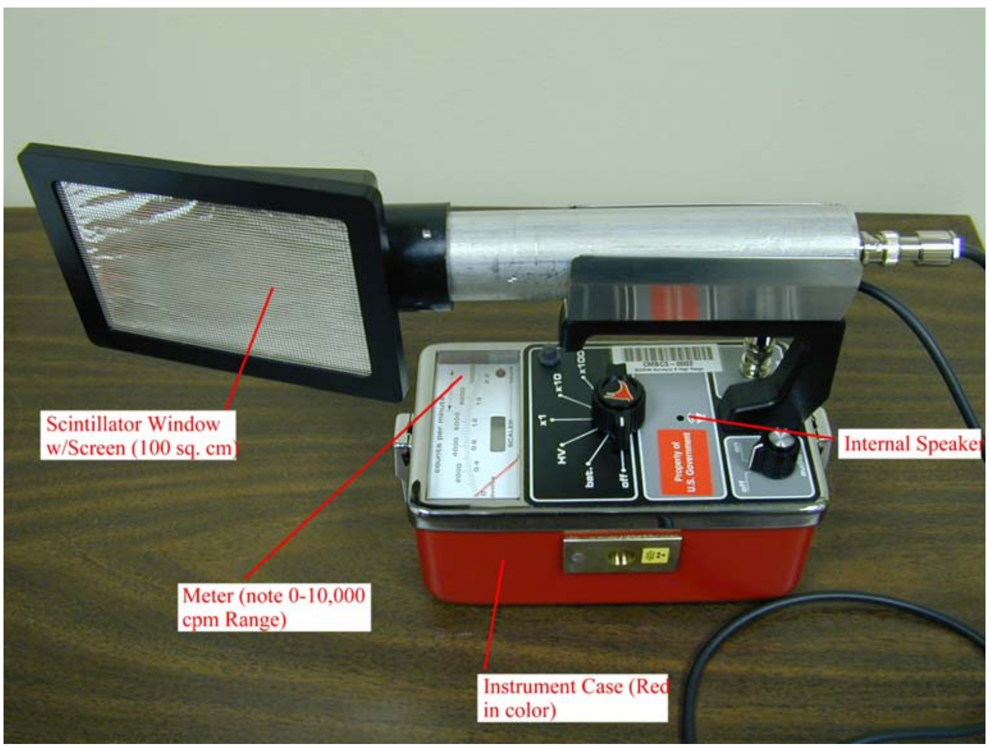

Figure 5.2. Bicron Model Surveyor X Count Rate Meter with Extended Range (BW PAM Configuration)

The alpha scintillation probe consists of a zinc sulfide decal backed with a 1/16-in. sheet of Plexiglas that is mounted on the face of the detector. The zinc sulfide is covered with two layers of 0.41-mg/cm^2 aluminized polycarbonate film for a total window density thickness of 0.82 mg/cm^2. The polycarbonate is protected by a fine stainless steel screen. Two detector sizes are available. The most commonly available has an active area of 54 cm^2 (4.5 cm x 12 cm); however, this size is typically referred to by its approximate size of 50 cm^2. A 100 cm^2 (8 cm x 12.5 cm) active area probe is also available, offering improved sensitivity for distributed sources. The light pulses from the scintillator are reflected to the photomultiplier tube in the probe handle. The probe has an internal preamplifier.

The thin window can be easily torn or punctured and should be used with care. Even tiny pinholes in the window will produce a light leak that causes extremely high count rates when the probe is exposed to light.

Each PAM probe is individually matched to a count rate meter. The PAM probes cannot be exchanged between instruments without invalidating the calibration. The PAM probes may have red paint on the end or may be a natural bare aluminum color; either probe is acceptable, if the count rate meter specified by the calibration decal is attached to the probe.

5.1.2 Radiation and Energy Response

The PAM responds to alpha radiation; if the alpha particle has enough energy to penetrate the thin window, the particle is counted by the instrument. In general, all alpha-emitting isotopes at the Hanford Site can be detected with a PAM. Detector response is dependent upon alpha energy. Although the response to ^{239}Pu and ^{241}Am is roughly equivalent, uranium response may be as much as 20% lower than ^{239}Pu response.

The PAM is insensitive to beta radiation but may be sensitive to gamma radiation.[1] Gamma sensitivity is evaluated during calibration, upon request. Section 5.4 provides details on the parameters used to establish beta/gamma sensitivity.

The PAM is sensitive to neutron radiation.[2]

5.1.3 Integral Sources

An alpha-emitting source is attached to the PAM and is used to verify that the instrument is operating properly in the field. These sources are typically on the order of 0.85 nCi (~2000 dpm) ^{230}Th.

5.2 Operating Instructions

Before using the PAM, perform the operability check to make sure the instrument is in good working condition (see Section 5.3). This check process should be performed each time the instrument is used.

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[1]PNL-9876, Evaluation of the Bicron Surveyor X Alpha Monitor with Hanford Alpha Contamination Probe using criteria in ANSI Standard N42.17A, July, 1994
[2]Hanford Instrument Evaluation Committee Minutes, February 6, 2001, Attachment 1

To perform a contamination survey, turn the PAM selector switch to the lowest range, hold the probe within 6 mm (¼ in.) from the surface to be surveyed, and move the PAM slowly while listening to the audible response (scan speed and other survey parameters are defined in Section 5.7).

CAUTION: *The Mylar window can be easily torn or punctured. Users must avoid touching the probe window to surfaces being surveyed, especially objects that are uneven or prickly (e.g., tumbleweeds). Even tiny pinholes in the Mylar will produce a light leak that causes extremely high count rates when the probe is exposed to light.*

NOTE: *The over-range alarm is enabled only when the audio switch is turned off. When the audio switch is in the* ON *position, the over-range alarm is not operational.*

When using a Surveyor X, an off-scale meter response will trigger the over-range alarm when the audio switch is off. Switch the instrument to the next highest range. The alarm will clear when the meter response drops back on scale.

After completing the survey, place the protective cardboard or metal cover (supplied with the instrument) over the detector window. The cover is recommended to protect the probe face when it is not in use. The cover protects the face from physical damage and the accumulation of dust. Radon attached to dust particles can be a source of elevated background.

To use the digital scaler, press the rubber-booted button on the front of the Surveyor X. A red LED, on lower right corner of the meter, will illuminate while the scaler is counting. When the count is complete, the LED will turn off. Pressing the button during a count will NOT reset the scaler (begin another count). To begin another count, wait for the count time to end, and press the scaler button again. Another option is to switch the PAM off and on, and then press the scaler button after switching it back on. When the PAM is used as a scaler, a sample holder jig is recommended to maintain a constant source-to-detector geometry.

5.2.1 Correction Factors

To obtain the correct count rate, the meter reading must be multiplied by the scale factor indicated on the range selector switch. If the count rate causes the meter to go off-scale high, the over-range alarm will sound if the speaker is switched off.

To convert an instrument response (in cpm) to an activity (in dpm), the general rule of thumb is to multiply the reading by a factor of 7 (reciprocal of the typical 16% efficiency). This is an acceptable practice for all measurements performed using the 50-cm^2 PAM survey instrument. For the 100-cm^2 PAM, the thumb rule correction factor is 10.

A more accurate measurement can be made by dividing the instrument response (cpm) by the instrument efficiency. The ^{239}Pu or ^{241}Am efficiency is printed on the calibration label. If uranium is of concern, contact the PNNL calibration laboratory for a uranium efficiency check.

To convert readings taken with a 50-cm^2 PAM probe to units of dpm/100 cm^2 for large-area uniform contamination, multiply the dpm/probe area by a factor of 2.

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:

$$50\ cpm\ x\ 7\ dpm/cpm\ x\ 2 = 700\ dpm/100\ cm^2 \qquad (5.1)$$

As a second example using "point" source contamination, a 6-mm (¼-in.) diameter source that reads 50 cpm can be converted to dpm/100 cm^2 as follows:

$$50\ \text{cpm x 7 dpm/cpm} = 350\ \text{dpm}/100\ \text{cm}^2 \qquad (5.2)$$

To convert readings taken with a 50-cm^2 PAM probe to units of dpm/100 cm^2 for large-area, non-uniform contamination, add two adjacent dpm/probe readings together.

5.3 Performance Test Instructions

5.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the PAM fails any of the operability checks, other than the battery test, fill out an Instrument Service Tag to identify the problem, attach it to the instrument, and return the instrument to the PNNL calibration laboratory for servicing.

1. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 pm) on the expiration date on the calibration sticker.
2. Ensure that the instrument source check is current. Source checks are generally valid for the day performed and typically do not cover more than 24 hours.
3. Inspect the instrument for physical defects, such as broken meter glass, loose knobs, punctured probe windows, or defective cables.
4. Turn the count rate meter selector switch to the battery check position (BATT). The meter should read above the BATT cutoff position shown on the meter. If the batteries are low, see Section 5.5.
5. Turn the selector switch to the X1 position and allow a 10-second warmup.
6. Use the ^{230}Th check source mounted on the instrument case to verify that the instrument responds to radiation.
7. Check the probe for light sensitivity by exposing the probe to the source of light at the work location. If an elevated count rate is observed when exposed to the light, then cover the probe with a light shield (such as the probe cover or dark cloth) and verify that the count rate drops. Tag the instrument out of service and return to the PNNL calibration laboratory for repair.
8. Proceed with the survey with the instrument on the X1 range (or other range if appropriate).

5.3.2 Source Check

The PAM is source checked using an alpha check source assembly. The initial source check is performed when the instrument is first received from the calibration laboratory. Source checks are performed daily or before each use if the PAM is used less often than daily. All three ranges of the instrument should be source checked.

Only the first three ranges of the BW can and need to be source checked in the field per compensatory actions approved by the HIEC.[3] As a result, the BW is calibrated quarterly.

5.3.2.1 Initial Source Check

Initial source checks should be performed immediately upon receiving the instrument from thecalibration laboratory. Instruments should not be placed into storage until after performing the initial source check.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure that the values are reasonable. For the PAM, the initial response is reasonable when the response is within*

- *the acceptable ranges printed on a calibrated source assembly*
- *±20% of the mean instrument response for that source.*

The acceptable range should allow for variations resulting from differing probe efficiencies.

Remove the cover from the detector (if applicable) and center the detector over the source position on the check source assembly. Move the source to the appropriate position for each range of the instrument, wait approximately two RC time constants (at least 10 seconds) for the meter to stabilize, and note the instrument response on each range. Multiply the instrument response by 0.8 and 1.2 to determine the acceptable range for that instrument. Background should be 3 cpm or less.

5.3.2.2 Daily Source Check

NOTE: *The source used to perform the initial source check is used to perform the daily source check. To perform a daily source check with a source other than the one used for the initial source check, first perform the daily source check on the source used for the initial source check. If the instrument passes that daily source check, then perform a new initial source check using the new source to establish response limits for that source/instrument combination.*

Remove the cover from the detector (if applicable) and center the detector over the source. Move the source to the appropriate position for each range of the instrument and allow two RC time constants (at least 10 seconds) for the meter to stabilize. The instrument response, on each range, should fall within the acceptable values determined during the initial source check. Perform a background count of at least one minute. Background should be three cpm or less. If the instrument fails, tag it with a completed Instrument Service Tag, and return it to the PNNL calibration laboratory.

(a) Hanford Instrument Evaluation Committee Minutes, June, 2001

5.3.2.3 Response Checks

Periodically verify that the PAM responds to radiation during continuous use. If the instrument is turned off for any reason, response check the instrument when it is turned on by placing the center of the probe over the check source mounted on the instrument case and verify that the speaker and meter respond to the source.

5.4 Calibrations Instructions

The PAM is calibrated at the PNNL CALIBRATION LABORATORY at the 318 Building in the 300 Area. The calibration described in this section is performed by THE CALIBRATION LABORATORY staff.

Before calibration, instruments are inspected to make sure they are in good working order.

Batteries are checked, the meter is checked for oscillations, and the instrument is inspected for physical damage. Damaged instruments are repaired before calibration. As-found count rate meter readings at 20 and 80% of each range and the as-found efficiency are recorded before calibration. If the as-found readings are greater than ±20% out of tolerance, the THE CALIBRATION LABORATORY contacts the radiological control organization that last used the instrument to inform them of the problem.

The Surveyor X meter is calibrated electronically using a calibrated pulse generator. The meter is calibrated at 80% of full scale on all three ranges. The response is then checked at 20% of full scale on each range. The response at both 20% and 80% of full scale must be within 5% of the true count rate for the instrument to pass calibration.

A scaler PAM is checked for proper scaler function by setting the scaler to a 1-minute count time and taking a 1-minute count with the meter connected to the pulser. The indicated total count must be within 2% of the true total count for the scaler to pass calibration. There are no calibration adjustments on the scaler.

The Surveyor X high voltage is then set by exposing the probe to a high-activity ^{90}Sr(Y) source (~10^8 dpm) and adjusting the high voltage to minimize the response to ^{90}Sr(Y) beta particles (no more than five counts in five seconds). The PAM is checked for light leaks using a high-intensity lamp. The background count rate is also checked. The background must be less than 2 cpm for the PAM to pass calibration.

The efficiency of the probe is then verified using a large area source ^{241}Am (50-cm^2 probe) or ^{239}Pu (100-cm^2 probe). The efficiency is measured with a jig that places the probe face 6 mm (¼ in.) from the source surface. The 50-cm^2 PAM's 4-π efficiency must be at least 16% (cpm/dpm) to pass calibration. The 100 cm^2 PAMs must measure at least 10% efficient. The actual efficiency of the instrument is printed in the limitations section of the calibration label. The 50-cm^2 counting efficiencies average 17% and may be as high as 20%.

Each PAM probe is individually matched to a count rate meter. The probes cannot be exchanged between instruments without invalidating the calibration. The calibration sticker on the PAM body identifies the barcode number of the assigned probe. Likewise, the calibration sticker on the PAM probe identifies the barcode number of the assigned body.

For more information on PAM calibration, refer to PNL-MA-563, Section 3.10.2.

5.5 Maintenance Instructions

Routine maintenance on the PAM is performed at the THE CALIBRATION LABORATORY and in the field. Routine maintenance includes checking the photomultiplier tube (PMT) for noise, checking the window for light leaks, and replacing batteries.

The PAM count rate meters should never be used with any probe other than the one they are assigned. The high voltage on PAM count rate meters is specially adjusted for each probe and may not be appropriate for other probes. If the probe is damaged, do not replace the probe with another probe. Return both the probe and the count rate meter to the PNNL THE CALIBRATION LABORATORY for servicing.

Common problems and causes are discussed in the next few paragraphs.

Low batteries: If the PAM has low batteries, the batteries may be replaced in the field. Open the instrument case and replace all four batteries with 9-V alkaline batteries. Make sure the batteries are firmly mounted in the battery clips.

Light sensitivity: If the PAM exhibits a high count rate when exposed to light, there may be holes in the polycarbonate (Mylar) window. Even very small pinholes, too small to be seen with the naked eye, can cause the PAM to exhibit light sensitivity. One way to verify light sensitivity is to expose the probe to a light source, verify the increased count rate, and then cover the probe with a light shield (such as a dark cloth) and verify that the count rate drops.

Small light leaks on the PAM probe face can be repaired in the field. Locating a light leak involves placing the probe under a source of light that causes easily perceived audible output and then covering small sections of the probe face until a decrease in the count rate is observed. Paint the hole in the Mylar using Testor brand (or equivalent) silver paint. The maximum area of the probe surface that is covered with paint should be limited to 1% (0.5 cm^2 for 50 cm^2 probes; 1 cm^2 for 100 cm^2 probes) of the total surface area (approximately 9 or 18 grid holes, respectively, of the mesh screen).

Cable noise: Damaged cables may cause the PAM to exhibit a noisy response, especially when the cable is moved. Damaged cables can be replaced in the field as long as they are replaced with a cable of equal length. Make sure the replacement cable has MHV connections on both ends before attempting to connect it to the instrument. Improper cable connectors can damage the instrument or the probe.

Cable noise may also be caused by bending cold cables. If the temperature is below freezing and the instrument is cold, flexing the cable can cause counts to register on the meter.

Saturation: Very large light leaks will cause the PAM to saturate (i.e., not respond at all). To verify that the PAM is exhibiting saturation, place a dark cloth (e.g., a coat) over the probe. Slowly remove the cloth while listening to the audible response. If the PAM has large light leaks, the audible response will first increase as the cloth is removed and then decrease as the probe face is fully exposed to the light. If the probe is exhibiting saturation, tag it with an Instrument Service Tag and return it to the PNNL calibration laboratory for servicing.

Photomultiplier tube noise: A faulty PMT will cause the PAM to have a noisy response when the probe is shaken or moved. To determine if the PMT should be replaced, lightly tap the back of the probe several times against your hand. If tapping the probe causes an audible response, the PMT should be replaced. Tag the PAM with an Instrument Service Tag and return it to the PNNL the calibration laboratory.

5.6 Instrument Specifications and Limitations

5.6.1 Temperature

The PAM is operable within the temperature range of -30°C to 50°C (-22°F to 122°F).[4][5]

At temperatures greater than 40°C, the meter face of a scaler PAM may warp and cause the meter needle to stick on an upscale reading. This is generally not a problem unless you are trying to quantify activity. Once cooled to room temperature, the meter face will return to its original, flat shape.

Batteries are affected by cold temperatures. More frequent response checks should be performed at cold temperatures (less than –10°C)[6]

5.6.2 Temperature Shock

The PAM is not affected by temperature shocks. However, it is good practice to allow the instrument temperature to equalize with the ambient temperature before using it to perform surveys.[7]

5.6.3 Humidity and Pressure

The PAM is not affected by changes in ambient humidity or pressure. [b] The PAM should not be used in condensing environments. For example, condensation could be encountered when moving a cold instrument into a warm, humid environment. Condensation (beads of water) may form on the instrument. The instrument should not be used under these conditions. The operator should allow the instruments to equalize with the ambient temperature and remove any remaining condensation.

(a) JT Rolph (PNNL) memo to Hanford Instrument Evaluation Committee, 3/1/05
(b) PNL-9876, Evaluation of the Bicron Surveyor X Alpha Monitor with Hanford Alpha Contamination Probe using criteria in ANSI Standard N42.17A, July, 1994
(a) Hanford Instrument Evaluation Committee Minutes, 3/1/2005
(b) PNL-9876, Evaluation of the Bicron Surveyor X Alpha Monitor with Hanford Alpha Contamination Probe using criteria in ANSI Standard N42.17A, July, 1994

5.6.4 Electromagnetic Field Interference

The PAM may be sensitive to electromagnetic fields. Though a PMT, in general, are very sensitive to magnetic fields, the PAM PMT is shielded to reduce this sensitivity. However, near high magnetic fields (10 gauss), the PAM's response may be affected. The magnetic field may cause the PAM response to read high or low. A common source of fields that may affect the PAM response is video displays. A PAM that is not adequately shielded may exhibit a high count rate when the probe face is near a video display. If magnetic fields are a potential concern, response checks should be performed in the field at the distances from the magnetic field source expected during use. Less than a ±20% deviation should be observed due to the effects of the potential source of magnetic fields.

The PAM is susceptible to the effects of static charges that may build up on the meter face. A static charge will attract the meter needle and cause errors in readings. A static charge will cause sluggish meter response. Lightly tapping the meter face will momentarily allow the needle to move toward the actual reading. Sprays are available that eliminate static charge build up.

5.6.4.1 Radio Frequency Interference

The PAM is not affected by external radio frequency fields.

5.6.5 Energies and Types of Radiation

The PAM responds to alpha-emitters with energies greater than about 4 MeV.

5.6.6 Interfering Ionizing Radiation Response

Some PAMs may exhibit slight sensitivity to photon backgrounds (see 5.1.2). Specially tuned count rate meter PAMs that have been selected for photon insensitivity are available upon request from the PNNL calibration laboratory. The standard PAM is very insensitive to gamma radiation and typically shows no response to gamma field strengths of 1 R/hr. PAMs labeled as gamma insensitive are checked in a 4-R/hr ^{137}Cs field and measure 0 counts in 30 seconds in the 4-R/hr field.

The PAM may also be sensitive to beta radiation. During calibration, the high voltage is set to minimize beta sensitivity, while maximizing the alpha efficiency. In some cases, slight beta sensitivity must be accepted in order to obtain an acceptable (> 14%) alpha efficiency. Typically, a PAM will exhibit no response to beta radiation up to 500 mrad/hr.[8] The requirement for beta insensitivity is not more than 5 counts in 5 seconds when exposed to a ~10^8-dpm ^{90}Sr(Y) source.

PAMs are sensitive to neutron radiation.[a] Sensitivity may be as high as 11 cpm/mrem/hr of neutron radiation and averages a few cpm/mrem/hr.

(10/a) PNL-9876, Evaluation of the Bicron Surveyor X Alpha Monitor with Hanford Alpha Contamination Probe using criteria in ANSI Standard N42.17A, July, 1994

5.6.7 Battery Life

The PAM battery life is at least 100 hours with four 9-V alkaline batteries without the scaler option on the Surveyor X.[a] Using the Surveyor X with the scaler option reduces battery life to over 750 hours.[9]

5.7 Applications

The PAM is used to survey material and personnel for alpha contamination by direct frisk or evaluating technical smears for removable alpha activity.

The limits given in the tables in this section are typical of contamination limits set forth in 10 CFR 835, Appendix D, for posting and conditional release surveys.

The limits given in the tables were also taken from DOE Order 5400.5, Radiation Protection Of The Public And The Environment, and the U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.86, Termination of Operating Licenses for Nuclear Reactors, as appropriate for unconditional release surveys.

The following subsections illustrate one method of counting statistics, minimum detectable activity analysis, and survey techniques. Users may have developed alternate approaches to these topics.

5.7.1 Direct Surface Contamination Measurements

The PAM can evaluate surfaces for alpha contamination. Surfaces should be clean and dry. Alpha contamination is easily attenuated and even a thin film of oil, water, or dust will shield alpha emitters. As little as 5 mg/cm^2 can completely shield a 5-MeV alpha particle.

The methods for performing surface contamination measurements for a few applications are described in the sections below.

The scan speeds listed are estimated based on the probability of the instrument indicating a count during the time the detector resides over the source. Assuming a Poisson distribution for this probability and setting the average number of possible counts during the residence time to the product of the residence time, source activity, and detector efficiency, the probability, or confidence level, can be estimated from the following equation[10]

$$confidence\ \ level = 1 - e^{-S\varepsilon t} \tag{5.3}$$

where:

S = source activity (dpm/100 cm^2)
ε = detector efficiency
t = residence time (min)

(b) Hanford Instrument Evaluation Committee Minutes, August, 1994
(a) G.F. Knoll, Radiation Detection and Measurement, 2nd ed., Wiley, New York, 1989, pg. 96.

The residence time for a specific confidence level can then be derived:

$$t = \frac{\ln(1 - confidence \;\; level)}{S \cdot \varepsilon} \tag{5.4}$$

For a specific detector width, the scanning speed can then be estimated from the following equation:

$$scan \;\; speed\ (in./\text{sec}) = \frac{W \cdot S \cdot \varepsilon}{\ln(1 - confidence\ level)} \tag{5.5}$$

Where:

W = detector width (in.)

The 50 cm^2 PAM probe has a width of 1.77 in. The 100 cm^2 PAM probe has a width of 3.15 in.

5.7.1.1 Scanning Surveys at a 95% Confidence Level

The levels tabulated for a 95% confidence level are based upon listening to the audible output count rate. When a count is detected, the operator should stop and evaluate the suspected area for five seconds. If no additional counts are detected, the survey is continued. Otherwise, the area should be considered contaminated. Background is assumed to be 0 cpm with a maximum background of 3 cpm. The probe efficiency is based on the detector being 6 mm (¼ in.) above the surface.

Table 5.2. Scanning Surveys at a 95% Confidence Level

Limit (dpm/100 cm^2)	Instrument	Maximum Scan Speed (in./sec)	Minimum Detectable Activity (MDA) (dpm/100cm^2)
100	50 cm^2 Probe	Not possible	Not applicable
	100 cm^2 Probe	0.2	100
500	50 cm^2 Probe	0.8	500
	100 cm^2 Probe	1	350

Scan surveys performed to three times the total contamination limits are accomplished as follows.

Table 5.3. Scan Surveys Performed to Three Times the Total Contamination Limits

Three Times Limit (dpm/100 cm^2)	Instrument	Maximum Scan Speed (in./sec)	MDA (dpm/100 cm^2)
300	50 cm^2 Probe	0.5	280
	100 cm^2 Probe	0.5	280
1500	50 cm^2 Probe	2	1400
	100 cm^2 Probe	2	1400

5.7.1.2 Scanning Surveys at a 67% Confidence Level

The levels tabulated for a 67% confidence level are based upon listening to the audible output count rate. When a count is detected, the operator should stop and evaluate the suspected area for five seconds. If no additional counts are detected, the survey is continued; otherwise, the area should be considered contaminated. Background is assumed to be 0 cpm with a maximum background of 3 cpm. The probe efficiency is based on the detector being 6 mm (¼ in.) above the surface.

Table 5.4. Scanning Surveys at a 65% Confidence Level

Limit (dpm/100cm²)	Instrument	Maximum Scan Speed (in./sec)	MDA (dpm/100 cm²)
100	50 cm² Probe	0.4	100
	100 cm² Probe	0.5	100
500	50 cm² Probe	2	500
	100 cm² Probe	2	500

Scan surveys performed to three times the total contamination limits are accomplished as follows.

Table 5.5. Scan Surveys Performed to Three Times the Total Contamination Limits

Three Times Limit (dpm/100 cm²)	Instrument	Maximum Scan Speed (in./sec)	MDA (dpm/100 cm²)
300	50 cm² Probe	1	250
	100 cm² Probe	1	250
1500	50 cm² Probe	6	1000
	100 cm² Probe	7	1300

5.7.1.3 Static Surveys at a 95% Confidence Level

The levels tabulated for a 95% confidence level are based upon listening to the audible output count rate for the time period specified. When a count is detected, the operator 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 should be considered contaminated.

Background is assumed to be 0 cpm with a maximum background of 3 cpm. The probe efficiency is based on the detector being held on contact with the surface.

Table 5.6. Static Surveys at a 95% Confidence Level

Limit (dpm/100 cm²)	Instrument	Count Time (sec)	MDA (dpm/100 cm²)
100	50 cm² Probe	21	90
	100 cm² Probe	8	90
500	50 cm² Probe	4	360
	100 cm² Probe	4	180

5.7.2 Removable Surface Contamination Measurements

The PAM is used to perform removable surface contamination measurements in the field to the 20 dpm/100-cm^2 limit. Methods to perform removable surface contamination measurements are described below. These measurements are based on taking a technical smear of a 100-cm^2 (15.5-in.^{2}) area.

A portable alpha scaler (PAS) is recommended for performing this procedure.

A non-scaling PAM and a stopwatch may be used in situations where a PAS is not available. The operator must count the number of audible "pops" heard while using the stop watch to measure the time period specified (1 minute).

NOTE: *For each of the methods that follows (Sections 5.7.2.1 through 5.7.2.4), if the result at the end of any 1-minute interval is within the criteria given, then no further counting of the sample is required. Performing additional counts on the same sample is only necessary when previous counts exceed the criteria given. Additional counts are performed to reduce the impacts due to false positive results from any single 1-minute count.*

5.7.2.1 Alpha Smear Counting on Contact (95% Confidence)

To perform this count:

1. Perform the daily background check by taking five 1-minute background counts. Calculate the average background count rate by adding all 1-minute counts and dividing by the total number of counts (five).
2. If the background count rate is < 1 cpm, then proceed to the next step. If the background count rate is ≥ 1 cpm then obtain another instrument, and repeat Step 1.

   NOTE: *For the method described in this section, technical smears are counted on contact with the detector (a sample holder may be used to ensure uniform distance). The technical smear should be centered on the detector.*

3. Count the technical smear for one minute. If no counts are observed, then the smear is free of contamination (with an MDA of less than 20 dpm/100 cm2 and a confidence level of 95%). If one or more counts are observed, then go to Step 4.
4. Count the technical smear for an additional minute (two minutes total). If fewer than four total counts (sum of counts from both 1-minute counts) are observed, then the smear is free of contamination (with an MDA of less than 20 dpm/100 cm2 and a confidence level of 95%). If four counts or more are observed, then go to Step 5.
5. Count the technical smear for an additional minute (three minutes total). If fewer than seven total counts (sum of counts from all three 1-minute counts) are observed, then the smear is free of contamination (with an MDA of less than 20 dpm/100 cm^2 and a confidence level of 95%). If seven or more counts are observed, then the smear is contaminated and any further evaluation of the smear should be performed using a miniscaler.

5.7.2.2 Alpha Smear Counting on Contact (67% Confidence)

To perform this count:

1. Perform the daily background check by taking five 1-minute background counts. Using the five 1-minute background counts, calculate the average background count rate.
2. If the background count rate is < 1 cpm, then proceed to the next step. If the background count rate is ≥ 1 cpm, then obtain another instrument and return to Step 1.

   NOTE: *For the method described in this section, technical smears are counted on contact with the detector (a sample holder may be used to assure uniform distance). The technical smear should be centered on the detector.*

3. Count the technical smear for one minute. If fewer than three counts are observed, then the smear is free of contamination (with an MDA of less than 20 dpm/100 cm^2 and a confidence level of 67%). If three or more counts are observed, then go to Step 4.
4. Count the technical smear for an additional minute (two minutes total). If fewer than seven total counts (sum of counts from both 1-minute counts) are observed, then the smear is free of contamination (with an MDA of less than 20 dpm/100 cm^2 and a confidence level of 67%). If seven counts or more are observed, then go to Step 5.
5. Count the technical smear for an additional minute (three minutes total). If fewer than 10 total counts (sum of counts from all three 1-minute counts) are observed, then the smear is free of contamination (with an MDA of less than 20 dpm/100 cm^2 and a confidence level of 67%). If 10 or more counts are observed, then the smear is contaminated, and any further evaluation of the smear should be performed using a miniscaler.

5.7.2.3 Alpha Smear Counting at 6 mm (¼ in.) (95% Confidence)

To perform this count:

1. Perform five 1-minute background counts and calculate the average background count.
2. If the background is ≥ 1 cpm, then obtain another instrument and return to Step 1.

   NOTE: *For the method described in this section, technical smears are counted within 6 mm (¼ in.) of the detector (a sample holder should be used to assure uniform distance). The technical smear should be centered on the detector.*

3. Count the technical smear for one minute. If no counts are observed, then the smear is free of contamination (with an MDA of 20 dpm/100 cm^2 and a confidence level of 95%). If one or more counts are observed, then go to Step 4.
4. Count the technical smear for an additional minute (two minutes total). If fewer than two total counts (sum of counts from both 1-minute counts) are observed, then the smear is free of contamination (with an MDA of 20 dpm/100 cm^2 and a confidence level of 95%). If two counts or more are observed, then go to Step 5.
5. Count the technical smear for an additional minute (three minutes total). If fewer than four total counts (sum of counts from all three 1-minute counts) are observed, then the smear is free of

contamination (with an MDA of 20 dpm/100 cm^2 and a confidence level of 95%). If four or more counts are observed, then the smear is contaminated, and any further evaluation of the smear should be performed using a miniscaler.

5.7.2.4 Alpha Smear Counting at 6 mm (¼ in.) (67% Confidence)

To perform this count:

1. Perform five 1-minute background counts and calculate the average background.
2. If the background is < 1 cpm then proceed to the next step. If the background is ≥ 1 cpm, then obtain another instrument and return to Step 1.

   NOTE: *For the method described in this section, technical smears are counted within 6 mm (¼ in.) of the detector (a sample holder should be used to assure uniform distance). The technical smear should be centered on the detector.*

3. Count the technical smear for one minute. If fewer than two counts are observed, then the smear is free of contamination (with an MDA of 20 dpm/100 cm^2 and a confidence level of 67%). If two or more counts are observed, then go to Step 4.
4. Count the technical smear for an additional minute (two minutes total). If fewer than five total counts (sum of counts from both 1-minute counts) are observed, then the smear is free of contamination (with an MDA of 20 dpm/100 cm^2 and a confidence level of 67%). If five counts or more are observed, then go to Step 5.
5. Count the technical smear for an additional minute (three minutes total). If fewer than seven total counts (sum of counts from all three 1-minute counts) are observed, then the smear is free of contamination (with an MDA of 20 dpm/100 cm^2 and a confidence level of 67%). If seven or more counts are observed, then the smear is contaminated and any further evaluation of the smear should be performed using a miniscaler.

5.7.3 Counting Air Samples

A field measurement of an air sample may be performed using the PAM probe. These measurements should be used for indication only and should be verified using count room instruments or a miniscaler.

5.8 References

10 CFR 835. 1999. U.S. Department of Energy. "Occupational Radiation Protection." *U.S. Code of Federal Regulations.*

U.S. Department of Energy (DOE). 1990. "Radiation Protection of the Public and the Environment." DOE Order 5400.5.

NRC Regulatory Guide 1.86, " Termination of Operating Licenses for Nuclear Reactors", dated June 1974, published by the Nuclear Regulatory Commission

International Atomic Energy Agency (IAEA). 1970. *Technical Report 120.*

6.0 Portable Geiger-Müller Survey Instruments

6.1 Instrument Description and Theory of Operation

The pancake Geiger-Müller (GM) contamination survey instrument consists of a count rate meter and a pancake GM detector. The count rate meter may be a Bicron Surveyor X, a Ludlum Model 3 or, most commonly a Eberline E-140 series meter (E-140, E-140B, BNW, and BNW-1). The Eberline count rate meters are commonly referred to as GMs.

In addition to the information provided in this document, detailed technical information can be found in the manufacturer's technical manuals listed in Section 6.8 or by calling the PNNL calibration laboratory at (509) 376-5624.

6.1.1 Physical Description

The Eberline E-140 has a rectangular metal case with an integral carrying handle and probe clip (see Figure 6.1). Attached to the side of the instrument is an external speaker with its own ON/OFF switch. A phone jack is provided for earphones or for counting events with a scaler. The probe attaches to the instrument with a bayonet nut connector (BNC). The Eberline E-140B, BNW, and BNW-1 are essentially identical to the Eberline E-140. Headphones can be obtained from the PNNL the calibration laboratory.

The Eberline E-140 weighs 1.5 kg (3.4 lb) and measures 22 cm (8.5 in.) long by 9.8 cm (3.9 in.) wide by 18 cm (6.9 in.) high, including the handle and probe clip.

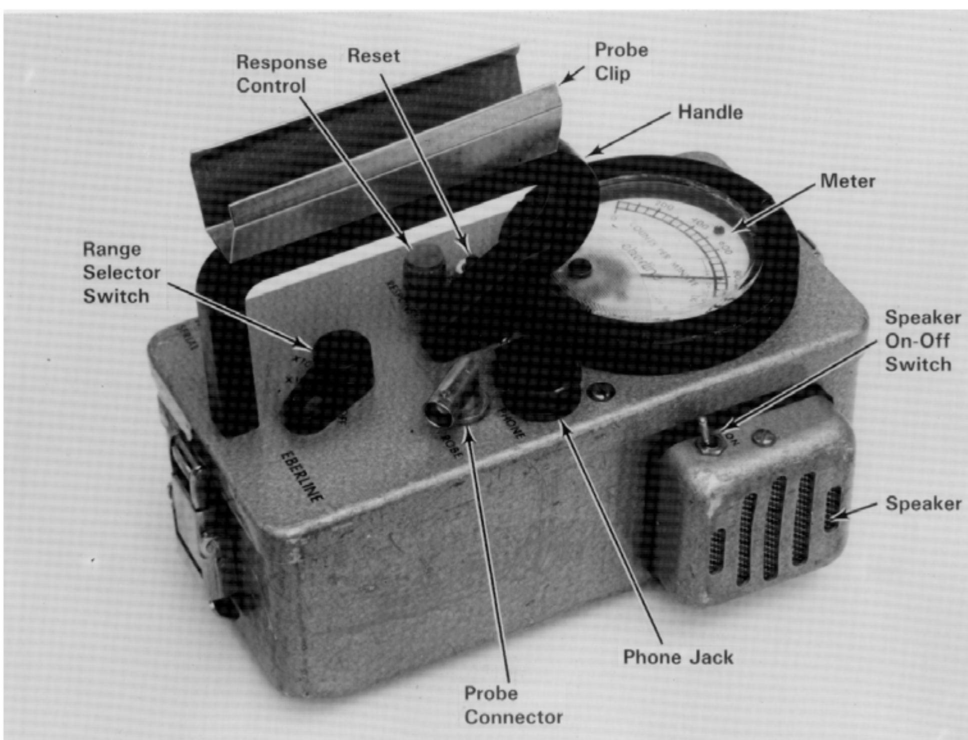

Figure 6.1. Eberline Model E-140 Count Rate Meter

The Bicron Surveyor X is similar in overall dimensions to the Eberline E-140. The Surveyor X is depicted in Figure 5.1. There are a few major physical differences between the two instruments. The Surveyor X has an internal speaker, a BNC or mega high voltage (MHV) connector, and a high-voltage indication position on the selector switch. The Surveyor X also has automatic dead-time compensation and anti-saturation circuitry, adjustable high-voltage supply, preset response times (optimized for each range), and an over-range alarm.

When using a Bicron Surveyor X, an off-scale meter response will trigger the over range alarm when the audio switch is off. Switch the instrument to the next highest range. The alarm will clear when the meter response drops back on scale.

The Ludlum Model 3 is similar in size and design to the E-140. The Ludlum Model 3 is shown in Figure 6.2. Like the E-140, the Ludlum Model 3 has an integral carrying handle and probe clip. The probe also attaches to the Ludlum Model 3 via a BNC connector. Like the Bicron Surveyor X, the Ludlum Model 3 has an internal speaker. All Ludlum Model 3 meters have a digital scaler.

NOTE: *The PNNL the calibration laboratoryTHE CALIBRATION LABORATORY has modified all Ludlum Model 3s used with GM probes to specifically accommodate these detectors. These Ludlum Model 3s are identified with a label reading "GM Only."*

Figure 6.2. Ludlum Model 3 Count Rate Meter

Response checks should be performed periodically during continuous use; at a minimum, when the instrument is turned on. Conduct the response check with the integral source.

The linearity of the E-140 and the Surveyor X is ±5% of full scale over the entire range of the instruments. With GM probes, there is an apparent change in linearity of the E-140 because of the long resolving time associated with GM tubes (see Section 6.6). The Surveyor X has dead-time compensation to maintain a linear response even at high count rates.

Both the Surveyor X and the E-140 have a 0 cpm to 1,000 cpm meter and a three-position range switch. The ranges are X1, X10, and X100. Both instruments have an upper count rate limit of 100,000 cpm. The Model 3 has a 0 cpm to 5,000 cpm meter and a four position range switch. The ranges are X0.1, X1, X10, and X100. The upper count rate limit is 500,000 cpm.

The response time is generally specified by the manufacturer as the time for the instrument reading to reach 90% of final value after a change in the radiation field. The RC time constant of the instrument can be calculated from the 0% to 90% response time by dividing the 0% to 90% response time by 2.3. The response time of the E-140 is continuously adjustable by the response control from 2 to 10 seconds (RC time constant of 0.9 to 4.3 seconds). The Surveyor X has preset response times for each range. The actual response time for each range is listed in Table 6.1.

Table 6.1. Surveyor X Response Time

Response Time and Time Constant (RC) of Bicron Surveyor X		
Range	**Response Time (s)(1)**	**RC Time Constant (s)**
X1 (0 to 1000 cpm)	12	5.2
X10 (0 to 10,000 cpm)	5	2.2
100 (0 to 100,000 cpm)	2	0.9
Response Time and Time Constant (RC) of Eberline E-140		
Range	**Response Time (s)(2)**	**RC Time Constant (s)**
All	2 to 10	0.9 to 4.3
Response Time and Time Constant of Ludlum Model 3		
Range	**Response Time (s)(3)**	**RC Time Constant (s)**
All	4 to 22	1.7 to 9.6

6.1.1.1 Pancake GM Probe

Two types of GM detectors, commonly referred to as a pancake probe or P-11, are used at the Hanford Site; a pancake GM detector (see Figure 6.3) and a shielded GM detector (Figure 6.4).

(a) Harshaw Bicron Surveyor X Portable Count-Rate Meter with Digital Scaler Option/User's Manual, Publication No. 1026-8-U-0294-0021, February 1994
(b) Technical Manual for Count rate Meter Model E-140, January 1977
(c) Ludlum Model 3 Survey Meter Instruction Manual, June 1995

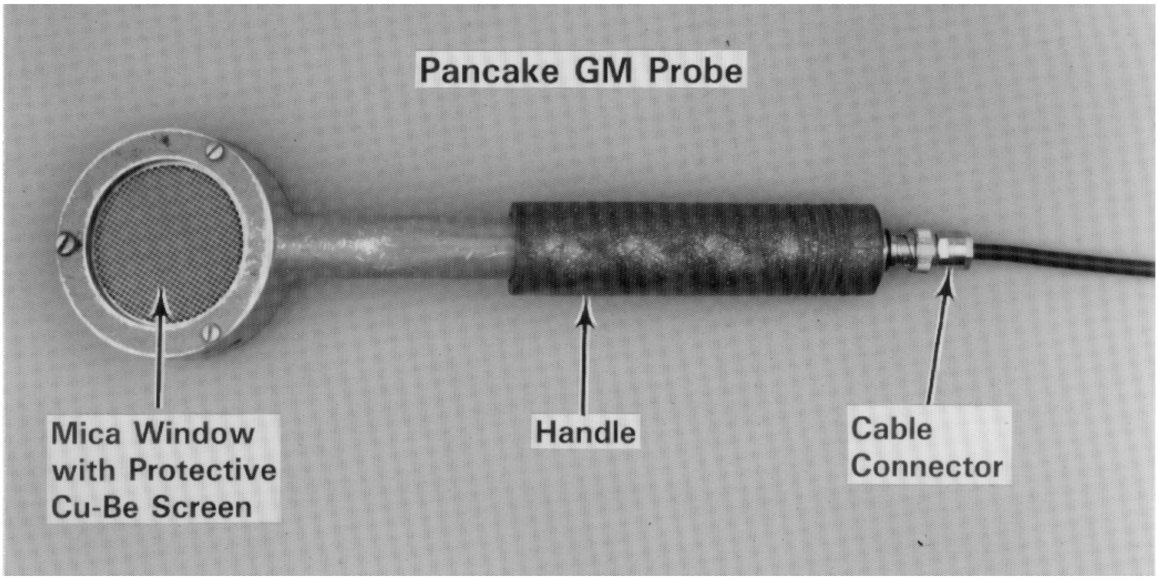

Figure 6.3. GM Pancake Probe

Figure 6.4. Shielded GM Detector

Both detectors use a pancake GM tube that has a thin mica window. The mica window is approximately 1.4 mg/cm^2 thick and has an active area of 15.5 cm^2. The thin mica window of the probe is very fragile and is protected by a fine mesh copper-beryllium or stainless steel screen. Both detectors operate at a high voltage of about 900 V.

The overall length of the unshielded probe is 26 cm (10.25 in.). The handle of the probe clips into the spring steel holder on the instrument handle.

Tungsten- and lead-shielded GM detectors are available for use in areas with high gamma backgrounds. These are functionally equivalent to the pancake GM detector. The tungsten option offers shielding equivalent to the lead shield without the hazardous material problems associated with lead. Shielded GM detectors are frequently used with an optional sample holder tray.

6.1.2 Radiation and Energy Response

The pancake GM detector responds to alpha, beta, and photon (gamma and x-ray) radiations. Beta and gamma radiation energy response is shown in Figures 6.4 and 6.5 (see Section 6.6.6). The pancake GM detector efficiency is about 8% for ^{230}Th, ^{239}Pu, or ^{241}Am. The pancake GM detector does not detect neutrons.

6.1.3 Integral Sources

Count rate meters provided with GM detectors have internal sources used to response check the instruments. The source is either ~0.3 μCi of natural uranium or 85 nCi of ^{90}Sr/Y. The source is mounted on a flapper assembly that shields the source when the instrument is held horizontally. When the instrument is held vertically (with the meter up), the flapper opens to expose the source. The location of the internal source is shown on the outside of the instrument with a radiation symbol sticker.

6.2 Operating Instructions

Connect a GM detector to an appropriate count rate meter using a cable that has BNC connectors.

NOTE: *Do not attempt to force mega high-voltage (MHV) cable connectors onto the detector or the count rate meter. Forcing mismatched connectors can damage the connectors.*

Ensure that performance tests have been performed (see Section 6.3).

Turn the instrument on, set the range switch on the lowest range, and allow a 10-second warm-up. Turn the instrument speaker on. Set the response, if adjustable, to the slowest setting and estimate the background. Wait approximately 2 RC time constants (see Section 6.1.1) for the instrument to reach the final value.

On Eberline count rate meters, the response control may be adjusted for the desired response time. For low count rates, a longer response time (slower meter movement) is generally more desirable. On Surveyor X count rate meters the response time is preset for each range and cannot be adjusted.

To survey material or personnel, hold the probe approximately 6 mm (¼ in.) from the surface to be surveyed and move the probe at the desired scan speed (see Section 6.7), while listening to the meter's audible response. Avoid touching the probe to potentially contaminated surfaces. The probe window is fragile and can be damaged by contacting small, sharp objects (e.g., pencil points, grass, and tumbleweeds).

If the audible count rate is elevated above background, investigate by pausing over the suspected area for five seconds, then scan approximately 13 cm (5 in.) of the previous path at a reduced rate.

NOTE: *For the Surveyor X, the over-range alarm is enabled only when the audio switch is turned off. When the audio switch is in the ON position, the over- range alarm is not operational.*

6.2.1 Correction Factors

To obtain the correct count rate, multiply the meter reading by the scale factor shown on the range selector switch.

To convert an instrument response (in cpm) to a beta activity (in dpm), the general rule of thumb is to multiply the reading by a factor of 10. This is an acceptable (and conservative) practice for all measurements performed with a GM survey instrument.

If the radionuclide of the source (contamination) is known, then a more accurate measurement can be made by dividing the count rate meter response by the appropriate instrument efficiency. Efficiencies for a few (i.e., ^{90}Sr/Y, ^{137}Cs, ^{99}Tc) radionuclides are printed on the calibration label of each detector.

To convert a measurement from dpm/probe area to dpm/100 cm^2, sum six adjacent probe areas to determine the dpm/100 cm^2 for the area.

If the measurements are constant over the area, then the dpm/100 cm^2 can be calculated by multiplying the dpm/probe area by six to obtain dpm/100 cm^2.

6.2.2 Correction Factor Rules of Thumb

The purpose of this section is to describe the circumstances under which it is acceptable to use the rules of thumb. A correction factor of 10 is frequently used to convert count rate from a GM pancake probe to dpm of beta activity per probe area. Another correction factor of five is then commonly used to convert the activity per probe area to activity per 100 cm^2.

The rules of thumb correction factors are appropriate if the lowest energy beta-emitter that contributes significantly to the total activity is ^{99}Tc. The next two paragraphs compare the correction factor using the rules of thumb to the worst case true correction factor.

If ^{99}Tc is the lowest energy beta-emitter, and the minimum efficiency for a pancake GM detector to pass calibration is 12%, then the maximum efficiency correction factor would be 8.33. Multiplying the efficiency correction factor by the area correction factor (six) gives a total maximum, correction factor of 50.

If the rules of thumb are applied, the total correction factor is also 50 (10 * 5). The conclusion is that using the rules of thumb provides a total correction factor that is equal to the worst case conditions for the true correction factor. For all other cases (i.e., higher ^{99}Tc efficiency, higher energy isotope of interest), the true correction factor will be less than 50.

6.3 Performance Test Instructions

6.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the instrument fails any of the operability checks, other than the battery test, fill out an Instrument Service Tag to identify the problem, attach it to the instrument, and return the instrument to the PNNL calibration laboratory for servicing.

1. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) on the expiration date on the calibration sticker.
2. Ensure that the instrument source check is current. Source checks are generally valid for the day performed and typically do not cover more than 24 hours.
3. Inspect the instrument for physical defects, such as broken meter glass, loose knobs, punctured probe windows, or defective cables.
4. Turn the count rate meter selector switch to the battery check position (BATT). The meter should read above the BATT cutoff position shown on the meter. If the batteries are low, see Section 6.5.
5. Turn the selector switch to the X1 position and allow a 10-second warm-up.
6. Use the integral source to verify that the instrument responds to radiation. On Eberline count rate meters, push the RESET button during the response check. The reading should drop to zero rapidly, than climb back to the original source reading when the RESET button is released.
7. Proceed with the survey with the instrument on the X1 range (or other range if appropriate).

6.3.2 Source Check

The GM probe is source checked using a GM check source assembly. The initial source check is performed when the instrument is first received from the calibration laboratory. Source checks are performed daily or before each use if the instrument is used less often than daily. All three ranges of the instrument should be source checked. Response limits are applicable to probes, not count rate meters.

6.3.2.1 Initial Source Check

Initial source checks should be performed immediately upon receiving a GM probe from the calibration laboratory. Probes should not be placed into storage until after performing the initial source check.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure the values are reasonable. For the GM, the initial response is considered reasonable when the response is within*

- *the acceptable ranges printed on a calibrated source assembly*
- *±20% of the mean instrument response for that source.*

The acceptable range should allow for variations resulting from differing probe efficiencies.

Connect the GM probe to any count rate meter (preferably one that has recently been calibrated). Remove the cardboard shield from the detector and place the detector over the check source assembly. Move the source to the appropriate position for the scale of the instrument being tested and note the instrument response. Multiply the instrument response by 0.8 and 1.2 to determine the acceptable range for that instrument scale. Repeat the initial source check for all instrument scales.

6.3.2.2 Daily Source Check

NOTE: *The source used to perform the initial source check is used to perform the daily source check. To perform a daily source check with a source other than the one used for the initial source check, first perform the daily source check on the source used for the initial source check. If the instrument passes that daily source check, then perform a new initial source check using the new source to establish response limits for that source/probe combination*.

Remove the cardboard cover from the probe, as applicable. Place the GM probe over the source position on the check source assembly. Move the source to the appropriate position for each range of the instrument. The instrument response, on all scales, should fall within the acceptable values determined during the initial source check.

If the instrument fails, it may be a defective GM detector or a defective count rate meter. First, replace the pancake probe and repeat the daily source check using the initial source check limits established for the new probe. If the instrument performs satisfactorily during the daily source check, then the original probe was at fault. Tag the original probe with a completed Instrument Service Tag and return it to the calibration laboratory. If the instrument does not perform properly during the second daily source check, the meter is probably faulty. Tag the count rate meter with a completed Instrument Service Tag, and return it to the calibration laboratory.

6.3.2.3 Response Checks

The GM survey instrument is response checked using the integral check source installed inside the case of the count rate meter. The check source, ^{238}U or ^{90}Sr/Y, is mounted in an assembly that includes a shield that swings out, exposing the source, when the instrument is held vertically. When the instrument is held horizontally, the flapper swings shut, shielding the source. The location of the source is marked with a sticker that has a radiation symbol.

To response check the instrument, turn it on and hold it vertically. Hold the detector against the case in the area near the check source. Verify that the instrument meter and audible response increase when the detector is placed over the check source.

6.4 Calibration Instructions

The GM detectors and count rate meters are calibrated at the PNNL calibration laboratory at the 318 Building in the 300 Area. The calibration described in this section is performed by the calibration laboratory staff.

Before calibration, instruments are inspected to make sure they are in good working order. Count rate meters are checked for low batteries and meter oscillations. Detectors are checked for contamination (maximum allowed background is 60 cpm). All instruments are inspected for physical damage and repaired before calibration.

As part of the calibration, as-found efficiency readings are measured for each pancake probe using ^{90}Sr/Y. A ~10,000 dpm source is used to evaluate efficiency after a 1-minute counting interval. If the as-found readings are below 21%, the probe fails the as-found test, and the calibration laboratory informs the radiological control organization that last used the instrument of the failure. Failed probes are sent to the repair facility for evaluation and repair. If the initial efficiency is 21% or greater, a second 1-minute efficiency measurement is made using a ~100,000 dpm ^{90}Sr/Y source. If the efficiency at ~100,000 dpm is > 3 percentage points from the ~10,000 dpm efficiency (indicating unacceptable dead time), the probe is sent to the repair facility for evaluation and repair. Pancake GM detectors are calibrated with ^{90}Sr/Y, with a minimum acceptable efficiency of 21%. The ^{99}Tc and ^{137}Cs efficiency are calculated, based upon an empirical study of GM detector response, relative to ^{90}Sr. The ^{137}Cs efficiency is 0.66 times and the ^{99}Tc efficiency is 0.48 times the ^{90}Sr/Y value. ^{60}Co efficiencies are not listed, but are equivalent to the ^{99}Tc efficiency. The GM detectors are also checked for increases in dead time due to aging by checking the efficiency with a high-activity ^{90}Sr(Y) source (~100,000 dpm). Typical efficiencies are 27% for ^{90}Sr(Y), 18% for ^{137}Cs, and 13% for ^{99}Tc. The calibration label for pancake GM probes includes the efficiency for ^{99}Tc, ^{137}Cs, and ^{90}Sr(Y). These probes are individually calibrated and may be transferred from one GM count rate meter to another in the field.[a]

Before calibration, as-found readings at 80% of each range of the count rate meter are evaluated and recorded. If the meter as-found readings are greater than ±20% out of tolerance, the calibration laboratory informs the radiological control organization that last used the instrument of the failure.

Count rate meters are calibrated electronically using a calibrated nuclear pulse generator. Meters are calibrated at 80% of full scale on all three ranges. The response is then checked at 20% of full scale on each range. The response at both 20% and 80% of full scale must be within 5% of the true count rate for the instrument to pass calibration. The meters are then checked with a GM detector to verify that they function correctly with the GM detector.

For more information on instrument calibration, refer to PNL-MA-563, Sections 3.7 and 3.9.2.

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[a] Letter from DM Fleming, Pacific Northwest National Laboratory, to JM Selby, Pacific Northwest National Laboratory, "Pancake Probe Usage with Multiple GM Count Rate Meters," February 12, 1990.

6.5 Maintenance Instructions

Routine maintenance on the GM survey instruments is performed both in the field and at the calibration laboratory. Routine maintenance includes checking the detector for aging, checking cables for noise, and replacing batteries.

Low battery: If a low-battery condition is indicated, batteries may be replaced in the field. To replace the batteries on a Surveyor X, open the clips and remove the case. Replace all four 9-V batteries at the same time with alkaline batteries. After replacing the batteries, perform a daily source check to verify that the instrument is working properly.

To replace the batteries on the E-140 and similar instruments, open the clips and remove the case. Replace both D cell batteries at the same time with alkaline batteries. After replacing the batteries, perform a daily source check to verify that the instrument is working properly.

Broken GM detector window: Pancake detectors are fragile and are easily broken. If the pancake detector tube breaks during use, return the probe with the broken window to the calibration laboratory.

Erratic response or no response: Cables can fail during routine use. Cable failures will either cause the instrument to not respond or will cause the instrument to be noisy (i.e., sporadic high count rate). Cables may be replaced in the field. After replacing the cable, perform a daily source check to verify that the instrument is working properly. Cables may be replaced with longer cables if the instrument, with the longer cable, passes the daily source check.

NOTE: *When replacing cables, make sure that the cable has BNC connectors. Forcing mismatched connectors can damage the cables, detectors, and/or the instruments*.

Transparent mica window: The mica window of the pancake GM detector is coated with a thin layer of graphite that serves two purposes. First, it contributes to the electric field inside the GM tube. Second, it shields the GM tube from light. For most Hanford applications, the absence of the graphite will not affect the GM tube's performance. If the graphite has been rubbed or washed off, the GM probe is still usable provided it passes the daily source check.

6.6 Instrument Specifications and Limitations

6.6.1 Temperature

The GM survey instrument is operable within the temperature range of -40°C to 60°C (-40°F to 140°F).[4]

(a) Battelle Northwest Laboratory Record Book 55840, Pg. 31-40, -10°C to 50°C

6.6.2 Temperature Shock

The Surveyor X and the E-140 are not affected by temperature shocks.[5] It is good practice to allow the instruments to equalize with the ambient temperature before performing a survey, but, if time does not permit, it is not necessary for these instruments.

6.6.3 Humidity and Pressure

The GM survey instrument is insensitive to changes in humidity and pressure. It may be used in all non-condensing conditions encountered on the Hanford Site. For example, condensation could be encountered when moving a cold instrument into a warm, humid environment. Condensation (beads of water) may form on the instrument. The instrument should not be used under these conditions. The operator should allow the instruments to equalize with the ambient temperature and remove any remaining condensation.

6.6.4 Electromagnetic Field Interference

The GM survey instruments are not affected by electromagnetic fields.[6]

6.6.5 Radio Frequency Interference

The GM survey instruments are not affected by external radio frequency fields.[a]

6.6.6 Energies and Types of Radiation

The GM survey instrument responds to alpha, beta, and gamma radiations. It will detect beta-emitters with energies above 100 keV (e.g., ^{14}C with $ß_{max}$ = 156 keV) and alpha-emitters with energy above about 3 MeV (e.g., uranium, ^{230}Th). Beta and photon radiation response is depicted in Figures 6.4 and 6.5, respectively. A typical efficiency for gamma radiation is <0.5%.

Beta response averages 2100 cpm/mrad/hr.[7]

6.6.7 Interfering Ionizing Radiation Response

The GM survey instrument is insensitive to neutrons.

Because the pancake probe has a thin window, it will respond to alpha emitting contamination. The typical efficiency for alpha-emitters is about 8%. However, because of the instrument's relatively high background (compared with a portable alpha meter) it is not suitable for alpha contamination surveys.

The pancake probe is also sensitive to gamma radiation. Though designed to minimize sensitivity to gamma radiation (which contributes to the instrument's background count rate), the pancake GM probe

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(b) Hanford Instrument Evaluation Committee Minutes, May, 1995, Attachment 5
(a) Hanford Instrument Evaluation Committee Minutes, May 1995, Attachment 5
(b) Letter from LA Rathbun, Pacific Northwest National Laboratory, to JJ Fix, Pacific Northwest National Laboratory, "P-11 Pancake Probe Response versus Measured Beta Doses," March 27, 1985

has an efficiency of less than 1% for gamma radiation. The typical count rate from background gamma radiation is approximately 3,600 cpm/mR/hr for ^{137}Cs photons and is highly energy dependent (see Figure 6.4).

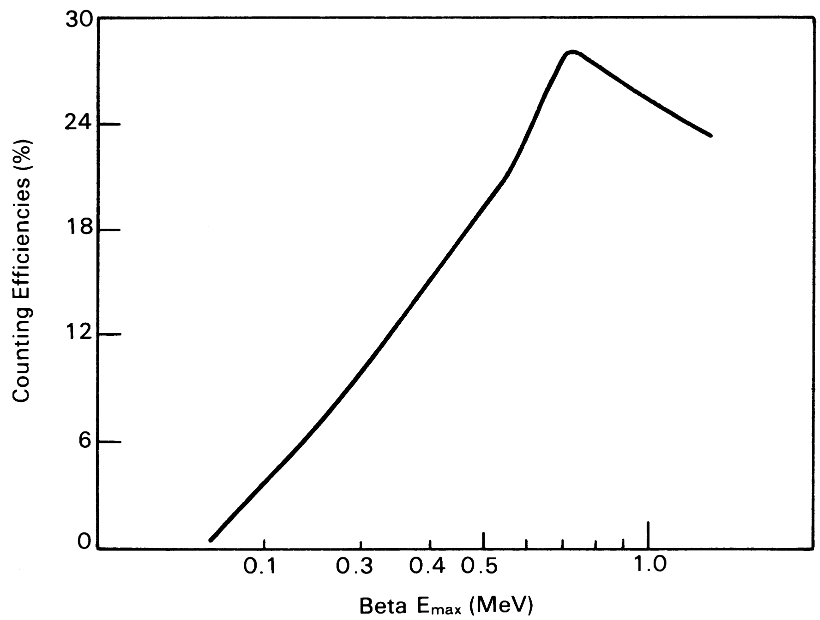

Figure 6.5. Beta Response of Pancake Probe

(Note: The high-energy data point was collected from a $^{90}Sr/Y$ source, and therefore the data point is influenced by the ^{90}Sr component.)

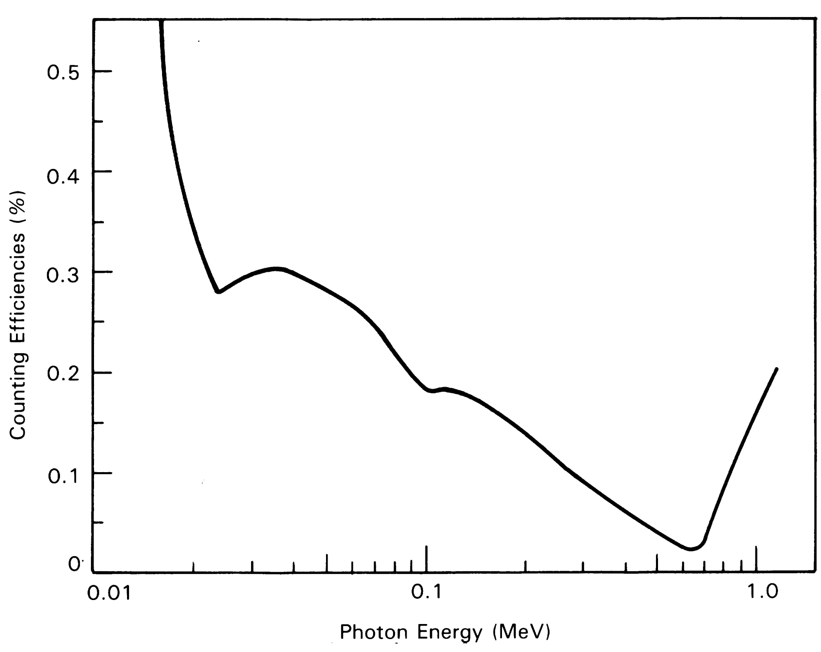

Figure 6.6. Photon Response of Pancake GM Probe

6.6.8 Battery Life

The E-140 has a battery life of approximately 200 hours. The Surveyor X has a battery life of approximately 400 hours.

6.6.9 Dead Time and Saturation

Extremely high count rates may cause an apparent decrease in the counting efficiency of pancake GM detectors (as much as 40%) because of increased dead-time losses. The calibration procedure limits the dead time to approximately 240 µs. With a dead time of 240 µs, an observed count rate of 80,000 cpm is equivalent to an actual corrected count rate of 120,000 cpm. The equation below can be used to correct observed readings when count rates above 50,000 cpm are encountered

$$R = \frac{R_o}{1 - R_o \tau} \tag{6.1}$$

where:

R = actual count rate (counts per second)
R_o = observed count rate (counts per second)
t = dead time (seconds)

When used with Eberline count rate meters, saturation may be evident in radiation fields of 7 R/hr or greater. When saturation occurs, the count rate meter will indicate a down-scale reading (possibly zero cpm) as the radiation field increases. Surveyor X count rate meters will lock on an off-scale high reading and alarm if the detector saturates.

6.7 Applications

The following subsections illustrate one method of counting statistics, minimum detectable activity analysis, and survey techniques. Users may have developed alternate approaches to these topics.

NOTE: *The following subsections represent common applications and provide specific guidance regarding scan speed, static measurement duration, probe to surface distance, radionuclides, and background radiation limitations. Alternative methods can be developed for specific applications. Contact the calibration laboratory for assistance*.

6.7.1 Total Surface Contamination Measurements

The GM survey instrument is most commonly used to perform direct measurements of total surface contamination. Methods to perform surface contamination measurements for a few applications follow. The limits given in the tables in this section are typical of contamination limits set forth in 10 CFR 835. The MDAs reported in this section were developed at PNNL.[(a)]

6.7.1.1 Scanning Surveys at a 95% Confidence Level (Total Limit)

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 and the efficiency is based on the detector being 6 mm (¼ in.) above the surface.

Table 6.2. Scanning Surveys at a 95% Confidence Level (Total Limit)

Limit (dpm/100 cm^2)	**Maximum Scan Speed (in./s)**	**MDA (dpm/100 cm^2)**	
ß 5,000	1	^{99}Tc worst case ^{137}Cs ^{90}Sr(Y)	4,400 2,900 2,000
Uranium: 5,000	2	3,200	
^{90}SrY: 1,000	Not possible	Not applicable	

Scan surveys performed to three times the total contamination limits are accomplished as follows.

Table 6.3. Scan Surveys Performed to Three Times the Total Contamination Limits

Three Times Limit (dpm/100 cm^2)	**Maximum Scan Speed (in./s)**	**MDA (dpm/100 cm^2)**	
ß 15,000	2	^{99}Tc worst case ^{137}Cs ^{90}Sr(Y)	11,000 7,300 5,000
Uranium: 15,000	8	13,000	
^{90}SrY: 3,000	1	2,000	

6.7.1.2 Scanning Surveys at a 67% Confidence Level (Total Limit)

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 and the efficiency is based on the detector being 6 mm (¼ in.) above the surface.

(a) Letter, ML Johnson, Pacific Northwest National Laboratory, to ME Hevland, Chair, Radiation Protection Forum, "Minimum Detectable Activity of Hanford Contamination Survey Instruments," December 27, 1993.

Table 6.4. Scanning Surveys at a 65% Confidence Level (Total Limit)

Limit (dpm/100 cm^2)	Maximum Scan Speed (in./s)	MDA (dpm/100 cm^2)	
ß 5,000	2	^{99}Tc worst case ^{137}Cs ^{90}Sr(Y)	4,400 2,900 2,000
Uranium: 5,000	6	3,900	

Scan surveys performed to three times the total contamination limits are accomplished as follows.

Table 6.5. Scanning Surveys Performed to Three Times the Total Contamination Limits

Three Times Limit (dpm/100 cm^2)	Maximum Scan Speed (in./s)	MDA (dpm/100 cm^2)	
ß 15,000	6	^{99}Tc worst case ^{137}Cs ^{90}Sr(Y)	13,000 8,700 6,000
Uranium: 15,000	18	12,000	
^{90}SrY: 3,000	2	2,000	

6.7.1.3 Static Surveys at a 95% Confidence Level (Total Limit)

These levels are based upon listening to the audible output count rate for five 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 150 cpm and efficiency is based on the detector being in contact with the surface.

Table 6.6. Static Surveys at a 95% Confidence Level (Total Limit)

Limit (dpm/100 cm^2)	MDA (dpm/100 cm^2)	
ß 15,000	^{99}Tc worst case ^{137}Cs ^{90}Sr(Y)	5,700 4,000 3,600
Uranium: 15,000	2,600	
^{90}SrY: 1,000	3,600	

6.7.2 Removable Surface Contamination Measurements

The GM survey instrument is used to perform removable surface contamination measurements. Methods to count removable surface contamination measurements are described in the following sections.

6.7.2.1 Scanning Surveys at a 67% Confidence Level (Removable Limit)

The only removable limit that is detectable using a direct scanning survey is the uranium limit. The GM probe is not capable of meeting the removable limit with a direct survey for any other category. These levels are based upon listening to the audible output count rate. Contamination is detected when the measurement is perceived to be above background. Background is limited to 150 cpm and the probe is within 6 mm (¼ in.) of the surface.

The MDA is 650 dpm/100 cm^2 at 67% confidence when scanning at 1 in./s.

6.7.2.2 Direct Static Surveys at a 67% Confidence Level (Removable Limit)

Based upon making a direct measurement of the surface using the meter on the slow time constant (10 seconds), holding the probe 6 mm (¼ in.) above the surface for 20 seconds and averaging the observed meter reading for the last 10 seconds (ignore first 10 seconds), contamination is detected, at a 67% confidence level, if the average indication is 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 50 cpm.

The MDA is 1,000 dpm/100 cm^2 or 155 dpm per probe area at 67% confidence for ^{99}Tc (mixed fission products [MFP]).

6.7.2.3 Evaluating Technical Swipes Surveys at a 95% Confidence Level (Removable Limit)

These levels are based upon listening to the audible output count rate for five seconds. Contamination is detected when the measurement is perceived to be above background. Background is limited to 150 cpm and the probe on contact with the swipe.

Table 6.7. Swipes Surveys at a 95% Confidence Level (Removable Limit)

Isotope and Release Limit (dpm/100 cm^2)	**MDA (dpm/100 cm^2)**	
ß 1,000	^{99}Tc worst case ^{137}Cs ^{90}Sr(Y)	900 625 560
Uranium: 1,000	400	
^{90}SrY: 200	550	

6.7.3 Counting Air Samples

A field measurement of an air sample may be performed using the GM probe. These measurements should be used for indication only and should be verified using count room instruments or a miniscaler.

6.7.4 Personnel Dose Rates

GM instruments should not be used to determine exposure rates. Uncompensated GM detectors, such as those used in the pancake probe and shielded GM probe, are very dependent on both the energy of the radiation being detected and the source-to-detector geometry.

7.0 Ludlum Model 177-X Series Count Rate Meter

7.1 Instrument Description and Theory of Operation

The Ludlum 177 series consists of a series of alarming count rate meters (CRM) used for detecting and measuring alpha, beta, and gamma radiation on the Hanford Site.

These CRMs are powered by alternating current (AC) and are capable of operating with several optional probes for contamination surveys. They are frequently referred to as bench monitors or friskers. These CRMs are generally used with scintillation probes for alpha contamination surveys or with GM detectors for beta-gamma contamination surveys.

7.1.1 Physical Description

The Ludlum CRMs are available in models 177 (Figure 7.1), 177-3, 177-8, 177-33, 177-36 (Figure 7.2), 177-37, 177-50, and 177-56.

The Ludlum CRMs are rectangular boxes measuring approximately 15 cm (6 in.) by 20 cm (8 in.) by 13 cm (5 in.). The instruments weigh approximately 1.8 kg (4 lb), including the battery. The Ludlum 177 series has a number of common features including a linear scale marked from zero to 500 cpm, an internal speaker, volume control, range selector, fast-slow response switch, RESET button, an MHV probe connector, and an alarm indicator light. These common features are located on and controlled from the front panel of the instrument. Common features located on and controlled from the back panel include a recorder jack, alarm set controls (step function or continuous), discriminator controls, calibration potentiometers, and a variable high-voltage potentiometer.

Ludlum 177 CRM has a fast-slow response time switch that selects a fast (2.2-second) or slow (22-second) response time. The response time is the time for the instrument response to increase from 0 to 90% of the full-scale reading.

These CRMs are operated as bench monitors from AC line voltage. Some may be used for a short time as portable bench monitors, using an internal rechargeable GEL-CELL battery.

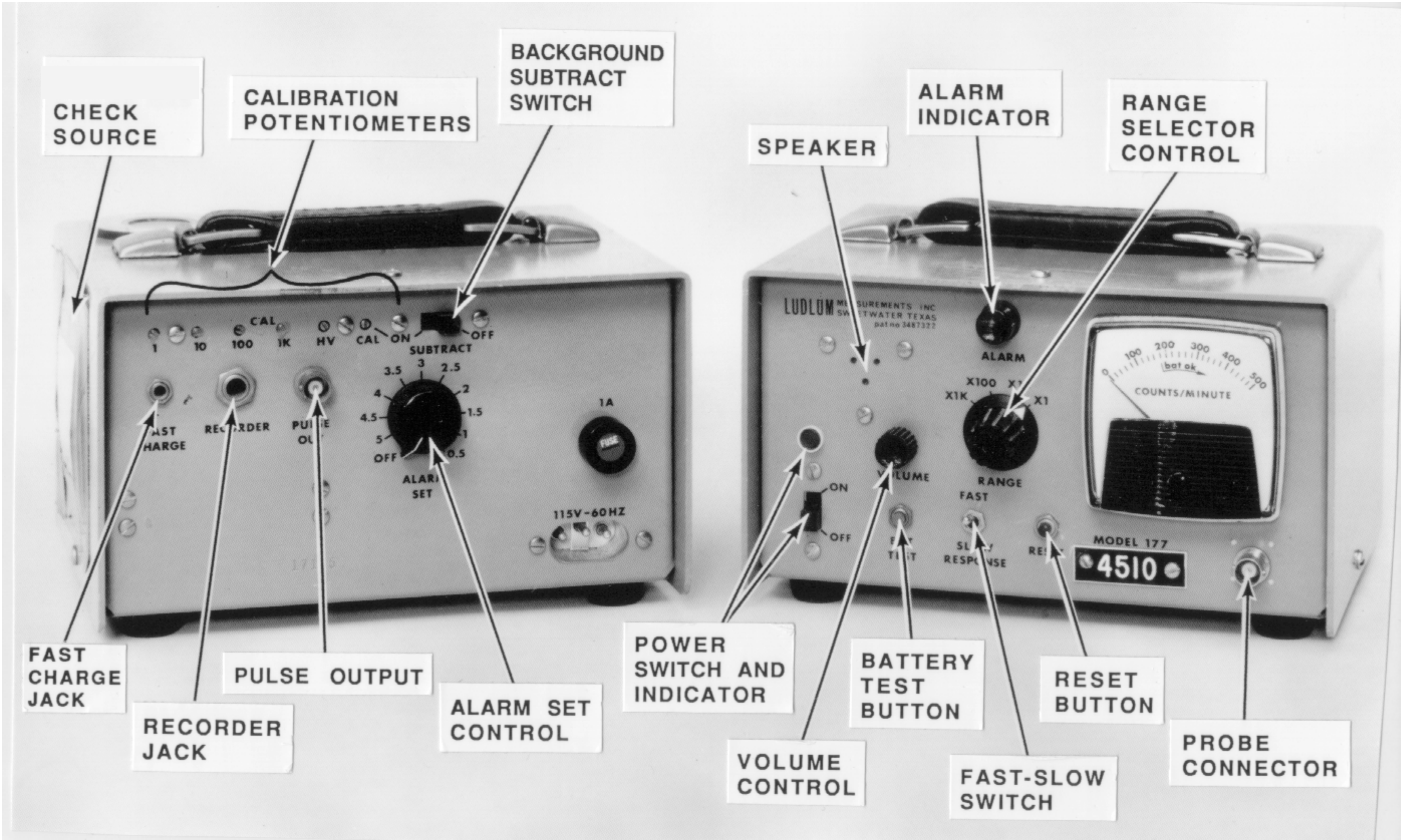

Figure 7.1. Ludlum Model 177 Count Rate Meter

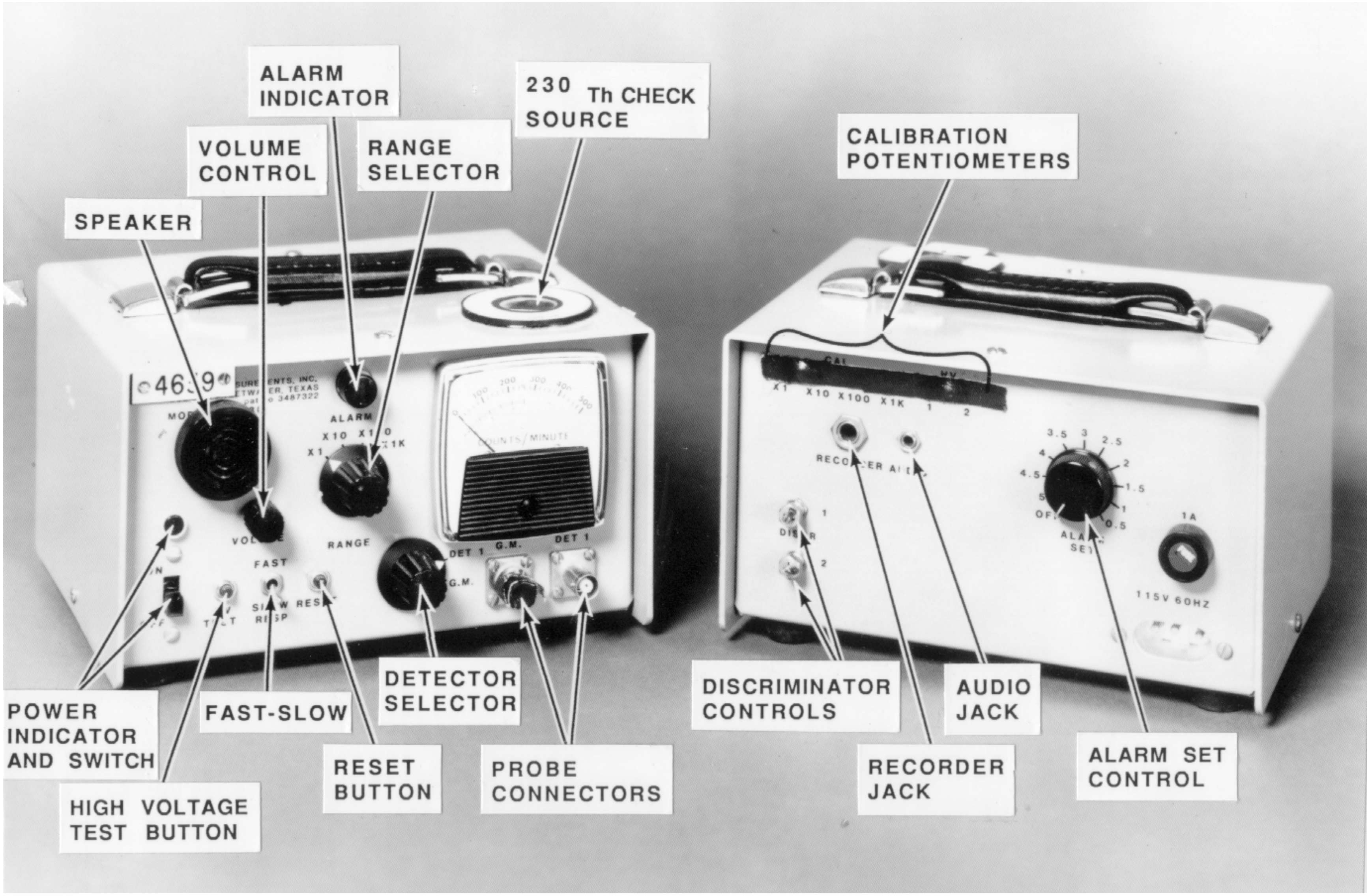

Figure 7.2. Ludlum Model 177-36 Count Rate Meter

With a few exceptions, the above features are basic to all Ludlum bench monitors. In addition, see Table 7.1 for distinctive features of each model in the series.

Table 7.1. Ludlum CRMs Features

Model	Description
Ludlum Model 177	The Model 177 (Figure 7.1) has all of the above basic features, plus a background subtraction switch and an adjustment that provides zero to full-scale background subtraction. It also has a fast-charge jack that allows the GEL-CELL battery to be fast charged from an external source.
Ludlum Model 177-3	The Model 177-3 has a high-voltage test button that, when activated, displays the high-voltage reading on the meter.
Ludlum Model 177-8	The distinguishing or additional features of the Model 177-8 include a low-battery indicator lamp, battery strength indicator button, and a fast battery charge jack allowing the GEL-CELL battery to be fast charged from an external source. The Model 177-8 also includes a BNC pulse output connector for external scaler connection, alarm test, and volume controls.
Ludlum Model 177-33	Additional features included on the Model 177-33 are a high-voltage test button and two probe connectors (one BNC and one MHV). The 177-33 can be set up for simultaneous use with an alpha scintillation probe on the connector labeled D.T. and a GM probe on the connector labeled G.M. A detector selector switch is provided for choosing the preferred detector. Corresponding discriminator controls and high-voltage controls for each connector are located on the back panel of the CRM.
Ludlum Model 177-36	The Model 177-36 (Figure 7.2) includes a high-voltage test button, two probe connectors (MHV for use with alpha scintillation detectors and BNC for use with GM detectors), a detector selector switch, corresponding discriminator, and high-voltage controls for each connector, and an audio jack for use with an external speaker. This unit also has an internal GEL-CELL battery.
Ludlum Model 177-37	Additional features of the Model 177-37 include a high-voltage test button and an audio jack for use with an external speaker.
Ludlum Model 177-50	This model features a 5-decade log meter with a range of 10 cpm to 1,000,000 cpm. A separate scale check is provided for the high-voltage readout and battery check. Other distinguishing features include a high-voltage test button, a battery test button, an alarm set test button, pulse output connector for external scaler connection, and a fast-charge jack for the GEL-CELL.
Ludlum Model 177-56	This model features dual probe connectors and a detector selector switch, allowing for both beta and alpha monitoring. Additional features include two discriminator potentiometers to set the discriminator sensitivity for the detectors. The high voltage can be read from the meter when the high-voltage test button is activated.

7.1.2 Radiation and Energy Response

The Ludlum CRMs may be used with pancake GM detectors, 50-cm^2 alpha scintillators, or 100 cm^2 alpha scintillators. Section 6.1.2 describes the pancake GM detector and Section 5.1.2 discusses the alpha scintillation detectors.

7.1.3 Integral Sources

Sources are attached to bench monitor bodies to provide for response checking the instruments. ^{230}Th is used for alpha monitors and a piece of lantern mantle provides a response check for beta detectors (e.g., GM). The ^{230}Th source may have an activity of either 500 or 5,000 dpm depending on the particular source used. The activity of the lantern mantle also varies depending on the size of the piece used. Typical count rates from lantern mantle check sources vary from a few hundred to a couple of thousand cpm.

7.2 Operating Instructions

Operation of these CRMs is dependent upon the attached probe. Operating instructions for CRMs used with GM pancake probes are contained in Section 6.2 of this manual. Likewise, when the Ludlum 177 is used with an alpha scintillation probe, Section 5.2 of this manual provides guidance for its use.

NOTE: *When switching between the GM probe and the alpha scintillation probe on Ludlum 177-series bench monitors that are calibrated with both, counts may continue to be heard from the GM probe for several seconds while the high voltage on the GM probe dissipates. Because the bench monitor does not have different tones for the GM and alpha channel, the counts from the GM probe are indistinguishable from alpha counts. Therefore, when switching from a GM to an alpha probe, allow several seconds (e.g., three to five) before making measurements with the alpha probe.*

7.2.1 Correction Factors

Correction factors are applied for the specific probes being used with the Ludlum 177 CRM. Refer to Section 6.2.1 for GM probes, and Section 5.2.1 for alpha probes for specific information regarding appropriate correction factors for use.

7.3 Performance Test Instructions

Performance testing protocols are governed by the probe type. Refer to Section 6.3 for GM probes and Section 5.3 for alpha probes.

7.4 Calibration Instructions

Survey instruments powered by AC are calibrated at the PNNL calibration laboratory located at the 318 Building in the 300 Area. The calibration described in this section is performed by the calibration laboratoryTHE CALIBRATION LABORATORY staff.

Prior to calibration, instruments are inspected to make sure they are in good working order. Each instrument is inspected for physical damage. Damaged instruments are repaired before calibration. As-found readings at 80% of full-scale on each range and the as-found efficiency are recorded before calibration. If the as-found readings are more than ±20% out of tolerance, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

Electronic and radiological calibrations are performed on bench monitors. The electronic calibration consists of verifying the discriminator or threshold setting and verifying the response of the meter using an electronic pulser. The meter response is calibrated on each range at 80% of full scale and verified at 20% of full scale.

Scintillation detectors are checked for minimum counting efficiency and maximum background count rate. GM detectors are checked for maximum acceptable background count rate and counting efficiency. Specific information regarding GM and scintillation probe calibration can be located in Sections 6.4 and 5.4, respectively.

Detailed information on calibrating AC-powered survey instruments can be found in PNL-MA-563, Section 4.1.10, Bench Monitors Calibration Procedure, and Section 3.7.0, GM Pancake Probe.

7.5 Maintenance Instructions

Routine maintenance on AC-powered survey instruments is performed at the calibration laboratory and includes checking rechargeable batteries and cleaning contacts. Probe-specific issues should be reviewed in Section 6.5 (GM) and Section 5.5 (scintillator).

GM probes can be replaced in the field in the same manner that GM probes are replaced on the portable GM survey instrument.

7.6 Environmental Specifications and Limitations

7.6.1 Temperature

Alternating current-powered instruments are intended for use indoors where the temperature is controlled. The Ludlum 177 series instruments may be used over the temperature range of -10°C to 50°C (14°F to 122°F). If the CRM is attached to a GM detector, the low-end temperature is -5°C based on Ludlum's temperature range for the CRM.

7.6.2 Temperature Shock

Alternating current -powered instruments are not intended to be moved rapidly between areas of different temperatures. When relocating the instrument, allow it to reach equilibrium with the surrounding temperature before use. Up to one hour may be necessary to thermally equalize the instrument with the surrounding temperature.

7.6.3 Humidity and Pressure

Alternating current -powered instruments are not affected by changes in ambient humidity or pressure. However, the instruments should not be used in areas where they are subject to condensing humidity (dew), sprays, or mists.

7.6.4 Electromagnetic Field Interference

Care should be taken to not use portable radios or other radio frequency generating devices in close proximity to the instruments. Refer to Section 5.6.4 for information regarding scintillation probes and electromagnetic fields.

7.6.5 Radio Frequency Interference

External radio frequency fields should not impact instrument performance.

7.6.6 Energies and Types of Radiation

Energy and radiation response is dependent upon the attached probe. Refer to Section 6.6.6 (GM detectors) and Section 5.6.6 (scintillation detectors) for probe-specific information.

7.6.7 Interfering Ionizing Radiation Response

Interfering ionizing radiation response is dependent upon the attached probe. Refer to Section 6.6.7 (GM detectors) and Section 5.6.7 (scintillation detectors) for probe-specific information.

7.6.8 Battery Life

Instruments equipped with GEL-CELL rechargeable batteries have a battery life of about 50 hours in a non-alarm condition.

7.7 Applications

Applications are based upon the attached probe. Refer to Section 6.7 (GM detectors) and Section 5.7 (scintillation detectors) for probe-specific information.

8.0 NRC AN/PDR-70 Snoopy

8.1 Instrument Description and Theory of Operation

The NRC Model AN/PDR-70 (Figure 8.1 and 8.2), commonly referred to as a Snoopy, is a portable survey instrument designed for measuring neutron dose equivalent rate over the neutron energy range from thermal to 15 MeV.

8.1.1 Physical Description

The Snoopy detector consists of a BF_3 proportional counter surrounded by a boron-loaded attenuator and inner and outer polyethylene moderators. The detector is cylindrical and has a fixed handle, which makes it easier to carry. The handle extends 7.0 cm (2.75 in.) above the outside diameter and, the feet extend 1.27 cm (0.5 in.) diagonally opposite the handle.

Attached to one end of the detector is the electronics unit containing the electronic circuits for amplifying, measuring, and displaying the probe signal, along with the battery enclosure and the high-and low-voltage power supplies.

The detector may be physically separated from the electronics unit for remote readout (see Figure 8.2). When separating the detector and electronics unit, the cable length may not be longer than 1.8 m (6 ft).

An Eberline Model SK-1 speaker, with its own battery, is mounted on the outside of the electronics unit to provide an audible indication of the relative dose rate. The speaker assembly has its own on/off switch.

The Snoopy weighs 11 kg (25 lb). The cylindrical detector measures 22 cm (8.5 in.) in diameter by 24 cm (9.4 in.) long. The electronics, mounted on top of the detector, measure 15 cm by 18 cm by 14 cm (5.8 in. by 7.1 in. by 5.4 in.)

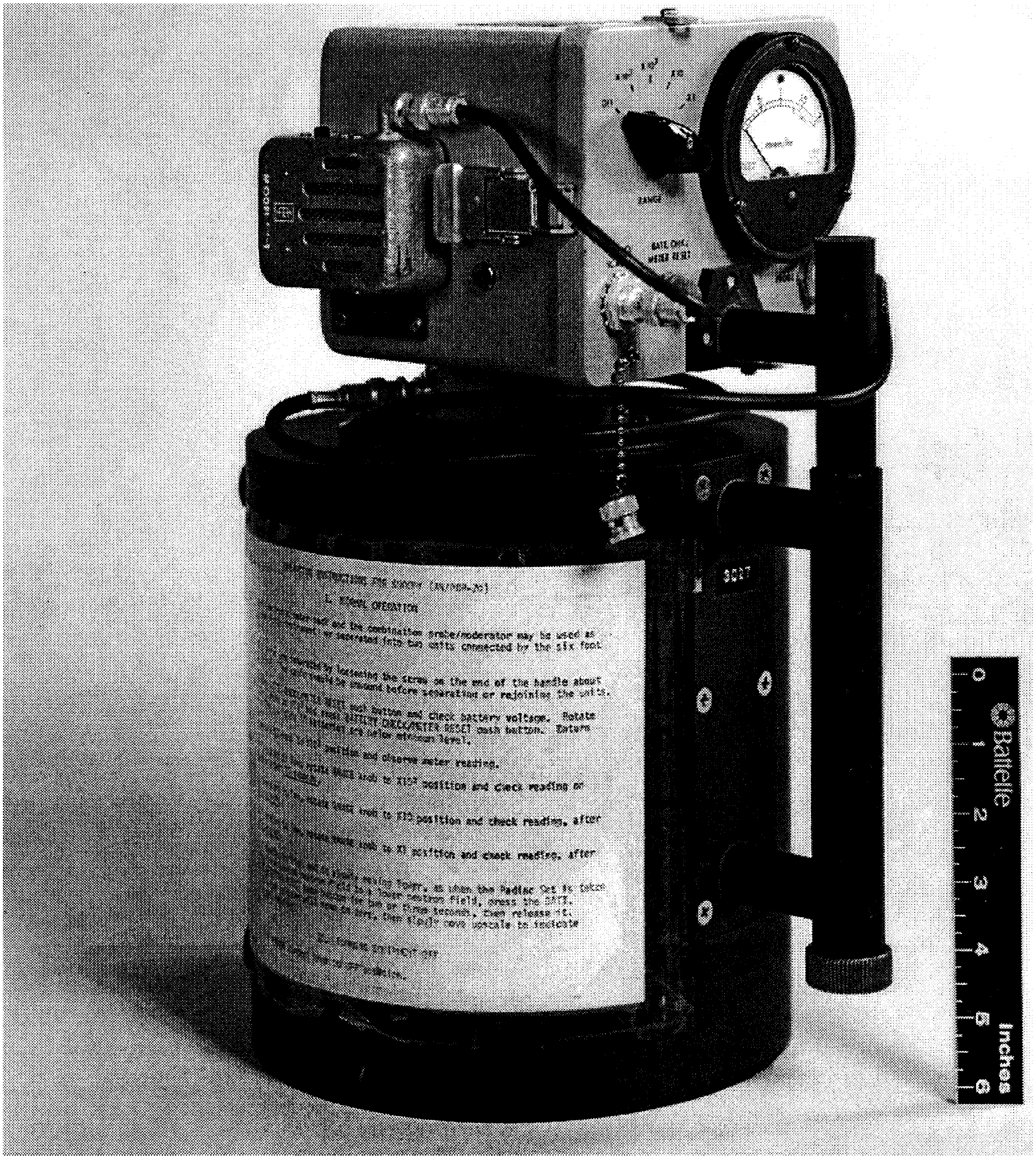

Figure 8.1. Snoopy-Neutron Dose Rate Meter

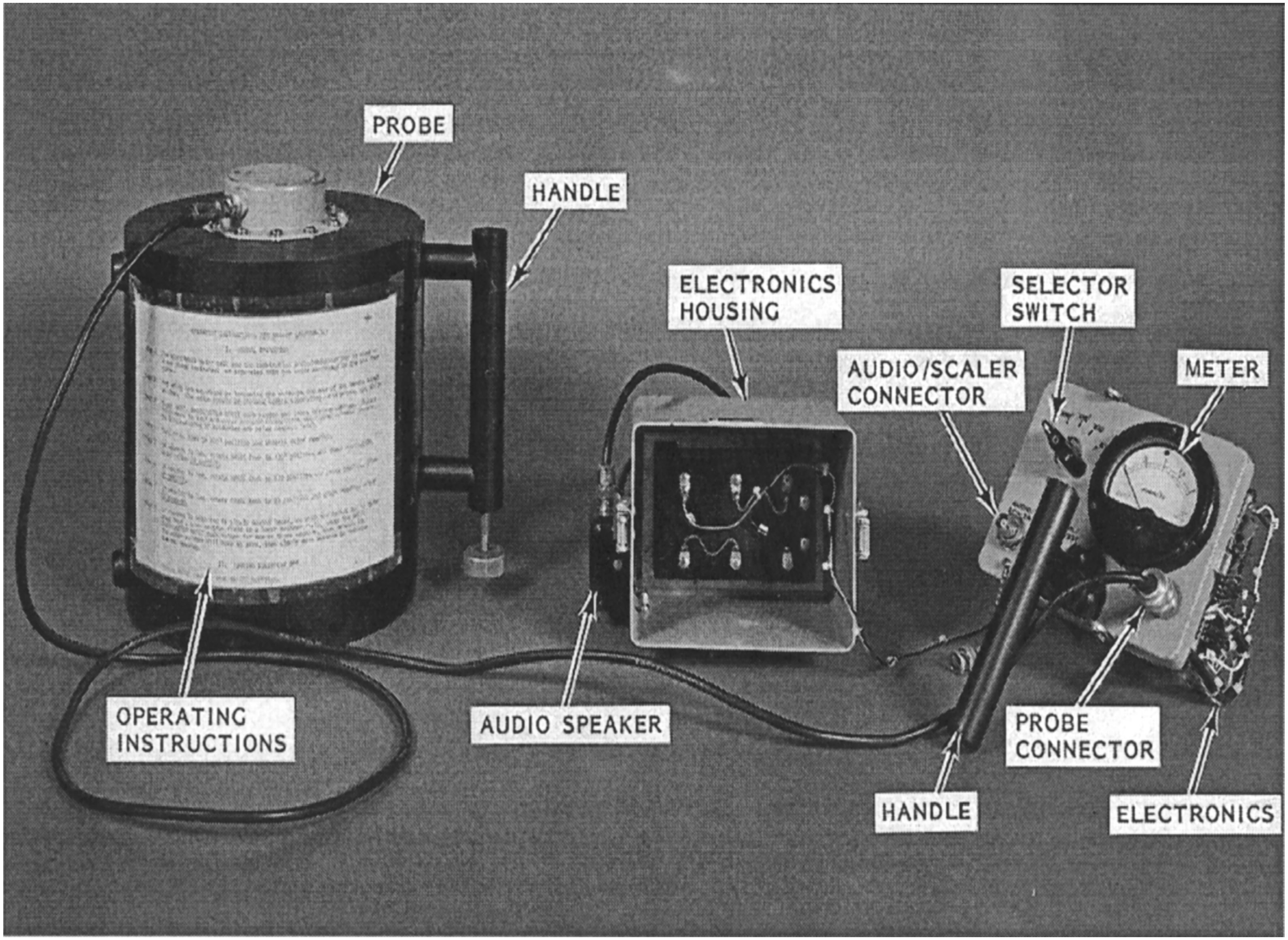

Figure 8.2. Snoopy Disassembled

The Snoopy has an analog meter with four linear ranges calibrated in units of dose equivalent rate. The range and response time of each range is listed in the table below.

Table 8.1. Snoopy Range and Response Time of Each Range

Range	**Response Time(s)**
X1 (0 to 2 mrem/hr)	30
X10 (0 to 20 mrem/hr)	8.5
$X10^2$ (0 to 200 mrem/hr)	3
$X10^3$ (0 to 2000 mrem/hr)	3

The meter's linearity is ±10% of the full-scale reading.

8.1.2 Radiation and Energy Response

The Snoopy responds to neutrons over the neutron energy range from thermal (0.025 eV) to 15 MeV. The response of the Snoopy is dependent on the neutron energy. Correction factors are discussed in Section 8.2.1 and indicated in Figure 8.5. However, under normal monitoring conditions, no energy corrections need to be made since the neutrons encountered in the field will be of a broad energy spectrum.

The Snoopy is calibrated to discriminate against gamma radiations. The Snoopy does not respond to gamma radiations in fields of up to 1 R/hr.

The Snoopy is insensitive to alpha and beta radiations.

8.1.3 Integral Sources

There are no radioactive sources attached, or inside, the Snoopy.

8.2 Operating Instructions

CAUTION: *The Snoopy has a cylindrical moderator (detector housing), and, as a result, the count rate may be as much as 20% low if the instrument is exposed with the end of the cylinder facing the source. When the instrument is positioned with the corner of the moderator between the source and the BF_3 tube (which is located at the center of the moderator) the count rate drops because of an increase in moderator thickness between the BF_3 tube and the source.*

Before using the Snoopy, perform the operability checks to make sure the instrument is in good working condition (see Section 8.3.1). These checks should be performed each time the instrument is used.

1. Turn the Snoopy on by moving the selector switch to the $X10^3$ position.

NOTE: *The 1-minute warm-up time is only required when the instrument is initially turned on.*

2. Allow the instrument to warm up for 1 minute before taking measurements. After 1 minute, observe the meter reading.
3. Turn on the speaker assembly.
4. If the reading is low or if the meter does not appear to respond, turn the selector switch to the $X10^2$, wait 10 seconds, and observe the meter reading.
5. If the reading is still low, switch to the X10 range, wait 30 seconds, and observe the meter reading.
6. If the reading is still low, switch to the X1 range, wait 90 seconds, and observe the meter reading. If the reading is still low, the dose rate is below the minimum detectable range of the meter (see Section 8.7 for low dose rate measurements).
7. Orient the Snoopy so that the side of the moderator (cylinder) is facing the source.
8. After the meter stabilizes, record the measurement and calculate corresponding dose rate according to Section 8.7.
9. After performing the survey, turn the selector switch to the OFF position and turn the speaker off.

8.2.1 Correction Factors

To obtain the correct exposure rate, the meter reading must be multiplied by the scale factor indicated on the range selector switch. In addition to range correction, a number of correction factors may be necessary to adjust meter deflection to occupational deep dose rate.

NOTE: *The exposure rate indicated on the instrument is the rate at the center of the detector. No correction factors have been established to correct the Snoopy dose rate readings to contact dose rate.*

8.2.1.1 Beam Correction Factors

During calibration (see Section 8.4), the entire detector is uniformly exposed to a known neutron flux. Therefore, a beam size correction factor is needed when measuring collimated neutron beams. Beam correction factors are given in Figure 8.3. Observe that beam corrections are made according to the beam cross-sectional area and not the beam diameter. Measurement of collimated beams with the Snoopy should be made with the beam centered on the side of the detector.

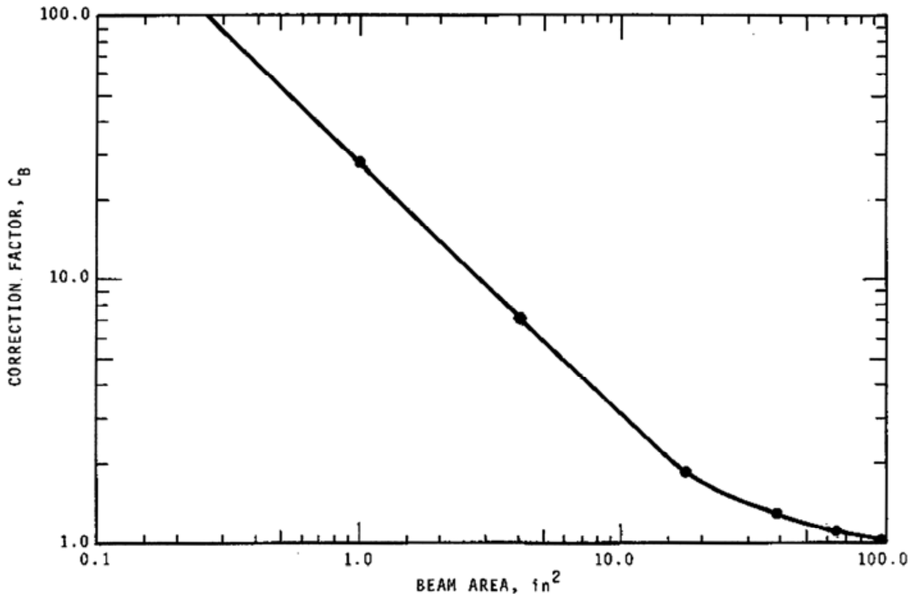

Figure 8.3. NRC AN/PDR-70 Snoopy Beam Correction Factor

8.2.1.2 Temperature Correction Factors

The response of the Snoopy is slightly temperature dependent over its operating range of -10°C to 50°C (14°F to 120°F). The response varies roughly +20% at -10°C and -6% at 50°C. The effect is bounded within ±5% across the temperature range 10°C to 46°C (50°F to 115°F). A temperature correction factor chart is available from PNNL calibration laboratory.

8.2.1.3 Energy Correction Factors

Snoopy response is energy-dependent. Energy correction factors are shown in Figure 8.4 and appropriate when measuring in monoenergetic neutron energy fields.

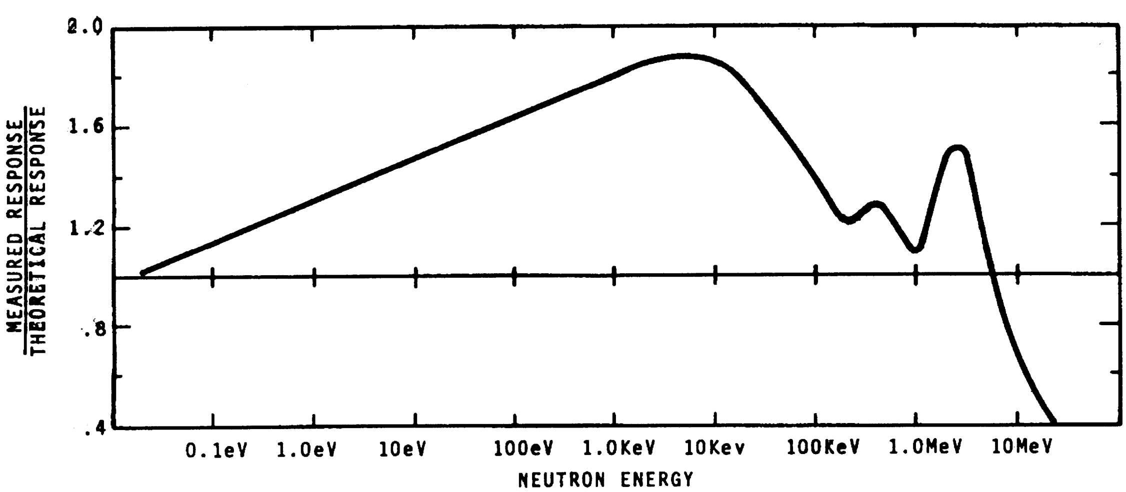

Figure 8.4. NRC AN/PDR-70 Snoopy Energy Correction Factors

8.3 Performance Test Instructions

Refer to contractor-specific performance testing instructions. Typical performance testing criteria are presented below.

8.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the Snoopy fails any of the checks listed, other than the battery test, return it to the calibration laboratory for servicing.

1. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) on the expiration date on the calibration sticker.
2. Inspect the instrument for physical defects, such as broken meter glass, loose knobs or other parts, or other observable defects. If defects are present, the instrument should not be used but should be tagged and returned to the calibration laboratory.
3. Turn the selector switch to the $X10^3$ position.
4. Press the BATT CHECK/METER RESET button to test battery voltage. The needle should register well within the BATT section on the meter. If the needle does not register above the BATT indicator on the meter, refer to Section 8.5.
5. Turn the speaker on and verify that there is an audible response.
6. If daily source checks are performed, ensure that the instrument source check is current. Source checks are generally valid for the day performed and typically do not cover more than 24 hours.

8.3.2 Source Check

When instrument users do not have access to neutron sources, A Snoopy cannot be source checked in the field. Maintaining neutron sources for source checking Snoopy instruments in the field is not practical for most facilities. When it is not practical to do source checks, then compensatory methods should be used to demonstrate instrument operability. As a compensatory action, each Snoopy is calibrated quarterly, and their calibration as-founds monitored closely.

8.3.2.1 Initial Source Check

Initial source checks should be performed immediately upon receiving the instrument from the calibration laboratory. Instruments should not be placed into storage until after performing the initial source check.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure that the values are reasonable. For the Snoopy, the initial response is reasonable when the response is within ±20% of the mean instrument response for that source.*

The acceptable range should allow for variations resulting from differing instrument response.

Center the detector over the check source. A jig or mark may be used to ensure reproducibility. Move the source to the appropriate position for each range of the instrument, wait for the corresponding response time (see Section 8.1.1) for the meter to stabilize and note the instrument response on each range. Multiply the instrument response by 0.8 and 1.2 to determine the acceptable range for that instrument. Record the acceptable range on the Daily Instrument Source Check Log. Attach a Daily Source Check Label (if used) to the side of the Snoopy.

8.3.2.2 Daily Source Check

Center the detector over the source, ensuring that the detector/source combination is in the same geometry as that used for the initial source check. Move the source to the appropriate position for each range of the instrument, and allow for the corresponding response time (see Section 8.1.1) for the meter to stabilize. The instrument response, on each range, should fall within the acceptable values determined during the initial source check. If the instrument fails, tag it with a completed Instrument Service Tag, and return it to the calibration laboratory.

Source checks are generally valid for 24 hours after they are performed. When daily source checks cannot be performed, the Snoopy should be calibrated more frequently (i.e., quarterly).

8.3.2.3 Response Checks

Periodic response may be performed on the Snoopy instrument when a stable neutron field exists in the facility to verify consistent detector response and speaker functionality. Response checks are typically performed on one range of the Snoopy.

8.3.2.3.1 Initial Response Check

If the facility has access to a stable, known neutron source, perform the initial response check when the Snoopy is received from the calibration laboratory.

The initial response check is performed by placing the Snoopy in a reproducible location in a stable neutron field. A suitable technique is to identify a location within the facility that has a stable neutron dose rate, and then mark the location (e.g., on the floor or wall) to place the Snoopy detector when performing source checks.

The initial response check may be performed on only one range.

To perform the initial response check, expose the detector to a stable neutron source or field. Multiply the instrument response by 0.8 and 1.2 to determine the acceptable range for that instrument.

8.3.2.3.2 Response Check

The instrument response should fall within the acceptable values determined during the initial response check. If the instrument response does not fall within the range of acceptable values, tag it with an Instrument Service Tag and return it to the calibration laboratory.

8.4 Calibration Instructions

Snoopys are calibrated at the PNNL calibration laboratory in the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff.

Before calibration, the instruments are inspected to make sure they are in good working order. The batteries are checked, the meter is checked for oscillations, and the instrument is inspected for physical damage. Damaged instruments are repaired before calibration. As-found dose rate readings for each range are recorded before calibration and after a five-minute warm-up period. If the as-found readings are more than ±20% out of tolerance, the calibration laboratory notifies the radiological control organization that last used the instrument. Less than 1% of Snoopy instruments fail the as-found criteria, indicating the adequacy of the quarterly calibration cycle as a compensatory measure for not source checking instruments in the field.

After a minimum 5-minute warm-up period, the Snoopy is calibrated in a uniform neutron field to a standard ^{252}Cf neutron source, which in turn, is calibrated to a free-field bare ^{252}Cf source. The instrument is placed so that the axis of the detector is perpendicular to the radiation beam. The instrument response is adjusted at multiple points on each range, with the exception of the X1 and X10^3, which are calibrated at only one point on each range. The actual exposure rates used in calibrating the Snoopy are nominally 20%, 50%, and 80% of full scale but may vary depending on the current calibration data for the ^{252}Cf source.

The instrument is also checked to verify that it does not respond to gamma radiations. To verify gamma rejection, the Snoopy is placed in an l-R/hr field and instrument response is verified to be no more than 0.1 mrem/hr.

For more information on the Snoopy calibration, refer to PNL-MA-563, Section 3.6.

8.5 Maintenance Instructions

Routine maintenance on the Snoopy is performed at the calibration laboratory and in the field. Routine maintenance includes checking the Snoopy for electronic noise, checking and replacing batteries, and cleaning connectors and cables.

Common problems and causes are discussed below.

Noisy response: The Snoopy may develop a high background count rate (in an area with no neutron fields) if dirt or moisture gets inside the cable connectors. A less likely source of a high background count rate is a shift in the threshold and/or high-voltage settings. Do not attempt to clean or replace the cables, or to adjust the electronic settings. A Snoopy that is exhibiting unusually high background count rates should be returned to the calibration laboratory.

No speaker response: If the speaker is not responding, verify that the speaker cable is connected to the audio/scaler output on the Snoopy electronics unit and turn the speaker on. If the speaker still does not respond, change the battery in the speaker.

To change the speaker battery:

1. Remove the speaker from the Snoopy.
2. Remove the screws from each end of the speaker, and remove the back plate.
3. Replace the battery with a fresh 15-V NEDA 220 battery.
4. Replace the back plate and screws, and install the speaker on the Snoopy.

Low batteries: If the Snoopy fails the battery check, either return the instrument to the calibration laboratory for new batteries or, provided the facility performs source or response checks, replace the batteries in the field. The Snoopy must be source or response checked after new batteries are installed. If the facility cannot perform source or response checks, battery changes should not be performed in the field.

To replace the batteries:

1. Set the switch to the OFF position.
2. Remove the bottom cover by loosening the four captive screws on the cover. Do not loosen the eight small screws on the enclosure.
3. Remove the cover completely to expose the eject strap. Pull the strap away from the enclosure to lift the batteries.
4. Install three fresh D cell alkaline batteries observing proper polarity.
5. Replace the cover and tighten the four screws, observing that the eject strap is inside the compartment.
6. Source or response check the Snoopy.

8.6 Instrument Specifications and Limitations

8.6.1 Temperature

The Snoopy is usable over the temperature range of -10°C to 50°C (14°F to 122°F) with appropriate corrections.

8.6.2 Temperature Shock

The Snoopy is not affected by temperature shocks. However, it is a good practice to allow the instrument temperature to equalize with the ambient temperature before using it to perform surveys.

8.6.3 Humidity and Pressure

The Snoopy is operable over the humidity range of 0% to 95% relative humidity. The Snoopy should not be used in condensing environments. An example of a condition where condensation could be encountered is moving a cold instrument into a warm humid environment. Condensation (beads of water) may form on the instrument. The instrument should not be used under these conditions. The operator should allow the instruments to equalize with the ambient temperature and remove any remaining condensation.

Because the Snoopy is calibrated on the Hanford Site at, essentially, the same altitude at which it is used, only minor changes in pressure due to changes in elevation are anticipated. The changes in ambient pressure caused by changing weather are minor and will not significantly affect the Snoopy's response.

8.6.4 Electromagnetic Field Interference

The Snoopy has no known susceptibilities to electromagnetic fields.

8.6.5 Radio Frequency/Electromagnetic Interference

The Snoopy is not affected by external radio frequency fields.

8.6.6 Energies and Types of Radiation

The Snoopy responds to neutrons over the neutron energy range from thermal (0.025eV) to 15 MeV. The response of the Snoopy is dependent on the neutron energy. Correction factors are discussed in Section 8.2.1.3 and indicated in Figure 8.5.

8.6.7 Interfering Ionizing Radiation Response

The Snoopy is calibrated to discriminate against gamma radiations. Snoopy gamma radiation response is limited to 0.1 mrem/hr while exposed to a ^{137}Cs field of 1 R/hr.

The Snoopy is insensitive to alpha and beta radiations.

8.6.8 Battery Life

Snoopy battery life is greater than 3 months under normal use conditions.

Speaker battery life is rated at greater than 1,000 hours when used 12 hours per day. Speaker battery life varies depending on how often the speaker is used and the neutron fields encountered.

8.7 Applications

CAUTION: *The Snoopy has a cylindrical moderator (detector housing), and, as a result, the count rate may be as much as 20% low if the instrument is exposed with the end of the cylinder facing the source. When the instrument is positioned with the corner of the moderator between the source and the*

BF_3 tube (which is located at the center of the moderator), the count rate drops because of an increase in moderator thickness between the BF_3 tube and the source.

The Snoopy is used to establish personnel dose rates from neutron radiation. The Snoopy is typically used over the range of 0.2 mrem/hr to 2,000 mrem/hr. The lower limit (0.2 mrem/hr) is based on 10% of the full-scale meter indication on the lowest range (10% of 2 mrem/hr). Neutron dose rate is calculated as follows:

$$\text{Dose equivalent rate} = \text{CFB x CFE x Cftemp x (Range) x (Meter Reading)} \tag{8.1}$$

where:

C_{FB} = beam size correction factor
C_{FE} = Energy correction factor
C_{ftemp} = temperature correction factor (not required)

Correction factors are discussed in greater detail further in Section 8.2.1.

The Snoopy can be used with a scaler to measure dose rates below the 0.2 mrem/hr. A typical application that requires neutron dose rate measurements below 0.2 mrem/hr is performing posting surveys for establishing Radiological Buffer Area (RBA) boundaries. The sensitivity required is approximately 0.05 mrem/hr (50 μrem/hr). A special calibration must be performed to establish the sensitivity and background of the instrument so that scaler measurements can be converted to mrem/hr. Requests for special calibration should be directed to the calibration laboratory. Requests should specify that the Snoopy is to be used with a scaler and that background, background count time, and sensitivity should be specified for the instrument. A typical sensitivity for the Snoopy is 150 cpm/mrem/hr and a typical background is 1.2 cpm. Using the scaler count time and background, a decision level can be established to determine if a measurement is statistically significant. The sensitivity can be used to convert scaler measurements to units of mrem/hr.

For example, a Snoopy is used with a scaler to determine if a location is above the 0.05 mrem/hr (50 μrem/hr) RBA posting limit. A 1-minute count results in 8 counts.

The data from the calibration laboratory are:

- Sensitivity = 120 cpm/mrem/hr
- Background = 12 counts in 10 minutes

In accordance with the statistical models given in NUREG-1400, *Air Sampling in the Workplace:*

$$D_L = 1.645 * \sqrt{R_b * \left(\frac{1}{T_b} + \frac{1}{T_g}\right)} \tag{8.2}$$

where:

D_L = decision level
R_b = background count rate, cpm
T_b = background count time, minutes
T_g = gross count time, minutes

$$D_L = 1.645 * \sqrt{1.2 * \left(\frac{1}{10} + \frac{1}{1}\right)} = 1.9 \text{ cpm}$$

The net count rate is 8 cpm - 1.2 cpm = 6.8 cpm

The result is statistically significant because 6.8 cpm > D_L (1.9 cpm).

The standard deviation of the result, σ, is given by:

$$\sigma = \sqrt{R_b * \left(\frac{1}{T_b} + \frac{1}{Tg} \right)} \qquad (8.3)$$

The measurements (plus associated error, ±2σ) in cpm are converted to mrem/h by dividing the count rate by the sensitivity (cpm/mrem/hr).

$$Dose\ Rate = \frac{6.8\ cpm}{120\ cpm/mrem/hr} \pm \frac{2*1.15\ cpm}{120\ cpm/mrem/hr} = 0.057 \pm 0.019\ mrem/hr$$

The result is above the RBA posting limit.

8.8 References

Hickey, E. E., Stoetzel, G. A., P.C. Olsen, and S.A. McGuire. 1993. *Air Sampling in the Workplace,* NUREG-1400, U.S. Nuclear Regulatory Commission.

9.0 Bicron Micro Rem Meter

9.1 Instrument Description and Theory of Operation

The Bicron Micro Rem meter is a portable radiation survey meter used to measure low-level, ambient gamma exposure rates. The instrument has a fairly flat energy response to photons above about 60 keV (see Section 9.1.2).

9.1.1 Physical Description

The Micro Rem meter is a box-shaped instrument measuring approximately 4 in. by 8 in. by 8 in. (including the handle). It is relatively light weight (3.1 lb). An older meter model is pictured in Figure 9.1, and a newer meter model in Figure 9.2.

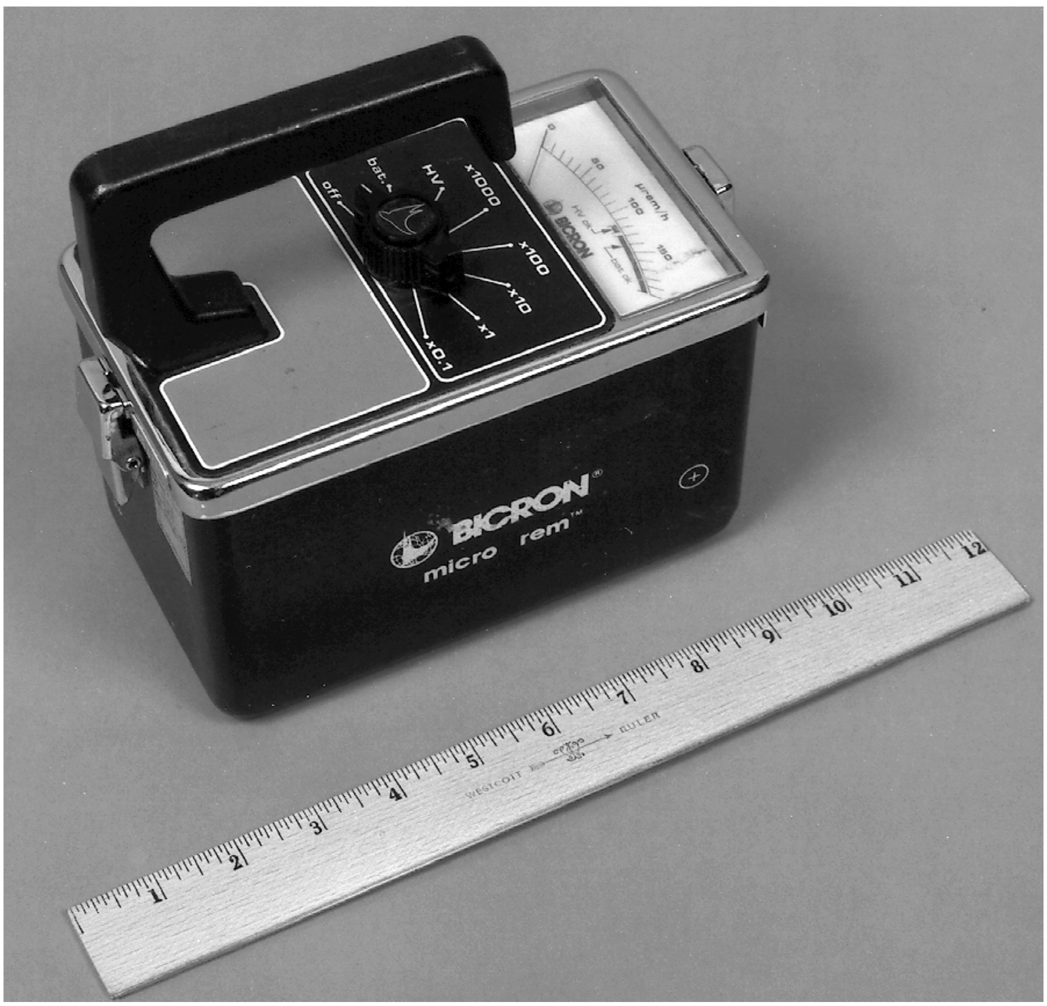

Figure 9.1. Bicron Micro Rem Meter

Figure 9.2. Bicron Micro Rem Meter with Adjustable Response Time and Audio

The instrument uses a tissue-equivalent organic scintillator detector, which is generally mounted within the instrument case. An optional extended detector, which relocates the detector outside of the case, is available but not commonly used at Hanford. A second option, also not widely used at Hanford, is a low-energy window that extends the instrument's energy response down to 17 keV. Micro Rem meters with the low-energy option are easily distinguished from the standard Micro Rem meters by the thin polycarbonate end window.

The sensitive volume of the detector, which is generally within the instrument case, is indicated with white cross hairs on the sides and front of the instrument.

The instrument meter is scaled from 0 μrem/hr to 200 μrem/hr. The instrument has an eight-position switch. Two positions are high voltage and battery check. The remaining positions select the instrument's range. The Micro Rem meter has five ranges, X0.1, X1, X10, X100, and X1000. The lowest range is 0 μrem/hr to 20 μrem/hr; the upper range is 0 μrem/hr to 200,000 μrem/hr (0 mrem/hr to 200 mrem/hr).

Older instruments (Figure 9.1) have only the single eight-position switch and no audible capabilities. For these instruments, the response time is optimized for each range and is not adjustable by the user. The actual response time for each range is listed below.

Table 9.1. Response Time for Micro Rem Meters Without Adjustable Response

Range	Response Times (s)
X0.1	< 15
X1	< 15
X10	< 5
X100	< 2
X1000	< 2

Newer instruments (Figure 9.2) have additional features including a reset switch for quickly resetting the meter to zero, internal speaker, audio switch, and response switch. On these instruments, the response time is fixed at 2 seconds for the X1000, X100, and X10 ranges. On these ranges, the response switch has no effect. On the lower ranges, the three-position switch (slow, medium, and fast positions) allows the user to vary the meter response time. Response times for the new instruments are listed below.

Table 9.2. Response Time for Micro Rem Meters with Adjustable Response

Range	Response Times (s)		
	Slow	Medium	Fast
X0.1	20	10	5
X1	20	10	5
X10	2	2	2
X100	2	2	2
X1000	2	2	2

The response time is generally specified by the manufacturer as the time for the instrument reading to reach 90% of final value after a change in the radiation field. The RC time constant of the instrument can be calculated from the 0% to 90% response time by dividing the 0% to 90% response time by 2.3.

For Micro Rem meters with the internal speaker, the audio switch provides the following features. In the Pulse mode, audible clicks proportional to the dose rate are produced. This option is only available in the X0.1, X1, and X10 ranges. When the audio switch is in the ALARM or PULSE position, an alarm (steady high-pitched tone) will occur if the reading is off scale high. This alarm occurs for each range. Placing the audio switch in the OFF position disables all audio response, including the alarm feature.

9.1.2 Radiation and Energy Response

The Micro Rem meter responds to x-rays and gamma radiations with energies above 40 keV. Beginning at about 60 keV (e.g., ^{241}Am), the response is generally within ±20% of the true exposure rate.

Micro Rem meters with the optional low-energy window (aluminized polycarbonate end window) respond to photons above 17 keV.

9.1.3 Integral Sources

The Micro Rem meter has no internal radioactive sources.

9.2 Operating Instructions

Perform the operability check (described in Section 9.3.1). Turn the instrument on, and select the appropriate scale. Slowly move the instrument close to radiation sources. When quantifying radiation levels, allow the instrument meter to stabilize before recording the instrument response (allow at least two times the response time).

The X0.1 and the X1000 ranges are not used to quantify dose rates because an effective source check method is not available for these ranges. These ranges may be used for scanning purposes or making relative (comparative) measurements. Measurements required in the X1000 range can be made using a Cutie Pie (CP) Eberline RO-3B rate meter.

9.2.1 Correction Factors

There are no correction factors used with the Micro Rem meter. The Micro Rem meter is calibrated under uniform field conditions. Correction factors for non-uniform field conditions (e.g., on contact with small items) have not been developed for the Micro Rem meter. The Micro Rem meter should not be used to measure dose rates in non-uniform field conditions (e.g., contact dose rates).

9.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions below are provided as examples of acceptable methods.

9.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the Micro Rem meter fails any of the checks listed below, other than battery test, return it to the PNNL calibration laboratory for servicing.

1. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) on the expiration date on the calibration sticker.
2. Ensure that the instrument source check is current. Source checks are generally valid for the day performed and typically do not cover more than 24 hours.
3. Inspect the instrument for physical defects, such as broken meter glass, loose knobs, or other observable defects.

4. Turn the control switch to the BATT position. The meter reading should be within the BATT OK check band. If not, go to Section 9.5.
5. Turn the control switch to the HV position. The meter reading should be within the HV OK check band.
6. Turn the control switch to the X0.1 range. The instrument should respond to ambient background radiation. Typical background readings are 2 μrem/hr to 10 μrem/hr (a reading of 20 to 100 on the X0.1 range). If the instrument does not respond to background radiation, tag and return the instrument to the calibration laboratory for servicing.

9.3.2 Source Check

The Micro Rem meter may be source checked using a Gamma Calibration System (Micro Rem meter check source assembly). The initial source check is performed when the instrument is first received from the calibration laboratory. Source checks are performed daily or before each use if the Micro Rem meter is used less often than daily. Ranges used to perform occupational monitoring should be source checked.

When sources are not available for source checking the Micro Rem meter, the Hanford Instrumentation Evaluation Committee (HIEC) recommends semi-annual calibrations of these instruments.

9.3.3 Initial Source Check

NOTE: *The response of a given Micro Rem meter to the check source assembly will vary. The average energy of the source is below the stated energy range of the instrument; therefore, the response is not necessarily consistent from instrument to instrument. However, the response is consistent/reproducible for a given detector over the calibration interval.*

Place the Micro Rem meter on the check source assembly. Indents are provided for aligning the detector feet. Move the source to the appropriate position for the X1, X10, and X100 ranges of the instrument and record the instrument response on each range. Multiply the instrument response by 0.8 and 1.2 to determine the acceptable range for that instrument. An initial source check may not be performed on the first range (X0.1) or on the last range (X1000).

9.3.4 Daily Source Check

NOTE: *The source used to perform the initial source check is used to perform the daily source check. To perform a daily source check with a source other than the one used for the initial source check, first perform the daily source check on the source used for the initial source check. If the instrument passes that daily source check, then perform a new initial source check using the new source to establish response limits for that source/instrument combination.*

Place the Micro Rem meter on the check source assembly. Move the source to the appropriate position for each of the three middle ranges of the instrument. The instrument response, on each range, should fall within the acceptable values determined during the initial source check. If the instrument fails, tag it with an Instrument Service Tag, and return it to the calibration laboratory.

Source checks are generally valid for 24 hours after they are performed.

9.4 Calibration Instructions

The Micro Rem meter is calibrated at the PNNL calibration laboratory at the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff.

Before calibration, instruments are inspected to make sure they are in good working order. Batteries are checked, the meter is checked for oscillations, and the instrument is inspected for physical damage. Damaged instruments are repaired before calibration. As-found readings at 80% of each range are also recorded before calibration. If the as-found readings are more than ±20% out of tolerance, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

The upper ranges of the Micro Rem meter are calibrated in uniform ^{137}Cs photon fields at 21±2°C (70±3.6°F). The uniform fields are produced using source wells that provide calibrated exposure rates in R/hr. The roentgen-to-rem conversion factor for ^{137}Cs fields is approximately 1.0 (i.e., Bicron recommends using a rem/R correction factor of 1.0 for ^{137}Cs to ensure ± 20% response over the range of 60 keV to 2 MeV). Therefore, the instrument is calibrated to correctly display the true exposure rate (in R/hr) from the source, and subsequently can measure µrem/hr without conversion. Each range is calibrated at 80% of the full-scale readings. The response is then checked at 20% of the full-scale reading. For example, the 2000-µrem/hr range is calibrated by placing the instrument in a 1600-µR/hr field (80% of 2,000 µrem/hr is 1600 µrem/hr) and adjusting the appropriate range potentiometer to achieve the required reading (1600 µrem/hr ± 10%). The instrument is then placed in a 400-µR/hr field (20% of 2000 µrem/hr). The instrument response at both the 20% and 80% points has to be within ±10% of the actual exposure rate for the instrument to pass calibration. In addition, the Micro Rem meter is exposed to a radiation field that is at least twice the full-scale reading (or at least 400 mR/hr) to make sure it properly indicates an off-scale condition. Instruments that do not off scale properly do not pass calibration.

The lowest range of newer Micro Rem meters is calibrated electronically with a pulser. Pulser count rates necessary to achieve readings of 20% and 80% of full scale on the upper ranges are scaled down to provide equivalent count rates on the lowest range. Some older Micro Rem meters are not equipped with circuits to allow for electronically calibrating the lowest range and, consequently, are not calibrated on the X0.1 range.

The Micro Rem meter is calibrated annually or semi-annually and after any maintenance is performed (other than battery changes). The calibration is valid through midnight of the expiration date listed on the calibration sticker.

For more detailed information on the Micro Rem meter calibrations, refer to PNL-MA-563, Section 3.8.5.

9.5 Maintenance Instructions

Routine maintenance on the Micro Rem meter is performed at the calibration laboratory and in the field. Typical maintenance includes cleaning the instrument and replacing batteries. The instrument having no response is a common problem.

Battery changes may be performed in the field by the user. To change the batteries in the instrument, do the following:

1. Turn the instrument off.
2. Open pull catches at both ends of the case and separate the bottom of the case from the top.
3. Remove the old batteries. Install two new 9-V batteries into the battery holders on the bottom circuit board, observing proper polarity. Always replace both batteries at the same time.
4. Replace the bottom part of the case, orienting the rubber pad under the batteries and the detector markings with the detector volume. Close the pull catches.
5. Turn the control switch to the BATT position. The meter should display a reading within the BATT OK checkband.
6. Source check instrument.
7. Dispose of the used batteries appropriately.

No response: The instrument may have no response due to a damaged scintillator or damaged photomultiplier tube. If the instrument does not respond to radiation, tag the instrument with an Instrument Service Tag, and return it to the calibration laboratory.

9.6 Instrument Specifications and Limitations

9.6.1 Temperature

The Micro Rem meter is usable at temperatures of -20°C to 50°C (-68°F to 122°F).

9.6.2 Temperature Shock

Test data indicate that the Micro Rem meter response to temperature shock is acceptable on the X1 range. A temperature shock from 22°C to 50°C (72°F to 122°F) has produced high readings on one instrument tested on the X0.1 range. Therefore, it is good practice to allow the instrument's temperature to equalize with the ambient temperature before using it to perform surveys.

9.6.3 Humidity and Pressure

The Micro Rem meter is usable for all ambient humidities and pressures encountered on the Hanford Site. Do not use the Micro Rem meter in condensing environments.

9.6.4 Electromagnetic Field Interference

The Micro Rem meter may be affected by magnetic fields. The variation in response to typical magnetic fields encountered on the Hanford Site is less than ±15%.

9.6.5 Radio Frequency/Electromagnetic Interference

The Micro Rem meter may be affected by radio frequency fields. The variation in response to typical radio frequency fields encountered on the Hanford Site is less than ±5%.

9.6.6 Energies and Types of Radiation

The Micro Rem meter responds to gamma radiations with energies greater than 40 keV. The response is within ±20% of the true exposure rate to photons from 40 keV to 60 keV. The response to photons above 60 keV is linear (response is within ±10% of the true exposure rate). See Figure 9.3 for instrument gamma energy response.

Micro Rem meters with the optional low-energy window (aluminized polycarbonate end window) respond to photons above 17 keV.

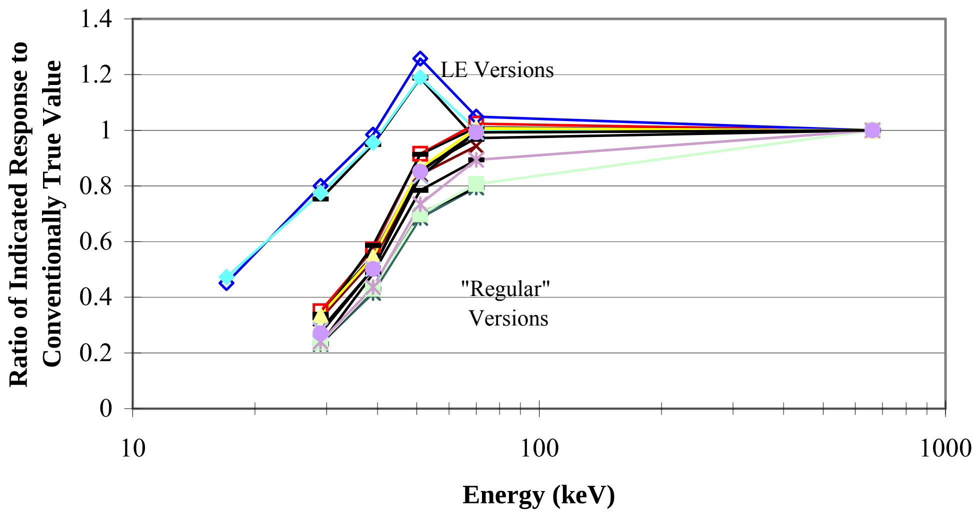

Figure 9.3. Gamma Energy Response

9.6.7 Interfering Ionizing Radiation Response

The Micro Rem meter is insensitive to alpha, beta, and neutron radiations.

9.6.8 Battery Life

The Micro Rem meter has a battery life of about 100 hours. Use in high exposure rate areas reduces battery life.

9.7 Applications

The Micro Rem meter is used to measure deep dose equivalent rates in uniform radiation fields.

10.0 Eberline Alpha 3, 4, 5, 5A, and 5AS Series Continuous Air Monitors

10.1 Instrument Description and Theory of Operation

The Eberline Alpha Air Monitor Models 3, 4, 5, 5A, and 5AS are semi-portable devices designed to monitor alpha radioactivity in the air (see Figures 10.1 through 10.3). Except as noted in this procedure, the alpha continuous air monitors (CAM) listed above are operated in the same manner and are essentially interchangeable. These alpha CAMs are only capable of monitoring alpha-emitting airborne particulates.

All instruments described in this section use a solid-state detector and single-channel pulse height analyzer to discriminate alpha particles of a specific energy while rejecting other energies.

More detailed information can be found in the manufacturer's technical manuals or by contacting the PNNL calibration laboratory at (509) 376-5624.

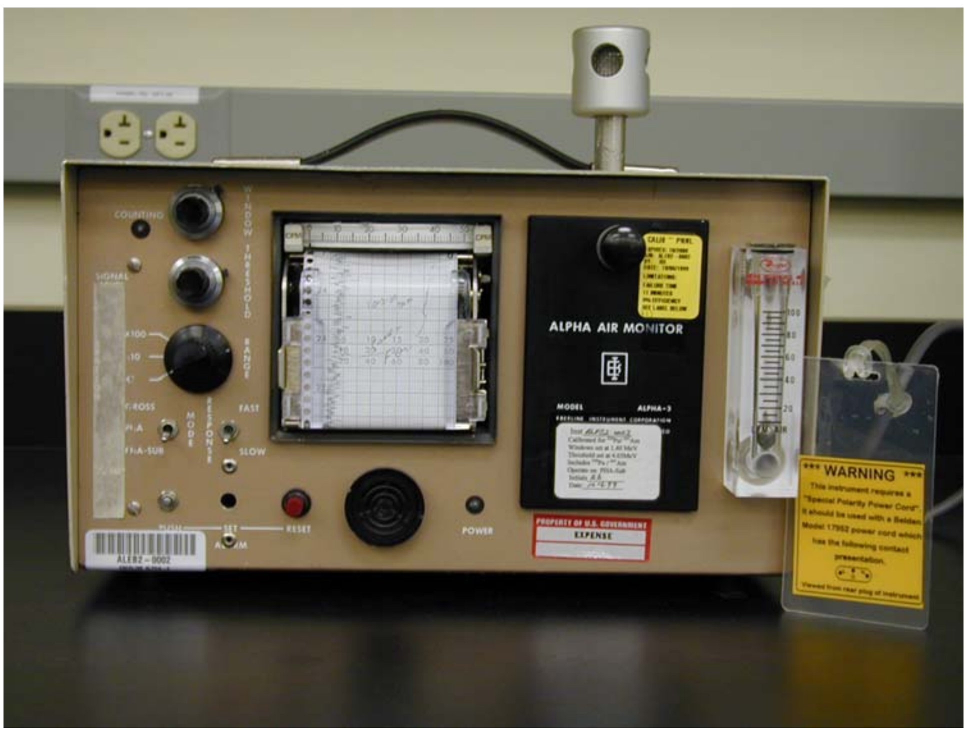

Figure 10.1. Eberline Alpha 3 CAM

Figure 10.2. Eberline Alpha 4 CAM

Figure 10.3. Eberline Alpha 5A CAM

10.1.1 Physical Description

There are numerous variations of Alpha 3, 4, 5, 5A, and 5AS CAMs used on the Hanford Site. The CAMs are frequently modified to fit specific applications or meet unique facility needs. Though the CAMs may have operational differences, they are, in general, functionally equivalent. This section describes typical alpha CAM features common to all units. Subordinate sections describe unique characteristics of specific models.

The CAMs use a 25-mm diameter, solid-state diffused junction detector to monitor activity collected on a 47-mm-diameter filter paper. The maximum sensitivity is approximately one derived air concentration sampled for 4 hours (4-DAC-hr) for ^{239}Pu.

The CAMs measure approximately 27 cm high by 38 cm wide by 32 cm deep (11 in. by 15 in. by 13 in.) and weigh approximately 6.6 kg (15 lb). They require 120/220 VAC, 50/60 Hz, and 0.5 amp current.

The alpha CAMs covered in this procedure have a background subtraction circuit that employs an adjustable window for subtraction purposes.

The CAMs provide a visual indication of the measured count rate resulting from activity collected on the filter paper. This indication may be a meter or a chart recorder. Strip chart recorders provide a visual indication of the CAM's count rate as well as a historical record that may be used in evaluating CAM alarms, including estimating DAC-h exposure. Strip chart recorders have a speed control on the side that may be set to X1 or X6. Typically, X1 is used to limit paper consumption. In addition, recorders have an on/off switch located on the right side. These switches are generally disabled because noise from the switching transient may cause the CAM to alarm.

In addition, CAMs provide alarm signals to indicate elevated levels of alpha-emitting airborne radioactivity. The alarm signals may be audible alarms, visual alarms, and/or remote alarm relays. The specific types of alarm signals vary depending on the facility and/or the application. Workplace CAMs typically have a visual beacon and an audible alarm bell. In some cases, CAMs may have a Sonalert brand, audible alarm instead of, or in addition to, the alarm bell. Radiation alarms are typically non-latching (i.e., the alarm indication will clear when the count rate decreases below the alarm set point). However, some instruments have been modified so that the radiation alarms are latching (i.e., the ACKNOWLEDGE button must be pressed before the alarm indication will clear).

The CAMs also provide a failure alarm to indicate loss of signal from the detector. Loss of signal (i.e., counts) may indicate a failed detector. Fail alarms are non-latching, and the alarm indication will clear as soon as the detector registers a count. The response time for a CAM to alarm upon loss of detector signal varies; typical response times are 11 to 19 minutes. The actual response time for each CAM is measured during calibration and is indicated in the limitations section of the calibration sticker (except for CAMs that have thorium keep-alive sources installed on the detector).

Alpha 3, 4, 5, 5A, and 5AS CAMs are equipped with rotameters to indicate flow rate. A variety of rotameters are used and typically read out in liters per minute (lpm). Some rotameters have knobs for adjusting the flow rate. In some cases, these knobs are disabled so the flow rate cannot be changed.

10.1.1.1 Model Specific Features

There are minor variations between alpha CAM models. Model-specific characteristics are given below.

Alpha 3: This model has a Sonalert annunciator only, and do not have a visible alarm (i.e., no beacon).

The count rate meter range is selected by a front panel switch with X1, X10, and X100 settings.

A response time toggle switch (fast or slow) allows the user to adjust instrument response time. Approximate response time is 30 seconds (fast) and 180 seconds (slow).

Alpha 4, 5, and 5A: The count rate is displayed on a Simpson chart recorder or a meter on the front panel. The recorder or meter both have logarithmic scales ranging from 1 to 10K cpm. Instrument response time is inversely proportional to measured count rate. A typical response time at 200 cpm is 18 seconds. At 40 cpm, the response time is roughly 40 seconds. At 1000 cpm, the response time is approximately 7 seconds.

Failure alarms are indicated by the counting light turning off and a failure light turning on.

The alarm acknowledge button is labeled ACKNOWLEDGE.

Alpha 5AS: The only difference between models 5A and 5AS is the type of chart recorder used. The Alpha 5AS has a Rustrack chart recorder. All other models use a Simpson chart recorder. As a result of changing the type of chart recorder, the chassis of the Alpha 5AS is slightly taller than the chassis of other CAMs. In all other respects, the 5AS is identical to the 5A.

10.1.1.2 CAM Controls

Alpha 3, 4, 5, 5A, and 5AS CAMs have the following external controls and indicators that are used during normal operation.

Push-to-Set: When pressed, the alarm set point is displayed on the meter or strip chart recorder.

Set: The SET button is used in conjunction with the PUSH-TO-SET button to adjust the alarm set point. In some facilities, the SET button is recessed to prevent inadvertent adjustment. In these cases, a simple tool is required to adjust the alarm set point.

Acknowledge: Pressing the ACKNOWLEDGE button silences the audible alarm.

Power: The power light will illuminate when the CAM is on.

Counting: The counting light will illuminate when the CAM is in the normal operating condition. During failure alarms, the counting light will turn off.

Additional external controls are used only during calibration and are typically covered with tape to prevent inadvertent adjustment. For a description of how these controls are used during calibration, refer to the appropriate procedures in PNL-MA-563 or to the CAM operating manual. The calibration controls include percent subtraction, threshold, window, subtract window, pulse width, zero, span, signal level, and mode (gross, PHA, PHA-SUB).

10.1.1.3 CAM Alarms

Alpha 3, 4, 5, 5A, and 5AS CAMs alarm on two basic conditions—high count rate and failure. Both alarms are typically non-latching alarms (the alarm indication clears when the alarm condition is removed).

An airborne alarm is initiated when the count rate in the window of interest exceeds the alarm set point. This alarm turns on the CAM beacon and alarm annunciator, if so equipped. In addition, relay contacts on the rear of the CAM can initiate remote alarms. When the alarm condition clears, either by pressing the ACKNOWLEDGE button or when the count rate drops below the alarm set point (unless the CAM is modified for latching alarms), the alarm signals reset. During an alarm condition, the ACKNOWLEDGE button on the front of the CAM will silence the audible alarm. However, the alarm beacon will remain on until the count rate drops below the alarm set point.

The fail alarm indicates the absence of a signal from the detector. If the signal from the detector is lost (i.e., no counts are detected within a pre-set count time), the counting light on the front panel turns off, and the failure light, if so equipped, turns on. In addition, a normally closed remote alarm relay will open. This alarm is non-latching and will reset once counts are registered by the detector.

10.1.2 Radiation and Energy Response

Alpha CAMs respond to alpha radiation (exclusively) because of the type of detector used and the pulse height discriminator. The instruments will not respond to neutron or beta radiation. The CAMs have a minimum efficiency of 9% for 47-mm diameter, electroplated ^{239}Pu sources.

Alpha CAMs respond to naturally occurring alpha-emitting airborne particulate, such as radon and thoron progeny. Pulse height discrimination is used to differentiate between naturally occurring alpha-emitting activity and radionuclides of interest (e.g., ^{239}Pu, ^{241}Am, or uranium).

10.1.3 Integral Sources

There are no radioactive sources attached to, or inside, these instruments. Some models may have had a commercial product (Coleman lantern mantel) applied to the detector to prevent failure alarms when used in low-background environments (e.g., downstream of high-efficiency particulate air filtered exhaust).

10.2 Operating Instructions

Placing a CAM in service requires local access to 120-VAC power and vacuum source utilities. Depending on the location and application, remote signal and/or alarm cables may be connected to the electronic output terminal strip located on the back of the CAM.

Prior to use, ensure that the performance test protocols of Section 10.3 are complete. Operating a CAM requires establishing air flow to a specific rate or range, installing a membrane filter paper, and setting the alarm setpoint. The Fluoropore membrane, manufactured by Millipore, is recommended. Glass fiber filters are strongly discouraged because of self-absorption characteristics that can cause false alarms.

10.2.1 Correction Factors

Correction factors are not used to operate these instruments.

10.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions below are provided as examples of acceptable methods.

10.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything below. When in service, operability checks are typically performed and documented daily. Daily checks should include the following steps:

1. Verify that the calibration of the instrument is current.
2. Verify that the positive airflow is within established range of 48.1 lpm - 65.1 lpm (1.7 cfm - 2.3 cfm).
3. Verify that there is a non-zero response to background.
4. Verify that the electronic chart recorder/meter is operational and adequate paper supply (paper out indicator not present) is present.
5. Verify that the vacuum lines are secure.
6. Remove any debris/obstructions present on the CAM.
7. Verify that the counting light is ON.
8. Verify that the failure light is OFF.
9. Verify that the sample door is shut tightly.
10. Verify the following CAM control settings:
    - Mode switch in the PHA/SUB position (switch is removed from some instruments).
    - Proper window setting: 1.0 for ^{239}Pu, 1.6 for uranium.
    - Proper threshold setting: 4.65 for ^{239}Pu, 3.6 for uranium.

- Alarm setpoint is appropriately set.

10.3.2 Source Check

Alpha CAMs are source checked with an electroplated or anodized alpha emitting source. The radionuclide of the source should match the radionuclide to which the CAM was calibrated.

10.3.2.1 Initial Source Check

Initial source checks should be performed immediately upon receiving the instrument from the calibration laboratory. Instruments should not be placed into storage until after performing the initial source check.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure the values are reasonable. For the alpha CAM, the initial response is considered reasonable when the response is within*:

- *±20% of the calibration measured efficiency*
- *±20% of the mean instrument response for that source.*

The acceptable range should allow for variations resulting from differing detector efficiency.

Open the sample door and remove the filter paper, replacing it with the source. Source configuration is such that the active side of the source will face the detector when the sample door is closed. Close the sample door and allow the instrument response to stabilize. Multiply the instrument's stable response by 0.8 and 1.2 to determine the acceptable range for that instrument/source pairing. Perform a background count with a radiologically clean filter paper to verify no counts are measured in 1 to 2 minutes.

10.3.2.2 Periodic Source Check

NOTE: *The source used to perform the initial source check is used to perform the periodic source check. To perform a periodic source check with a source other than the one used for the initial source check, first perform the periodic source check on the source used for the initial source check. If the instrument passes that periodic source check, then perform a new initial source check using the new source to establish response limits for that source/instrument combination.*

Source checks are typically performed weekly and often coordinated with filter paper exchange.

Open the sample door and remove the filter paper, replacing it with the source. Source configuration is such that the active side of the source will face the detector when the sample door is closed. Close the sample door and allow the instrument response to stabilize. The instrument response should fall within the acceptable range for that instrument/source pairing determined during the initial source check.

10.3.2.3 Alarm Function Test

Periodically, an in-service CAM should be tested to ensure the proper operation of alarming capabilities. A CAM alarm is initiated during the periodic source check by maintaining the alarm set point within the stable reading established with the source. Source activity should be sufficient to produce a count rate that is, at a minimum, within the decade of, and greater than, a typical alarm set point for the CAM.

Alarm function tests are typically performed monthly.

10.4 Calibration Instructions

The Eberline alpha CAMs are calibrated at the PNNL calibration laboratory at the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff.

Before calibration, instruments are inspected to make sure they are in good working order. Detector background is measured and maintained to 0 counts in 2 minutes. The detector is also checked for noise. Before calibration, as-found efficiency is measured using a ~10,000-dpm ^{239}Pu source. A pulser is used to evaluate as-found conditions for the count rate meter. Alpha 4, 5, 5A, and 5AS models are checked at 10 cpm, 100 cpm, 1,000 cpm, and 10,000 cpm. Alpha 3 is checked at 40 cpm, 400 cpm, and 4,000 cpm. If the as-found readings are more than ±20% out of tolerance, the calibration laboratory informs the radiological control organization that last used the instrument. During the as-found efficiency measurement, a scaler is used to evaluate the accuracy of the CAM meter or chart. The output relays are inspected for resistance and preamp linearity is evaluated.

Calibration of the Alpha 3, 4, 5, 5A, and 5AS involves verifying electronic settings and instrument operating parameters. Parameters that are verified include the pulse height and the threshold. The preamplifier is tested to verify that it has a linear response. Finally, the subtraction window is set. A calibration source traceable to the National Institute of Standards and Technology (NIST) is then used to verify the instrument efficiency for ^{239}Pu. In addition, the instrument rotameter is calibrated against a NIST-traceable flow meter. As part of calibration, the CAM is checked for inleakage by placing flow meters upstream and downstream of the CAM and verifying that the flow rate into the CAM equals the flow rate out of the CAM.

As the last step, the CAM is run overnight to verify it has a stable response.

Unless otherwise specified, the CAM is calibrated annually or after any maintenance that voids the existing calibration. The calibration is valid until 23:59 on the last day of the month, as indicated on the calibration sticker.

For more detailed information on Alpha 3, 4, 5, 5A, or 5AS calibrations, refer to PNL-MA-563, Section 4.2.2.

10.5 Preventive Maintenance

Routine maintenance on the CAM is performed at the calibration laboratory and in the field. Routine maintenance includes changing filter papers, cleaning detectors, changing chart paper, and inspecting and replacing o-rings.

Change filter paper: The filter exchange frequency depends on the concentration of suspended particulate (e.g., dust or radioactive material). Common practice is to exchange CAM filters weekly. Because the CAM is susceptible to filter loading effects (self absorption), the exchange frequency should be adjusted when attenuation causes operational problems such as spurious alarms. The CAM should use a membrane filters and the Millipore Fluoropore membrane filter is preferred.

High background: If the CAM background becomes elevated, the detector may be cleaned according to manufacturer's recommendations. (It is very easy to damage the detector during cleaning.)

Change chart paper: Chart paper must be periodically replaced on CAMs that use strip chart recorders. Used chart paper is handled according to facility directives. Chart paper should be replaced with paper compatible to the instrument. Typically, the CAMs use Eberline part 10814-C14C logarithmic paper. To install the paper, feed it under the fixed paper guide, over the rolling paper guide, over the tractor feed, and then onto the take-up spool. The chart recorder speed should be set to X1.

O-rings: O-rings should be inspected for cracks, seating, and dirt at each filter exchange. During calibration, o-rings are inspected and either lubricated or replaced depending upon if they are excessively dirty, do not fit properly, or are cracked.

10.6 Instrument Specifications and Limitations

The Laboratory has tested the functional performance of Eberline AMS-3 family of CAMs (specifically an AMS-3A-1) against a suite of environmental conditions specified in American National Standards Institute (ANSI) standards N42.17B and N42.18 (ANSI 1989, 1974). The most important testing data along with available manufacturer's information is summarized below (PNNL-10938).

10.6.1 Temperature

The operational temperature range of Eberline alpha CAMs is -7°C (19°F) to 54°C (129°F).

10.6.2 Temperature Shock

The CAMs are typically operated indoors and not exposed to temperature shocks. However, it is good practice to allow the instrument temperature to equalize with the ambient temperature before placing it in service.

10.6.3 Humidity and Pressure

The CAMs are appropriate for all ambient humidity and pressure encountered on the Hanford Site. Do not use these instruments in condensing environments.

10.6.4 Electromagnetic Field Interference

The CAMs should be relatively insensitive to external electromagnetic fields. If electromagnetic interference is suspected, or the instrument is going to be placed in high field strength, source checks should be performed under expected conditions to assess impacts.

10.6.5 Radio Frequency/Electromagnet Interference

Mobile communication transceivers operated in close proximity to an operational CAM may induce instrument response. Cellular phones should not be used in close proximity (e.g., 1.5 m [5 ft]) to alpha CAMs because they have been shown to induce counts to the rate meter and cause spurious alarms.

10.6.6 Energies and Types of Radiation

Alpha 3, 4, 5, 5A, and 5AS CAMs are sensitive to alpha radiation. The solid-state detector exhibits uniform energy response to alpha particles in the MeV range.

The calibration determines the energy range of interest. For example, an alpha CAM calibrated for ^{239}Pu (Window = 1.0 MeV, Threshold = 4.65 MeV) monitors alpha radiation between 4.65 MeV and 5.65 MeV as the region of interest.

10.6.7 Interfering Ionizing Radiation Response

The Alpha 3, 4, 5, 5A, and 5AS CAMs are not responsive to gamma, beta, or neutron radiation.

Alpha 3, 4, 5, 5A, and 5AS CAM detectors are sensitive to visible light. Light leaks will generate spurious counts within the spectrum. These counts typically register across the entire spectrum. Instruments are particularly susceptible to strobe lights or light sources near the air inlet that can transmit (reflect) light to the detector.

10.6.8 Particle Transport Efficiency

Texas A&M University Mechanical Engineering Department's Aerosol Technology Laboratory (McFarland et al. 1989, 1990) tested the particle transport capabilities of the Alpha 6 sampling head (identical to the Alpha 3, 4, 5, 5A, 5AS design).

Table 10.1 summarizes these results.

Table 10.1. Particle Transport Efficiency

Particulate Penetration Percentages (per particle size and air speed)						
Sampler	**Flow Rate**	**3 μm @ 1 m/s**	**7 μm @ 1 m/s**	**7 μm @ 0.3 m/s**	**14.8 μm @ 1 m/s**	**14.8 μm @ 0.3 m/s**
Inlet and Detector Filter Assembly	2 cfm	83.0%	1.8%	1.2%	1.0%	-----
Inlet	2 cfm	88.5%	73.6%	67.1%	48.1%	54.4%
Full System	2 cfm	73.5%	-----	-----	-----	-----
Full System	1 cfm	92.3%	-----	-----	-----	-----

10.7 Applications

The Alpha 3, 4, 5, 5A, and 5AS CAMs are designed to selectively measure airborne concentrations of man-made alpha-emitters in the presence of naturally occurring radon and their progeny. These instruments provide both visual and audible alarms, if equipped, if airborne concentrations of the isotope being monitored exceed a predetermined, user selectable value (DAC-h equivalent alarm set point). This instrument is most often used as a workplace monitor although it may be used to stack, duct, or plenum exhaust monitoring.

10.8 References

McFarland, A.R., C.A. Ortiz, and J.C. Rodgers, *Performance Evaluation of Continuous Air Monitor (CAM) Sampling Heads*, Aerosol Technology Laboratory, Department of Mechanical Engineering, Texas A&M University, College Station, Texas, and Health Safety and Environmental Division, Los Alamos National Laboratory, New Mexico, March 28, 1989.

McFarland, A.R., C.A. Ortiz, and J.C. Rodgers. 1990. "Performance Evaluation of Continuous Air Monitor (CAM) Sampling Heads." *Health Physics* 58:3.

11.0 Eberline AMS-3 Series of Beta Continuous Air Monitors

11.1 Instrument Description and Theory of Operation

The Eberline AMS-3 series CAMs measure airborne particulate concentrations of beta-emitting radionuclides in the presence of ambient gamma-fields. The CAM uses both physical shielding and electronic subtraction to compensate the beta counting data for external gamma-fields. An equivalent of 2 in. of lead shields the instrument's aerosol filter and adjacent pancake GM detector from background gamma fields. A second pancake GM, also located within the shielded containment, electronically compensates for residual γ-fields penetrating the lead shielding material. The instrument's integral chart recorder and/or rate meter displays and tracks the beta activity collected on the sample filter. An adjustable alarm circuit triggers both local (audio and visual) and remote (relay contact closure) annunciators when measured activity exceeds the alarm set point. An analog output is also provided with most Hanford Site CAMs that allows the logarithmic count rate data to be monitored remotely.

Three functionally similar models of the Eberline AMS-3 are present onsite—AMS-3, AMS-3A, and AMS-3A-1. The only major difference between the models, beyond the chart recorder/rate meter displays, is that the AMS-3A-1 separates the shielded filter/detector assembly from the electronics package to simplify the transport logistics associated with the calibration. More detailed technical information can be found in Eberline AMS 3 beta CAM technical manuals or by calling PNNL calibration laboratory at (509) 376-5624.

11.1.1 Physical Description

The AMS-3 (see Figures 11.1 and 11.2) and AMS-3A CAMs both possess a single integrated electronics/detector package. Their physical dimensions, however, differ slightly. The AMS-3 measures 28 cm high by 65 cm wide by 46.4 cm deep (11 in. by 25.5 in. by 18.25 in.), while the AMS-3A measures 39.4 cm high by 63.5 cm wide by 39.4 cm deep (15.5 in. by 25 in. by 15.5 in.). These instruments weigh 72.6 kg (160 lb).

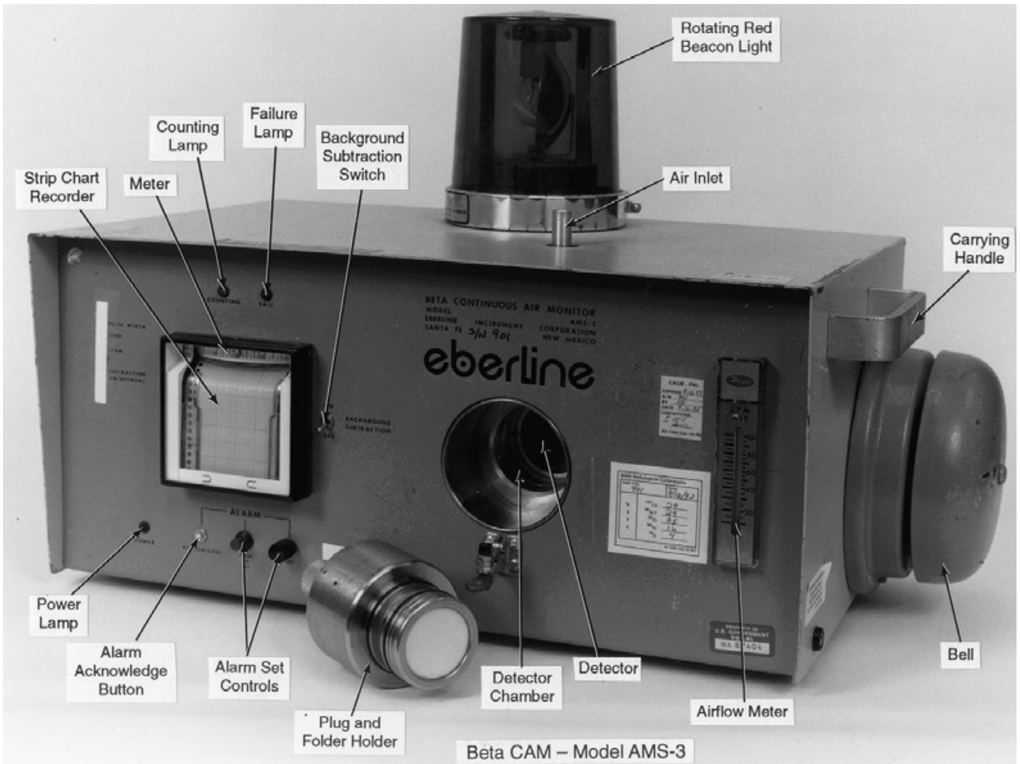

Figure 11.1. AMS-3 Beta CAM (front)

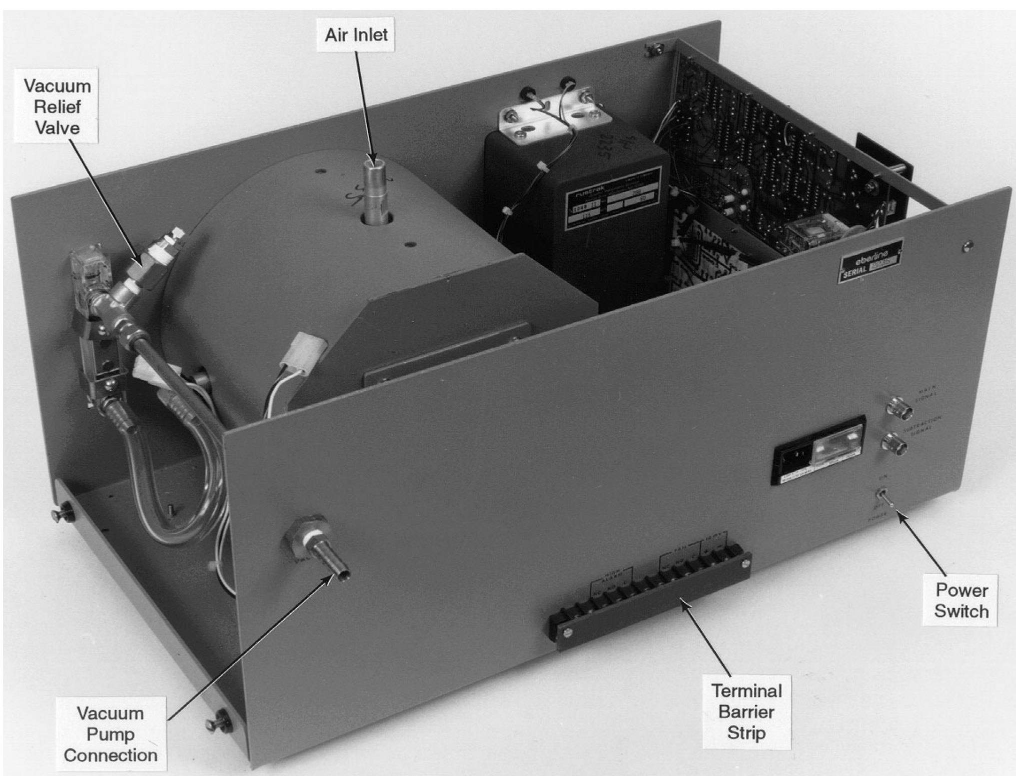

Figure 11.2. AMS 3 Beta CAM (rear w/cover removed)

The electronics package of the AMS-3A-1, weighs 11.7 kg (26 lb), and its physical dimensions are 24 cm high by 40 cm wide by 36 cm deep (9.5 in. by 16 in. by 14 in.). The shielded detector component of the AMS-3A-1 weighs 53.1 kg (117 lb) and measures 24 cm high by 32 cm wide by 36 cm deep (9.5 in. by 12.5 in. by 14 in.). A multi-COAX cable links the AMS-3A-1 detector head to the electronic controller/display unit (see Figure 11.3). As in the other AMS-3 CAMs, both power and regulated vacuum services are applied directly to the AMS-3A-1 electronics package.

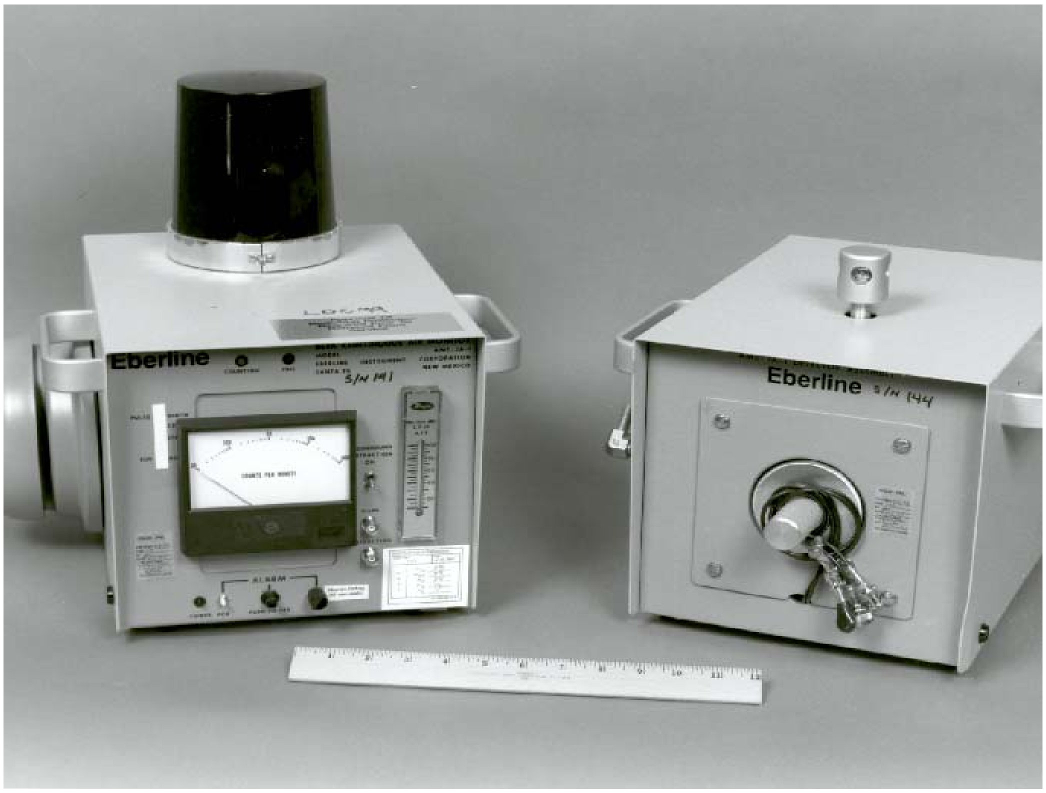

Figure 11.3. AMS-3A-1 Beta CAM

Instrument response time is inversely proportional to measured count rate. A typical response time at 200 cpm is 18 seconds. At 40 cpm, the response time is roughly 40 seconds. At 1000 cpm, the response time is approximately 7 seconds.

The CAMs provide a visual indication of the measured count rate resulting from activity collected on the filter paper. Typically, the measurement range is 10^1 cpm to 10^5 cpm. The indicator may be a meter or a chart recorder. Strip chart recorders provide a visual indication of the CAM's count rate as well as a historical record that may be used in evaluating CAM alarms, including estimating DAC-h exposure. Strip chart recorders may be set to X1 (2 cm/hr) or X6 (12 cm/hr). Typically, X1 is used to limit paper consumption. In addition, recorders have an on/off switch located on the right side. These switches are generally disabled because noise from the switching transient may cause CAMs to alarm.

In addition, CAMs provide alarm signals to indicate elevated levels of beta-emitting airborne radioactivity. The alarm signals may be audible alarms, visual alarms, or remote alarm relays. The specific types of alarm signals vary depending on the facility and/or the application. Workplace CAMs typically have a visual beacon and an audible alarm bell. Radiation alarms are typically non-latching (i.e., the alarm indication will clear when the count rate decreases below the alarm set point). However, some instruments have been modified so that the radiation alarms are latching (i.e., the ACKNOWLEDGE button must be pressed before the alarm indication will clear).

The CAMs also provide a failure alarm to indicate loss of signal from the detector. Loss of signal (i.e., counts) may indicate a failed detector. Fail alarms are non-latching and the alarm indication will clear as soon as the detector registers a count. The response time for a CAM to alarm upon loss of detector signal is between 12.5 and 20 minutes. The actual response time for each CAM is measured during calibration and is indicated in the limitations section of the calibration label.

These CAMs are equipped with rotameters to indicate flow rate. A variety of rotameters are used and typically read out in liters per minute. Some rotameters have knobs for adjusting the flow rate. In some cases, these knobs are disabled so the flow rate cannot be changed.

11.1.1.1 CAM Controls

AMS-3 CAMs have the following external controls and indicators that are used during normal operation.

Push-to-set: When pressed, the alarm set point is displayed on the meter or strip chart recorder.

Set: The set button is used in conjunction with the push-to-set button to adjust the alarm set point. In some facilities, the SET button is recessed to prevent inadvertent adjustment. In these cases, a simple tool is required to adjust the alarm set point.

Acknowledge: Pressing the ACKNOWLEDGE button silences the audible alarm.

Power: The power lamp will illuminate when the CAM is on.

Counting: The counting lamp will illuminate when the CAM is in the normal operating condition. During failure alarms, the counting lamp will turn off.

Failure: The failure lamp illuminates when the detector does not receive a count in the failure delay interval (~45 seconds).

Background subtraction: In the ON position, this toggle switch subtracts counts recorded with the gamma background detector to be subtracted from counts recorded by the detector that’s counting the filter paper detector.

Additional external controls are used only during calibration and are typically covered with tape to prevent their inadvertent adjustment. For a description of how these controls are used during calibration, refer to the appropriate procedures in PNL-MA-563 or to the CAM operating manuals. The calibration controls include pulse width, zero, span, and percent subtraction.

11.1.2 Radiation and Energy Response

TheAMS-3 CAMs are primarily designed to detect beta emissions from an aerosol filter (typically an LB5211). Beta detection efficiencies for common Hanford Site contaminants (^{99}Tc, ^{137}Cs, ^{36}Cl and ^{90}Sr[^{90}Y]) range from 20% to 25%.

These CAMs are slightly sensitive (< 1%) to gamma rays. The instrument is operated in the background subtraction mode to compensate for internally or externally generated gamma fields.

These CAMs are also sensitive to alpha particles. Alpha efficiency for the GM detector is approximately 5%.

These instruments also respond to beta-emitting (~20% efficient) and alpha-emitting (at most ~5% efficient) radon progeny collected on the filter.

11.1.3 Integral Sources

There are no radioactive sources attached to, or inside, the CAMs.

11.2 Operating Instructions

Placing a CAM in service requires local access to 120-VAC power and vacuum source utilities. Depending on the location and application, remote signal or alarm cables may be connected to the electronic output terminal strip located on the back of the CAM.

Prior to use, ensure that the performance test protocols of Section 11.3 are complete. Operating a CAM requires establishing air flow to a specific rate or range, installing a filter paper, and setting the alarm set point. Glass fiber filters are recommended.

11.2.1 Correction Factors

Correction factors are not used to operate these instruments.

11.3 Performance Test Instructions

Refer to contractor specific procedures for performance test instructions. The instructions below are provided as examples of acceptable methods.

11.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. When in service, operability checks are typically performed and documented daily. Daily checks should include the following:

1. Verify that the calibration of the instrument is current.
2. Very that the positive airflow is within established range of 48.1 lpm - 65.1 lpm (1.7 cfm - 2.3 cfm).
3. Verify that the response to background is greater than zero.
4. Verify that the electronic chart recorder/meter is operational and adequate paper supply (paper out indicator not present) is present.
5. Verify that the vacuum lines are secure.
6. Remove any debris or obstructions present on the CAM.
7. Verify that the counting light is on.
8. Verify that the failure light is off.
9. Verify that the sample plunger is securely and completely installed.
10. Verify CAM control settings:
    - Alarm set point is appropriately set.
    - Background subtraction switch is on.

11.3.2 Source Check

Beta CAMs are source checked with an electroplated or anodized beta-emitting source (typically ^{90}Sr/Y or ^{137}Cs). The radionuclide of the source should match a radionuclide to which the CAM has been calibrated and should represent a facility isotope of concern. When more than one isotope of concern is present, it is recommended to source check with the lower beta energy radionuclide.

11.3.2.1 Initial Source Check

Initial source checks should be performed immediately upon receiving the instrument from the calibration laboratory. Instruments should not be placed into storage until after performing the initial source check.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure the values are reasonable. For the beta CAM, the initial response is reasonable when the response is within*

- *±20% of the calibration efficiency.*
- *±20% of the mean instrument response for that source.*

The acceptable range should allow for variations resulting from differing detector efficiency.

Remove the sample plunger and filter ring. Remove the filter paper, replacing it with the source. Source configuration is such that the active side of the source will face the detector when the plunger is installed. Gently seat the plunger in the detector chamber and allow the instrument response to stabilize. Multiply the instrument's stable response by 0.8 and 1.2 to determine the acceptable range for that instrument/source pairing. Record the acceptable range on the performance testing record. Perform a background count with a radiologically clean filter paper to verify less than 50 cpm background over a 1 to 2 minute interval.

11.3.2.2 Periodic Source Check

NOTE: *The source used to perform the initial source check is used to perform the periodic source check. To perform a periodic source check with a source other than the one used for the initial source check, first perform the periodic source check on the source used for the initial source check. If the instrument passes that periodic source check, then perform a new initial source check using the new source to establish response limits for that source/instrument combination.*

Source checks are typically performed weekly and often coordinated with filter paper exchange.

Remove the sample plunger and filter ring. Remove the filter paper, replacing it with the source. Source configuration is such that the active side of the source will face the detector when the sample door is closed. Gently seat the sample plunger in the detector chamber and allow the instrument response to stabilize. The instrument response should fall within the acceptable range for that instrument/source pairing determined during the initial source check.

11.3.2.3 Alarm Function Test

Periodically, an in-service CAM should be tested to ensure the proper operation of alarming capabilities. Alarms are initiated during the periodic source check by maintaining the alarm set point within the stable reading established with the source. Source activity should be sufficient to produce a count rate that is, at a minimum, within the decade of, and greater than, a typical alarm set point for the CAM.

Alarm function tests are typically performed monthly.

11.4 Calibration Instructions

AMS-3 series CAMs are calibrated at the PNNL calibration laboratory located at the 318 Building in the 300 Area, or by facility maintenance organizations. The calibration described in this section is based on the calibration laboratory procedure.

Prior to calibration, the instruments are inspected to make sure they are in good working order. Damaged instruments are repaired before calibration. As-found instrument settings and source response parameters are also recorded before calibration. If the as-found readings vary from their calibrated values by more than 20%, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

Calibration of AMS-3 CAM includes the following:

- Leak checking the CAM sample flow system, including o-rings, adjusting the vacuum relief valve to open between 11 and 13 in. of mercury, and calibrating the CAM rotameter.
- Electronically checking, adjusting, and calibrating the instrument high voltage, detector pulse width, rate meter indicator, gamma-subtraction circuit, and alarm delay period.
- Functionally testing the CAM alarm circuitry, verifying alarm relay operation, and measuring contact closure resistance.
- Checking the instrument linearity using an electronic pulser at one point on each decade of the instrument range.
- Establishing instrument detection efficiencies for a range of beta-emitters including ^{14}C, ^{36}Cl, $^{90}Sr(Y)$, ^{99}Tc, and ^{137}Cs. To pass calibration, the instrument shall have a minimum efficiency of 15% for each of the isotopes except ^{14}C.
- Measuring CAM background (typical background count rates are less than 40 cpm).
- Cleaning and inspecting o-rings. The plunger should be returned with the CAM to the calibration laboratory to ensure that maintenance is performed on the o-rings.

Unless otherwise specified, the CAM is calibrated annually or after any maintenance that voids the existing calibration. The calibration is valid 23:59 of the last day of the month, as indicated on the calibration sticker.

For more detailed information on AMS-3 beta CAM calibrations, refer to PNL-MA-563, Section 4.2.17, or refer to facility calibration procedures.

11.5 Maintenance Instructions

Routine maintenance on the CAM is performed at the calibration laboratory and in the field. Routine maintenance includes changing filter papers, cleaning detectors, changing chart paper, and inspecting and replacing o-rings.

Change filter paper: The filter exchange frequency is dependent upon the concentration of suspended particulate (e.g., dust and radioactive material). Common practice is to exchange CAM filters weekly. The CAM can use any durable, high-efficiency filter paper, although glass fiber filters are most commonly used.

High background: If the CAM background becomes elevated, the detector may be cleaned according to manufacturer's recommendations. (It is very easy to damage the detector during cleaning.)

Change chart paper: Chart paper must be periodically replaced on CAMs that use strip chart recorders. Used chart paper is handled according to facility directives. Chart paper should be replaced with paper compatible for the instrument. The chart recorder speed should be set to X1.

O-rings: O-rings should be inspected for cracks, seating, and dirt at each filter exchange. During calibration, o-rings are inspected and either lubricated or replaced depending upon if they are excessively dirty, do not fit properly, or are cracked.

11.6 Instrument Specifications and Limitations

The Laboratory has tested the functional performance of AMS-3 CAMs (specifically an AMS-3A-1) against a suite of environmental conditions specified in American National Standards Institute (ANSI) standards N42.17B and N42.18 (ANSI 1989, 1974). The most important testing data along with available manufacturer's information is summarized below (PNNL-10938).

11.6.1 Temperature

The design temperature range of AMS-3 CAMs is -7°C to 49°C (20°F to 120°F). However, these CAMs can be equipped with an optional heater that extends the lower operating temperature range of these CAMs to -18°C (0°F).

Laboratory testing data indicated non-compliance with the ANSI N42.17B temperature standard above 40°C (104°F) (the instruments under responded by greater than 50% at temperatures greater than 40°C). Therefore, the upper operating temperature should be considered to be 40°C (104°F) and not 49°C (120°F).

11.6.2 Temperature Shock

A CAM is typically operated indoors and not exposed to temperature shocks. However, it is good practice to allow the instrument temperature to equalize with the ambient temperature before placing it in service.

11.6.3 Humidity and Pressure

Although the manufacturer does not provide operational specifications for humidity and pressure, AMS-3 CAMs were tested to, and met, the ANSI N42.17B humidity (40% to 95%) standard (ANSI 1989).

The Laboratory also tested three CAMs against ANSI N42.17B pressure 525-795 torr (70-106 kPa) guidelines. At 70 kPa, one of the three CAMs under-responded by ~50% relative to its reference response recorded at 101 kPa. The ANSI standard allows for a maximum response deviation of ±15% over the entire specified pressure range. However, these instruments are operated at the same pressure at which they are calibrated. As such, these CAMs may be used at atmospheric pressure but should not be used within an operating vacuum or pressure vessel.

11.6.4 Electromagnetic Field Interference

The CAM should be relatively insensitive to external electromagnetic fields. If electromagnetic interference is suspected, or the instrument is going to be placed in high field strength, source checks should be performed under expected conditions to assess impacts.

11.6.5 Radio Frequency/Electromagnetic Interference

Although no manufacturer ratings are specified, the effects of radio frequency-induced interference upon CAM performance was tested against the ANSI N42.17B standard by PNNL. The results were found to be acceptable at 60 Hz but failed over the radio frequency ranges of 0.3 to 35 MHz and 140 MHz. Consequently, portable and mobile communication transceivers may create instrument response if brought into close proximity to an operational beta CAM. Response interference is also expected from any electrical spark source in the immediate vicinity of an AMS-3 CAM.

11.6.6 Energies and Types of Radiation

The AMS-3 series CAMs respond to alpha, beta, and gamma radiations. It will detect beta-emitters with energies above 100 keV (e.g., ^{14}C with $ß_{max}$=0.156 MeV) and alpha emitters with energy above about 3 MeV (e.g., uranium and ^{230}Th). Beta response is energy dependent, increasing with energy. On the low end, ^{14}C measures ~10% efficient. On the high end, $^{90}Sr/Y$ (β_{max} = 2.28 MeV) measures ~25% efficient.

11.6.7 Interfering Ionizing Radiation Response

Gamma: The manufacturer specifies the instrument's uncompensated ambient gamma response to a ^{60}Co field as 200 cpm/(mR/h). However, the electronic subtraction circuit can compensate for this response.

Neutron: The AMS-3 CAMs do not respond to neutron radiation.

Alpha: Because of the combined effects of the filter to detector air gap and the thickness of the pancake GM detector window, beta CAM detection sensitivities for alpha emitting aerosols are at most ~5%.

11.6.8 Particle Transport Efficiency

Texas A&M University Mechanical Engineering Department's Aerosol Technology Laboratory tested the particle transport capabilities of the Alpha 6 sampling head (similar to the AMS-3 design [McFarland 1989]). Table 11.1 summarizes these testing results. AMS-3 values are not anticipated to deviate substantially from these values.

Table 11.1. Particle Transport Efficiency

Particulate Penetration Percentages (per particle size and air speed)						
Sampler	**Flow Rate**	**3 μm @ 1m/s**	**7 μm @ 1 m/s**	**7 μm @ 0.3 m/s**	**14.8 μm @ 1 m/s**	**14.8 μm @ 0.3 m/s**
Inlet and Detector Filter Assembly	2 cfm	83.0%	1.8%	1.2%	1.0%	----
Inlet	2 cfm	88.5%	73.6%	67.1%	48.1%	54.4%
Full System	2 cfm	73.5%	----	----	----	----
Full System	1 cfm	92.3%	----	----	----	----

11.7 Applications

The AMS-3 series CAMs are designed to measure airborne concentrations of beta-emitting radionuclides. These instruments provide both visual and audible alarms, if airborne concentrations exceed a predetermined, user selectable, value (DAC-h equivalent alarm set point). This instrument is most often applied as a workplace monitor although it may be applied to stack, duct, or plenum exhaust monitoring.

11.8 References

NOTE: *For information on technical manuals, see Bibliography.*

ANSI N42.17B-1989. 1989. *Performance Specification for Health Physics Instrumentation - Occupational Airborne Radioactivity Monitoring Instrumentation.* American National Standards Institute, New York.

ANSI N42.18-1974 (R 1980). 1980. *Specification and Performance on On-Site Instrumentation for Continuously Monitoring Radioactivity in Effluents.* American National Standards Institute, New York.

McFarland, A.R., Carlos A.O., and J.C. Rodgers. 1990. "Performance Evaluation of Continuous Air Monitor (CAM) Sampling Heads." *Health Physics* 58:3.

Johnson, M.L. 1996. PNNL-10938, *Evaluation of the Eberline AMS-3A and AMS-4 Beta Continuous Air Monitors*. Pacific Northwest National Laboratory, Richland, Washington.

12.0 Eberline AMS-4 Beta Continuous Air Monitor

12.1 Instrument Description and Theory of Operation

The AMS-4 CAM is designed to measure airborne particulate concentrations of man-made, beta-emitting radionuclides in the presence of naturally occurring radon progeny and ambient gamma fields. The CAM uses a sealed gas proportional detector and a dual-channel analyzer to electronically distinguish between alpha and beta events, thereby allowing compensation for naturally occurring activities. Furthermore, the AMS-4 uses a second proportional detector to counterbalance the effects of ambient gamma fields. The time dependent activity collected on the sample filter, after compensating for the presence of radon progeny and gamma fields, is used with integrated mass flow rate data to derive running averages of the airborne concentration of beta-emitting isotopes. The isotope of concern, typically ^{90}Sr or ^{137}Cs, is continually compared to its corresponding derived air concentration (DAC) value. The AMS-4 posts an alarm if these averages exceed a preset condition for a predetermined period of time (e.g., DAC-hr alarm set point).

The AMS-4 provides the user with a 2-line by 20-character dot matrix display with up to nine different pages of information that can be viewed while the unit is in the normal operational mode. The arrow keys on the keypad scroll through the pages to display the operational data of interest. Only the numerical value of the displayed readings and their corresponding units are displayed. A legend of the currently displayed readings can be shown by pressing Enter. In addition, a percent of alarm display is also provided by the AMS-4 controller.

More detailed technical information can be found in the Eberline AMS-4 Technical Manual or by calling the PNNL calibration laboratory at (509) 376-5624.

12.1.1 Physical Description

The AMS-4 is composed of a central processor and detector module. A vacuum pump is also necessary for operation. The most common Hanford configuration is the radial inlet detector/sampling head physically attached to the system controller (see Figure 12.1), and a separate vacuum pump. With this configuration, the AMS-4 weighs 6.0 kg (13.3 lb) and measures 41.6 cm (16.4 in.) wide by 32.5 cm (12.8 in.) high by 18.5 cm (7.3 in.) deep. The AMS-4 radial inlet sampling/detector head can be removed for remote monitoring (see Figure 12.2). Cable lengths of 50 ft and 100 ft are common for separating the electronics unit from the detector/sampling head assembly. An optional remote in-line detector/sampling head is also available for stack or duct monitoring applications. A multi-conductor cable links the remote head to the controller/display unit. However, in all cases, a regulated vacuum source must be applied directly to the detector head assembly.

The physical dimensions of the remote in-line head are 18.4 cm (7.25 in.) wide by 24.1 cm (9.5 in.) high by 16.2 cm (6.4 in.) deep, and the unit weighs 5.5 kg (12 lb). The remote head can be separated from the controller/display unit by up to 305 m (1,000 ft).

Figure 12.1. AMS-4 with Attached Radial Entry Detector/Sampling Head

Figure 12.2. AMS-4 with Detached Radial Entry Detector/Sampling Head

12.1.2 Radiation and Energy Response

TheAMS-4 detector is sensitive to both alpha and beta radiation. However, the AMS-4 only uses its alpha sensitivity to compensate for the presence of naturally occurring radon progeny. Beta detection efficiencies for common Hanford Site contaminants range from 9% for ^{99}Tc to 18% for $^{90}Sr(^{90}Y)$. Although the AMS-4 CAM is only slightly sensitive to gamma-radiation, a second detector is used to compensate instrument response for ambient gamma-fields.

12.1.3 Integral Sources

There are no radioactive sources attached to or inside the CAM.

12.1.4 AMS-4 Alarms

The AMS-4 CAM is configured with five user-modifiable alarm set points. When the alarm is posted the local and remote horns will sound until the appropriate alarm ACKNOWLEDGE button is pressed. The alarm acknowledge key on the base unit will silence the local and remote horn; the alarm acknowledge switch on the sampling head will silence only the remote horn. Additionally, when an alarm occurs, a change of status is logged into the history file, the alarm relay will actuate (if equipped), and both the local strobe and the alarm light on the sampling head will turn on. The strobe, remote alarm light, and alarm relay will continue to be active until the alarm condition ceases. The name and purpose of each of these alarms are summarized below.

Slow Alarm: The slow concentration alarm set point determines the concentration at which a slow concentration alarm will occur. The amount of history used to make this determination is defined by the slow alarm interval. An alarm will be posted if the current interval of slow alarm concentration history exceeds the concentration of the previous history interval by the value specified by the slow alarm set point. This condition is checked every minute. The default slow alarm set point is 10.59 Bq/ft3.

Fast Alarm: The fast concentration alarm set point determines the concentration at which a fast concentration alarm will occur. The amount of history used to make this determination is defined by the fast alarm interval. An alarm will be posted if the current interval of fast alarm concentration history exceeds the concentration of the previous history interval by the value specified by the fast alarm set point. This condition is checked every 5 seconds. The default fast alarm set point is 1059.07 Bq/ft3.

Net Alarm: The beta net count rate alarm set point determines the beta net count rate at which an alarm will occur. The amount of history used to make this determination is defined by the net alarm interval. An alarm will be posted if the current history interval of beta net count rate exceeds the beta net count rate of the previous history interval by the amount selected as the net alarm set point. This condition is checked every 5 seconds. The default net alarm set point is 60,000 cpm.

Stack Alarm: The stack alarm (release rate) set point determines the activity per unit time at which a stack alarm will occur. An alarm will be posted if the current release rate is equal to or greater than the alarm set point. This condition is checked every minute. The stack alarm is disabled if the alarm set point is 0. The default stack alarm set point is 0.

DAC-Hour Alarm: The DAC-hour alarm set point determines the total DAC-hours at which a DAC-hour alarm will occur. An alarm will be posted if the current total DAC-hour reading is equal to or greater than the alarm set point. The DAC hour total is updated, then compared to the DAC-hour alarm set point every minute. The DAC-hour alarm is disabled if the alarm set point is 0. The default DAC-hour alarm set point is 0.

Various types of internal checks are performed to determine a system failure condition. If one or more of the following fail parameters is out of limits, the AMS-4 will suspend history logging, store the change of status conditions in the history buffer, illuminate the front panel malfunction light, and actuate the fail relay (if equipped). History logging will continue after all fail parameters are within limits. At this time, the malfunction light will turn off, the fail relay will deactivate, and normal operation will resume. Changes to any of the fail parameters will log an Operate Parameter Change message into the history log. The history log can be retrieved by a host computer or printed from the AMS-4 using the Print Log Buffer feature in the test menu.

Min Flow Rate: The minimum flow rate parameter is the flow rate value at which a flow rate failure is determined. A measured flow rate which is less than this value, defaulted at 0.3 ft3/min, will cause a malfunction condition.

Max Flow Rate: The maximum flow rate parameter is the flow rate value at which a maximum flow rate failure is determined. Valid settings range from 0.3 ft^3/min to 4 ft^3/min or the equivalent in other flow units. The default setting is 4 ft^3/min.

Min Beta Count Rate: The minimum beta count rate parameter determines the count rate value at which a failure is determined after each 5-second counting interval. A beta channel count rate less than this value will cause a malfunction condition. The minimum setting for minimum beta count rate is 0 cpm. Setting the value to 0 will disable checking of this error. The default value is 0.

Max Beta Count Rate: The maximum beta count rate parameter determines the count rate value at which a failure is determined. A beta channel count rate greater than this value will cause a malfunction condition. The default value is 600,000 cpm.

When the malfunction condition exists, the counting circuit is disabled and the CAM does not monitor airborne radioactivity levels.

12.1.5 Setting Alarm Set Points

To set or alter AMS-4 operating, alarm or detector parameters, the instrument must be placed in the TEST MODE. To enter the TEST MODE, the user must press Menu on the keypad. The user is then prompted to enter the current TEST MODE password. After the correct password is entered, the user may scroll through the main menu by pressing the ↑ and ↓ keys. To alter a particular parameter, select the appropriate menu item by using the arrow keys to display the menu item of interest and then press Enter. A listing of sub-menu items can be viewed by using the ↑ and ↓ keys. When the desired parameter value is displayed, it can be edited using the instrument's key pad.

12.2 Operating Instructions

Placing a beta CAM in service requires local access to 120-VAC power and vacuum source utilities. Depending on the location and application, remote signal or alarm cables may be connected to the electronic output terminal strip located on the back of the CAM.

Prior to use, ensure that the performance test protocols of Section 12.3 are complete. Operating a CAM requires establishing air flow to a specific rate or range, installing a filter paper, and setting the alarm set point. Membrane filters are recommended.

All calibration dependent CAM variables are protected by password code; unfortunately, other user-dependent parameters are protected in the same manner. Consequently, if a variable, like alarm level, needs to be changed, extreme care should be taken to ensure that other menu-selectable variables are not inadvertently altered. Current data and many operating parameters can be displayed at any time without the use of a password code.

The radial entry detector assembly for the AMS-4 CAM does not use a filter retaining ring like the AMS-3 CAM. Rather, the filter paper is placed directly on the filter support (typically a white porous durable foam). On the radial entry head, the detector is contained on a swing arm that pivots upward, allowing access to the filter paper support. A retaining ring is used on in-line heads. The filter paper support is contained on a swing arm that rotates out from the detector housing allowing access to the filter support. Filter papers are secured with the retaining ring.

12.2.1 Correction Factors

Correction factors are not used to operate these instruments.

12.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions below are provided as examples of acceptable methods.

12.3.1 Operability Check

Operating a CAM requires establishing air flow to a specific rate or range, installing a membrane filter paper, and setting the alarm set point. The Millipore Fluoropore membrane is recommended for alpha and beta filtering. Glass fiber filters are strongly discouraged for alpha particles because of self-absorption characteristics that can cause false alarms.

Check everything listed below. When in service, operability checks are typically performed and documented daily. Daily checks should include the following:

1. Verify that the calibration of the instrument is current.
2. Verify that the positive airflow is within established range of 48.1 lpm - 65.1 lpm (1.7 cfm to 2.3 cfm).
3. Verify that the response to background is greater than 0.

4. Verifying that vacuum lines are secure.
5. Remove any debris/obstructions present on the CAM.
6. Verifying that the Ready light is on.
7. Verify that the Malfunction light is off.
8. Verify that the detector arm is securely and completely lowered.
9. Verify that CAM alarm set point is appropriately set.

12.3.2 Source Check

NOTE: *AMS-4 source checks are performed using the CAM source check protocol. The discussion below identifies an appropriate sequence of events and does not define specific key strokes for accomplishing the event. Refer to contractor specific procedures for specific guidance on performing source response checks. Vacuum pumps should be turned off prior to commencing sources checks.*

Beta CAMs are source checked with an electroplated or anodized beta-emitting source (typically ^{90}Sr/Y or ^{137}Cs). The radionuclide of the source should match a radionuclide to which the CAM has been calibrated and should represent a facility isotope of concern. When more than one isotope of concern is present, it is recommended to source check with the lower beta energy radionuclide.

12.3.2.1 Initial Source Check

Initial source checks should be performed immediately upon receiving the instrument from the calibration laboratory. Instruments should not be placed into storage until after performing the initial source check.

NOTE: *To evaluate CAM efficiency, a special source certification is required to account for the portion of the source masked by the retaining ring (in-line head) or compression ring (radial entry head). AMS-4 source certifications are available from the calibration laboratory.*

Instrument response observed during the initial source check should be evaluated to ensure that the values are reasonable. For the beta CAM, the initial response is reasonable when the:

- *measured efficiency is within ±20% of the calibration efficiency*
- *response is within ±20% of the mean instrument response for that source.*

The acceptable range should allow for variations resulting from differing detector efficiency.

Depress the silver button on the detector arm and lift the arm. Remove the filter paper, replacing it with the source. Source configuration is such that the active side of the source will face the detector after lowering the detector arm. Gently lower the detector arm until it rests in the lowered position. Allow the instrument response to stabilize. Multiply the instrument's stable response by 0.8 and 1.2 to determine the acceptable range for that instrument/source pairing. Record the acceptable range on performance testing record.

12.3.2.2 Periodic Source Check

NOTE: *The source used to perform the initial source check is used to perform the periodic source check. To perform a periodic source check with a source other than the one used for the initial source check, first perform the periodic source check on the source used for the initial source check. If the instrument passes that periodic source check, then perform a new initial source using the new source to establish response limits for that source/instrument combination.*

Source checks are typically performed weekly and often coordinated with filter paper exchange.

Depress the silver button on the detector arm and lift the arm. Remove the filter paper, replacing it with the source. Source configuration is such that the active side of the source will face the detector when the sample door is closed. Gently lower the detector arm until it rests in the lowered position. Allow the instrument response to stabilize. The instrument response should fall within the acceptable range for that instrument/source pairing determined during the initial source check.

12.3.2.3 Alarm Function Test

Periodically, an in-service CAM should be tested to ensure the proper operation of their alarming capabilities. Alarms are initiated during the periodic source check by maintaining the alarm set point within the stable reading established with the source. Source activity should be sufficient to produce a count rate that is, as a minimum, within the decade of, and greater than a typical alarm set point for the CAM.

Alarm function tests are typically performed monthly.

12.4 Calibration Instructions

The AMS-4 CAM is calibrated at the PNNL calibration laboratory located in the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff.

Prior to calibration, the instruments are inspected to make sure they are in good working order. Damaged instruments are repaired before calibration. As-found instrument settings and source response parameters are also recorded before calibration. If the as-found readings vary from their corresponding calibrated values by more than 20%, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

Calibration of an AMS-4 CAM includes setting or verifying software operating parameters. These parameters and typical values are summarized in Table 12.1. Electronic adjustments are made, as needed, to establish the standard instrument operating conditions such as the operating plateau voltage. A calibration source traceable to the NIST is then used to conduct final electronic calibration adjustments and establish the instrument's efficiency. In addition, the instrument flow rate circuit is thoroughly leak tested and electronically calibrated against an accurate mass flow meter that itself possesses a NIST-traceable calibration.

Table 12.1. Typical AMS-4 Software Configuration and Standard Operational Parameters

Instrument Parameters	
Sampling head:	Partiodine
Alpha subtract factor:	2.75
Gamma subtract factor:	(set by the user)
Fixed ß Bkg:	0.0
Fixed flow rate:	0.0
Stack flow alarms:	0.0
Beta efficiency:	(set at cal)
Log interval:	I
Log to printer:	Off
Instrument address:	1
Host baud rate:	9600
ULAN:	Off
Calib count time:	60 s
Calib source activity:	(set at cal)
Count units:	cpm
Flow units:	ft^3
Activity units:	dpm
Time units:	min
Min analog value:	60 dpm/ft3
Keypad beep:	On
Password 1:	
Password 2:	
Fail Parameters	
Min flow rate:	0.3 ft3/min or 8495 cc/min
Max flow rate:	3.99 ft3/min or 1.13E+5 cc/min
Flow weight factor:	0.0
Min beta count rate:	1 cpm
Max beta count rate:	6.00E+5 cpm
Beta weight factor:	10
Alarm Parameters	
Slow alarm interval:	30 min
Slow alarm set point:	(set by the user)
Fast alarm interval:	60 s
Fast alarm set point:	(set by the user)
Net alarm interval:	60 s
Net alarm set point:	60,000 cpm
Stack alarm set point:	0.0
DAC alarm set point:	0.0 DAC hr

Detector Parameters	
Alpha threshold:	50% of max
Beta threshold:	14% of max
Beta high voltage:	(set during cal)
Bkg threshold:	14% of max
Bkg high voltage:	(set during cal)

Unless otherwise specified, the CAM is calibrated annually or after any maintenance that voids the existing calibration. The calibration is valid through midnight of the expiration date listed on the calibration sticker.

For more detailed information on AMS-4 calibrations, refer to PNL-MA-563, Section 4.2.22.

12.5 Maintenance Instructions

Routine maintenance on the AMS-4 CAM is performed at the calibration laboratory and in the field. Routine maintenance includes changing filter papers and cleaning detectors.

Change filter paper: The filter exchange frequency is dependent upon the concentration of suspended particulate (e.g., dust and radioactive material). Common practice is to exchange CAM filters weekly. The CAM can use any durable, high-efficiency filter paper, although glass fiber filters are most commonly used.

High background: If the CAM background becomes elevated, the detector may be cleaned according to the manufacturer's recommendations. Detector cleaning involves removing contamination from the thin mica window using a soft brush or water rinse. The detector window is very fragile and can be easily damaged during cleaning. The detector is pressurized and the window has little flexibility.

12.6 Instrument Specifications and Limitations

The Laboratory has tested the functional performance of AMS-4 CAMs against a suite of environmental conditions specified ANSI Standards N42.17B and N42.18 (see Section 6.8, ANSI 1989 and ANSI 1980).[(a)] The most important testing data along with available manufacturer's information is summarized in the following sections (PNL-10938).

12.6.1 Temperature

The design temperature range of the AMS-4 CAM is -20°C to 85°C (-4°F to 185°F). Laboratory testing data indicated that the AMS-4 rate meter stability met the requirements of the standard but its flow transducer response was found to be noncompliant above 40°C (104°F). Therefore, the upper operating temperature should be considered 40°C (104°F) and not 85°C (185°F).

(a) PNL-10938, *Evaluation of the Eberline AMS-3A and AMS-4 Beta Continuous Air Monitors.*

12.6.2 Temperature Shock

The CAM is typically operated indoors and not exposed to temperature shocks. However, it is good practice to allow the instrument temperature to equalize with the ambient temperature before placing it in service.

12.6.3 Humidity and Pressure

Although the manufacturer does not provide operational specifications for humidity and pressure, the AMS-4 CAM was tested to, and met, the ANSI N42.17B humidity (40 to 95%) standard but were only partially compliant with regard to the pressure (500-800 torr [66-107 kPa]) requirements. Specifically, the AMS-4 met the count-rate stability condition set forth by the standard. However, the instrument failed flow stability requirements (±15%), over responding by as much as 22% at 66 kPa. The standard allows for a maximum response deviation of ±15% over the entire specified pressure range. As such, the CAM may be used at atmospheric pressure but should not be used within an operating vacuum or pressure vessel.

12.6.4 Electromagnetic Field Interference

The CAM should be relatively insensitive to external electromagnetic fields. If electromagnetic interference is suspected, or the instrument is going to be placed in high field strength, source checks should be performed under expected conditions to assess impacts

The AMS-4 CAM was found to be immune to interference when tested against a ANSI N42.17B specified microwave field of 2,450 MHz at 100 mW/m^2 power density. Manufacturer performance information is not available on this subject.

12.6.5 Radio Frequency Interference

Although no manufacturer ratings are specified, the effects of radio frequency-induced interference upon beta CAM performance was tested against the ANSI N42.17B standard by PNNL. The results were found to be acceptable at 60 Hz but failed over radio-frequency ranges of 0.3 to 35 MHz and 140 MHz. Consequently, portable and mobile communication transceivers may create instrument response problems if brought into close proximity to an operational CAM. Response interference would also be expected from any electrical spark source in the immediate vicinity of an AMS-4 CAM.

12.6.6 Energies and Types of Radiation

The AMS-4 CAM responds to alpha, beta, and gamma radiations. It will detect beta-emitters with energies above 100 keV (e.g., ^{14}C with $ß_{max}$ = 0.156 MeV) and alpha-emitters with energy above about 3 MeV (e.g., uranium and ^{230}Th). Beta response is energy dependent, increasing with energy. On the low end, ^{99}Tc measures ~9% efficient. On the high end, $^{90}Sr/Y$ (β_{max} = 2.28 MeV) measures ~18% efficient.

A guard detector compensates for ambient gamma response and electronic discriminators segregate alpha from beta radiation based on energy. Although the detector is sensitive to alpha, beta, and gamma radiation, the instrument is monitoring beta radiation for the user.

12.6.7 Interfering Radiation Response

Gamma: The electronic shielding circuit, under normal conditions, compensates for this response.

Neutron: The AMS-4 CAM does not respond to neutron radiation.

Alpha: Electronic discriminators establish an alpha window at higher energy and separate from the beta window. For monitoring purposes, the AMS-4 reads the beta window exclusively.

12.7 Applications

The AMS-4 CAM is designed to selectively detect airborne concentrations of man-made beta-emitters in the presence of radon progeny and ambient gamma fields. These instruments provide both visual and audible alarms if airborne particulate concentrations of beta-emitters exceed a predetermined, user-selected time interval (e.g., DAC-hr alarm set point). This instrument is most often applied as a workplace monitor, although remote sampling heads are available for conducting stack, duct, or plenum exhaust monitoring.

12.8 References

NOTE: *For information on technical manuals, see Bibliography.*

ANSI N42.17B-1989. 1989. *Performance Specification for Health Physics Instrumentation - Occupational Airborne Radioactivity Monitoring Instrumentation.* American National Standards Institute, New York.

ANSI N42.18-1974. (R 1980). 1980. *Specification and Performance of On-Site Instrumentation for Continuously Monitoring Radioactivity in Effluents.* American National Standards Institute, New York.

13.0 Eberline RO-7 Series Survey Instrument

13.1 Instrument Description and Theory of Operation

The RO-7 instrument (Figures 13.1 and 13.2) provides direct or remote monitoring in high beta and gamma fields. The instrument consists of a handheld digital ion chamber with basic digital readout, three standard detectors, and one modified detector, and various interconnecting devices. For gamma fields, the ion chamber detectors extend from 1 mR/hr to 20,000 R/hr in three overlapping ranges. For beta fields, the range is 100 mR/hr to 20,000 R/hr in two overlapping ranges. Beta sensitivity can be extended down to 10 mR/hr with the modified detector.

The detectors are connected to the RO-7 by flexible cables, rigid extensions, or by being mounted directly on the instrument. Combinations of flexible cables and rigid extensions may also be used. A special housing is available to permit use of the detectors under water.

More detailed technical information can be obtained in the Eberline RO-7 technical manual or by calling the PNNL calibration laboratory at (509) 376-5624.

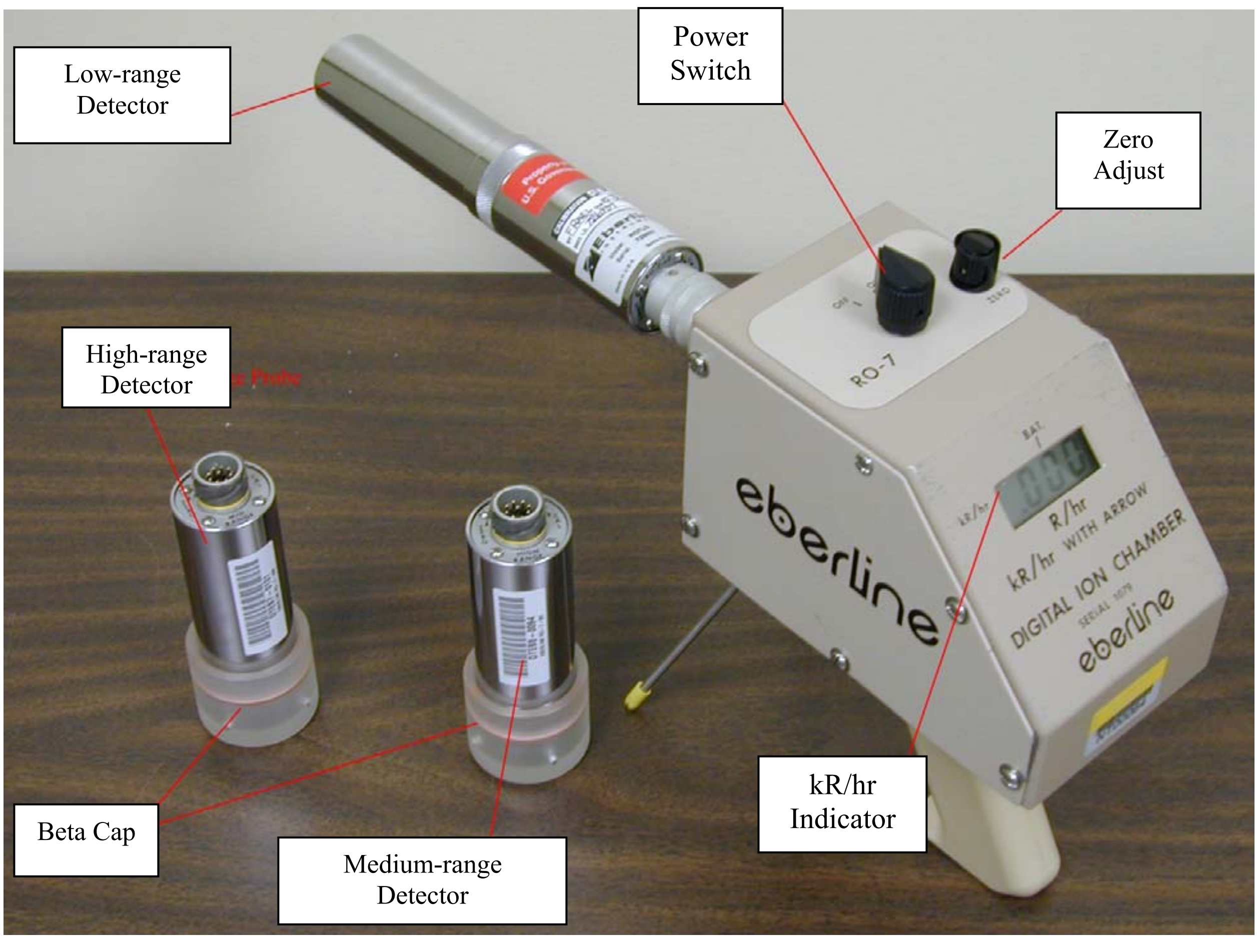

Figure 13.1. RO-7 with Low-, Mid-, and High-Range Detectors

Figure 13.2. RO-7 with Extension Cable and Exposed Beta Window

13.1.1 Physical Description

The basic RO-7 instrument measures 24.13 cm (9 ½ in.) high by 10.16 cm (4 in.) wide by 24.13 cm (9 ½ in.) long and weighs about 1.36 kg (3 lb). The instrument uses a liquid crystal display to indicate exposure rates in R/hr. When the high-range probe is connected, a high-range indicating arrow is illuminated and the instrument reads out in kR/hr.

The liquid crystal display has 4 digits, a decimal, minus sign, high-range indicating arrow, and a low-battery indication. A light is provided to improve readability under low-light conditions.

The RO-7 has three external controls—an ON/OFF switch, zero knob, and light switch. The light switch is located on the underside of the RO-7's body.

Linearity of the RO-7 low and mid-range detectors is ±5%. Linearity is ±10% for the high-range probe. The response time of the instrument is not adjustable and averages 2.5 seconds. The response time is generally specified by the manufacturer as the time for the instrument reading to reach 90% of final value after a change in the radiation field. The RC time constant of the instrument can be calculated from the 0% to 90% response time by dividing the 0% to 90% response time by 2.3.

Up to 152.4 m (500 ft) of cable can be used between a probe and the RO-7 body. When using the underwater housing, cable length is limited to 18.29 m (60 ft).

13.1.1.1 RO-7-BH High-Range Detector

The RO-7-BH high-range detector is a 7-cm^3 ion chamber with a thin beta end window. A plastic end cap is provided as a beta shield for discriminating between penetrating and non-penetrating exposure rates.

With the end cap removed, the ion chamber has a sidewall density thickness of about 800 mg/cm^2 and an end window density thickness of 7 mg/cm^2. With the end cap in place, the sidewall and end window density thicknesses are both 1,000 mg/cm^2.

The detector is 3.81 cm (1.5-in.) in diameter, 11.68 cm (4.6 in.) long, and weighs about 0.23 kg (0.5 lb.). The ion chamber detector at the end of the detector is 2.54 cm (1 in.) in diameter and 0.6-cm (0.24 in.) deep.

When the RO-7-BH high-range detector is connected to the RO-7, the high-range arrow is illuminated and flashes.

With the high-range detector, the RO-7 has a range of 10 R/hr to 19.99 kR/hr. The resolution is 10 R/h (i.e., with the high-range probe, the RO-7 cannot differentiate between exposure rates that differ by less than 10 R/hr, nor can it register exposure rates less than 10 R/hr).

13.1.1.2 RO-7-BM Mid-Range Detector

The RO-7-BM mid-range detector is identical to the high-range detector with two exceptions.

When the RO-7-BM mid-range detector is connected to the RO-7, the high-range arrow is not illuminated.

With the mid-range detector, the RO-7 has a range of 0.1 R/hr to 199.9 R/hr. The resolution is 0.1 R/hr (i.e., with the mid-range detector, the RO-7 cannot differentiate between exposure rates that differ by less than 100 mR/hr, nor can it register exposure rates less than 100 mR/hr).

CAUTION: *Placing the mid-range detector in radiation fields greater than 200 R/hr for extended periods can permanently damage the detector. This effect can occur whether or not the instrument is powered on.*

13.1.1.3 RO-7-BM-M-Modified Mid-Range Detector

The modified mid-range detector is physically identical to the standard mid-range detector. However, with the modified mid-range detector, the RO-7 has an effective range of 10 mR/hr to 19.99 R/hr. The modification effectively provides an order of magnitude better resolution when measuring beta exposure rates.

The RO-7 display unit is modified to accommodate the modified mid-range detector. This modification disables the "K" character on the liquid crystal display.

CAUTION: RO-7 display units modified for use with modified mid-range detector should not be used with high-range detectors.

Placing the modified mid-range detector in radiation fields greater than 200 R/hr for extended periods can permanently damage the probe. This effect can occur whether or not the instrument is powered on.

13.1.1.4 RO-7-LD Low-Range Detector

The RO-7-LD low-range detector is a 50-cm3 ion chamber. The ion chamber walls and end window have a density thickness of about 800 mg/cm2. The low-range detector does not have a beta window or a removable end cap.

The detector is 3.81 cm (1.5 in.) diameter, 20.83 cm (8.2 in.) long, and weighs about 0.23 kg (0.5 lb). The ion chamber detector is at the end of the detector and is 2.54 cm (1 in.) in diameter and 10.16 cm (4 in.) deep.

When the low-range detector is connected to the RO-7, the RO-7 has a range of 10 mR/hr to 1.999 R/hr. The resolution is 1 mR/hr (i.e., with the low-range probe, the RO-7 cannot differentiate between exposure rates that differ by less than 1 mR/hr, nor can it register exposure rates less than 10 mR/hr).

CAUTION: Placing the low-range detector in radiation fields greater than 2 R/hr for extended periods can permanently damage the probe. This effect can occur whether or not the instrument is powered on.

13.1.2 Radiation and Energy Response

With the beta cap on and the side of the detector toward the source, the mid- and high-range detectors respond to photons with energies greater than 50 keV. With the beta cap on and the face of the detector toward the source, the mid- and high-range detectors respond to photons with energies greater than 25 keV. However, in this configuration, the instrument will tend to over respond to photons near 60 keV (40% over response). With the beta cap off and the end window facing the source, the mid- and high-range detectors respond to photons with energies greater than 8 keV. In this configuration, the instrument will tend to over respond to photons near 60 keV (40% over-response).

The mid- and high-range detectors respond to beta particles above approximately 200 keV when the beta cap is off.

The low-range detector responds to photons with energies greater than 50 keV.

The energy response of the low-range detector and the mid- and high-range detectors are illustrated in Figures 13.3 and 13.4, respectively.

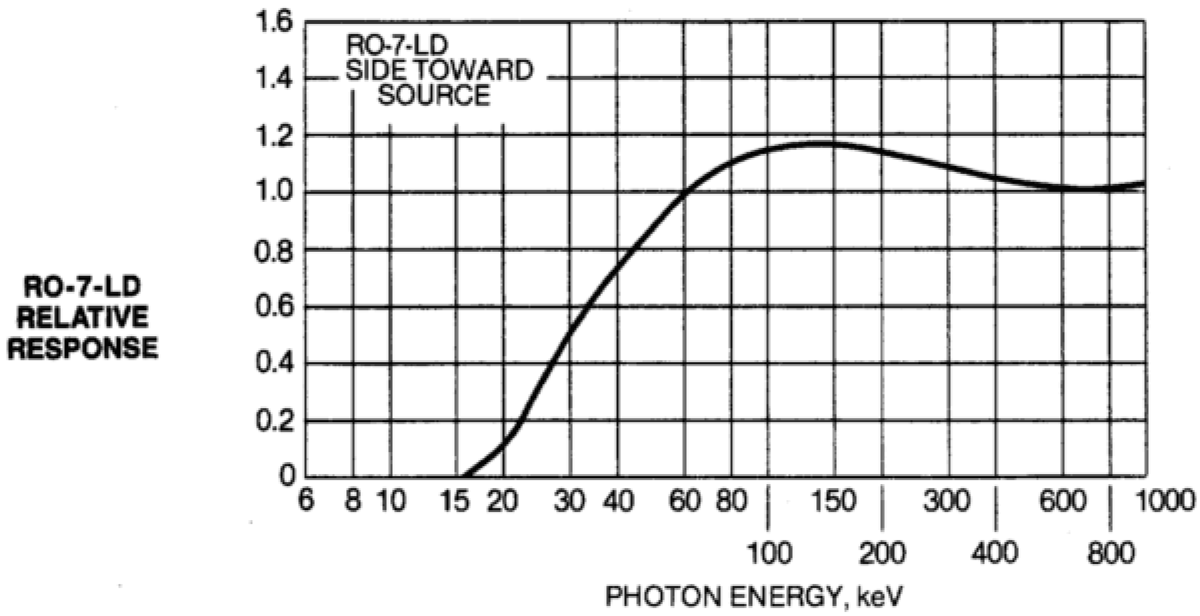

Figure 13.3. Low-Range Detector Photon Response

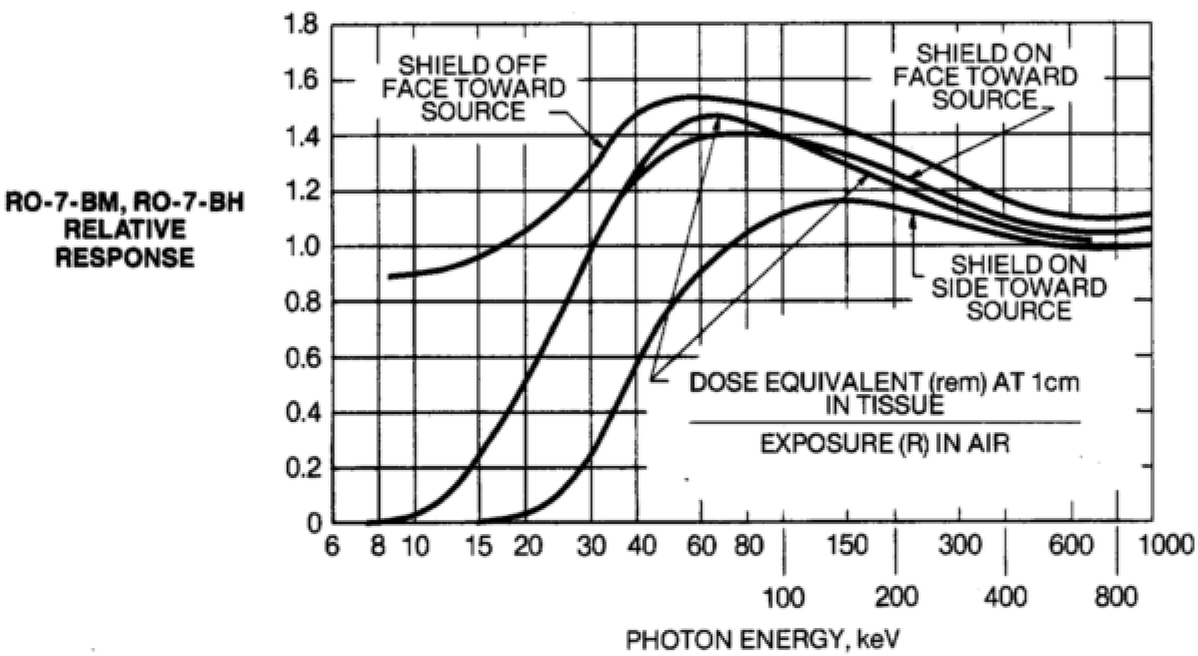

Figure 13.4. Mid- and High-Range Detector Photon Response

13.1.3 Integral Sources

There are no radioactive sources attached to, or inside, the RO-7.

13.2 Operating Instructions

Before using the RO-7, perform the operability checks to make sure the instrument is in good working condition (see Section 13.3). These checks should be performed each time the instrument is used.

To perform a radiation survey, attach the appropriate detector to the RO-7. Cables or rigid extensions may be used between the detector and the RO-7. If the instrument will be used in a wet or underwater environment, use an underwater housing to protect the detector. The instrument's calibration is not affected by using the rigid extensions, cables, or the underwater housing. However, when using the underwater housing, note that the displayed dose rate is the dose rate measured inside the housing and does not account for shielding provided by the housing.

Turn the instrument on. In a low background area, use the zero dial to set the instrument to zero. For this purpose, exposure rates in a low background area should be less than half of the minimum dose increment for the detector in use (i.e., for the RO-7-LD, < 0.5 mR/hr). Place the detector in the area to be measured.

When measuring exposure rates in non-uniform geometries, remember the displayed value is a conservative estimate of the exposure rate at the center of the detector volume. For example, a measurement taken with the low-range detector's face in contact with a source will be representative of the penetrating dose rate at 5 cm (2 in.) from the surface (half the length of the ion chamber). For the mid- and high-range detectors, the detector dimensions are quite small, 2.5 cm (1 in.) in diameter and 1.5 cm (0.6 in.) deep. Therefore, the center of the detector volume can be placed much closer to the surface of an object.

CAUTION: *When the beta cap is removed, the thin end window is easily torn or punctured. Avoid touching the detector window to the surface being monitored.*

NOTE: *Contact correction factors have not been developed for the RO-7; therefore, the RO-7 cannot be used to establish contact dose rates. The uncorrected reading on the RO-7 can be used to establish the dose rate at the center of the detector volume. Contact correction factors for specific application can be developed. Contact the calibration laboratory for assistance.*

The penetrating dose rate is the instrument response with the beta cap on. The non-penetrating dose rate is calculated using the equation below, where Window Open (WO) equals cap off and Window Closed (WC) equals cap on.

Calculate shallow and deep dose rates as follows.

Deep Dose Rate = WC (All non-contact dose rate measurements of penetrating radiation do not require a geometry correction factor, $CF_{pen} = 1$)

$$\text{Shallow Dose Rate} = (WO-WC)CF_{non\text{-}pen} + WC \qquad (13.1)$$

where:

$CF_{non\text{-}pen}$ = nonpenetrating (i.e., beta) correction factor

When the WC indication is less than one tenth of the WO indication, then the calculation for shallow dose can be simplified as:

$$\text{Shallow Dose Rate} = \text{WO} \times \text{CF}_{\text{non-pen}}; \ \text{WC} < \text{WO}/10 \tag{13.2}$$

13.2.1 Correction Factors

Far field geometry correction factors are used when making general area dose rate measurements (non-contact geometry). Multiply all non-penetrating exposure rate (WO-WC) readings by 2 ($CF_{non\text{-}pen}$ = 2). This is based on RO-7 response to a point source ^{204}Tl at a distance of 30 cm (11.81 in.) (Johnson 1997).[a]

All non-contact dose rate measurements of penetrating radiation do not require a geometry correction factor (CF_{pen} = 1).

Close geometry corrections factors for small diameter gamma or beta sources have not been developed (contact measurements). Therefore, the RO-7 is not used to establish contact dose rates. Contact correction factors for specific applications can be developed. Contact the calibration laboratory for assistance.

Contact dose rates, 125 ml sample bottle correction factors to estimate contact shallow dose rates from 125-ml sample bottles of tank waste were developed for tank farms (Johnson 2000)[b]. The correction factors are 1.4 and 1.7 for the side of the bottle and the bottom of the bottle. Before using these correction factors, the reference should be reviewed to ensure that they are applicable.

13.3 Performance Test Instructions

Refer to contractor-specific procedures for performance testing. The procedure below is provided only as an example of an acceptable method.

13.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the RO-7 fails any of the checks, other than the battery check, return it to the calibration laboratory for servicing.

1. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 pm) of the expiration date on the calibration sticker.

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[a] Memo, ML Johnson, PNNL, to RA Gregg, PNNL, "RO-7 Beta Measurements," March 26, 1997.
[b] Letter, ML Johnson, PNNL, to RM Pierson, Lockheed Martin Hanford, "Correction Factor for Eberline RO-7 for 125 ml Sample Bottle," June 23, 2000.

2. Verify that the instrument source check is current. Source checks are generally valid for the day performed and typically do not cover more than 24 hours.
3. Inspect the instrument for physical defects, such as broken meter glass, loose knobs and connectors, punctured probe windows, or defective cables. If any defects are found, tag the instrument to identify the problem and return the instrument to the calibration laboratory. Turn the RO-7 on and check the display for a colon. If the colon is displayed, the instrument batteries are low, and the instrument should not be used. See Section 13.5, Maintenance Instructions.
4. Use the zero knob to zero the instrument (the exposure rate should be less than half of the minimum dose increment for the probe in use). If the RO-7 won't zero properly, tag the instrument with an Instrument Service Tag and return it to the calibration laboratory.

13.3.2 Source Check

The RO-7 may be source checked using an ICCS. The initial source check is performed when the instrument is first received from the calibration laboratory. Source checks are performed daily or before each use if the RO-7 is used less often than daily. Each probe should be source checked. Response limits are applicable to detectors, not bodies.

13.3.2.1 Initial Source Check

Initial source checks should be performed immediately upon receiving an RO-7 detector from the calibration laboratory. Detector should not be placed into storage until after performing the initial source check.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure the values are reasonable. For the RO-7, the initial response is considered reasonable when the response is within ±20% of the mean instrument response for that source.*

The acceptable range should allow for variations resulting from differing probe response.

If the detector has a beta end cap, remove it prior to source checking. Center the end of the detector (beta window for mid- and high-range probes) over the off-scale source position (500 scale position for modified mid-range probes) on the check source assembly and depress the source plunger on the ICCS. Note the instrument response. Multiply the instrument response by 0.8 and 1.2 to determine the acceptable range for that probe.

Perform an initial source check for all detectors. Typical values measured using an ICCS source with the RO-7 probes are listed below (HIEC Minutes for 11/21/95)[a] (HIEC Minutes for 10/07/03).[b]

Table 13.1. Values Measured Using an ICCS Source with the RO-7 Detectors

Range	Detector	Typical Indication
0 - 2 R/hr	RO-7-LD (low-	ICCS, » .029,

(a) HIEC Meeting Minutes for April 9 and April 16, issued May 17, 1996.
(b) HIEC Meeting Minutes for October 7, 2003, for modified mid-range probes.

.001 R/hr increment	range)	1.4% of Full Scale
0 - 200 R/hr 0.1 R/hr increments	RO-7-BM (mid-range)	ICCS, » 67.0, 33.5% of Full Scale
0 – 20 R/hr 0.01 R/hr increments	RO-7-BM-M (modified mid-range)	ICCS, » 2.0 (500 Scale) 10% of Full Scale
0 - 20 kR/hr .01 kR/hr increment	RO-7-BH (high-range)*	ICCS, » 0.06, 0.3% of Full Scale
*Round RO-7-BH (high-range) check source acceptable range to the nearest hundredths		

13.3.2.2 Daily Source Check

NOTE: *The source used to perform the initial source check is used to perform the daily source check. To perform a daily source check with a source other than the one used for the initial source check, first perform the daily source check on the source used for the initial source check. If the instrument passes that daily source check, then perform a new initial source check using the new source to establish response limits for that source/probe combination.*

If the detector has a beta end cap, remove it prior to source checking. Center the detector over the off-scale source position on the check source assembly and depress the source plunger on the ICCS. The instrument response should fall within the acceptable values determined during the initial source check. Perform the daily source check on all detectors to be used.

If the instrument fails, it may be a failed detector or RO-7 body. First, replace the detector and repeat the daily source check using the initial source check limits established for the new detector. If the instrument performs satisfactorily, then the original detector was at fault. Tag the original detector with a completed Instrument Service Tag and return it to the calibration laboratory. If the instrument does not perform properly during the second daily source check, the body is probably faulty. Tag the meter with a completed Instrument Service Tag and return it to the calibration laboratory.

13.3.2.3 Response Checks

Periodic response checks are not performed on the RO-7 meter.

13.4 Calibration Instructions

The RO-7 is calibrated by the PNNL calibration laboratory at the 318 Building in the 300 Area. The calibration described in this section is performed by the calibration laboratory staff. Detectors and bodies are calibrated separately and independently to allow detectors to be used with any body.

Before calibration, the instruments are inspected to make sure they are in good working order. The batteries are checked, the meter is checked for erratic response, and the instrument is inspected for physical damage. Damaged instruments are repaired before calibration. Before calibration, as-found exposure rate readings at the mid-point of each decade within the range of the detector and at 75% of full scale (e.g., the low-range detector is recorded at 5, 50, 500, and 1500 mR/hr). If the as-found readings are more than ±20% out of tolerance, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

The RO-7-LD is calibrated using the ^{137}Cs source wells. The RO-7-BM and RO-7-BH are calibrated in the high-exposure facility using a combination of ^{137}Cs and ^{60}Co sources. The response is adjusted at 75% of full scale and then verified at the midpoint of each decade (e.g., the mid-range detector is calibrated at 150 R/hr and the response is verified at 0.5, 5, and 50 R/hr). Finally, the instruments are exposed to a field greater than the probe's full-scale response to verify an off-scale response is displayed.

RO-7 bodies are calibrated by shorting two pins together and adjusting the zero. Next, a small voltage is applied to these same pins and the body's digital volt meter verified to within ±1%. Finally, a measuring and test equipment mid-range detector is attached to the body and the response at 10 R/hr is verified within 20%.

For more information on the RO-7 calibration, refer to PNL-MA-563, Section 3.2.2.

13.5 Maintenance Instructions

Routine maintenance on the RO-7 is performed at the calibration laboratory and in the field. Routine maintenance includes cleaning contacts and checking the batteries.

Common problems and causes are discussed in the next few paragraphs.

Low batteries: If the RO-7 has low batteries, a colon will be displayed when the instrument is turned on (if a high-range detector is attached, the colon may appear to be a column of three dots due to the presence of the decimal point). A low-battery indication will result due to a low-battery condition on any of the five batteries in the RO-7. Battery changes may be performed by the user. A battery change should never be performed in a contamination area, high-contamination area, airborne radioactivity area, or radiological buffer area.

The battery complement of the RO-7 is as follows:

- BT1 chamber bias voltage (two 30-V NEDA 210 batteries)
- BT2 minus voltage for operational amplifier (op amp) (one 9-V NEDA 1604 battery)
- BT3 plus voltage for op amp (one 9-V NEDA 1604 battery)
- BT4 minus voltage for comparators, display board power, backlight power (one 9-V NEDA 1604 battery).

To change the batteries in the instrument, perform the following steps:

1. Turn the instrument off.
2. Open the case by removing the side panels of the RO-7 (six screws each side).
3. Remove all three 9-volt batteries (BT2-BT4).
4. Install three new 9-V batteries into the battery holders observing proper polarity. Always replace all three batteries at the same time.

5. Replace the side panels of the RO-7.
6. Turn on the RO-7 and observe the display for a low-battery indication.
7. If the RO-7 continues to indicate a low-battery condition, then the chamber bias batteries should be changed. These batteries should be changed at the calibration laboratory. Return the instrument to the calibration laboratory, and indicate on the service tag that a battery change is only required for the chamber bias batteries.
8. Dispose of the used batteries as appropriate.
9. Perform the daily source check (see Section 13.3.2.2).

Erratic response: The RO-7 may develop an erratic response if moisture gets inside the detector. The detector is vented to the atmosphere and does not have desiccant. Therefore, moisture can get inside the chamber when it is used in humid or wet conditions. If the RO-7 has an erratic response, tag it with a completed Instrument Service Tag, and return it to the calibration laboratory.

Torn or punctured beta window. The thin beta window is easily damaged. If the window is damaged, take care to not touch the electrode inside the ion chamber. The electrode potential is 60 volts direct current, which could provide a minor shock. Touching the anode could also cause static damage to the electronics within the probe. Tag the instrument with a completed Instrument Service Tag, and return it to the calibration laboratory.

13.6 Instrument Specifications and Limitations

13.6.1 Temperature

The RO-7 is usable over the temperature range of -30°C to 70°C (-20°F to 160°F). RO-7 detectors are temperature compensated; therefore, temperature corrections are not required.

13.6.2 Temperature Shock

The RO-7 is not affected by temperature shocks. However, it is good practice to allow the instrument temperature to equalize with the ambient temperature before using it to perform surveys.

13.6.3 Humidity and Pressure

The RO-7 may be affected by humid environments. The RO-7 should not be used in condensing environments nor subjected to sprays or mists. If the RO-7 needs to be used in a humid or wet environment, waterproof housings are available to protect the detector.

The RO-7 may be affected because of change in ambient pressure. However, for use at the Hanford Site, no corrections are required.

13.6.4 Electromagnetic Field Interference

The RO-7 may respond to interfering radio frequency or electromagnetic fields, such as portable radios and cellular phones. Radio frequency emitting devices should be kept at least 30 cm (12 in.) from the RO-7 to avoid influencing the RO-7's response. Questions regarding the influence of radio frequency and electromagnetic fields on the RO-7's response should be referred to the calibration laboratory.

13.6.5 Energies and Types of Radiation

In general, the RO-7 responds to photons with energies greater than about 50 keV. The mid- and high-range detectors respond, with the end cap off, to beta particles with energy greater than 200 keV. More detailed information on photon energy response is provided in Figures 13.3 and 13.4.

13.6.6 Interfering Ionizing Radiation Response

The RO-7 has not been tested for its response to interfering ionizing radiations, such as neutrons or alpha-emitters. However, based on the construction of the detectors, the RO-7 will not respond to alpha radiations typical to the Hanford Site. Only alpha particles of 10 MeV or greater can penetrate the 7 mg/cm^2 beta window of the mid- and high-range detectors.

Ionization chamber detectors, such as those used on the RO-7, do not typically response to neutron radiation. If there are any questions regarding its response to neutron fields, contact the calibration laboratory at (509) 376-5624.

13.6.7 Battery Life

The RO-7 battery life is approximately 160 hours.

13.7 Applications

The RO-7 is used to measure deep and shallow dose rates (the RO-7-LD measures only deep dose rates). Contact correction factors have not been developed for the RO-7; therefore, the RO-7 cannot be used to establish contact dose rates. The RO-7 offers capabilities that are not available with the RO-3B type instrument, including:

- high-dose rate range capability, up to 19.99 kR/hr
- small detector size (improving the instrument response to non-uniform fields)
- approximately 1,000-mg/cm2 chamber walls (improves the deep dose rate measurement accuracy when used in high-energy beta fields)
- remote detector capability.

13.8 References

Project Hanford Lessons Learned. 2000-RL-HNF-0006. *High Dose Rates Can Damage Eberline RO-7 Low-range and Mid-range Detector Probes*. Fluor Hanford, Inc, Richland, Washington.

14.0 Eberline Personnel Contamination Monitors

14.1 Instrument Description and Theory of Operation

The HFM-4/4A, HFM-6, HFM-7A, PM-6A, and PCM-1B are installed devices designed to monitor radioactive contamination on a person's body. These units are generically referred to as automated personnel monitors (APM). The HFM series is capable of monitoring only the hands and the bottom of the feet while the PCM monitors the entire body one side at a time. The PM-6A is a pass-through portal monitor providing defense-in-depth monitoring independent of required sensitivity levels.

PCM-1B **HFM-4** **HFM-6** **HFM-7A** **PM-6A**

Figure 14.1. PCM-1B, HFM-4, HFM-6, HFM-7A, and PM-6A Personnel Contamination Monitors

All instruments described in this section use large area, gas-flow proportional detectors. The carrier gas is P-10 (90% argon, 10% methane). The detectors are all capable of detecting alpha and beta contamination. However, specific units may not have the necessary firmware to discriminate alpha and beta particles.

A bias (~1500 V) is applied to each detector. Alpha and beta particles interacting with the carrier gas create electrical pulses. The electrical pulses are amplified and routed through discriminators to determine if the pulse is from beta or alpha (if so equipped) radiation. The signal is finally registered in the corresponding channel as a count.

More detailed information can be found in the Eberline Technical Manuals or by contacting the PNNL calibration laboratory at (509) 376-5624.

14.1.1 Operational Description

14.1.1.1 HFM-4

There are three models of HFM-4—the 4A, 4B, and 4C. These instruments differ in their channel definitions (e.g., channel 1 may measure both hands or the left hand only). These channel definitions affect panel markings and configuration. The most common HFM-4 at Hanford is the HFM-4A. All HFM-4s are designed to monitor personnel for alpha and beta contamination on their hands and soles of the feet. These instruments use six gas-flow proportional detectors.

The instrument is controlled by solid-state circuitry. When contamination is measured above the preset alarm set point, the instrument indicates via a series of light-emitting diodes (LED) and an audible sonalert that an alarm condition exists. The LEDs assist in locating the contaminated areas by illuminating the alarming channels (hands alpha, hands beta, left foot alpha, left foot beta, right foot alpha, and right foot beta). Failure and high background lights also illuminate to indicate trouble with the HFM-4.

The HFM-4 counts and stores beta background when it is not counting personnel. The instrument subtracts the stored beta background during the count cycle to compare net counts against the alarm set point. Alpha background is not stored or subtracted. The alarm set points are preset and are not updated as background rate changes.

14.1.1.2 HFM-6

The HFM-6 is a microprocessor-controlled instrument for the detection of beta and, depending on the exact model (switch settings), alpha contamination on the hands and soles of the feet. Six gas-flow proportional detectors monitor the hands and feet. The instrument display shows a variety of messages to indicate alarm conditions and the general machine status.

All HFM-6s have three operating modes—Preset All (Mode 1), Maximum Sensitivity (Mode 2), and Minimum Count Time (Mode 3).

There are advantages to each mode of operation. In Mode 1, the activity levels that cause an alarm are at or near the reliably detectable activity (RDA) setting. A sufficiently long count time (over 20 seconds per side depending on background) serves to improve the counting statistics to greatly reduce the number of false alarms. Mode 2 allows exact count times to be established. In Mode 3, the number of likely false alarms increases but survey times are shorter and the instrument has a greater ability to adjust to changing background rates.

- Mode 1 Preset All
  In Mode 1, both the count time and the alarm set point are fixed. The monitor will indicate high background if the fixed alarm set point cannot be achieved within the fixed count time.
- Mode 2 Maximum Sensitivity
  In Mode 2, the count time is fixed. The alarm set point is calculated by the HFM as a function of the background count rate and the fixed count time. The alarm set point may be any value up to the RDA. In this mode, the monitor may alarm on contamination levels below the RDA.

- Mode 3 Minimum Count Time
  In Mode 3, the alarm set point is fixed at the RDA, analogous to classical minimum detectable activity. The count time is calculated by the HFM as a function of the background count rate and the alarm set point. The count time may be any value up to a preset maximum count time

The RDA setting is not a fixed alarm set point. Rather, it represents a probability of detection based on the confidence level chosen during the calibration. If a monitor is set for a 95% confidence level (RDA confidence factor of 1.65), the monitor will alarm at the RDA 95% of the time. This same instrument alarms upon contamination below the RDA with a reduced probability of detection. As a result, it is not strictly correct to state that a given monitor has a fixed portable instrument equivalent detection level. Instead, monitor alarms are possible with varying frequency over a range of portable instrument count rates. This situation is evident when a monitor alarms and subsequent manual frisks fail to find contamination. In this situation, the instrument alarmed at a contamination level below its RDA, a level that portable instruments cannot detect; the monitor alarmed at the set point due to distributed contamination (such a radon decay progeny), or the instrument has experienced a false alarm based on the probability of this occurrence.

While not in use the HFM-6 counts and stores the alpha and beta background and uses the data to compensate for changes in background rate. Depending on the mode of operation, the HFM-6 uses the stored background count rate (along with other stored parameters) to either determine if the background rate is too high for the set alarm set points (Mode 1), the alarm set point (Mode 2), or instrument count time (Mode 3).

The HFM-6 has separate alarm set points and indications for the following channels—left hand palm beta/gamma, left hand palm alpha, left hand back beta/gamma, left hand back alpha, right hand palm beta/gamma, right hand palm alpha, right hand back beta/ gamma, right hand back alpha, left foot beta/gamma, left foot alpha, right foot beta/gamma, right foot alpha.

14.1.1.3 PCM-1B

The PCM-1B is a microprocessor-based radiation detection system providing evaluation of beta/gamma contamination and, with optional upgrade, alpha contamination. Each PCM has 15 independent gas-flow proportional detectors. Detectors form a tight bundle that measures the whole-body one half at a time. The PCM uses stand and count techniques for measuring contamination. Individuals first stand sideways in the monitor and insert an arm into the hand/forearm cavity to initiate the first count. Upon count completion, the person turns around and repeats the procedure with the opposite arm in the hand/forearm cavity. In this manner, PCMs monitor each side of the body, foot, top/side of head, and hand/ forearm once, while monitoring the face and back of the head twice.

The options for PCM-1B for alpha monitoring are none, all detectors, or hands, forearms, and feet. Any PCM-1B can be configured with any of these options with a relatively minor software and hardware upgrade.

NOTE: *The PCM-1B is of limited utility for alpha monitoring at or near the total contamination values listed in 10 CFR 835 because of the short range of alpha particles in air and the normal distance between the surface being surveyed and the surface of the detector. Reliable alpha detection is limited to the hands and soles of feet.*

All PCMs have three operating modes discussed in the HFM-6 section, above.

14.1.1.4 HFM-7A

The HFM-7A is a microprocessor-based radiation detection system providing evaluation of beta/gamma and alpha contamination on the hands and soles of the feet. This monitor operates in the minimum count time mode (Mode 3 for HFM-6 and PCM-1B units). This operational mode is discussed in the HFM-6 section above. Like all HFMs discussed in this procedure, the HFM-7A employs six gas-flow proportional detectors to monitor the hands and feet. The HFM-7A is designed to house two #2 (0.59 ft^3) P-10 gas bottles. An optional 100-cm^2 hand-held probe and belly probe are available to add monitoring capabilities to the basic hand and foot operation.

14.1.1.5 PM-6A

The PM-6A is a microprocessor-based radiation detection system that monitors for beta/gamma contamination on the body. A firmware upgrade enables alpha detection on the feet. A combination hardware and firmware upgrade adds hand pods to the unit and facilitates low-level (equivalent to the HFMs) monitoring of the hands and feet. Alpha capabilities can be enabled in the hand pods with a firmware upgrade.

Each PM-6/6A has 11 independent gas-flow proportional detectors. Detectors form an array about the body. The PM-6A has the three operating modes—Preset All [Mode 1], Maximum Sensitivity [Mode 2], and Minimum Count Time [Mode 3]—discussed in the HFM-6 section, above. In addition, the PM-6A has four profiles, dictating the monitoring format, as identified here:

- Profile 1 (Beta/Gamma Portal Walk-Through)
  In Profile 1, the instrument operates as a walk-through beta/ gamma portal monitor (personnel walk through the detector array without stopping).
- Profile 2 (Beta/Gamma Portal with Alpha/Beta/Gamma Hands and Feet)
  This profile is an alpha/beta/gamma hand and foot monitor and a beta/gamma portal monitor. The instrument operates as a stand-and-count portal while the hands and feet are measured. Hand pods are required to enable Profile 2.
- Profile 3 (Beta/Gamma Portal Pause)
  Profile 3 is identical to Profile 1 except that the instrument uses stand-and-count protocols rather than walk-through. The user pauses within the detector array for a specific count duration. The count duration is determined based on the Mode of operation.
- Profile 4 (Beta/Gamma Portal with Alpha/Beta/Gamma Feet)
  Profile 4 is identical to Profile 3 except the foot detectors are alpha sensitive.

NOTE: *The PM-6A is of limited utility for contamination monitoring at or near the total contamination values listed in 10 CFR 835 because of the large distance between personnel and the detectors. However, Profile 2 equips the instrument with 10 CFR 835-compliant hand-and-foot monitoring capabilities for beta and alpha contamination. Profile 4 allows 10 CFR 835-compliant monitoring of the feet for beta and alpha contamination.*

Each portal tower is designed to house a single 1A cylinder of P-10 counting gas.

The PM-6A is equipped with an ultrasonic motion detector that initiates counting protocols based on the selected profile and mode.

14.1.2 Physical Description

14.1.2.1 HFM-4/4A and HFM-6

The instruments measure approximately 150 cm (59 in.) high, 70 cm (27 in.) wide, and 104 cm (42 in.) deep. Without shielding installed, the instruments weigh 107 kg (235 lb). The optional lead shielding adds 204 kg (450 lb) if all of it is installed.

The six detectors are the gas-flow proportional type consisting of a metal housing with a Mylar-covered window. The hand (palm and back of hand) detectors are 323 cm^2 with a 60% open cover, while the foot probes are 503 cm^2 with a 54% open probe cover, depending on the installed metal housing.

14.1.2.2 PCM-1B

The PCM-1B is 228 cm (89.6 in.) high by 75 cm (29.5 in.) wide by 112 cm (44 in.) deep. Without any shielding or gas cylinders, the instrument weight is 250 kg (550 lb).

The 15 detectors in the PCM-1B are the gas-flow proportional type consisting of a metal housing with a Mylar-covered window. The hand (palm and back of hand) detectors are 323 cm^2 with a 60% open cover, while the remaining probes are 503 cm^2 with a 54% open probe cover, depending on the installed metal housing.

14.1.2.3 HFM-7A

The instrument measures 146 cm (58 in.) high, 55 cm (22 in.) wide, and 84 cm (33 in.) deep. Without internal gas bottles, the instruments weigh 114 kg (250 lb). Two #2 P-10 bottles add 68 kg (150 lb).

The six detectors are the gas-flow proportional type consisting of a metal housing with a Mylar-covered window. The hand (palm and back of hand) detectors are 323 cm^2 with a 60% open cover, while the foot probes are 503 cm^2 with a 54 to 58% open probe cover, depending on the installed metal housing.

14.1.2.4 PM-6A

The instrument measures 220 cm (86.5 in.) high by 123 cm (48.5 in.) wide by 102 cm (40.3 in.) deep. Without shielding, gas cylinders, or hand pods, the instrument weighs 159 kg (350 lb).

The 11 detectors in the PM-6A are the gas-flow proportional type consisting of a metal housing with a Mylar-covered window. Each probe is 503 cm^2. The optional hand probes are 323 cm^2. The active area of each probe is reduced by the protective screens over each detector. This reduction depends on the type of installed metal screen.

14.1.3 Radiation and Energy Response

The APMs are designed for the detection of low levels of alpha and beta contamination. Alpha particles above ~3 MeV and beta particles above ~200 keV are measured. Specific calibration adjustments can impact energy response. These instruments are not intended to measure hard to detect beta-emitting radionuclides, such as ^{3}H and ^{14}C. The detectors are energy dependent (i.e., efficiency increases with incident radiation energy). See Section 14.4 for a discussion of beta energy response and its tie to the calibration.

The average distance between the detector surface and the surface being surveyed is three inches. As such, the instruments have limited utility as alpha contamination monitors. A typical Hanford alpha particle (~5 MeV) travels only 3.8 cm (1.5 in.) in air.

The instruments are sensitive to gamma radiation (approximately 105,000 cpm/mR/hr for ^{137}Cs, and 135,000 cpm/mR/hr for ^{60}Co) and therefore may require shielding to obtain sufficiently low background rates.

The instruments are not sensitive to neutron radiation.

14.1.4 Integral Sources

There are no radioactive sources attached to, or inside, the APMs.

14.2 Operating Instructions

CAUTION: *Persons wearing spike-heeled shoes must avoid puncturing the detector covering by ensuring that heel points rest on the metal housing and do not slip down and puncture the Mylar.*

14.2.1 HFM Monitors

This section provides general instructions for using an HFM model instrument to perform a contamination survey of hands and feet.

CAUTION: *Do not slam down on the hand or foot probes. The actuating switches located under the probes may be damaged.*

NOTE: *Ensure that the entire sole of the foot is over the probe.*

1. Step onto the monitor, placing feet over the detectors. For HFM-7As, a light sensor requires the feet to be fully forward to break the light beam and allow counting.
2. Insert hands completely into the cavities.
3. For the HFM-4 and HFM-6, press the hands down. HFM-7A hand switches are actuated by pressing the fingers forward.

NOTE: *A tone will sound when the counting cycle is complete.*

4. Step off the monitor if the instrument alarms on any channel.

5. Repeat Steps 1 through 4 after the HFM recounts the background.
6. Contact Radiological Control if the HFM alarms a second time.

14.2.2 PCM-1B

NOTE: *When approaching the instrument, the ultrasonic motion detector, if so equipped, will cause the instrument to sound a tone and display STEP UP -- INSERT (RIGHT or LEFT) ARM.*

1. Approach the PCM-1B.

NOTE: *The LED in the detector column will start flashing indicating instrument counting.*

2. Insert the requested arm into the detector cavity. Some PCMs have actuating red buttons that must be depressed with the free hand, others have a light beam that is interrupted when the hand is inserted into the cavity.
3. Place the foot over the detector fully forward and inward (against the foot detector's placement guides).
4. Face the detector Mylar (a reflection of the face should be observable in the Mylar).
5. Tilt the head slightly (~10°) inward, avoiding contacting the head detector.

NOTE: *When the counting cycle is complete (typically 10 to 20 seconds), the count status LED will stop flashing, a tone will sound, and the unit will display (RIGHT or LEFT) SIDE OK -- INSERT (LEFT or RIGHT) ARM.*

6. Repeat Steps 2 through 5 for the remaining side.
7. If the instrument alarms, step out of the monitor and allow the instrument to perform a background count, and repeat Steps 1 through 6.
8. Contact Radiological Control if the instrument alarms a second time.

14.2.3 PM-6A (Profile 2, 3, or 4)

NOTE: *When approaching the instrument, the ultrasonic motion detector causes the instrument to initiate the selected monitoring routine. When equipped with hand pods, the ultrasonic sensors in the hand pods themselves must also actuate to begin the counting routine*.

1. Step onto the monitor, placing feet over the detectors.
2. If the detector is equipped with hand pods, insert hands into cavities.
3. If the instrument alarms, step out of the monitor and allow the instrument to perform a background count, repeat Steps 1 through 2.
4. Contact Radiological Control if the instrument alarms a second time.

14.2.4 PM-6A (Profile 1)

NOTE: *When approaching the instrument, the ultrasonic motion detector causes the instrument to initiate the selected monitoring routine.*

1. Walk through the monitor.
2. If the instrument alarms, return to the front of the monitor and walk through a second time.
3. Contact Radiological Control if the instrument alarms a second time.

14.2.5 General Operating Precautions

Body positioning is essential to ensuring that the instrument can adequately monitor for contamination. Personnel should observe the specific positioning requirements for the employed APM.

14.2.6 Correction Factors

There are no correction factors to use with an APM.

14.3 Performance Test Instructions

Refer to contractor-specific procedures for performance testing. The processes below are provided as examples of acceptable methods.

14.3.1 Operability Check

The APMs constantly monitor functionality and background levels. If errors are encountered, the instruments will post a trouble message or indicator, and may take themselves out of service, depending upon the failure (or problem), instrument, and setup configuration. Operability checks are therefore performed by the monitors and require no effort on the part of the user or maintaining organization.

To set up a PCM-1B to take itself out of service when a trouble light actuates, the calibration laboratory must install a jumper to ground terminal 14 of TB-4. This is an optional configuration used by some PCM-1Bs at the Hanford site.

14.3.2 Source Check

The following equipment may be necessary to complete source checking of the APMs.

- A 100-cm^2 beta check source with an activity equivalent to the beta RDA and radionuclide content of concern for the facility.
- A beta source holder (clip) capable of maintaining the source about 3 in. from the detectors (PCMs only).
- A 100-cm^2 alpha check source with an activity equivalent to the alpha RDA and radionuclide content of concern for the facility (for instruments with alpha capabilities only).

- Plastic sheeting, if applicable (plastic wrap or equivalent).
- Instrument cabinet keys, if applicable (may be required for entry into the cabinet to verify gas supply, usage, and elapsed time).

14.3.2.1 Initial Source Check

Initial source checks are not performed on the APMs. Periodic source checking is quantitative in nature and does not require initial source checking immediately post-calibration, as required for source checking protocols commonly used for portable instruments.

14.3.2.2 Periodic Source Check and Inspection

Monitors should be periodically inspected and source checked to ensure their proper operation. Frequencies vary depending upon location, operating history, and requirements base. These inspections are commonly performed daily or weekly.

1. Inspect the monitor for damage.
2. Check the P-10 gas supply pressure regulator and gas flow rotameters values (not applicable for APMs equipped with gas management systems).
3. Replace the P-10 bottle when pressure is less than 200 psig.
4. Ensure P-10 gas supply pressure regulator reads between 4 and 6 psig.
5. Ensure that the P-10 gas flow rotameter reads within the values specified in **Error! Reference source not found.**.

Table 14.1. Flow Rates for APMs

Model	Desired Flow Rate
PCM/HFM-7A/PM-6A	20 to 30 cc/min.
HFM-4/HFM-6	30 to 70 cc/min.

6. Clean foot detector area using a vacuum cleaner (as needed to remove dust and debris).
7. Replace plastic wrap, as needed.
8. Place a beta source on the detector to be tested. Use source holders to maintain the desired distance between the source and all detectors (except hand and foot detectors which are tested on contact). For PCM-1Bs, this distance is 3 in. For PM-6As, this distance depends on the facility-specific application.
9. Initiate a count and verify that the monitor alarms.
10. Repeat Steps 5 and 6 for each detector.
11. Repeat Steps 5 through 7 for each detector location equipped with an alpha channel using an alpha-emitting source in place of the beta source. Do not use a source holder with alpha sources (i.e., place alpha sources on contact with detectors).
12. Verify instrument operation by observing that indications, alarms, and/or displays are consistent with expected conditions.

13. Verify that all alarms are cleared and the monitor is operating normally.

14.4 Calibration Instructions

Monitors are calibrated by the PNNL calibration laboratory located at the 318 Building in the 300 Area, or by facility maintenance organizations. These monitors can be calibrated in the field by the calibration laboratory staff, if requested. The calibration described in this section is based on the calibration laboratory procedures. Prior to calibration, the instruments are inspected to make sure they are in good working order. Damaged instruments are repaired before calibration. As-found APM source response parameters are recorded before calibration. If the as-found readings vary from their calibrated values by more than 20%, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

Monitors are calibrated electronically and radiologically. Low- and high-voltage power supplies are adjusted to within ±0.1 V and ±5 V, respectively against a maintenance and test equipment Digital Multi-Meter. Alpha and beta thresholds are adjusted and a pulser is used to stimulate each detector to 10,000 cpm. Each detector must fall within ±10% of the pulsed value. Finally, radioactive sources are used to measure each detector's efficiency and system alarms are verified operational. PCM-1Bs are placed in Mode 3 during calibration.

Beta calibration is typically performed using ^{137}Cs (beta/gamma) sources. This establishes detector efficiency to the ^{137}Cs beta energy (511 keV β_{max}). As such, APMs calibrated with ^{137}Cs may not adequately monitor for isotopes emitting lower energy particles (e.g., ^{99}Tc). Isotopes used during calibration should be representative of the facility's energy spectrum. Calibrating with a beta energy lower than the facility's isotopic mix introduces a conservative bias (i.e., sensitivity to the facility mix is enhanced due to the presence of higher-energy particles).

Unless otherwise specified, APMs are calibrated annually or after any maintenance that voids the existing calibration. The calibration is valid through midnight of the expiration date listed on the calibration sticker. If the expiration date is given as a month and year, the calibration is valid through midnight on the last day of the month.

For more detailed information on APM calibrations, refer to PNL-MA-563, Sections 4.4.2, and 4.4.3, or to facility-specific calibration procedures.

14.5 Maintenance Instructions

Periodic maintenance is performed during routine performance testing and calibration. Maintenance includes cleaning, replacing damaged detectors and/or Mylar coverings, exchanging P-10 gas bottles, and returning the instrument to service after power loss.

Detector Mylar is replaced as needed (when damaged or contaminated) using 0.00025-in. thick Mylar that is aluminized on both sides. Contaminated Mylar may be decontaminated and need not be replaced unless decontamination efforts fail.

The lithium battery (3.6 V) strength should be assessed annually during the calibration. Batteries should be replaced based on strength and/or age.

It may not be necessary to calibrate the entire instrument when a detector is replaced. Only the detection channels associated with the replaced probe require re-calibration and that effort could be limited to reassessing detector efficiency. Purge detectors at twice the normal flow rate for four hours when restoring gas service to an instrument (return flow to normal values prior to placing the instrument in service).

These systems are susceptible to damage from power transients. Using a power conditioner may protect the instrument from transient induced damage. If an instrument is locked-up by a power transient, the instrument should be reset. After resetting, operating parameters must be reestablished (the reset process returns all operating parameters to their default values). Source check the instrument before returning it to service.

These instruments rely on random access memory to maintain counting parameters and detector efficiency. HFMs, with the NVRAM board, and PCM-1Bs, with the MEM II board, rely on batteries to maintain operating parameters during power outages. If batteries are low, the operating parameters may change to their default values when power to the instrument is disrupted. Instruments equipped with batteries should be source checked after a power outage and before returning the instrument to service. Instruments that are not equipped with batteries should have their counting parameters verified/reset and be source checked before returning to service, following a power loss.

14.6 Instrument Specifications and Limitations

14.6.1 Temperature

The APMs are intended for use indoors. They have not been tested for operation in conditions other than normal laboratory conditions. The instruments are designed to operate in temperatures between 0°C (32°F) and 50°C (122°F).

14.6.2 Temperature Shock

These instruments are not intended to be moved between areas of different temperatures. Allow APMs to reach equilibrium with the ambient temperature (usually about 1 hour) before using them.

P-10 gas bottles should also be thermally acclimatized before connecting to an instrument.

14.6.3 Humidity and Pressure

Monitors should not be used in condensing environments. Because the APMs are calibrated at the same altitude at which they are used, no changes in pressure due to elevation are anticipated. The changes in ambient pressure caused by changing weather are minor and will not significantly affect the APM response.

14.6.4 Radio Frequency/Electromagnetic Interference

Monitors are not generally affected by external non-ionizing radiation fields such as microwaves, portable radios, or cellular phones.

14.6.5 Energies and Types of Radiation

The APMs detect alpha particles above ~3 MeV and beta particles above ~200 keV. Specific calibration adjustments can impact energy response. These instruments are not intended to measure hard to detect beta-emitting radionuclides, such as ^{3}H and ^{14}C.

14.6.6 Interfering Ionizing Radiation Response

Gamma: These instruments are sensitive to gamma radiation. Typical response for ^{137}Cs gamma emissions is 105,000 cpm/mR/hr and 135,000 cpm/mR/hr for ^{60}Co (503-cm^2 detectors). For the 323 cm^2 detectors, typical gamma response is 50,000 cpm/mR/hr (^{137}Cs) and 66,000 cpm/mR/hr (^{60}Co). As a result, instruments may require shielding or relocation to obtain a sufficiently low background count rate.

Neutron: These instruments do not respond to neutron radiation.

14.6.7 Battery Life

Installed 3.6 V lithium batteries will last for years. Battery strength should be assessed annually during the calibration and replaced based on age or voltage.

14.7 Applications

Monitors are used to monitor personnel for contamination on their skin and clothing. PM-6As are typically deployed as defense-in-depth monitors and not generally capable of detecting the required contamination limits in 10 CFR 835, except for the hands (if so equipped) and feet.

14.7.1 HFM-6 Operating Parameters

Error! Reference source not found. contains typical operating parameters for the HFM-6 at Hanford Site facilities. Refer to contractor-specified procedures for facility-specific parameters.

Table 14.2. Typical Operating Parameters for HFM-6

System Parameter	Beta Instruments	Alpha Instruments
Mode	2	2
Sigma Factor (SF)	4.0	4.0
Weighting Factor	10.0	50.0
Minimum Counts to Alarm	1	4
Max Alarm Limit	Calculated for each detector according to the equation below	Calculated for each detector according to the equation below
Alarm Hold Time	>3.0	>3.0
Units	cps	cps

The alarm setting (R_A) on the HFM-6 is the count rate above background that results in an alarm 50% of the time. Users should calculate a R_{Amax} value for each HFM-6 detector that is low enough to provide a desired confidence level to detect the required contamination limit for the application.

R_{Amax} is calculated as follows:

$$R_{A\max}\ (cps) = \text{Required Sensitivity in Bq} * Eff - z\sqrt{\frac{\text{Required Sensitivity in Bq} * Eff + R_B}{t}} \quad (14.1)$$

where:

- Eff = Fractional detector efficiency (cps/dps)
- Z = Normal Distribution one-tailed sigma multiplier (1.645 for 95% confidence, 0.0675 for 67% confidence)
- t = Selected count time
- R_B = Detector background in cps

HFM-6s calculate R_A as follows:

$$R_A\ (cps) = SF\sqrt{\frac{R_B}{t}} \quad (14.2)$$

A high background alarm actuates if the calculated R_A exceeds the preset R_{Amax}, alerting that the instrument background is too large to detect the required activity level with the desired confidence.

14.7.2 PCM-1B Operating Parameters

Error! Reference source not found. contains typical operating parameters for the PCM-1B at Hanford Site facilities. Refer to contractor-specified procedures for facility-specific parameters.

Table 14.3. Typical Operating Parameters for PCM-1B

System Parameter	Beta Instruments	Alpha Upgrade Instruments

System Parameter	Beta Instruments	Alpha Upgrade Instruments
Mode	3	3
Sigma Factor	4.0	4.0
Weighting Factor	10.0	NA
Beta Weighting Factor	N/A	10.0
Alpha Weighting Factor	N/A	50.0
Alarm Hold Time	>3.0	>3.0
Maximum Count Time	≥20.0	≥40.0
Units	cps	cps
Auto Background Count After	10	10
Background Check Sum Factor	6.0	6.0
Sum Zone Sigma Factor	4.0	8.0
Update Background After Alarm	Yes	Yes
RDA Confidence Factor	1.65	1.65
Master Reliably Detectable Activity (RDA) Setting	8.33E+1 (general limit) 5.0E+1 (Sr limit)	NA
Master Beta RDA Setting	NA	8.33E+1 (general limit) 5.0E+1 (Sr limit)
Master Alpha RDA Setting	NA	8.33
Master Low (LO) Fail Setting	5	NA
Master Beta LO Fail Setting	NA	5
Master Alpha LO Fail Setting	NA	1.67E-8
Master LO Sensitivity (SENS) Setting	0.5	NA
Master Beta LO SENS Setting	NA	0.5
Master Alpha LO SENS Setting	NA	0.5
Measure Right Side First	Yes	Yes
Regular Time for Source Check	Yes	Yes
NA = Not applicable		

14.7.3 HFM-7A Operating Parameters

Unlike earlier models, alpha sensitivity cannot be disabled. The HFM-7A has radon compensation capabilities that may be useful in facilities that have only alpha or beta emitting contaminants. Radon compensation should be disabled in mixed facilities where alpha and beta contamination may be present regardless of the relative ratio of the mixture. For facilities with a mixed source term (beta and alpha present) where the relative ratios are known and allow for surveying for beta contamination only, the alpha channel RDA can be raised to effectively disable the alpha monitoring, thereby avoiding false alarms due to radon progeny. (**Error! Reference source not found.**)

Table 14.4. Typical Operating Parameters for the HFM-7A

System Parameter	Parameter Value
Base Units	Cps
Activity Units	Dpm
Sigma Factor	4
RDA Confidence	95%
Max Count Time	≥20 seconds
Alarm Hold Time	≥2 seconds
Alpha RDA	500 dpm
Beta RDA	5000 dpm
Alpha Low Fail Background	0.001 cps
Beta Low Fail Background	1 cps
Alpha Sensitivity Factor	0.01 - 0.2
Beta Sensitivity Factor	0.10 - 0.60
Alpha Contamination Factor	5 - 9.9
Beta Contamination Factor	5 - 9.9
Minimum Alpha Efficiency	9%
Minimum Beta Efficiency	13%
Minimum Alpha Foot Efficiency	5%
Minimum Beta Foot Efficiency	9%
Radon Compensation (Comp)	Off

14.7.4 PM-6A Operating Parameters

Operating parameters are selected based upon the specific PM-6A features and intended application. A generic set of parameters is not recommended for these units.

15.0 Eberline RO-20 Ion Chamber

15.1 Instrument Description and Theory of Operation

The Eberline RO-20 (Figures 15.1 and 15.2) is a portable, air-filled ionization chamber rate meter used to detect beta, gamma, and x-ray radiation. The ionization chamber is contained within the instrument body. Indentations on the case indicate the center of the chamber. The ionization chamber consists of a conductive plastic tube with a thin Mylar covering over one end. The instrument case has a beta shield, under which lies a second Mylar covering. The beta shield prevents non-penetrating radiation from entering the chamber.

More detailed information can be obtained from the manufacturer's technical manual, or by contacting the PNNL calibration laboratory at (509) 376-5624.

15.1.1 Physical Description

The RO-20 weighs 1.6 kg (3.6 lb) and measures 20 cm (8 in) long by 11 cm (4.2 in.) wide by 20 cm (7.7 in.) tall. The ion chamber is 8.25 cm (3.25 in.) in diameter by 7 cm (2.75 in.) long. The ion chamber volume is 220 cm^3 (13.4 $in.^3$). The combined wall thickness of the body and ion chamber equals 1000 mg/cm^2. Two Mylar windows combine to a density thickness of 7 mg/cm^2 in the window-open position. The beta shield's density thickness is 1000 mg/cm^2.

The RO-20 has five linear ranges calibrated in units of exposure rate—0 mR/hr to 5 mR/hr, 0 mR/hr to 50 mR/hr, 0 mR/hr to 500 mR/hr, 0 R/hr to 5 R/hr, and 0 R/hr to 50 R/hr. The response time is generally specified by the manufacturer as the time for the instrument reading to reach 90% of final value after a change in the radiation field.

The RC time constant of the instrument can be calculated from the 0% to 90% response time by dividing the 0% to 90% response time by 2.3. The response time of the RO-20 is relatively rapid; less than five seconds are required for the instrument to reach 90% of the final reading on the mR/hr ranges. Response time drops to less than 2 seconds on the R/hr ranges.

Figure 15.1. Eberline RO-20

Figure 15.2. RO-20 Window Detail

15.1.2 Radiation and Energy Response

With the beta shield in place (window closed), the RO-20 responds to photons with energies above 50 keV. Instrument response is relatively flat between 50 keV and 1.3 MeV. Photons with energies below 50 keV will be significantly attenuated by the beta shield.

With the beta shield removed (window open), the RO-20 responds to beta particles of energy greater than 65 keV and photons with energy greater than a few keV. The two Mylar coverings are too thick to allow transmission of alpha particles with energies less than 6 MeV. For practical purposes, the instrument does not respond to alpha radiation.

The RO-20 may respond slightly to fast neutrons. Instrument response is approximately 8% of the true neutron field. The instrument is not intended for assessing fast neutron dose rates but may be subject to interference in mixed gamma/fast neutron fields (e.g., PuBe). Integral Sources

There are no radioactive sources attached to, or inside, the RO-20.

15.2 Operating Instructions

Before using the RO-20, perform operability checks (see Section 15.3.1) to make sure the instrument is in good working condition. These checks should be performed each time the instrument is used.

If RO-20 damage is suspected during survey (e.g., the instrument is dropped or static discharge is observed or suspected), then do an operational check and a source check (see Section 15.3.2). An alternative to performing a source check, if an established field is available, is to ensure that the response is within ±20% of the known value. An established field may be a previous reading or a well-known, constant, non-zero field. To perform a radiation survey, turn the RO-20 selector switch to the desired range and move the instrument slowly while observing the meter response. Rapid movement of the instrument can cause momentary measurement inaccuracy due to the effects of inertia on the needle and/or response time. When a measurement is performed at a particular location, allow at least five seconds for the reading to stabilize.

NOTE: *When selecting the most sensitive range (5 mR/hr), switching noise may cause a temporary meter deflection. This can be avoided by first selecting the 50 mR/hr or 500 mR/hr range and letting the needle settle. After settling on the higher range, switching to the 5 mR/hr range will not produce significant meter deflection.*

In unknown fields, use the instrument in the window open position to measure both penetrating and non-penetrating radiation. Point the open window toward all possible sources of radiation. If the area is known to have only gamma radiation, the beta shield does not need to be opened.

Avoid contact between the instrument and other objects. Besides possible instrument contamination, pressure on the thin window will cause false and erratic meter reading (from capacitive effects) and might puncture or rupture the window. If the metal case touches other metal objects, the reading may drop suddenly to zero (with recovery after a short delay).

Correction factors are required when measuring non-uniform fields (e.g., beta radiation fields, beams, and contact measurements). Correction factors are provided later in this section.

Calculate shallow and deep dose rates as follows (include neutron dose contribution as applicable):

$$\textit{Deep Dose Rate} = \mathrm{WC} \times \mathrm{CF}_{pen} \tag{14.3}$$

$$\textit{Shallow Dose Rate} = (WO\text{-}WC)\mathrm{CF}_{non\text{-}pen} + WC \times \mathrm{CF}_{pen} \tag{14.4}$$

where:

WC	=	instrument response with the window closed
WO	=	instrument response with the window open
$CF_{non\text{-}pen}$	=	non-penetrating correction factor
CF_{pen}	=	penetrating correction factor

When the WC indication is less than one tenth of the WO indication then the calculation for shallow dose can be simplified as

$$WO \; x \; CF_{non\text{-}pen} \tag{14.5}$$

Readings below 0.5 mR/hr are typically considered below the minimum sensitivity of the instrument and are recorded as < 0.5 mR/hr. The minimum sensitivity of the RO-20 should be considered when choosing the appropriate instrument to perform a survey.

For example, the RO-20 may not have sufficient sensitivity to perform a posting survey establishing the boundary of an RBA (100 mRem/yr).

When determining the sensitivity of the RO-20, the effects of geometry (i.e., correction factors) should be considered. For example, a contact measurement of shallow exposure rate on a small source (diameter < ½ in.) may result in a reading < 0.5 mR/hr when the actual (corrected) exposure rate is as high as 50 mR/hr. Therefore, if the survey required a sensitivity < 50 mR/hr, the RO-20 would not have appropriate sensitivity for the survey due to geometric conditions.

15.2.1 Correction Factors

One of the following geometry correction factors should be used for each measurement taken with the RO-20.

Small-beam correction factors are used when the radiation exists as a beam and is too narrow to ionize the air in the chamber uniformly. This occurs when the beam diameter is less than 2 in. coaxial to the chamber or 3 in. perpendicular to the chamber. Small beam correction factors are calculated as the ratio of the chamber cross-sectional area to the beam cross-sectional area (coaxial), or the ratio of chamber to beam volume (perpendicular). When measuring beams, the chamber axis may be parallel with or perpendicular to the beam (i.e., the beam must center on one of the indentations on the instrument case or be coaxial with the chamber). Beams are not typically observed with non-penetrating radiation. Beam correction factors are listed in **Error! Reference source not found.**. **Error! Reference source not found.** appears on the side of the instrument.

Table 15.1. Beam Correction Factors for the RO-20

Beam Diameter, cm (in.)	Correction Factor for Gamma Beams	
	Perpendicular to Chamber	Coaxial with Chamber
<1.27 (0.5)	97	129
1.27 (0.5)	24	32
1.9 (0.75)	11	14
2.54 (1.0)	6	8
3.81 (1.5)	3	4
5.08 (2.0)	2	2
≥7.62 (3.0)	1	1

Table 15.2. RO-20 Contact and 1/8 in. Correction Factors for Disc Sources

Disk Diameter, cm (in.)	Correction Factor for Contact Measurements		
	For exposure rate on contact with source		For exposure rate at 3 mm (1/8 in.) from source
	Beta (a,b)	Gamma (a,c)	Beta (b)
1.27 (0.5)	250	54	180
2.54 (1.0)	46	26	55
5.08 (2.0)	15	8	13
χ7.62 (3.0)	6	5	6

NOTE: When making measurements where the meter is ≥2.54 cm (≥1 in.) away from the source and for beams ≥7.62 cm (≥3 in.), the general correction factors below are used:

- 2 for window-open beta readings
- 1 for window-closed gamma readings

a. Measured with source surface on contact with the beta shield guide rails.
b. Nonpenetrating radiation correction factors based on ^{204}Tl (β_{max} = 0.763 MeV).
c. Penetrating radiation correction factors are based on ^{137}Cs, source in contact with the beta shield.

Contact geometry correction factors are applied to RO-20 measurements taken with the RO-20 window on contact with the source. These correction factors are listed below and on the instrument. Figure 15.3 provides extrapolation curves of beta and gamma contact correction factors

NOTE: *Disc correction factors may be used for measuring cylinders with the RO-20.*

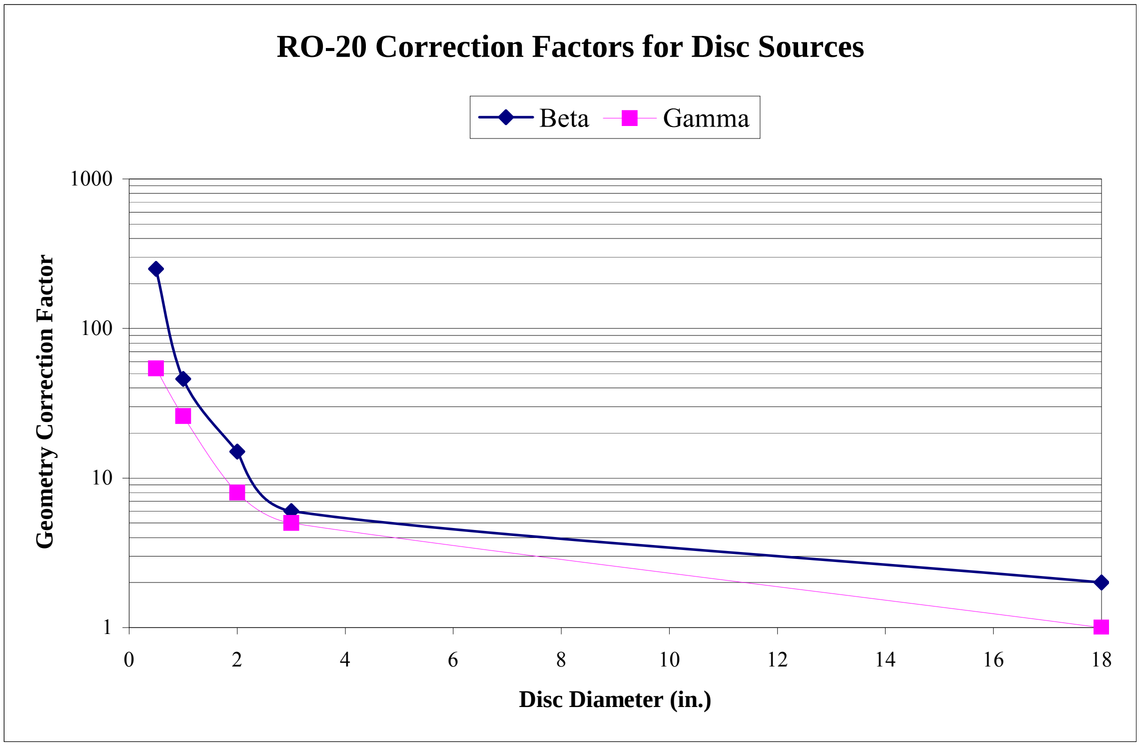

Figure 15.3. RO-20 Correction Factor Curves

NOTE: *Field geometry correction factors can be applied to objects with a smallest dimension >18 in., provided that dose rates are uniform across the surface.*

Field geometry correction factors are used when radiation fields are measured at distances greater than 2.54 cm (1 in.) from the source. In this situation, $CF_{non\text{-}pen} = 2$ and $CF_{pen} = 1$.

Temperature correction factors are not used with the RO-20 because the instrument is fully temperature compensated.

15.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions below are provided as examples of acceptable methods.

15.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the instrument fails any of the checks listed below, other than the Battery 1 test, return it to the calibration laboratory for servicing.

1. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) of the expiration date on the calibration sticker.
2. Ensure that the instrument source check is current. Source checks are generally valid for the day performed and typically do not cover more than 24 hours.
3. Inspect the instrument for physical defects such as broken meter glass, loose knobs, or other observable defects.
4. Check the batteries (turn the selector switch to BAT 1. The meter reading should be above the BATT cutoff line. Repeat this procedure for the BAT 2 position.)
5. Set the instrument zero (turn the selector switch to the ZERO position and, using the zero knob, set the instrument to zero.)
6. Check for erratic meter response. (Turn the selector switch to the 5 mR/hr range and observe the meter needle for erratic behavior. Rotate the instrument from side to side and observe the meter needle.)

15.3.2 Source Check

The RO-20 is source checked using an ICCS assembly. The initial source check is performed when the instrument is first received from the calibration laboratory. Source checks are performed daily or before intermittent use if the meter is used less often than daily. All five ranges are source checked. The off-scale response is not evaluated with an ICCS.

A jig is available for the ICCS to accommodate the RO-20 feet and ensure consistent and reproducible geometry during RO-20 source checks. Contact the PNNL calibration laboratory for more information.

15.3.2.1 Initial Source Check

Open the beta shield and center the open window over the source position on the check source assembly. Move the source to the appropriate position for each range of the instrument and record the instrument response on each range. The ICCS off-scale position is used to source check the 50 R/hr range. Multiply the instrument response by 0.8 and 1.2 to determine the acceptable range for that instrument.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure that the values are reasonable. For the RO-20, the initial response is considered reasonable when the response is within*

- *the acceptable ranges printed on a calibrated source assembly.*
- *±20% of the mean instrument response for that source.*

The acceptable range should allow for variations resulting from differing instrument response.

15.3.2.2 Daily Source Check

NOTE: *The source used to perform the initial source check is used to perform the daily source check. To perform a daily source check with a source other than the one used for the initial source check, first perform the daily source check on the source used for the initial source check. If the instrument passes that daily source check, then perform a new initial source check using the new source to establish response limits for that source/instrument combination.*

Open the beta shield and center the open window over the source position on the check source assembly. Move the source to the appropriate position for each range of the instrument. The instrument response, on each range, should fall within the acceptable values determined during the initial source check. If the instrument fails, tag it with an Instrument Service Tag and return it to the calibration laboratory.

Source checks are generally valid for 24 hours after they are performed.

15.4 Calibration Instructions

The RO-20 is calibrated by the PNNL calibration laboratory at the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff.

Before calibration, the instruments are inspected to make sure they are in good working order. The batteries are checked, the meter is checked for oscillations, and the instrument is inspected for physical damage. Damaged instruments are repaired before calibration. As-found readings at 80% of each range are also recorded before calibration. If the as-found readings are more than ±20% out of tolerance, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

The instruments are calibrated in uniform ^{137}Cs and ^{60}Co photon fields at 21 ±2°C (70 ±3.6°F). The uniform fields are produced using source wells and the high exposure facility. Each range is calibrated at 80% of the full-scale readings. The response is then checked at 40% of the full-scale reading. As an example, the 5 mR/hr range is calibrated by placing the instrument in a 4 mR/hr field (80% of 5 mR/hr is 4 mR/hr) and adjusting the appropriate range potentiometer (located on the panel below the meter) to achieve the required reading (4 mR/hr ±5%). The instrument is then placed in a 2 mR/hr field (40% of 5 mR/hr). The instrument response at both the 40% and 80% points has to be within ±5% of the actual exposure rate for the instrument to pass calibration. In addition, the RO-20 is exposed to a radiation field that is at least twice the full-scale reading (or at least 100 R/hr) to make sure it properly indicates an off-scale condition. Instruments that do not off-scale properly do not pass calibration.

The RO-20 is calibrated annually and after any maintenance is performed (other than battery changes). The calibration is valid through midnight of the expiration date listed on the calibration sticker.

For more detailed information on RO-20 calibrations, refer to PNL-MA-563, Section 3.2.1.

15.5 Maintenance Instructions

Routine maintenance on the RO-20 is performed at the calibration laboratory and in the field. Routine maintenance includes battery changes, checking and replacing desiccant, and repairing Mylar windows.

Common problems and causes are discussed in the next few paragraphs.

Erratic meter response: This may be caused by moisture in the chamber or cracks in the conductive coating (dag) on the interior surfaces of the chamber. Moisture in the chamber may be caused by desiccant failure. Instruments with erratic meter response should be returned to the calibration laboratory for repair.

Low battery: If a low-battery condition is indicated on BAT 1, the batteries may be changed in the field (excluding any Contamination Area, High Contamination Area, or Airborne Radioactivity Area to prevent potential internal contamination). The RO-20 uses five C cell alkaline batteries.

NOTE: *The C cell batteries must be placed inside a cardboard sleeve before placing batteries in the instrument.*

The RO-20 case must be removed to change batteries. This prominently exposes the signal path to damage from static discharge. Care should be taken to prevent damage to the instrument by using antistatic workstations and/or equipment (e.g., antistatic wrist bands). After batteries are changed, a daily source check must be performed before use. If the facility does not have the capability to change RO-20 batteries, the instrument may be returned to the calibration laboratory for battery replacement. The Instrument Service Tag should show that a battery change only is required.

Spent dessicant: The calibration laboratory recommends sending instruments for fresh desiccant when the desiccant is becoming clear or pink. However, as long as the instrument functions correctly (as evidenced by successful completion of daily source checks) the instrument can be used in the field.

Low Bat 2: The RO-20 also has ten 3-V lithium coin cells to maintain chamber bias. If these batteries are low, the instrument must be returned to the calibration laboratory for new batteries.

15.6 Instrument Specifications and Limitations

15.6.1 Temperature

The Laboratory tested the RO-20 against the criteria in ANSI N42.17A (ANSI 1989) and verified consistent operation (within ±20%) across the range -10°C to 50°C (14°F to 122°F). (The manufacturers operating temperature range is listed as -40°C to 60°C (-40°F to 140°F).)

15.6.2 Temperature Shock

The RO-20 is sensitive to sudden changes in temperature (such as moving the instrument from indoors to outdoors on a cold day). Allow the instrument to equilibrate, with the beta shield open, for at least an hour at the ambient temperature before making measurements. The Laboratory tests against ANSI N42.17A showed consistent response (within ±15%) from 22°C to 50°C (71.6°F to 122°F) and -10°C to 22°C (14°F to 71.6°F).

15.6.3 Humidity and Pressure

The RO-20 is normally insensitive to changes in ambient humidity. However, if it is used in areas of high humidity for an extended period, the desiccant may become saturated and the instrument may develop an erratic response. In this case, return the instrument to the calibration laboratory for maintenance.

The RO-20 response is affected by changes in altitude because of the associated change in ambient pressure. Because the RO-20 is calibrated on the Hanford Site at essentially the same altitude at which it is used, no corrections are required. Changes in ambient pressure caused by changing weather are minor and do not significantly affect the instruments response.

15.6.4 Radio Frequency/Electromagnetic Interference

The Laboratory tested the RO-20 against ANSI N42.17A magnetic field interference requirements and showed that instrument response remained consistent (within ±15%) up to 10 gauss.

The RO-20 is generally not affected by external, non-ionizing radiation fields, such as microwaves, portable radios, or cellular phones. High electromagnetic fields, such as from generators or ignition sources, may affect instrument response. Sources of these fields should be turned off, shielded, or avoided when using the RO-20. Alternatively, the instrument can be source checked in these environments when they cannot be eliminated.

15.6.5 Energies and Types of Radiation

With the beta shield in place (window closed), the RO-20 responds to photons with energies above 50 keV. Instrument response is relatively flat between 50 keV and 1.3 MeV. Photons with energies below 50 keV will be significantly attenuated by the beta shield. In the window closed position, the RO-20 does not respond to beta radiation, including ^{90}Sr/Y.

With the beta shield removed (window open), the RO-20 responds to beta particles of energies greater than 65 keV and photons with energies greater than a few keV.

15.6.6 Interfering Ionizing Radiation Response

The instrument does not respond to alpha radiation.

The RO-20 may respond slightly to fast neutrons. Instrument response is approximately 8% of the true neutron field. The instrument is not intended for assessing fast neutron dose rates but may be subject to interference in mixed gamma/fast neutron fields (e.g., PuBe).

15.6.7 Battery Life

The manufacturer states a battery life of approximately 6900 hours when used on the mR/hr ranges. Battery life slips to 350 hours in high dose rate fields (R/hr ranges). The Laboratory testing identified a battery life in excess of 1400 hours.

Leaving the instrument in the BATTERY 2 position significantly reduces battery life.

15.7 Applications

15.7.1 Dose Rate Measurements

The RO-20 is used to establish beta and gamma personnel dose rates. When establishing non-penetrating dose rates, slide the shield down from the end of the ionization chamber (see Figure 15.2). Replace the shield to measure penetrating radiation.

15.7.2 Surface Contamination Measurements

When beta/gamma contamination values are greater than the range of the typical contamination monitoring instruments (e.g., pancake GM), a measurement using the RO-20 is performed. The measurement is performed by placing the open window as close as possible to the source of contamination, without touching it, and recording the meter indication. The area of the contamination should also be recorded.

The RO-20 reading can be directly converted to a value in dpm if the contaminated object is a 47 mm air sample or technical smear. A typical correction factor for converting an RO-20 response to ^{137}Cs activity on a 47 mm smear is 75K dpm/mR/hr.[a] Instrument specific correction factors can be obtained from the calibration laboratory.

15.8 References

ANSI N42.17A 1989. *Performance Specifications for Health Physics Instruments-Portable Instruments for use in Normal Environments*, American National Standards Institute, New York.

(a) M.L. Johnson, Pacific Northwest National Laboratory, to File, "Correction Factor to Correct RO-20 Response to ^{137}Cs Activity on a Filter," June 20, 2001.

16.0 NE Electra with DP6BD Detector

16.1 Instrument Description and Theory of Operation

The NE Electra (Electra) is a portable, digital ratemeter used with a variety of pancake GM and scintillation detectors for measuring radioactive contamination and radiation. The Electra (Figure 16.1) has a liquid crystal display with both a digital output and a simulated analog output (sliding bar graph). Two channels allow the Electra to discriminate between alpha and beta radiation. The instrument may be set up with alarm thresholds for either channel.

Although it may be used with a variety of detectors, the most common detector used with the Electra at the Hanford Site is the DP6BD. The DP6BD is a dual phosphor, alpha/beta contamination detector (Figure 16.1). The DP means that it is a dual phosphor detector capable of detecting both alpha and beta radiations. The B in DP6BD refers to the fact that the detector has a mega high-voltage (MHV) connector. The detector has a thin layer of zinc sulfide (ZnS) on a piece of NE102 plastic scintillator.

More detailed technical information can be obtained by calling the PNNL calibration laboratory at (509) 376-5624 and requesting a copy of the NE Electra/ Selectra technical manual or the NE Technology's "Instrument Manual for Non-Intelligent and Intelligent Scintillation Probes."

Figure 16.1. NE Electra with DP6BD Detector

16.1.1 Physical Description

16.1.1.1 Electra

The Electra meter measures 25 cm (10 in.) long by 11 cm (4 in.) by 7.1 cm (3 in.), excluding the handle. The handle increases instrument height to 13.5 cm (5 in). The instrument weighs about 1.22 kg (2.7 lb), excluding batteries. A liquid crystal display indicates rate (count rate or exposure rate), units, and range. If the instrument is set for dual alpha/beta probe, it also displays the channel (either alpha, beta, or alpha/beta).

A headphone jack is provided for using the instrument in high noise areas. Appropriate headphones can be obtained by contacting the calibration laboratory.

A backlit display improves readability under low-light conditions.

16.1.1.2 DP6BD Detector

The DP6BD measures approximately 30 cm (12 in.) by 9 cm (3.5 in.) by 4 cm (1.6 in.) and weighs about 650 g (1.4 lb). The probe has a 100-cm^2 active area that is protected by a metal grill.

16.1.1.3 External Controls

The Electra has 10 external switches that may be operated by the user (Figure 16.2). A detailed explanation of each switch is provided in **Error! Reference source not found.**. In general, the switches are used to switch between modes (rate mode or integrate/scaler mode), turn the speaker on or off, and to select the channel.

Figure 16.2. Close up of the Electra Keypad

Table 16.1. Functions of the Electra Keys

Key		Function
1.	ON/OFF	Turn the instrument on or off.
2.	α, β, α+β	Switch between the alpha, beta, and gross (alpha + beta) channels. This switch is inoperable unless the Electra is set up for a dual phosphor detector.
3.	Sounder	Turn the audible response on and off.
4.	Light	Turn the display backlight on or off.
5.	Up Arrow	Scroll through the setup menu or increase the display value (when editing parameters)
6.	RATE INTEG	Switch between the rate mode (display count rate or exposure rate) and the integrate mode (perform scaler counts)
7.	SET UP	Enter the setup mode. From this mode various parameters can be edited including the alarm set point and scaler count time. The specific parameters that may be edited vary depending on how the instrument was calibrated. A complete list of all parameters that may be accessible from the setup menu is printed on the side of the instrument.
8.	Inhibit symbol	Used in the setup menu to prohibit a menu option from being changed by the user. This key is normally nonfunctional (i.e., used only when the instrument is in the calibrate mode).
9.	ENTER	Press this key to enter the edit mode (when editing parameters) or to store a new value.
10.	Down Arrow	Scroll through the setup menu or decrease the display value (when editing parameters)

16.1.2 Radiation and Energy Response

Radiation and energy response for the Electra is dependent on the attached detector.

The DP6BD detector responds to alpha radiation above ~3 MeV. Alpha response may be energy dependent but should be relatively consistent for ^{241}Am and ^{239}Pu. The average ^{239}Pu efficiency is 14% at 0.25 in. from the 2-in. source.

These detectors respond to beta radiation above a few hundred keV. Beta response is energy dependent. The average beta efficiencies are 18% (^{137}Cs), and 28% (^{90}Sr/Y) at 0.25 in. from the 2-in. sources.

16.1.3 Integral Sources

The Electra may have an alpha-emitting source attached to its side for performing response checks in the field. These sources are typically on the order of 0.85 nCi (~2000 dpm) ^{230}Th. (See Section 5.0, Figure 5.1, of this manual for an example of these sources.) Alternatively, a piece of Coleman lantern mantle may be attached to the side for response checks.

16.2 Operating Instructions

Before using the Electra, perform the operational checks to make sure the instrument is in good working condition (see Section 16.3.1). These checks should be performed each time the instrument is used.

To perform a radiation survey, attach the appropriate probe to the Electra.

Turn the instrument on by pressing the ON/OFF button on the keypad.

16.2.1 Correction Factors

The actual count rate is automatically displayed. There is no need to correct the displayed value for range switch settings. To convert an instrument response (in cpm) to an activity (in dpm), divide the cpm reading by the appropriate efficiency (typically ^{137}Cs [beta] or ^{239}Pu [alpha]) established by PNNL and provided on the calibration label. The efficiency is unique for each probe.

If the ^{239}Pu efficiency is at least 10% and the ^{137}Cs efficiency is at least 20%, a generic alpha correction factor of 10 and beta correction factor of 5 may be used. Likewise, if the ^{137}Cs efficiency is 15%, or greater, a beta correction factor of 7 may be used. These are acceptable (and conservative) practices for measurements performed with the Electra/DP6BD survey instrument.

The DP6BD probes have active areas of 100 cm^2; therefore, no area conversions are needed.

16.2.1.1 Setting the Alarms

The Electra may be set up to alarm when the count rate of either channel exceeds the alarm threshold. The following steps are used to set the alarm setpoints:

1. Press SET UP.
2. Press ↑ until the alpha-alarm screen is displayed.
3. Press ENTER to enter the edit mode (which will allow changing the alpha-alarm setting).
4. Press ↑ or ↓ to set the alarm to the desired value.
5. Press ENTER to exit.
6. Press the CHANNEL SELECTION button to display the beta-alarm screen.
7. Repeat Steps 3 through 5 to set the beta-alarm.
8. Press SET UP to exit the setup. Do not change any other parameters in the setup.

16.3 Performance Test Instructions

16.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the Electra fails any of the checks listed, return it to the calibration laboratory for servicing.

1. Verify that the calibration of the instrument is current. The calibration expires at midnight of the expiration date on the calibration sticker.
2. Verify that the probe and Electra have matching calibration stickers (the limitations section of the probe calibration sticker should list the Electra to which the probe is calibrated and vice versa).
3. Ensure that the instrument source check is current. Source checks are typically valid for 24 hours.
4. Inspect the instrument for physical defects, such as damaged liquid crystal display, cut membrane covers on keypad, punctured probe windows, or defective cables. If any defects are found, tag the instrument to identify the problem and return it and its probe to the calibration laboratory.
5. Turn the Electra on and check the display for a low battery icon (Figure 16.4). If the icon is displayed, the instrument batteries are low, and the instrument should not be used. See Section 16.5 of information on changing the batteries.

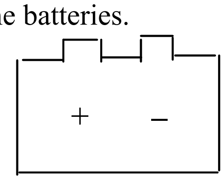

Figure 16.3. Electra Low Battery Icon

16.3.2 Source Check

DP6BD probes are source checked with appropriate alpha and beta sources (e.g., ^{239}Pu or ^{241}Am and ^{137}Cs or ^{90}Sr/Y). Because the instrument is digital, only one decade is source checked. For example, sources used to performance test continuous air monitors or miniscalers may be used to source check DP6BD probes. Source activity should be greater than 1,200 dpm to minimize statistical fluctuations and reduce the probability of failing a functioning instrument.

16.3.2.1 Initial Source Check

Initial source checks should be performed immediately upon receiving the instrument from the calibration laboratory. Instruments should not be placed into storage until after performing the initial source check.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure the values are reasonable. The initial response is considered reasonable when the response is within ±20% of the mean instrument response for that source. The acceptable range should allow for variations resulting from differing probe efficiency.*

Center the detector over the check source. A jig or mark may be used to ensure reproducibility. Allow the reading to stabilize and note the instrument's response. Multiply the instrument response by 0.8 and 1.2 to determine the acceptable range for that instrument/source combination.

16.3.2.2 Daily Source Check

NOTE: *The source used to perform the initial source check is used to perform the daily source check. To perform a daily source check with a source other than the one used for the initial source check, first perform the daily source check on the source used for the initial source check. If the instrument passes that daily source check, then perform a new initial source check using the new source to establish response limits for that source/instrument combination*.

Remove the cover from the detector, if applicable, and establish the source-to-detector geometry used during the initial source check. Allow the reading to stabilize and note the instrument's response. The instrument response should fall within the acceptable values determined during the initial source check.

16.3.2.3 Response Checks

Periodically verify that the DP6BD responds to radiation during continuous use. Response check the instrument by placing the probe over the check source mounted on the instrument case and verify that the speaker and meter respond to the source. Alternatively, background radiation may be used to response check the instrument when check sources are not present.

16.4 Calibration Instructions

The Electra and DP6BD are calibrated at the PNNL calibration laboratory in the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff.

Before calibration, the instruments are inspected to make sure they are in good working order. The batteries are checked, the meter is checked for damage or failed icons, and the instrument is inspected for physical damage. The detector is inspected for damaged windows or screens. Damaged instruments are repaired before calibration. Before calibration, as-found readings are recorded. As-found readings for the Electra consist of one point within each decade of the range. The as-found reading for the detector is the as-found efficiency measurement. If any of the as-found readings are greater than ±20% out of tolerance or if the as-found efficiency is not within ±20% of the as-left efficiency from the previous calibration, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

The Electra is calibrated electronically using a nuclear pulser. The response of the instrument is checked at the midpoint of each decade of the instrument range (i.e., at 50 cpm, 500 cpm, 5K cpm, and 50K cpm). The scaler function is then verified by completing a 1-minute count at 50K cpm. The tolerance for as-left readings for the count rate meter is ±5%. The tolerance for the scaler response is ±2%.

The DP6BD is calibrated using electroplated alpha and beta sources. Large area sources of approximately the same physical dimensions as the detector active area are placed 6 mm (¼ in.) from the front face of the detector grill. Efficiency measurements are then completed for ^{90}Sr(Y), ^{137}Cs, and ^{239}Pu. If the detector is calibrated for "alpha only" or "beta only," only the applicable isotopes are used. To pass calibration, the ^{90}Sr(Y) efficiency must be greater than 20%, and the ^{239}Pu efficiency greater than 10%. Beta-alpha crosstalk must be less than 1% for the DP6BD.

In addition to passing efficiency limits, the detector background count rate must be within limits. The upper background limits are 350 cpm for the beta channel and 2 cpm for the alpha channel.

For more information on Electra calibrations, refer to PNNL-MA-563, Sections 3.9.3.

16.5 Maintenance Instructions

Routine maintenance on the Electra and DP6BD is performed at the calibration laboratory and in the field. Routine maintenance includes cleaning contacts, checking the batteries, and repairing light leaks.

The Electra should never be used with detectors other than those to which they are calibrated. If a detector is damaged, return both the detector and the Electra to the calibration laboratory for servicing.

Common problems and causes are discussed in the next few paragraphs.

Low batteries: If the Electra has low batteries, a low battery icon will be displayed when the instrument is turned on (see Figure 16.4). Batteries may be changed by the user. To change the batteries, remove the black battery cap from the detector end of the meter. Replace the batteries with three C cell batteries. It is good practice to perform the daily source check after replacing batteries.

NOTE: *The correct battery orientation is illustrated on the side of the instrument.*

High background: The thin-windowed DP6BD detector is easily damaged. Pin-hole light leaks in the window will cause the instrument to have a high background count rate. To check for light leaks, turn the instrument on and place the probe face down on a clean surface (or cover it with a dark cloth). Slowly expose the detector to light by lifting it away from the surface or removing the cloth. If the probe is light sensitive, the background count rate may increase. Small light leaks may be repaired in the field using Testor silver paint (or equivalent). Care should be taken to not mask too much active area with the paint because it will reduce probe efficiency. Refer to contractor-specific procedures for additional guidance on repairing light leaks.

Cable noise: Damaged cables may cause an erratic response or high background count rate. To check for damaged cables, turn the instrument and the audible response on. Listen to the background count rate while jiggling the cable, particularly in the area around the cable connections. An erratic response or spikes of high count rate may indicate a faulty cable. Cables may be replaced in the field if the replacement cable is of the same length as the original and has the correct connections. Forcing the wrong cable connectors onto the instrument or the detector can damage the connectors.

16.6 Instrument Specifications and Limitations

16.6.1 Temperature

The Electra is usable over the temperature range of -10°C to 50°C (14°F to 122°F).

16.6.2 Temperature Shock

The Electra is sensitive to thermal shocks. The instrument should be allowed to equalize for an hour when it is moved between extreme temperatures (e.g., from indoors to outdoors in winter).

16.6.3 Humidity and Pressure

The Electra is not affected by humidity or by normal variations in atmospheric pressure. The Electra should not be used in condensing environments.

16.6.4 Electromagnetic Field Interference

The Electra has demonstrated sensitivity to handheld radios. The instrument may respond high or go into alarm when exposed to portable radios. The antenna of hand-held radios should not be allowed to contact the case of the Electra.

When tested with more uniform radio frequency fields, the Electra is insensitive to radio frequency interference.

16.6.5 Energies and Types of Radiation

The Electra and DP6BD detector respond to and measure alpha and beta radiations. Typical efficiencies for various isotopes are summarized in the following table.

16.6.6 Interfering Ionizing Radiation Response

The Electra and DP6BD respond to interfering gamma radiation. A typical response is about 50,000 cpm/mR/hr.

Table 16.2. Electra and DP6BD Response to Interfering Gamma Radiation

Isotope	Typical Efficiency
^{90}Sr(Y)	32%
^{137}Cs	20%
^{238}U	36%
^{99}Tc	9%
^{14}C	1%
^{239}Pu	14%

The Electra and DP6BD also respond to interfering neutron radiation. Typical values for neutron interference are 2,000 cpm/mrem/hr in the beta channel, and less than 1 cpm/mrem/h in the alpha channel.

16.6.7 Battery Life

The Electra battery life is approximately 90 hours with a scintillation probe. Battery life will vary depending on the type of probe, intensity of radiation field, and use of the speaker.

16.7 Applications

The Electra may be used for contamination surveys for both removable and total activity.

When performing direct surveys for contamination, the MDA for the Electra for a 5 cm/s scan speed with the probe 6 mm (¼ in.) from the surface being surveyed is given in Table 16.2 (HIEC 1996[a]). Scan speeds to achieve various detection limits for alpha activity is given in Table 16.3.[b]

Table 16.3. Minimum Detectable Activity for NE DP6BD for Various Beta Emitters, 95% Confidence Level

Isotope	MDA (dpm / 100 cm^2)
^{90}Sr(Y)	860
^{137}Cs	1400
^{238}U	760
^{99}Tc	3100

(a) HIEC Meeting Minutes for April 9 and April 16, issued May 17, 1996.
(b) M.L. Johnson, Pacific Northwest National Laboratory, to G.A. Stoetzel, Pacific Northwest National Laboratory, "Minimum Detectable Alpha Activity for NE Electra with DP6BD Detector," September 22, 1977.

Table 16.4. Scan Speeds to Meet Detection Limits with NE DP6BD at Two Confidence Levels

^{239}Pu Activity (dpm/100 cm^2)	Scan Speed, 67% CF	Scan Speed, 95% CF
100	1.4 cm/s	0.5 cm/s
300	4.2 cm/s	1.5 cm/s
500	7 cm/s	2.5 cm/s

16.8 References

H. Cember, *Introduction to Health Physics*, *Third Edition*, 1996.

17.0 The Ludlum 2929 Dual-Channel Scaler

17.1 Instrument Description and Theory of Operation

The Ludlum 2929 is a two-channel scaler powered by AC that can be equipped to detect and measure alpha and beta radiation. The 2929 can simultaneously monitor radiation in two channels. When equipped with a dual alpha/beta detector, the 2929 measures a sample (e.g., filter paper or technical smear) for gross alpha and beta activity with a single sample count. Three detectors are currently used with the 2929 at Hanford, the Ludlum 43-1-1, 43-10-1, and 43-78-5. All detectors are ZnS(Ag) scintillators accommodating 2 in. (43-10-1) or 4 in. (43-1-1, 43-78-5) sample diameters respectively. These detectors provide a sample drawer to ensure consistent and reproducible geometry. The 2929 is most commonly connected to a Ludlum 43-10-1 alpha/beta sample counter.

The 2929 can be equipped with an optional printer (Ludlum Model 264) providing hard-copy printouts of sample results.

More detailed technical information can be obtained by contacting PNNL calibration laboratory at (509) 376-5624.

17.1.1 Physical Description

The 2929 weighs 5.7 kg (12.6 lb) including an attached 43-10-1. It measures 22 cm (8.5 in.) high by 37 cm (14.5 in.) wide by 23 cm (9 in.) deep including an attached 43-10-1 (see Figure 17.1). The front panel includes a dial denoting the applied detector voltage, HV adjustment potentiometer, two-digit count time dial, four-position count time range dial (X.1, X1, X10, external), power switch, two six-digit light-emitting diode (LED) scaler displays (one for each channel), count and hold push-buttons, red light indicating counting status, and a single MHV connection. The rear panel includes a 1 amp fuse, amp out connector, and 15-pin connectors for alpha and beta data output. Internal controls, used during calibration, include amplifier gain, alpha and beta discriminators, and beta window potentiometers.

The 43-10-1 detector weighs 1.9 kg (4.1 lb) and measures 24 cm (9.3 in.) high by 11 cm (4.5 in.) wide by 24 cm (9.3 in.) long (see Figure 17.2). The 43-10-1 detector physically attaches to the 2929, as depicted in Figure 17.1. The 43-10-1 uses ZnS(Ag) plated on a plastic scintillation disc that is 2 in. in diameter and 0.01 in. thick.

The 43-78-5 detector weighs 36 kg (80 lb) and measures 17 cm (6.5 in.) in diameter and 29 cm (11.4 in.) high (see Figure 17.2). Increased weight is the result of integral lead shielding. The 43-78-5 uses ZnS(Ag) plated on a plastic scintillation disc that is 4.125 in. in diameter and 0.01 in. thick. The associated photomultiplier tube (PMT) is 3 in. in diameter with a 14-pin base and 10-pin dynode structure.

Figure 17.1. Ludlum 2929 Dual-Channel Scaler with Attached 43-10-1 Detector

Figure 17.2. Ludlum 43-10-1 and 43-78-5 Alpha/Beta Scintillation Detectors

17.1.2 Radiation and Energy Response

These detectors will respond to alpha radiation above ~3 MeV. Alpha response may be energy-dependent but should be relatively consistent for ^{241}Am and ^{239}Pu. Ludlum states that the energy response of the 43-10-1 is flat from 4 to 5.2 MeV. The 43-10-1 average ^{239}Pu efficiency is 36%. The 43-78-5 average ^{239}Pu efficiency is 40% (2 in. source) and 37% (4 in. source).

These detectors respond to beta radiation above ~100 keV. Beta response is energy dependent. The 43-10-1 average efficiencies are, 23% (^{99}Tc), 31% (^{137}Cs), and 43% (^{90}Sr/Y). The 43-78-5 average efficiencies are comparable for 2” sources. The 4” ^{90}Sr/Y average efficiency is 37%.

Detector response to gamma and neutron radiation is unknown. Based on detector type, neutron and gamma response should be slight at best.

17.1.3 Integral Sources

There are no radioactive sources attached to, or inside, the Ludlum 2929 and 43-10-1/43-78-5 detectors.

17.2 Operating Instructions

Before using the 2929, perform the operability checks to make sure the instrument is in good working condition (see Section 17.3.1). These checks should be performed each time the instrument is used.

To count a contamination smear or air sample filter, rotate the sample drawer locking knob counter-clockwise, pull the sample drawer out, and place the sample in the tray. Planchets should be used to hold samples (minimizing handling and the potential for cross contamination). Slide the sample holder back beneath the detector and lock it into position by rotating the locking knob clockwise. The sample holder must be pushed completely in to trip a microswitch, enabling the detector voltage.

NOTE: *Sample tray for 43-1-1 does not have a locking knob.*

Set the desired count time, and then press COUNT to start the count cycle. Count times between 0.1 minutes (6 seconds) and 990 minutes (16.5 hours) are possible.

General counting precautions include the following:

- The 2929 is intended for counting dry technical smears and air sample filters. Placement of other types of materials into the counters may result in contamination of the instrument, inaccurate measurements, and/or detector damage.
- The sample drawer should be maintained clean. A cotton swab may be used to remove any residual debris.
- Bent technical smears and air sample filters require extra care because they may easily lodge inside the sample drawer. A thin layer of adhesive between the sample and its planchet may help bent samples lie flat.
- The potential for significant instrument contamination increases with the activity of the sample. Highly radioactive samples may contaminate counting instruments and should be handled with extreme care. Portable survey instruments should be used to survey samples before placing them into the sample drawer. Contact the calibration laboratory technical staff if questions arise regarding sample activity limitations.
- Samples that are wet or that will break apart should not be counted.
- The 2929 cannot discriminate radon or radon progeny.
- Use the efficiency values determined during calibration (normally ^{239}Pu and ^{90}Sr/Y), unless the radionuclide and the counting efficiency for another radionuclide of concern is known. Contact the calibration laboratory to request specific isotopic efficiency values.
- Sample counting times will vary to obtain desired MDA or minimum detectable concentration (MDC) values. The longer a sample is counted, the lower the MDA/MDC value. Sample count times should be long enough to yield the required sensitivity (MDA/MDC).

- Sample count times should be less than or equal to the background count time.
- The 43-10-1 detector includes a sample holder that is approximately 1 cm (3/8 in.) thick. This holder must be used for accurate analysis results.
- When counting 2-in. sample media on a 43-78-5, a jig should be used to ensure that the sample is centered beneath the detector.

17.2.1 Correction Factors

To obtain the gross cpm, the displayed number must be divided by the number of minutes counted.

To obtain an activity in dpm, divide the net cpm (gross cpm - background cpm) by the detector efficiency. If the sample is a smear, this activity is the dpm/100 cm^2, provided the area smeared is ≤ 100 cm^2. When the smeared area is larger than 100 cm^2, divide the measured activity by the ratio area smeared/100 to obtain the dpm/100 cm^2 (e.g., if the smear area 300 cm^2, then divide the measured activity by 300/100 or 3).

17.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions in this section are provided as an example of acceptable methods.

Sources used for performance testing should be traceable to an established calibration standard or have a manufacturer's certificate to document source activity and radioisotopic purity.

17.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the instrument fails either of the first two operability checks, fill out an Instrument Service Tag to identify the problem, attach it to the instrument, and return it to the calibration laboratory for servicing.

1. Inspect the instrument for broken or loose knobs, meters, and displays.
2. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) of the expiration date on the calibration sticker
3. Verify that the initial source check has been completed.
4. Ensure that the instrument source check is current. Source checks are generally valid for the day performed and typically do not cover more than 24 hours.
5. Ensure that the periodic performance test is current. A periodic performance test is commonly valid for 30 calendar days, expiring at midnight of the 30th day after it is performed.

17.3.2 Source Check

The 2929 is typically maintained under statistical process control to ensure its reliable and consistent operation. A combination of daily source checks and periodic surveillance tests provide confidence regarding instrument operation and data validity.

17.3.2.1 Initial Source Check

Upon receipt from the calibration laboratory, or prior to placing an instrument into service, the 2929 should be tested to ensure that its operation is consistent with the calibration. The initial source check may also establish the performance criteria to be used for subsequent daily source checks and surveillance tests. Initial source checks typically consist of:

- a background measurement
- a chi square test
- checking efficiency within ±10% of calibration efficiency
- establishing response limits.

17.3.2.2 Daily Source Check

Once each day, or prior to intermittent use, 2929 should be evaluated for instrument response. Daily source checks typically consist of:

- a background measurement
- checking response within limits established during the initial source check.

17.3.2.3 Periodic Performance Test

Periodically, when in use, the 2929 should be evaluated for response and reproducibility. Periodic performance tests typically consist of:

- a background measurement
- a chi square test
- checking response within limits established during the initial source check.

17.4 Calibration Instructions

The 2929 is calibrated at the PNNL calibration laboratory in the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff. Before calibration, the instruments are inspected to make sure they are in good working order, switches and buttons are functionally checked, and the instruments are inspected for physical damage. Damaged instruments are repaired before calibration. As-found readings are recorded for ^{239}Pu and ^{90}Sr/Y efficiency, the instrument alpha and beta background is evaluated, and the counting circuit is evaluated using a calibrated pulse generator. If the as-found readings are more than ±20% out of tolerance, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

Amplifier gain is evaluated and adjusted as necessary. A ^{14}C source is used to establish the detector voltage such that the measured efficiency is at least 6%. Thresholds are adjusted to ensure a maximum of 10% alpha-to-beta and 1% beta-to-alpha cross-talk and to ensure background levels do not exceed 80 cpm (2-in. detectors) or 200 cpm (4-in. detectors) beta and 0.5 cpm alpha.

Finally, a series of efficiencies are recorded for ^{14}C, ^{99}Tc, $^{90}Sr/Y$, and ^{239}Pu. Minimum acceptable values for the 2-in. detectors are 6%, 17%, 33%, and 30%. Limits for the 4-in. detectors are 6%, 10%, 20%, and 10%. Additional efficiency measurements are performed upon request (e.g., ^{137}Cs, ^{241}Am). A sticker is attached to the detector listing the evaluated efficiencies.

The 2929 is calibrated annually and after any maintenance is performed that voids the existing calibration. The calibration is valid through midnight of the expiration date listed on the calibration sticker.

For more detailed information on instrument calibration, refer to PNL-MA-563, Section 11.12.

17.5 Maintenance Instructions

Routine maintenance of the 2929 is performed at the calibration laboratory when needed. Routine maintenance includes cleaning the detector chamber, repairing damaged detectors, and replacing o-rings. The only reason for field personnel to open the detector case is to remove stuck samples from the drawer or to decontaminate the counting chamber/detector.

Stuck sample: Occasionally a sample may become lodged inside the detector. To remove the sample, unplug the instrument and dismantle the sample tray assembly. Contact the calibration laboratory for assistance, as needed.

High background: A 2929 that develops a high background count rate may have a contaminated sample chamber/detector or a light leak. Contaminated instruments should be decontaminated as soon as possible. Instruments should be decontaminated before sending them to the calibration laboratory. After decontamination, return the instrument to the calibration laboratory for recalibration if the instrument fails a source check.

Instruments with improperly adjusted sample trays or dislodged o-rings may respond to external light. If the instrument appears light sensitive (e.g., high background or fails chi square test), tag it with an Instrument Service Tag and return it to the calibration laboratory. The cause of high background should be evaluated to ensure that the counting chamber is not contaminated. Placing the instrument in a dark environment, or covering with a thick piece of cloth (e.g., coat), should reduce the background count rate if the cause is light leakage.

17.6 Instrument Specifications and Limitations

17.6.1 Temperature

The 2929 is intended for use indoors. It has not been tested for proper operation in conditions other than controlled environments (indoors). Ludlum states a temperatures range between -20°C (4°F) and 50°C (122°F) for the 2929 and 43-10.1. No temperature data are available for the 43-78-5.

17.6.2 Temperature Shock

When moving the 2929 from one area to another (of different temperature), allow the instrument to reach equilibrium with the ambient temperature (usually about 1 hour) before use.

17.6.3 Humidity and Pressure

No data are available regarding instrument response to varying humidity and pressure. The 2929 is intended for use indoors. Performance testing in the intended environment should ensure proper functionality.

17.6.4 Electromagnetic Field Interference

No data are available regarding instrument response to external electromagnetic fields. However, the 2929 may be sensitive to electromagnetic fields. Photomultiplier tubes, in general, are very sensitive to magnetic fields. Magnetic fields may cause the instrument to read high or low. A common source of fields that may affect 2929 response is video displays. If magnetic fields are a potential concern, response checks should be performed in the field at the distances from the magnetic field expected during use.

17.6.5 Radio Frequency/Electromagnetic Interference

No data are available regarding instrument response to external radio frequency fields. However, the 2929 should be relatively insensitive to radio frequency fields.

17.6.6 Energies and Types of Radiation

The 2929 responds to alpha radiation above ~3 MeV and beta radiation above ~100 keV.

17.6.7 Interfering Ionizing Radiation Response

Detector response to gamma and neutron radiation is unknown. Based on detector type, neutron and gamma response should be slight at most.

17.7 Applications

17.7.1 Air Sample Measurements

The 2929 is used to measure the activity on air sample filter media. Excessive dust loading may degrade alpha measurements.

17.7.2 Surface Contamination Measurements

The 2929 is used to measure the activity on dry technical smear media. Excessive dust loading and/or moisture may degrade alpha measurements.

18.0 Commonly Encountered Portable Sodium Iodide Radiation Detectors Used at Hanford

This chapter describes the most commonly used portable, Sodium Iodide (NaI) radiation detectors at the Hanford Site.

18.1 Instrument Description and Theory of Operation

Photon-sensitive detectors typically consist of NaI(Tl) scintillating crystals. As the crystal absorbs energy in the form of photon or beta radiation, electrons in the valence band are moved to the conduction band as a result of energy conservation laws. When electrons in the conduction band return to the valence band, energy must be released. This energy is released in the form of visible light ($\lambda_{max\,=}$ 415 nm) assured by the Thallium impurity. The amount of light is proportional to the amount of radiation that was originally absorbed. These probes are often used to perform pulse height analysis/energy discrimination.

Crystals come in a variety of shapes and sizes. The most common crystals at Hanford are 2 in. by 2 in., because they are appropriate for a wide energy range and offer relatively high efficiency. Larger and smaller crystals are also available. Larger crystals increase efficiency and energy range. Crystal size and shape can be used as a mechanical discriminator, tuning detector response to low-energy radiation (e.g., ^{129}I). Commonly used NaI detectors are shown in Figures 18.1 and 18.2.

Ludlum 44-62 Ludlum 44-3 Ludlum 44-10 Eberline SPA-3 Bicron G1LE

Figure 18.1. Common NaI Detectors

Figure 18.2. Bicron G5 'FIDLER' Low-Energy Photon Detector with Common Mounting Hardware

18.1.1 Physical Description

The Ludlum 44-62 is 2.3 cm (0.9 in.) in diameter, 20 cm (8 in.) long, and weighs 0.1 kg (0.3 lb). The crystal is 1.3-cm (0.5 in.) in diameter and 2.5 cm (1 in.) thick. The detector includes a magnetically shielded PMT, 1.3-cm (0.5-in.) in diameter. The crystal and PMT are housed in an aluminum case. A single connector (e.g., Series "C") is used for both high voltage and signal.

The Ludlum 44-3 is 5 cm (2 in.) in diameter, 18 cm (7 in.) long, and weighs 0.5 kg (1 lb). The crystal is 2.5 cm (1 in.) in diameter and 1 mm thick. The detector has a 15 mg/cm^2 entry window and includes a 3.8-cm (1.5-in.) diameter, magnetically shielded PMT. The crystal and PMT are housed in an aluminum case. A single connector is used for both high voltage and signal.

The Ludlum 44-10 is 7 cm (2.6 in.) in diameter, 28 cm (11 in.) long, and weighs 1.1 kg (2.3 lb). The crystal is 5 cm (2 in.) in diameter and 5 cm (2 in.) thick. The detector includes a 5-cm (2 in.) diameter, magnetically shielded PMT. The crystal and PMT are housed in an aluminum case. A single connector is used for both high voltage and signal.

The Eberline SPA-3 is 7 cm (2.6 in.) in diameter, 28 cm (11 in.) long, and weighs 1.5 kg (3.4 lb). The crystal is 5 cm (2 in.) in diameter and 5 cm (2 in.) thick. The crystal and PMT are housed in an aluminum case. A single connector is used for both high voltage and signal.

The Bicron G1LE is 3.5 cm (1.4 in.) in diameter, 18 cm (7 in.) long, and weighs 0.21 kg (0.5 lb). The crystal is 2.5 cm (1 in.) in diameter and 1 mm thick. The detector has a 7-mg/cm^2 entry window and includes a 2.8-cm- (1.1-in.-) diameter, magnetically shielded PMT. The crystal and PMT are housed in an aluminum case. A single connector is used for both high voltage and signal.

The Bicron G2LE is 6 cm (2.3 in.) in diameter, 21 cm (8.4 in.) long, and weighs 0.81 kg (1.8 lb). The crystal is 5 cm (2 in.) in diameter and 1 mm thick. The detector has a 7-mg/cm^2 entry window and includes a 5-cm- (2-in.-) diameter, magnetically shielded PMT. The crystal and PMT are housed in an aluminum case. A single connector is used for both high voltage and signal.

The standard Bicron G5 FIDLER (Field Instrument for detecting low-energy radiation) is 14.1 cm (5.6 in.) in diameter, 25.7 cm (10.1 in.) long. A ruggedized version is available that measures 15.9 cm (6.25 in.) in diameter, 26.9 cm (10.6 in.) long. Both detectors weigh approximately 4.1 kg (6 lb). The crystal is 12.7 cm (5 in.) in diameter and 1.6 mm (0.063 in.) thick. The detector has a beryllium entrance window that is 0.25 mm (0.01 in.) thick and includes a 12.7-cm (5-in.) diameter PMT. The crystal and PMT are housed in an aluminum case. A single connector is used for both high voltage and signal. Optional window materials are available, including low-background beryllium and aluminum.

18.1.2 Radiation and Energy Response

In general, these detectors respond to gamma radiation. Photon response is energy dependent and the energy at which a probe displays its maximum response varies depending upon crystal size and shape.

These probes are also sensitive to high-energy beta radiation (e.g., ^{90}Sr/Y) of sufficient energy to penetrate the detector housing. Detectors with entrance windows respond to beta radiation above ~50 keV (e.g., ^{14}C β_{avg} @ 50 keV).

These detectors do not respond to neutron or alpha radiation.

Error! Reference source not found. summarizes photon energy range for the common NaI detectors used at Hanford.

Table 18.1. Photon Energy Range for Hanford NaI Detectors

Probe Model	Energy Range of Measurement	Sensitivity
Ludlum 44-62	60 keV to 1.25 MeV (^{241}Am to ^{60}Co)	49 cpm/uR/hr (^{137}Cs)
Ludlum 44-3	10 keV to 60 keV	2-pi efficiencies: 38% (^{125}I), 10% (^{14}C), 56% (^{32}P)
Ludlum 44-10	60 keV to 2 MeV	900 cpm/μR/hr (^{137}Cs)
Eberline SPA-3	60 keV to 2 MeV	1,200 cpm/μR/hr (^{137}Cs)
Bicron G1LE	10 keV to 60 keV	375 cpm/μR/hr (^{125}I)
Bicron G2LE	10 keV to 60 keV	1,500 cpm/μR/hr (^{125}I)
Bicron G5 "FIDLER'	10 keV to 100 keV[(a)]	~200 cpm/μCi/m^2 (^{241}Am)
(a) FIDLER response declines rapidly above 100 keV.		

18.1.3 Integral Sources

Probes used with portable rate meters do not have integral sources. However, some fixed location detectors (e.g., NaI detectors used with area radiation monitors) and rate meters have integral check sources. These detectors/integral sources are outside the scope of this chapter.

18.2 Operating Instructions

Before any of the portable probes may be used, they must be attached to an appropriate rate meter or scaler. With the exception of the Eberline SmartPak-equipped detectors, these NaI detectors will be calibrated with a specific meter or scaler. Detectors that are calibrated to a specific meter or scaler cannot be exchanged between instruments.

Before using a portable detector, perform the operability checks to make sure the instrument is in good working condition (see Section 18.3.1). These checks should be performed each time the instrument is used.

Radiological surveys are performed according to contractor-specific operating procedures.

18.2.1 Correction Factors

Sodium Iodide detectors used as qualitative surveying devices do not require the application of correction factors. Quantifying activity requires applying the geometry-specific efficiency to measured count rate.

18.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions in this section are provided as examples of acceptable methods. The instructions in this chapter represent a generic performance testing process.

18.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the instrument fails one of the first three operability checks, fill out an Instrument Service Tag identifying the problem, attach it to the instrument, and return it to the PNNL calibration laboratory for servicing.

1. Inspect the instrument for physical defects, such as broken meter face, loose knobs or switches, punctured probe windows, light leaks, or defective cables (as equipped).
2. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) on the expiration date on the calibration sticker.
3. If so equipped, verify that the HV reading shows upscale value on meter.
4. Ensure that battery strength (if so equipped) is above the cutoff and replace batteries as needed.
5. Verify that the initial source check has been completed.

6. Ensure that the instrument source check is current. Source checks are generally valid for the day performed and typically do not cover more than 24 hours.

18.3.2 Source Check

Digital instruments (e.g., Eberline E-600) require only one source activity to ensure their proper operation (i.e., each range need not be checked). In these cases, source activity should be large enough to minimize statistical fluctuations and reduce the probability of failing a functioning instrument.

Sources are selected based on the specific probe and calibration method (e.g., source emission matches calibrated energy window).

18.3.2.1 Initial Source Check

Initial source checks should be performed immediately upon receiving the instrument from the calibration laboratory. Instruments should not be placed into storage until after performing the initial source check.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure the values are reasonable. The initial response is considered reasonable when the response is within ±20% of the mean instrument response for that source.*

Center the detector over the check source. A jig or mark may be used to ensure reproducibility. Allow the reading to stabilize (rate meter) and note the instrument response. Alternatively, a scaler count may be performed, as equipped. Multiply the instrument's response by 0.8 and 1.2 to determine the acceptable range for that instrument/source combination.

18.3.2.2 Daily Source Check

NOTE: *The source used to perform the initial source check is used to perform the daily source check. To perform a daily source check with a source other than the one used for the initial source check, first perform the daily source check on the source used for the initial source check. If the instrument passes that daily source check, then perform a new initial source check using the new source to establish response limits for that source/instrument combination.*

Remove the cover from the detector, if applicable, and establish the source-to-detector geometry used during the initial source check. Allow the reading to stabilize (rate meter) and note the instrument response. Alternatively, a scaler count may be performed, as equipped. The instrument response should fall within the acceptable values determined during the initial source check.

For smart detectors, an instrument failure may be a failed detector or a failed count rate meter. First, replace the detector with another smart detector and repeat the daily source check using the initial source check limits established for the new smart detector. If the instrument performs satisfactorily during this source check, then the original detector was at fault. Tag the original detector with a completed Instrument Service Tag and return it to the calibration laboratory. If the instrument does not perform properly during the second daily source check, the meter is probably faulty. Tag the meter with a completed Instrument Service Tag, and return it to the calibration laboratory.

18.3.3 Response Checks

Periodically verify that the probe responds to radiation during continuous use. Response check the instrument by verifying response to background radiation, when specific radiation sources are not available.

18.4 Calibration Instructions

The NaI detectors referenced in this chapter are calibrated at the PNNL calibration laboratory in the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff.

Before calibration, the instruments are inspected to make sure they are in good working order, switches and button are checked for functionality and the instrument is checked for physical damage. Damaged instruments are repaired before they are calibrated. If the as-found readings are more than ±20% out of tolerance, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

Rate meters and scalers are calibrated electronically using a pulse generator. Instrument response is typically evaluated at 20% and 80% of each decade. The scaler function is also verified by performing a 1-minute count. The meter count rate must fall within ±5%, and the scaler response must be within ±2% of the conventionally true value to pass calibration.

As-found efficiencies are recorded for an appropriate gamma-emitting radionuclide (e.g., ^{137}Cs, ^{129}I, ^{241}Am) and the background is evaluated.

Threshold and window settings are established and an HV plateau is performed. After setting the electronics, the efficiency for the requested radionuclide is measured.

Photon detectors are commonly calibrated with an energy-specific window of interest (e.g., ^{137}Cs) and a gross gamma window (e.g., 300 keV to 2 MeV or 50 keV to 2 MeV). This type of calibration may be used to evaluate the relative ratio of a particular gamma-emitting radionuclide to the entire gamma spectrum. These ratios can be useful in characterizing waste streams and determining radionuclide character for radiation protection purposes.

For more detailed information on instrument calibration, refer to PNL-MA-563, Sections 3.9.4, 3.9.8, 3.9.12, and 3.31.

18.5 Maintenance Instructions

Routine maintenance on detectors are performed at the calibration laboratory and in the field. Routine maintenance includes repairing connections, replacing cables, and checking PMTs for noise. Common problems and causes are discussed in the next few paragraphs.

Cable noise: Damaged cables may cause the instrument to exhibit a noisy response, especially when the cable is moved. Damaged cables can be replaced in the field. Make sure that the replacement cable has appropriate connections on both ends and is the same length as the original cable.

PMT noise: Faulty PMTs will cause the detector to have a noisy response when shaken or moved. To determine if the PMT should be replaced, tap the detector lightly several times. If tapping the detector causes an audible response, the PMT should be replaced. Tag the probe with an Instrument Service Tag, and return it to the calibration laboratory. If the detector is married to a meter, return both the detector and meter.

Damaged NaI crystal: When using NaI scintillation detector, mechanical shock should be avoided. Mechanical shocks can damage the crystal to the extent that it produces erroneous readings or becomes inoperable. If the detector is exhibiting unstable response, tag it with an Instrument Service Tag, and return it to the calibration laboratory for servicing.

Low response: Scintillation based instruments may develop a low response when the optical coupling between the crystal and PMT is degraded. If the detector is exhibiting low response, tag it with an Instrument Service Tag, and return it to the calibration laboratory for servicing.

18.6 Instrument Specifications and Limitations

18.6.1 Temperature

Ludlum states a temperature range of -20°C to 50°C (-4°F to 122°F) for the 44-62, 44-3, and 44-10 detectors.

Bicron states a temperature range of -40°C to 50°C (-40°F to 122°F) for the G1LE and G2LE detectors. For the G5 Fidler, Bicron states a temperature range of 4°C to 43°C (39°F to 109°F).

Eberline states a temperature range of -30°C to 60°C (-22°F to 140°F) for the SPA-3 detector.

18.6.2 Temperature Shock

NaI detectors are vulnerable to thermal shocks. Thermal shocks may damage the detector to the extent that they produce erroneous readings and become inoperable.

When moving a NaI detector from one area to another (of different temperature), allow the instrument to reach equilibrium with the ambient temperature (usually about 1 hour) before use.

Bicron states a temperature shock limitation of 10°C (18°F) per hour for the G5 FIDLER.

18.6.3 Humidity and Pressure

No data are available for the common NaI detector regarding instrument response to varying humidity and pressure. Performance testing in the intended environment should ensure proper functionality.

These detectors should not be used in condensing environments.

18.6.4 Electromagnetic Field Interference

The NaI detectors are likely responsive to electromagnetic fields. Photomultiplier tubes, in general, are very sensitive to magnetic fields. Magnetic fields may cause the instrument to read high or low. A common source of fields that may affect NaI detector response is video displays. If magnetic fields are a potential concern, response checks should be performed in the field at the distances from the magnetic field expected during use.

18.6.5 Radio Frequency/Electromagnetic Interference

No data are available regarding the NaI detector response to external radio frequency fields. These detectors should be relatively insensitive to radio frequency fields. However, if these fields are a potential concern, response checks should be performed at the location where the instrument will be used.

18.6.6 Energies and Types of Radiation

The NaI detector photon response is dependent upon photon energy. Crystal size, shape, and entrance window construction affect energy response. See Table 18.1 for additional information. Standard 2-in.-by-2-in. detectors (e.g., SPA-3, 44-10) typically over-respond to photons at 100 keV by 10 times, and under-respond at 1 MeV by 0.5, relative to the ^{137}Cs response.

18.6.7 Interfering Ionizing Radiation Response

These detectors are sensitive to high-energy beta radiation (e.g., ^{90}Sr/Y) of sufficient energy to penetrate the detector housing. Detectors with thin entrance windows can respond to low-energy beta radiation above ~50 keV (e.g., ^{14}C β_{avg} @ 50 keV).

These detectors do not respond to neutron or alpha radiation.

18.6.8 Battery Life

The detectors do not have internal batteries. Refer to the corresponding meter or scaler chapter in this manual for information on instrument battery life.

18.7 Applications

Sodium Iodide detectors typically perform qualitative assessment of gamma radiation levels. Refer to contractor-specific operational procedures. Some may be calibrated for quantitative monitoring of air samples and swipes as well.

19.0 The Eberline E-600 Portable Radiation Monitor

19.1 Instrument Description and Theory of Operation

The E-600 is a portable, digital rate meter used with a variety of probes, including ion chambers, scintillation detectors, neutron detectors, and GM detectors, for measuring radioactive contamination and radiation. The E-600 (Figure 19.1) has a liquid crystal display with both digital and a simulated analog output (sliding bar graph). Three channels allow the E-600 to perform pulse height analysis and discriminate radiation based on incident energy, as allowed by attached detector. Alarms can be set independently for each channel.

E-600 **NRD** **SHP380AB/SHP380A**

Figure 19.1. Eberline E-600, NRD, and SHP380AB/SHP380A

Although the E-600 supports a wide variety of detectors, the most commonly paired combinations at Hanford are the E-600/SHP380AB, E-600/SHP380A, and E-600/NRD as shown in Figure 19.1.

The SHP380AB and SHP380A are essentially identical, differing only in their phosphor plates. The S indicates that these are smart detectors. A memory chip in the handle retains the detector calibration settings, allowing these smart detectors to be connected to any E-600 calibrated with smart channels. Alpha detection is achieved with a thin coating of ZnS(Ag). The AB detector (alpha/beta) also includes an NE102 plastic scintillator for beta monitoring (see Figure 19.1). The SHP380 indicates the detector model, the A stands for alpha detection, B for beta detection.

The neutron rem detector (NRD) consists of a BF_3 tube surrounded by a 9-in., cadmium-loaded polyethylene moderating sphere. The NRD is not a smart detector and should be married to an E-600 and calibrated as a conventional instrument. A Smart Pak may be used with the Eberline NRD to allow operation with any E-600.

More detailed technical information can be obtained by contacting the PNNL calibration laboratory at (509) 376-5624.

19.1.1 Physical Description

The E-600 weighs about 1.53 kg (3.4 lb) with batteries and measures 22.9 cm (9.0 in.) long by 10.5 cm (4.1 in.) wide by 15.3 cm (6.0 in.) high including the handle. The instrument has an internal speaker, smart probe connector, three buttons (membrane type) on the body (for selecting range, gross or net mode, and speaker on/off), a three-position toggle switch for response time selection, four buttons (membrane type) on the handle for thumb operation (selects channel, data logging, light on/off and a programmable * key) and a rotary multi-position selector switch to set the operating mode (off, check, ratemeter, integrate, scaler, peak hold, and background). The instrument high voltage is adjustable (computer controlled) and is set during calibration. The response time is set during calibration. The conventional channel response time is set to 20 seconds, regardless of the switch setting. Smart channel response times are set to 20 seconds, 10 seconds, and 3 seconds, respectively, for slow, medium, and fast response.

The E-600 rate meter response time acts like a RC time constant unless one of two conditions are met 1) the background is greater than 300 cpm or 2) the instrument detects a change in count rate of three sigma. When one of these conditions is met, the instrument drops the existing background and provides an instantaneous reading update.

The audible output of the E-600 is limited to 75 counts per second, or 4500 cpm. As such, the audible output is not necessarily representative of the measured radiation level and should not be relied upon in high-count rate situations.

The SHP380 is approximately 28.6 cm long, 7 cm wide and 8.3 cm high (11.25 in by 2.75 in. by 3.25 in.) and weighs 0.58 kg (1.28 lb.). The detector has an active area of 6.9 cm by 14.5 cm (2.72 in. by 5.7 in.) or 100 cm^2. The open area is approximately 85%. The window thickness of the SHP380 is 0.87 mg/cm^2 of aluminized plastic film. The SHP380AB may be fitted with a layer of Tyvek to protect the detector from damage during outdoor use. The Tyvek cover does not appreciably reduce response to medium energy beta particles (^{90}Sr or ^{137}Cs). The Tyvek critically reduces low-energy beta response and eliminates alpha-measuring capabilities. Similarly, additional layers of Mylar may be applied to ease decontamination efforts in highly contaminated environments. The additional Mylar degrades alpha sensitivity but does not eliminate it. Probes should be calibrated with any desired additional layers to account for degraded response (i.e., layers should not be added in the field). The response time for the SHP380 detectors is set according to customer requirements.

The NRD is a 9-in. sphere, weighing 6.3 kg (14 lb). The response times for the NRD are set to 60 seconds (slow), 30 seconds (medium), and 10 seconds (fast).

19.1.2 Radiation and Energy Response

19.1.2.1 SHP380AB

The detector responds to alpha radiation above ~3 MeV. Alpha response may be energy-dependent but should be relatively consistent for ^{241}Am and ^{239}Pu. The average ^{239}Pu efficiency is 12% (100-cm^2 source).

The detector responds to beta radiation above ~200 keV. Beta response is energy dependent. The average beta efficiencies are 1% (^{14}C), 8% (^{99}Tc), 18% (^{137}Cs), and 30% ($^{90}Sr/Y$) at 0.25 in. from 2 in. sources. For sources with 100 cm^2 active areas, the average efficiencies at 0.25 in. are 22% ($^{90}Sr/Y$) and 17% (^{137}Cs).

The detector responds to gamma radiation above a few keV. An average response to ^{137}Cs photons is 25,000 cpm/ mR/hr. Detector neutron radiation is unknown. Based on detector type, neutron response should be slight at most.

19.1.2.2 SHP380A

The detector responds to alpha radiation above ~3 MeV. Alpha response may be energy-dependent but should be relatively consistent for ^{241}Am and ^{239}Pu. The average ^{239}Pu efficiency is 15% (100 cm^2 active area).

Detector construction and discriminator settings minimize response to beta radiation. Typical beta response is 0.15 cpm/1X10^6 dpm (^{137} Cs) and 1.0 cpm/1X10^5 dpm ($^{90}Sr/Y$).

SHP380A response to gamma radiation is minimal, averaging 0.004 cpm/mR/hr (^{137}Cs).

Detector response to neutron radiation is unknown. Based on detector type, neutron response should be slight at best.

19.1.2.3 Neutron Rem Detector

The NRD responds to neutron radiation from thermal (0.025 eV) to ~10 MeV.

The NRD does not respond to alpha or beta radiation. Gamma response is minimized during calibration with the instrument typically measuring less than 0.03 cpm/R/hr.

19.1.3 Integral Sources

E-600s may have an alpha-emitting source attached to their side for performing response checks in the field. These sources are typically on the order of 0.85 nCi (~2000 dpm) ^{230}Th. (See Chapter 5.0, Figure 5.1, of this manual for an example of these sources.)

19.2 Operating Instructions

Before using the E-600, perform the operability checks to make sure the instrument is in good working condition (see Section 19.3.1). These checks should be performed each time the instrument is used.

Ensure that the appropriate probe is attached to the E-600 and commence with a radiological survey according to contractor-specific operating procedures.

19.2.1 Correction Factors

19.2.1.1 Contamination Measurements with SHP380 Probes

The actual count rate is automatically displayed by the E-600 and there is no need to correct the displayed value for range switch settings. To convert an instrument response (in cpm) to an activity (in dpm), divide the cpm reading by the appropriate efficiency (typically ^{137}Cs [beta] or ^{239}Pu [alpha]) established by PNNL and provided on the calibration label. The efficiency is unique for each probe.

If the ^{239}Pu efficiency is at least 10% and the ^{137}Cs efficiency is at least 20%, a generic alpha correction factor of 10 and beta correction factor of 5 may be used. Likewise, if the ^{137}Cs efficiency is 15%, or greater, a beta correction factor of 7 may be used. These are acceptable (and conservative) practices for measurements performed with the SHP380 detectors.

The SHP380 detectors have active areas of 100 cm^2, therefore, no area conversions are needed.

19.2.1.2 Neutron Rem Detector Dose Rate Measurements

The dose rate at the center of the NRD sphere is displayed by the E-600.

There are no contact or beam correction factors for the NRD. The NRD is configured to measure general area neutron dose rates where the sphere is uniformly exposed. Therefore, the NRD is not used to establish contact dose rates or evaluate beaming radiation. Contact correction factors for specific applications can be developed. Contact the calibration laboratory for assistance.

19.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions in this section are provided as examples of acceptable methods.

19.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the instrument fails a critical operability check (identified with an '*'), fill out an Instrument Service Tag identifying the problem, attach it to the instrument, and return it to the calibration laboratory for servicing.

1. *Inspect the instrument for physical defects, such as broken meter face, loose knobs or switches, punctured probe windows, light leaks, or defective cables (if so equipped).
2. *Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) of the expiration date on the calibration sticker. Depending upon configuration, the instrument may indicate if the calibration has expired by displaying OUT OF CAL.

3. Verify that the initial source check has been completed.
4. Ensure that the instrument source check is current. Source checks are generally valid for the day performed and typically do not cover more than 24 hours.
5. *If the meter will not turn on, or indicates other failures that cannot be corrected in the field, return the instrument to the calibration laboratory for servicing. Indicate the failure on the service tag.
6. Turn the count rate meter selector switch to CHECK. The meter will show a scale indicating battery level. When the display indicates < 70% of full scale, replace the batteries (NRD equipped instruments with low batteries should be sent to the calibration laboratory unless a source check can be performed in the field.)
7. *If the high voltage fails, HV will be displayed in the lower left-hand corner of the display. During some channel switching, a flashing HV may be momentarily displayed as the high voltage adjusts to the needs of the selected channel. If the HV icon does not disappear after ~30 seconds, the HV has failed.
8. Turn the selector switch to SCALER and initiate a count. Verify that the background reading is within tolerance for the attached probe. This step is not typically performed on NRD-equipped instruments.
9. Response checks should be performed for each active channel (e.g., background, light leakage). This step is not typically performed on NRD-equipped instruments.

19.3.2 Source Check

The SHP380A detector is source checked with an appropriate alpha source (e.g., ^{239}Pu, ^{241}Am). SHP380AB detector is source checked with appropriate alpha and beta sources (e.g., ^{239}Pu or ^{241}Am and ^{137}Cs or ^{90}Sr/Y). Because the instrument is digital, only one decade is source checked. For example, sources used to performance test continuous air monitors or miniscalers may be used to source check SHP380 detectors. Source activity should be greater than 1,200 dpm to minimize statistical fluctuations and reduce the probability of failing a functioning instrument. Response limits are applicable to detectors, not count rate meters.

Sources are not readily available for source checking the E-600/NRD. As compensatory actions for not source checking the instrument, these instruments are calibrated quarterly.

19.3.2.1 Initial Source Check

Initial source checks should be performed immediately upon receiving the instrument from the calibration laboratory. Instruments should not be placed into storage until after performing the initial source check.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure the values are reasonable. The initial response is reasonable when the response is within ±20% of the mean instrument response for that source. The acceptable range should allow for variations resulting from differing probe efficiency.*

Center the detector over the check source. A jig or mark may be used to ensure reproducibility. Allow the reading to stabilize (RATEMETER mode) and note the instrument response. Alternatively, a scaler count may be performed in the SCALER mode. Multiply the instrument response by 0.8 and 1.2 to determine the acceptable range for that instrument/source combination.

19.3.2.2 Daily Source Check

NOTE: *The source used to perform the initial source check is used to perform the daily source check. To perform a daily source check with a source other than the one used for the initial source check, first perform the daily source check on the source used for the initial source check. If the instrument passes that daily source check, then perform a new initial source check using the new source to establish response limits for that source/instrument combination.*

Remove the cover from the detector, if applicable, and establish the source-to-detector geometry used during the initial source check. Allow the reading to stabilize (RATEMETER mode) and note the instrument response. Alternatively, a count may be performed in the SCALER mode. The instrument response should fall within the acceptable values determined during the initial source check.

If the instrument fails, it may be a failed probe or a failed count rate meter. First, replace the probe and repeat the daily source check using the initial source check limits established for the new probe. If the instrument performs satisfactorily during the daily source check, then the original probe was at fault. Tag the original probe with a completed Instrument Service Tag and return it to the calibration laboratory. If the instrument does not perform properly during the second daily source check, the meter is probably faulty. Tag the E-600 with a completed Instrument Service Tag, and return it to the calibration laboratory.

19.3.2.3 Response Checks

Periodic response may be performed on the NRD, when a stable neutron field exists in the facility, to verify consistent detector response and speaker functionality.

Periodically verify that the SHP380 detector responds to radiation during continuous use. Response check the instrument by placing the detector over the check source mounted on the instrument case and verify that the speaker and meter respond to the source. Alternatively, background radiation may be used to response check the instrument when check sources are not present.

19.4 Calibration Instructions

The E-600 is calibrated at the PNNL calibration laboratory in the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff.

Before calibration, instruments are inspected to make sure they are in good working order, switches and buttons are functionally checked, and instruments are inspected for physical damage. Damaged instruments are repaired before calibration. If the as-found readings are more than ±20% out of tolerance, the calibration laboratory contacts the radiological control organization that last used the instrument and informs them of the problem.

The E-600 rate meter is calibrated electronically using a pulse generator. Instrument response is evaluated at 20% and 80% of each decade and at the approximate midpoint of the first decade (i.e., at 200 cpm, 400 cpm, 800 cpm, 2,000 cpm, 8,000 cpm, 20,000 cpm, 80,000 cpm, 200,000 cpm, and 800,000 cpm). The scaler function is then verified by performing a 1-minute count at 80,000 cpm. The count rate meter must fall within ±5% and the scaler response must be within ±2% of the true count rate to pass calibration.

The E-600 has four channels, three smart channels and a conventional channel. Any one, or multiple, smart channels may be disabled depending on the probe connected to the instrument. The conventional channel is calibrated for a pancake GM detector.

For more detailed information on instrument calibration, refer to PNL-MA-563, Sections 3.9.5, 3.9.6, and 3.9.11 .

19.4.1 SHP380 Calibration

As-found efficiencies are recorded for ^{239}Pu and ^{90}Sr/Y (Pu only for SHP380A) and the background count rate is evaluated. The detector is checked for light leakage using a high-intensity light source.

Parameters, thresholds, and the high-voltage setting are established. A series of efficiencies are recorded using large-area anodized sources containing ^{137}Cs, ^{90}Sr/Y, and ^{239}Pu (Pu only for SHP380A). Minimum acceptable values are 15%, 20%, and 10%, respectively. If the detector is fitted with additional Mylar layers, the minimum efficiency values are 10%, 15%, and 10% respectively. Efficiency measurements for other isotopes are performed upon request with 2 in. disk sources. The evaluated efficiencies are stated in the limitations section of the calibration sticker. On the SHP380AB beta-to-alpha crosstalk is maintained less than 1%.

SHP380 detector is calibrated annually and after any maintenance that voids the existing calibration. The calibration is valid through midnight of the expiration date listed on the calibration sticker.

A Quick Check is available for detectors whose outer Mylar surface has been damaged and at least 3 months remain in their calibration. These detectors are repaired and then the measured efficiency is verified to be within 10% of the current calibration. If the measured efficiency agrees with the calibration efficiency, the probe is returned to the field without performing a calibration.

19.4.2 NRD Calibration

As-found response is evaluated using the ^{252}Cf source well at 1.5 mrem/hr, 5 mrem/hr, 50 mrem/hr, 100 mrem/hr, and the upper capability of the well (currently 400 mrem/hr). The sphere is then placed in a 10-R/hr ^{137}Cs field for a 1-minute scaler count.

Instrument parameters are set and the high voltage is adjusted with the sphere in a 10-R/hr ^{137}Cs field. The high voltage is set to minimize gamma response. A 1-minute scaler count is performed with the NRD in the 10-R/hr photon field and the E-600 must measure 0-mrem/hr neutron to pass calibration. After establishing the high voltage, the sphere is returned to the ^{252}Cf well and the response at 1.5 mrem/hr, 5 mrem/hr, 50 mrem/hr, 100 mrem/hr, and the upper capability of the well, is verified/adjusted to within ±10% of the true value.

A calibration sticker is attached to both the E-600 and NRD indicating that they are a married pair and cannot be used with other instruments, unless the NRD is equipped with an Eberline Smart Pak.

19.5 Maintenance Instructions

Routine maintenance on the E-600 is performed at the calibration laboratory and in the field. Routine maintenance includes checking/replacing the batteries. Additionally, for the SHP380 detectors, maintenance includes checking the PMT for noise and the window for light leaks. Common problems and causes are discussed below.

Low batteries: In the CHECK mode, a battery indicator is displayed. Full scale indication corresponds to 4.5 V. The battery icon will come on when the battery falls below 3.15 V and begins to flash at 3.08 V. Because the batteries tend to fail quickly once they fall below 60%, it is best to change batteries when the battery icon first appears. If the E-600 has low batteries, the batteries may be replaced in the field (when a source check can be performed). Open the instrument case, by removing the screw in the center of the bottom of the instrument. Replace all three batteries with C cell alkaline batteries. Reuse the cardboard battery sleeves (if so equipped), making sure the batteries are firmly mounted in the battery clips.

Light sensitivity: If the SHP380 exhibits a high count rate when exposed to light, there are probably holes in the Mylar window. Even very small pinholes, too small to be seen with the naked eye, can cause the E-600 to exhibit light sensitivity. To verify light sensitivity, expose the probe to a light source and verify an increased count rate. Then, cover the probe with a light shield (such as a dark cloth) and verify that the count rate drops. If the probe has a light leak, tag it with an Instrument Service Tag and return it to the calibration laboratory for servicing.

Small light leaks on the probe face can be repaired in the field. Locating a light leak involves placing the probe under a source of light that causes audible output and then covering small sections of the probe face until a decrease in the count rate is observed. Using Testor brand (or equivalent) silver paint, cover the holes in the Mylar. The maximum area of the probe surface that is covered with paint should be limited to ≤ 1% of the total surface area.

Cable noise: Damaged cables may cause the E-600 to exhibit a noisy response, especially when the cable is moved. Damaged cables can be replaced in the field. Make sure that the replacement cable has appropriate connections on both ends (the E-600 smart probe connector is very unique).

Saturation: Very large light leaks will cause the SHP380 to saturate (i.e., not respond at all). To verify that an SHP380 is exhibiting saturation, place a dark shield over the detector. Slowly remove the shield while listening to the audible response. If the SHP380 has large light leaks, the audible response will first increase as the shield is removed and then decrease as the detector face is fully exposed to the light. If the detector is exhibiting saturation, tag it with an Instrument Service Tag and return it to the calibration laboratory for servicing.

PMT noise: Faulty PMTs will cause the E-600 to have a noisy response when the SHP-380AB detector is shaken or moved. To determine if the PMT should be replaced, lightly tap the back of the detector several times with your hand. If tapping the detector causes an audible response, the PMT should be replaced. Tag the SHP380 with an Instrument Service Tag and return it to the calibration laboratory.

19.6 Instrument Specifications and Limitations

19.6.1 Temperature

Based on testing performed at Hanford, the temperature range for the E-600/SHP380AB is -20°C to 50°C (-4°F to 122°F). The mean instrument response over this range was within 20% of the response at 22°C. Eberline states a temperature range of -40°C to 60°C (-40°F to 140°F) for the SHP380 detectors. Temperature data for the NRD was not available from Eberline.

Testing performed at Oak Ridge National Laboratory showed the NRD was operational across the range -10°C to 50°C (14°F to 122°F).

19.6.2 Temperature Shock

The E-600/SHP380AB successfully completed temperature shock testing according to the ANSI Standard N42.17A (ANSI 1989).

Oak Ridge National Laboratory data have shown that the NRD is adversely affected by temperature shocks.

When moving the E-600and probe from one area to another of different temperatures, it is good practice to allow the instrument to reach equilibrium with the ambient temperature (usually about 1 hour) before use.

19.6.3 Humidity and Pressure

The E-600/SHP380AB is not affected by changes in ambient humidity or pressure. However, it is not advisable to use the SHP380 or E-600 in condensing environments. Condensation could be encountered when moving a cold instrument into a warm, humid environment. Condensation (beads of water) may form on the instrument. The instrument should not be used under these conditions. The operator should allow the instruments to equalize with the ambient temperature and remove any remaining condensation.

Oak Ridge National Laboratory successfully evaluated the NRD across the range 40 to 95% relative humidity. Low humidity testing has not been completed. The NRD should not be used in condensing environments. Pressure is not expected to impact the NRD response at Hanford because the instrument is calibrated at essentially the same elevation as it is used and slight meteorological pressure changes are not likely to affect instrument response.

19.6.4 Electromagnetic Field Interference

E-600 test data provided by Eberline (with a GM probe) showed no response to magnetic or electric fields. However, the SHP380 detectors have not been evaluated. These detectors are likely responsive to electromagnetic fields. In general, PMTs are very sensitive to magnetic fields. Magnetic fields may cause the instrument to read high or low. A common source of fields that may affect SHP380 response is video displays. If magnetic fields are a potential concern, response checks should be performed in the field at the distances from the magnetic field expected during use.

No data are available regarding NRD response to electromagnetic fields. If magnetic fields are a potential concern, response checks should be performed in the field at the distances from the magnetic field expected during use.

19.6.5 Radio Frequency Interference

Testing data from Eberline show that external radio frequency fields may influence instrument performance. Interference was observed at radio frequency ranges of approximately 140 to 160 MHz. Consequently, portable and mobile communication transceivers may interfere with readings when in close proximity to an E-600. If these fields are a potential concern, performance tests should be performed at the location where the instrument will be used.

Eberline tested the E-600 with additional radio frequency/electromagnetic interference. No effects were observed due to fields of up to 100 V/m meter at 915 or 2450 MHz.

No data are available regarding NRD response to external radio frequency fields. The NRD should be relatively insensitive to radio frequency fields. However, based on potential E-600 response, if these fields are a potential concern, response checks should be performed at the location where the instrument will be used.

19.6.6 Energies and Types of Radiation

Radiation and energy response is dependent upon the attached probe. SHP380AB detector responds to alpha, beta, and gamma radiation. Specific information regarding this response is listed in Section 19.1.2.1.

SHP380A detector responds to alpha radiation. Specific information regarding this response is listed in Section 19.1.2.2.

The NRD responds to neutron radiation from thermal (0.025 eV) to 10 MeV. Specific information regarding this response is listed in Section 19.1.2.3.

19.6.7 Interfering Ionizing Radiation Response

Response to interfering ionizing radiation is dependent upon the attached probe.

The SHP380 detectors respond to gamma radiation above a few keV. An average SHP380AB response to ^{137}Cs photons is 25,000 cpm/mR/hr. Detector neutron radiation response is unknown. Based on detector type, neutron response should be slight at most.

The SHP380A detector construction and discriminator settings minimize response to beta and gamma radiation.

The NRD-applied voltage is adjusted to effectively eliminate response to gamma radiation.[(a)] The NRD does not respond to alpha or beta radiation.

19.6.8 Battery Life

The E-600 battery life is approximately 50 to 100 hours with three C cell size alkaline batteries.

19.7 Applications

The E-600 performs a number of measurements depending upon the attached probe. The SHP380 detectors are used for direct and removable contamination surveys and the NRD is used to establish neutron deep dose equivalent rates.

19.7.1 NRD and Neutron Dose Rate Measurements

The NRD is used to establish personnel dose rates from neutron radiation. The NRD is typically used over the range of 1 mrem/hr to 500 mrem/hr.

The NRD can be used with a scaler to measure dose rates below 0.2 mrem/hr. A typical application that requires neutron dose rate measurements below 0.2 mrem/hr is performing posting surveys for establishing RBA boundaries. The sensitivity required is approximately 0.05 mrem/hr (50 μrem/hr). A special calibration must be performed to establish the sensitivity and background of the instrument so that scaler measurements can be converted to mrem/hr. Requests for special calibration should be directed to the calibration laboratory. Requests should specify that the NRD is to be used as a scaler, and that background, background count time, and sensitivity should be specified for the instrument.

19.7.2 SHP380 Detectors and Direct Frisking

For alpha surveys, levels are based upon listening to the audible output count rate. When a count is detected, the operator should stop and evaluate the suspected area for 5 seconds. If no additional counts are detected, the survey continues, otherwise the area should be considered contaminated. The background is assumed to be zero and a maximum background of 3 cpm allows for efficient operation. The probe should be within 6 mm (¼ in.) of the surface.

For beta surveys, levels are based upon listening to the audible output count rate. When an increase in the measured count rate is perceived, the operator should stop and evaluate the suspected area for 5 seconds. If no additional counts are detected, the survey continues, otherwise the area should be considered contaminated. The background is assumed to be less than 1,000 cpm. The probe should be within 6 mm (¼ in.) of the surface.

The minimum detectable amounts for alpha and beta surveys are summarized in Table 19.1.

(a) JL Kenoyer, RK Piper, "NRD/E-600 Testing Results," Pacific Northwest National Laboratory. Published in the HIEC Minutes for November 7, 2000.

Table 19.1. Alpha and Beta Detection Scan Speeds and Corresponding MDA for the SHP380 Probe at Two Confidence Levels

(Johnson 1997).[(a)]

MDA	Decision Level	95% confidence	67% Confidence
		Scan Speed (in./s)	Scan Speed (in./s)
Alpha Surveys			
500 dpm (based on ^{239}Pu)	α - no audible counts	1	2.5
300 dpm (based on ^{239}Pu)	α - no audible counts	0.6	1.5
100 dpm (based on ^{239}Pu)	α - no audible counts	0.2	0.5
Beta Surveys			
5,000 dpm (^{90}Sr/Y)	β - increase in count rate	6	8
3,000 dpm (^{90}Sr/Y)	β - increase in count rate	2	2
1,000 dpm (^{90}Sr/Y)	β - increase in count rate	2	2
5,000 dpm (MFP[a])	β - increase in count rate	2	2
(a) MFPs (mixed fission products) were approximated using ^{137}Cs (average efficiency 18%).			

19.7.3 SHP380 Detectors and Static Measurements

Consult facility-specific procedures for static measurement methods and corresponding minimum detectable activity levels. The calibration laboratory can assist in developing static measurement techniques upon request.

19.7.4 SHP380 Detectors and Removable Alpha Contamination Measurements

Consult facility-specific procedures for removable contamination measurement methods and corresponding MDA levels. The calibration laboratory can assist in developing removable contamination measurement techniques upon request.

19.7.5 SHP380 Detectors and Counting Air Samples

Field measurements of air samples may be performed using the SHP380 detectors. However, these measurements should be used for indication only and should be verified using count room instruments or mini-scalers.

19.8 References

NOTE: *For information on technical manuals, see Bibliography.*

(a) Johnson 1997, Report, "Evaluation of the Eberline Model E-600 Survey Meter with Model SHP380 AB Alpha/Beta Duel Scintillation Probe Using Criteria in ANSI N42.17A," July 1997.

ANSI N42.17A-1989. 1989. *Performance Specifications for Health Physics Instrumentation - Portable Instrumentation for Use in Normal Environmental Conditions*. American National Standards Institute, New York.

20.0 Eberline SAC-4 Alpha Scintillation Counter

20.1 Instrument Description and Theory of Operation

The Eberline SAC-4 is an alpha scintillation counter that is powered by AC. The SAC-4 uses a ZnS(Ag) scintillator accommodating 2-in. samples (e.g., air filter papers and technical smears). The SAC-4 includes a sample drawer to ensure consistent and reproducible geometry.

More detailed technical information can be obtained by contacting the PNNL calibration laboratory at (509) 376-5624.

20.1.1 Physical Description

The SAC-4 weighs about 7.6 kg (16 ¾ lb) and measures 15.2 cm (6 in.) wide by 29 cm (11 ½ in.) high by 36 cm (14 in.) deep (see Figure 20.1). The front panel includes a three-position count time switch, three-position count time range switch (X.1, X1, X10), count mode switch (timed, stop, manual), six-digit LED scaler display, start/reset push button, red LED indicating counting status, and sample drawer. The rear panel includes two fuses, high-voltage adjustment, power switch, and electrical connection. The amplifier gain adjustment is located internally.

Figure 20.1. Eberline SAC-4

The SAC-4 uses a scintillation phosphor, consisting of a plastic light pipe with ZnS(Ag) powder deposited on it. The associated PMT is 2 in. in diameter with a 10-pin dynode structure.

Samples up to 5.2 cm (2 in.) in diameter and 1.0 cm (3/8 in.) thick can be placed in the sample drawer on the front of the instrument. The height of the sample holder can be adjusted for different sample thickness. The sample holder height is set during the calibration and must be maintained to use the calibration efficiency. The sample holder height should not be adjusted unless directed by facility-specific protocols. The calibration laboratory can provide calibrations with differing sample holder heights upon request.

20.1.2 Radiation and Energy Response

The SAC-4 will respond to alpha radiation above ~3 MeV. Alpha response may be energy dependent but should be relatively consistent for ^{241}Am and ^{239}Pu. The average ^{239}Pu efficiency is 39%.

A discriminator is set during calibration to ignore pulses from beta radiation.

Detector response to gamma and neutron radiation is unknown. Based on detector type, neutron and gamma response should be slight at best.

20.1.3 Integral Sources

There are no radioactive sources attached to, or inside, the SAC-4.

20.2 Operating Instructions

Before using the SAC-4, perform the operability checks to make sure the instrument is in good working condition (see Section 20.3.1). These checks should be performed each time the instrument is used.

To count a contamination smear or air sample filter, pull the sample drawer out, and place the sample in the tray. Planchets should be used to hold samples (minimizing handling and the potential for cross contamination). Slide the sample holder back beneath the detector.

Set the desired count time, and then press START/RESET to start the count cycle. Count times between 0.1 minutes (6 seconds) and 50 minutes are possible.

General counting precautions include the following:

- The SAC-4 is intended for counting dry technical smears and air sample filters. Placement of other types of materials into the counters may result in contamination of the instrument, inaccurate measurements, and/or detector damage.
- The sample drawer should be maintained clean. A cotton swab may be used to remove any residual debris.
- Bent technical smears and air sample filters require extra care because they may easily lodge inside the sample drawer. A thin layer of adhesive between the sample and its planchet may help bent samples lie flat.
- The potential for significant instrument contamination increases with the activity of the sample. Highly radioactive samples may contaminate counting instruments and should be handled with extreme care. Portable survey instruments should be used to survey samples before placing them into the sample drawer. Contact facility technical staff if questions arise regarding sample activity limitations.

- Samples that are wet or that will break apart should not be counted.
- The SAC-4 cannot discriminate against radon or radon progeny.
- Use the efficiency values determined during calibration (normally 239Pu), unless the radionuclide and the counting efficiency for another radionuclide of concern is known. Contact the Radiological Calibration Laboratory to request specific isotopic efficiency values.
- Sample counting times will vary to obtain desired minimum detectable activity (MDA) or minimum detectable concentration (MDC) values. The longer a sample is counted, the lower the MDA/MDC value. Sample count times should be long enough to yield the required sensitivity (MDA/MDC).
- Sample count times should be less than or equal to the background count time.
- The sample height is set during calibration and the efficiency values on the calibration sticker are valid for that position only. This sample height must be used for accurate analysis results.

20.2.1 Correction Factors

To obtain the gross cpm, the displayed number must be divided by the number of minutes counted.

To obtain an activity in dpm, divide the net cpm (gross cpm - background cpm) by the detector efficiency, provided the sample height has not been altered. If the sample is a smear, this activity is the dpm/100 cm^2, provided the area smeared is less than, or equal to, 100 cm^2. When the smeared area is greater than 100 cm^2, divide the measured activity by the ratio area smeared/100 to obtain the dpm/100 cm^2 (e.g., if the smear area 300 cm^2, then divide the measured activity by 300/100 or 3).

20.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions in this section are provided as an example of acceptable methods.

Sources used for performance testing should be traceable to an established calibration standard or have a manufacturer's certificate to document source activity and radioisotopic purity.

20.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the instrument fails either of the first two operability checks, fill out an Instrument Service Tag to identify the problem, attach it to the instrument, and return it to the calibration laboratory for servicing.

1. Inspect the instrument for broken or loose knobs and display.

2. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) on the expiration date on the calibration sticker.
3. Verify that the initial source check has been completed.
4. Ensure that the instrument source check is current. Source checks are generally valid for the day performed and typically do not cover more than 24 hours.
5. Ensure that the periodic performance test is current. The periodic performance test is commonly valid for 30 calendar days, expiring at 23:59 of the 30th day after it is performed.

20.3.2 Source Check

The SAC-4 is typically maintained under statistical process control to ensure reliable and consistent operation. A combination of daily source checks and periodic surveillance tests provides confidence regarding instrument operation and data validity.

20.3.2.1 Initial Source Check

Upon receipt from the Radiological Calibration Laboratory, or prior to placing an instrument into service, the SAC-4 should be tested to ensure that its operation is consistent with the calibration. The initial source check may also establish the performance criteria to be used for subsequent daily source checks and surveillance tests. Initial source checks typically consist of:

- a background measurement
- a chi square test
- checking efficiency within ±10% of calibration efficiency
- establishing response limits.

20.3.2.2 Daily Source Check

Once each day, or prior to intermittent use, SAC-4s should be evaluated for instrument response. Daily source checks typically consist of a:

- background measurement
- response within limits established during the initial source check.

20.3.2.3 Periodic Performance Test

Periodically, when in use, SAC-4s should be evaluated for response and reproducibility. Periodic performance tests typically consist of a:

- background measurement
- chi square test
- response within limits established during the initial source check.

20.4 Calibration Instructions

The SAC-4 is calibrated at the PNNL calibration laboratory in the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff.

Before calibration, the instruments are inspected to make sure they are in good working order, switches and buttons are checked for functionally and the instrument is checked for physical damage. Damaged instruments are repaired before calibration. As-found readings are recorded for ^{239}Pu efficiency, the instrument alpha background is evaluated, and the counting circuit is evaluated using a calibrated pulse generator. If the as-found readings are more than ±20% out of tolerance, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

A voltage plateau is performed and the voltage is selected near the center of the plateau region.

Finally, the ^{239}Pu is measured. The minimum acceptable efficiency for ^{239}Pu is 30%. Additional efficiency measurements are performed upon request (e.g., ^{241}Am). The ^{239}Pu efficiency is listed on the calibration sticker.

The SAC-4 is calibrated annually and after any maintenance is performed that voids the existing calibration. The calibration is valid through midnight on the expiration date listed on the calibration sticker.

For more detailed information on instrument calibration, refer to PNL-MA-563, Section 4.1.5.

20.5 Maintenance Instructions

Routine maintenance of the SAC-4 is performed at the calibration laboratory during the calibration. Routine maintenance includes cleaning the detector chamber, adjusting the sample slide tray position, and verifying that the correct polarity power cords are attached. The only reason for field personnel to open the detector case is to remove stuck samples from the drawer or to decontaminate the counting chamber/detector.

The calibration laboratory permanently attaches power cords to the SAC-4 using a metal lanyard to ensure that correct polarity power cords are used. Cords with the proper polarity that are not yet attached by lanyard are marked with green tape. If an instrument is found without a lanyard and without green tape on the power cord, contact the calibration laboratory for a replacement power cord.

CAUTION: *Using a SAC-4 with an improper power cord can result in a personnel shock hazard and/or damage to the instrument.*

Common problems include stuck samples and high background count rates.

Stuck sample: Occasionally, a sample may become lodged inside the SAC-4. To remove the sample, unplug the instrument, and open the instrument case by removing one screw from each side of the instrument and lifting the cover up. Remove the screw from the end of the sample tray, and pull the sample tray out of the SAC-4. If the stuck sample still cannot be removed, contact the calibration laboratory for assistance.

High background: A SAC-4 that develops a high background count rate may have a contaminated sample chamber/detector or a light leak. Contaminated instruments should be decontaminated as soon as possible. Instruments should be decontaminated before sending them to the calibration laboratory. After decontamination, return the instrument to the calibration facility for recalibration if the instrument fails a source check.

Instruments with improperly adjusted sample trays may respond to external light. If the instrument appears to be light sensitive (e.g., high background, fails the chi square test), tag it with an Instrument Service Tag, and return it to the calibration laboratory. The cause of high background should be evaluated to ensure the counting chamber is not contaminated. Placing the instrument in a dark environment, or covering it with a thick piece of cloth (e.g., coat), should reduce the background count rate if the cause is light leakage.

20.6 Instrument Specifications and Limitations

20.6.1 Temperature

The SAC-4 is intended for use indoors. It has not been tested for proper operation in conditions other than controlled environments (indoors). Eberline states a temperatures range between 0°C (32°F) and 60°C (140°F) for the SAC-4.

20.6.2 Temperature Shock

When moving the SAC-4 from one area to another of different temperature, allow the instrument to reach equilibrium with the ambient temperature (usually about 1 hour) before use.

20.6.3 Humidity and Pressure

No data are available regarding instrument response to varying humidity and pressure. The SAC-4 is intended for use indoors. Performance testing in the intended environment should ensure proper functionality.

20.6.4 Electromagnetic Field Interference

No data are available regarding instrument response to external electromagnetic fields. However, the SAC-4 may be sensitive to electromagnetic fields. Photomultiplier tubes, in general, are very sensitive to magnetic fields. Magnetic fields may cause the instrument to read high or low. A common source of fields that may affect SAC-4 response is video displays. If magnetic fields are a potential concern, response checks should be performed in the field at the distances from the magnetic field expected during use.

20.6.5 Radio Frequency Interference

No data are available regarding instrument response external radio frequency fields. However, the SAC-4 should be relatively insensitive to radio frequency fields.

20.6.6 Energies and Types of Radiation

The SAC-4 responds to alpha radiation above ~3 MeV.

20.6.7 Interfering Ionizing Radiation Response

Detector response to gamma and neutron radiation is unknown. Based on detector type, neutron and gamma response should be slight at best. Beta radiation response is discriminated electronically.

20.7 Applications

20.7.1 Air Sample Measurements

The SAC-4 is used to measure the activity on air sample filter media. Excessive dust loading may degrade alpha measurements.

20.7.2 Surface Contamination Measurements

The SAC-4 is used to measure the activity on dry technical smear media. Excessive dust loading and/or moisture may degrade alpha measurements.

21.0 The Eberline BC-4 GM Counter

21.1 Instrument Description and Theory of Operation

The Eberline BC-4 is a GM-based sample counter that is powered by AC. The BC-4 accommodates 2-in. samples (e.g., air filter papers and technical smears). The BC-4 includes a sample drawer to ensure consistent and reproducible geometry.

More detailed technical information can be obtained by contacting the PNNL calibration laboratory at (509) 376-5624.

21.1.1 Physical Description

The BC-4 weighs about 12 kg (26 lb) and measures 27 cm (10 ½ in.) wide by 13 cm (5 in.) high by 34 cm (13 in.) deep (see Figure 21.1). The front panel includes a three-position count time switch, three-position count time range switch (X.1, X1, X10), count mode switch (timed, stop, manual), six-digit LED scaler display, start/reset push-button, red LED indicating counting status, and sample drawer. The rear panel has two fuses, power switch, electrical connection, and slide stop adjustment screw. The high-voltage adjustment is located internally.

Figure 21.1. Eberline BC-4

The detector is a standard pancake GM tube identical to those used with portable beta-gamma contamination survey instruments (e.g., HP-260 and HP-210) with a 4.4-cm (1-¾ in.) diameter window. The window has a density thickness of 1.4 to 2.0 mg/cm^2. Total window density is increased to approximately 7 mg/cm^2 when the

The calibration laboratory adds a 0.002-in.-thick Mylar window. The detector is shielded on the top and sides by a minimum of 2.2 cm (7/8 in.) lead shielding.

The density-thickness of the window is not necessarily uniform across the entire face of the detector. Similarly, the activity on many electroplated sources is not uniformly distributed across the active area of the source. These two non-uniformities may result in count rates that are dependent upon the orientation of the source within the sample holder.

Samples up to 5.2 cm (2 in.) in diameter and 1.0 cm (3/8 in.) thick can be placed in the sample drawer on the front of the instrument. The height of the sample holder can be adjusted to allow for different sample thicknesses. The sample holder height is set during the calibration and must be maintained to use the calibration efficiency. The sample holder height should not be adjusted unless directed by facility-specific protocols. The calibration laboratory can provide calibrations with differing sample holder heights upon request.

21.1.2 Radiation and Energy Response

The BC-4 will respond to beta and gamma radiation. Beta response is energy dependent; the BC-4 responds to beta radiation above ~200 keV (^{99}Tc). The average efficiency is 29% for ^{90}Sr/Y, 10% for ^{99}Tc. Gamma radiation response is also energy dependent, with an efficiency of ~0.5%, responding to gamma radiation above a few keV.

Higher efficiencies and a lower energy limit (i.e., down to ^{14}C or 150 keV) can be achieved by removing the Mylar window. Contact the calibration laboratory for additional information.

The detector window is sufficient to prevent alpha radiation from being detected.

The BC-4 is insensitive to neutron radiation.

21.1.3 Integral Sources

There are no radioactive sources attached to, or inside, the BC-4.

21.2 Operating Instructions

Before using the BC-4, perform the operational checks to make sure the instrument is in good working condition (see Section 21.3.1). These checks should be performed each time the instrument is used.

To count a contamination smear or air sample filter, pull the sample drawer out and place the sample in the tray. Planchets should be used to hold samples (minimizing handling and the potential for cross contamination). Slide the sample holder back beneath the detector.

Set the desired count time, and then press START/RESET to start the count cycle. Count times between 0.1 minutes (6 seconds) and 50 minutes are possible.

General counting precautions include the following:

- The BC-4 is intended for counting dry technical smears and air sample filters. Placement of other types of materials into the counters may result in contamination of the instrument, inaccurate measurements, and/or detector damage.
- The sample drawer should be maintained clean. A cotton swab may be used to remove any residual debris.
- Bent technical smears and air sample filters require extra care because they may easily lodge inside the sample drawer. A thin layer of adhesive between the sample and its planchet may help bent samples lie flat.

- The potential for significant instrument contamination increases with the activity of the sample. Highly radioactive samples may contaminate counting instruments and should be handled with extreme care. Portable survey instruments should be used to survey samples before placing them into the sample drawer. Contact facility technical staff if questions arise regarding sample activity limitations.
- Samples that are wet or that will break apart should not be counted.
- The BC-4 cannot discriminate against radon or radon progeny.
- Use the efficiency values determined during calibration (normally ^{90}Sr/Y), unless the radionuclide and the counting efficiency for another radionuclide of concern are known. Contact the calibration laboratory to request specific isotopic efficiency values.
- Sample counting times will vary to obtain desired MDA or MDC values. The longer a sample is counted, the lower the MDA/MDC value. Sample count times should be long enough to yield the required sensitivity (MDA/MDC).
- Sample count times should be less than or equal to the background count time.
- The sample height is set during calibration and the efficiency values on the calibration sticker are valid for that position only. This sample height must be used for accurate analysis results.

21.2.1 Correction Factors

To obtain the gross cpm, the displayed number must be divided by the number of minutes counted.

To obtain an activity in dpm, divide the net cpm (gross cpm - background cpm) by the detector efficiency, provided the sample height has not been altered. If the sample is a smear, this activity is the dpm/100 cm^2, provided the area smeared is less than or equal to 100 cm^2. When the smeared area is greater than 100 cm^2, divide the measured activity by the ratio area smeared/100 to obtain the dpm/100 cm^2 (e.g., if the smear area 300 cm^2, then divide the measured activity by 300/100 or 3).

21.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions in this section are provided as an example of acceptable methods.

Sources used for performance testing should be traceable to an established calibration standard or have a manufacturer's certificate to document source activity and radioisotopic purity.

21.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the instrument fails either of the first two operability checks, fill out an Instrument Service Tag to identify the problem, attach it to the instrument, and return it to the calibration laboratory for servicing.

1. Inspect the instrument for broken or loose knobs and display.
2. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) on the expiration date on the calibration sticker
3. Verify that the initial source check has been completed.
4. Ensure that the instrument source check is current. Source checks are generally valid for the day performed and typically do not cover more than 24 hours.
5. Ensure that the periodic performance test is current. The periodic performance test is commonly valid for 30 calendar days expiring at 23:59 on the 30th day after it is performed.

21.3.2 Source Check

The BC-4 is typically maintained under statistical process control to ensure its reliable and consistent operation. A combination of daily source checks and periodic surveillance tests provides confidence regarding instrument operation and data validity.

21.3.2.1 Initial Source Check

Upon receipt from the calibration laboratory, or prior to placing an instrument into service, the BC-4 should be tested to ensure that its operation is consistent with the calibration. The initial source check may also establish the performance criteria to be used for subsequent daily source checks and surveillance tests. Initial source checks typically consist of:

- a background measurement
- a chi square test
- checking efficiency within ±10% of calibration efficiency
- establishing response limits.

21.3.2.2 Daily Source Check

Once each day, or prior to intermittent use, BC-4s should be evaluated for instrument response. Daily source checks typically consist of a:

- background measurement
- response within limits established during the initial source check.

21.3.2.3 Periodic Performance Test

Periodically, when in use, BC-4s should be evaluated for response and reproducibility. Periodic performance tests typically consist of a:

- background measurement
- chi square test
- response within limits established during the initial source check.

21.4 Calibration Instructions

The BC-4 is calibrated at the PNNL calibration laboratory in the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff. Before calibration, the instruments are inspected to make sure they are in good working order. Buttons and switches are checked for functionally and to the instrument is checked for physical damage. Damaged instruments are repaired before calibration. As-found readings are recorded for ^{90}Sr/Y and ^{99}Tc efficiency, the instrument beta background is evaluated, and the counting circuit is evaluated using a calibrated pulse generator. If the as-found readings are more than ±20% out of tolerance, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

The applied detector voltage is set to 900 V (±25%).

Finally, a series of efficiencies are recorded, including, at a minimum, ^{90}Sr/Y and ^{99}Tc. The minimum acceptable efficiency for ^{90}Sr/Y is 24%. Additional efficiency measurements are performed upon request (e.g., ^{137}Cs). The ^{90}Sr/Y efficiency is listed on the calibration sticker.

The BC-4 is calibrated annually and after any maintenance is performed that voids the existing calibration. The calibration is valid through midnight on the expiration date listed on the calibration sticker.

For more detailed information on instrument calibration, refer to PNL-MA-563, Section 4.1.5.

21.5 Maintenance Instructions

Routine maintenance of the BC-4 is performed at the calibration laboratory during the calibration. Routine maintenance includes cleaning the detector chamber, adjusting the sample slide tray position, and verifying that the correct polarity power cords are attached. The only reason for field personnel to open the detector case is to remove stuck samples from the drawer or to decontaminate the counting chamber/detector.

The calibration laboratory permanently attaches power cords to the BC-4 using a metal lanyard to ensure that correct polarity power cords are used. Cords with the proper polarity, not yet attached by lanyard, are marked with green tape. If an instrument is found without a lanyard and without green tape on the power cord, contact the calibration laboratory for a replacement power cord.

CAUTION*: Using a BC-4 with an improper power cord can result in a personnel shock hazard and/or damage to the instrument.*

Common problems are stuck samples, high background count rates, and no counts.

Stuck sample: Occasionally, a sample may become lodged inside the BC-4. To remove the sample, unplug the instrument and open the instrument case by removing one screw from each side of the instrument and lifting the cover up. Remove the screw from the end of the sample tray, and pull the sample tray out of the BC-4. If the stuck sample still cannot be removed, follow the instructions for changing a contaminated window to gain access to the stuck sample, or contact the calibration laboratory for assistance.

High background: A BC-4 that develops a high background count rate may have a contaminated Mylar window, detector, or sample chamber. Contaminated instruments should be decontaminated as soon as possible to avoid cross-contaminating samples. They should also be decontaminated before they are sent to the calibration laboratory. To remove a contaminated Mylar window and to clean the detector, take the following steps:

1. Turn the BC-4 off and unplug the AC-power cable.
2. Remove the screws from the instrument cover and remove the cover from the instrument.
3. Remove the four screws from the top of the detector assembly.
4. Disconnect the high-voltage lead.
5. Lift the top shield toward the inside and lay it on its side exposing the GM tube.
6. Remove the GM tube, taking care to not puncture the thin mica window.
7. Remove the Mylar window (if present).
8. If the detector is contaminated, gently clean the detector surface.
9. Reassemble the instrument, reversing the instructions above.
10. If a Mylar window was removed in Step 7, then send the instrument to the calibration laboratory for calibration.
11. If a Mylar window was not removed in Step 7, then perform a daily source check before restoring the instrument to service.

21.6 No counts: **The BC-4 will respond with a low count rate, or not respond at all, if the thin mica window on the detector is broken. GM tubes may not be replaced in the field. If the BC-4 responds low or does not respond, tag it with an Instrument Service Tag, and return it to the calibration laboratory. Instrument Specifications and Limitations**

21.6.1 Temperature

The BC-4 is intended for use indoors. It has not been tested for proper operation in conditions other than controlled environments (indoors). Eberline states a temperatures range between 0°C (32°F) and 60°C (140°F) for the BC-4.

21.6.2 Temperature Shock

When moving the BC-4 from one area to another of different temperature, allow the instrument to reach equilibrium with the ambient temperature (usually about 1 hour) before use.

21.6.3 Humidity and Pressure

No data are available regarding instrument response to varying humidity and pressure. The BC-4 is intended for use indoors. Performance testing in the intended environment should ensure the proper functionality of the instrument.

21.6.4 Electromagnetic Field Interference

No data are available regarding instrument response to external electromagnetic fields. However, the BC-4 should be relatively insensitive to radio frequency fields.

21.6.5 Radio Frequency Interference

No data are available regarding instrument response to external radio frequency fields. However, the BC-4 should be relatively insensitive to radio frequency fields.

21.6.6 Energies and Types of Radiation

The BC-4 responds to beta radiation above ~200 keV and gamma radiation above a few keV.

21.6.7 Interfering Ionizing Radiation Response

The BC-4 will not respond to alpha or neutron radiation.

21.7 Applications

The BC-4 is used to measure the activity on air sample filters and on dry technical smear media.

22.0 The Eberline EC4-X Portable Area Radiation Monitor

22.1 Instrument Description and Theory of Operation

The Eberline Model EC4-X, commonly referred to as the EC4, is a portable area radiation monitor with audible and visual alarms (see Figure 22.1). The monitor displays gamma dose rate in mR/hr, R/hr, or cpm, on a logarithmic scale. The “-X” in the Eberline model number refers to the sensitivity configuration (meter face markings). Most Hanford units range from 0.01 mR/hr to 100 mR/hr, 0.1 mR/hr to 1,000 mR/hr, and 1 mR/hr to 10,000 mR/hr.

Figure 22.1. Eberline EC4-X with Attached Detector

The EC4-X uses GM detectors, DA1-1 and DA1-6, or ionization chambers, DA1-4, DA1-5, and DA1-8. The DA1-6 GM tube is energy compensated. The detector is typically attached to the display side of the unit, as depicted in Figure 22.1.

Each detector housing contains a high-voltage power supply, pulse amplifier, and signal processors. Detectors can be attached with long cables (several hundred feet) to accommodate remote monitoring. The detector may also contain a check source assembly that is operated from the display unit.

The EC4-X requires 105 VAC to 125 VAC and 50 Hz to 60 Hz at 0.60 amps. The display unit supplies the detector low-voltage power through the connecting cable.

The EC4-X display units can be equipped with optional 4 to 20-mA output relays allowing the unit to drive separate remote readout stations or control panels. Alarm relays for low, high, and fail are also available.

More detailed technical information can be obtained by contacting the PNNL calibration laboratory at (509) 376-5624.

22.1.1 Physical Description

The EC4-X display unit measures 31 cm (12 in.) wide by 51 cm (20 in.) high by 18 cm (7 in.) deep and weighs approximately 12 kg (26 lb). The DA1-X detector measures 24 cm (9.5 in.) high by 10 cm (3.9 in.) wide by 12 cm (4.85 in.) deep and weighs 1.13 kg (2.5 lb). If the optional check source is installed, detector weight increases to 1.26 kg (2.75 lb).

The display unit meter uses a 4- or 5-decade log scale depending on the EC4-X model and detector selected. The scale length is 9.8 cm (3.87 in.) and is mounted vertically. Specific instrument ranges are listed in Table 22.1.

Table 22.1. Eberline EC4-X Instrument Range

EC4-X Model Number	Measurement Range
EC4-1	0.01 mR/hr to 100 mR/hr
EC4-2	0.1 mR/hr to 1,000 mR/hr
EC4-3	1.0 mR/hr to 10,000 mR/hr
EC4-4	0.01 R/hr to 100 R/hr
EC4-5	0.1 R/hr to 1,000 R/hr
EC4-6	1.0 R/hr to 10,000 R/hr
EC4-7	10 cpm to 1,000,000 cpm
EC4-8	0.1 mR/hr to 10,000 mR/hr

Detector selection is typically paired with instrument range. Table 20.2 lists the detector ranges for DA1-X series detectors.

Response time varies continuously with count rate. An internal switch enables the selection of either a fast or slow response. Fast response is most commonly used at Hanford. The specific response time setting is chosen by the facility.

Table 22.2. Eberline DA1-X Detector Range

DA1-X Model Number	Measurement Range
DA1-1	0.01 mR/hr to 100 mR/hr (1200 cpm/mR/hr)
DA1-6	0.1 mR/hr to 10,000 mR/hr (80 cpm/mR/hr)
DA1-4	1.0 mR/hr to 100 R/hr (any four decades)
DA1-5	100 mR/hr to 10,000 R/hr (any four decades)
DA1-8	0.1 mR/hr to 10,000 R/hr (any four decades)

To adjust the response time, remove the two locking screws from the right of the front panel, and swing the panel open. Locate switch S5 on the rear of the front panel and position it in the desired setting (S for slow or F for fast).

The display unit includes high (red), alert (amber), and normal (green) indication lights, buzzer, red rotating beacon, ACKNOWLEDGE push button, output relays (as equipped), and a meter.

The alarms and alarm adjustments have been modified at Hanford from the Eberline configuration. When the measured dose rate exceeds the alert alarm set point, the beacon actuates, but the buzzer remains silent. The beacon remains active as long as the measured dose rate exceeds the alert level and cannot be disabled with the ACKNOWLEDGE button. When the measured dose rate exceeds the high-level alarm set point, the buzzer actuates. The ACKNOWLEDGE button silences the buzzer only. In most situations, if the dose rate drops below an alarm set point, the corresponding alarm indicator will be turned off (i.e., alarm indicators are typically non-latching). The alarm adjustments have been relocated so that they may be adjusted without opening the instrument case. A toggle switch was added to the top of the instrument case, typically on the right side of the beacon. The toggle is a two-position switch, one position for each alarm (Alert and High). Two potentiometers were added, one for each alarm. These are typically located to the left of the beacon.

The fail time was increased to approximately 15 minutes for Hanford units.[a] This modification prevents spurious fail alarms in low-background applications. These modifications have been performed on most EC4s in use on the Hanford Site. . Modification of newly purchased units is performed upon request. Upon request, the calibration laboratory will also install two bars around the meter to protect the display from damage if the unit falls forward on its front face.

22.1.2 Radiation and Energy Response

The EC4-X will respond to gamma and high-energy beta radiation. Gamma response, and corresponding linearity, for the various detectors are listed below:

- DA1-1: ±20 percent from 40 keV to 1.25 Mev
- DA1-6: ±15 percent from 40 keV to 1.25 Mev

(a) Memo from ML Johnson, Pacific Northwest National Laboratory, to Eberline EC4-X Configuration File, "Eberline EC4-X Alarm Modifications," October 27, 1998.

- DA1-4: ±10 percent from 50 keV to 1.25 Mev
- DA1-5: ±10 percent from 50 keV to 1.25 Mev
- DA1-8: ±10 percent from 50 keV to 1.25 Mev

The casing is sufficient to discriminate alpha radiation from being detected.

The EC4-X is insensitive to neutron radiation.

22.1.3 Integral Sources

Some EC4s have a detector with a solenoid-operated check source. The internal ^{90}Sr check source is actuated by pushing the Normal light on the front panel. The activity of the source is between 0.15 μCi and 1 μCi, depending on the type of detector. The activity is less than the accountable sealed source activity level (7700 μCi). The calibration laboratory records the check source reading at the time of calibration.

The detector model has the suffix CC (i.e., DAI-8CC) to indicate the presence of a check source. A DAI-8SR (upper range of 1K or 10K R/hr) has a 4- to 5-μCi ^{90}Sr check source.

In some situations, check sources are installed as keep-alive sources. This application is performed for instruments used in areas with low background radiation levels to prevent failure alarms. In these cases, the solenoid actuator is not equipped and the source cannot be actuated by pushing the normal light on the front panel. Detectors with keep-alive sources will be labeled as containing radioactive material, but the detector model will not include CC indicating it contains a check source.

22.2 Operating Instructions

Before using the EC4-X, perform the operational checks to make sure the instrument is in good working condition (see Section 22.3.1). These checks should be performed each time the instrument is used.

1. To set an alarm set point on units that have been modified, as discussed in Section 20.1.1, hold the toggle switch in the direction of the alarm that is to be set, and adjust the corresponding potentiometer until the meter indicates the exposure rate desired as an alarm set point. If the Alert level is set above the High level, the beacon will not actuate at the lower set point. The beacon only actuates with the Alert level, the buzzer with the High level.
2. The EC4-X provides alarm notification to personnel when area gamma radiation levels exceed levels determined by the facility radiological control organization.

   NOTE: *The instrument is generally delivered from PNNL with the POWER switch (internal to the instrument) in the ON position.*

3. Select a suitable location for the instrument. Ensure that the instrument is not located where it may become a hazard to personnel working in the area. The detector may be located remotely from the instrument location if necessary.

Plug the instrument into a 120-VAC power receptacle. Ensure that the Normal light is illuminated.

The detector is affixed to a bracket on the side of the instrument case. The design of the bracket allows the detector to be located remotely from the instrument by using the extension cable normally supplied with the instrument. Detectors are not to be exchanged between instruments. The calibration is only valid with the detector delivered with the instrument from the calibration laboratory. This marriage is denoted on each calibration sticker.

Use common sense and proper lifting techniques when lifting and carrying the instrument. Approximate weight is 13.6 kg (30 lb) with detector.

22.2.1 Correction Factors

No correction factors are used with the EC4-X.

22.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions in this section are provided as an example of acceptable methods.

22.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the instrument fails any of the first three operability checks, fill out an Instrument Service Tag to identify the problem and return it to the calibration laboratory for servicing.

1. Inspect the instrument for broken or loose knobs, and display.
2. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) of the expiration date on the calibration sticker. For the mm/yy formatted expiration date, calibration expires at midnight of last day of the month.
3. Verify that the green Normal light is on.
4. Verify that the Initial Source Check has been completed.
5. Ensure that the instrument source check is current. Source checks are generally valid for three months (one quarter).

22.3.2 Source Check

The EC4-X is typically source checked with the internal source (if so equipped) or with a gamma-emitting source, such as a ^{60}Co V-Block. However, ICCS may also be used in the off-scale position.

22.3.2.1 Initial Source Check

If an internal check source with solenoid actuator is not installed, an initial source check must be performed upon receipt from the calibration laboratory to establish detector response limits.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure the values are reasonable. For the EC4-X, the initial response is reasonable when the response is within*

- *±20% of the response printed on the calibration sticker for an internal source.*
- *±20% of the mean instrument response for that source/detector type.*

In either case, the acceptable range should allow for variations resulting from differing probe efficiency.

Position the source over the detector markings on the DA1-X case, if so equipped. Mark the source position so that subsequent source checks use the same geometry.

Record the instrument response to the source. Multiply the instrument response by 0.8 and 1.2 to determine the acceptable range for that instrument.

22.3.2.2 Periodic Source and Alarm Function Check (Typically Quarterly)

NOTE: *The source used to perform the initial source check is used to perform the periodic source check. To perform a periodic source check with a source other than the one used for the initial source check, first perform the periodic source check on the source used for the initial source check. If the instrument passes that source check, then perform a new initial source check using the new source to establish response limits for that source/EC4 combination.*

Return the source used for the initial source check to the position established during the initial check. The instrument response should fall within the acceptable values determined during the initial source check.

If the instrument has an internal check source with solenoid actuator, depress the green Normal button and allow the detector response to stabilize. Verify that the reading falls within ±20% of the reading identified on the calibration sticker.

While the source is present, actuated if an internal source is used, lower the Alert level set point below the current reading and verify that the beacon actuates. Lower the High level set point below the current reading and verify that the buzzer actuates. Return both set points to the desired settings.

If the instrument fails, tag it with an Instrument Service Tag, and return it to the calibration laboratory.

22.4 Calibration Instructions

The EC4-X is calibrated at the PNNL calibration laboratory in the 318 Building in the 300 Area. The calibration described in this section is performed by the calibration laboratory staff.

Prior to calibration, instruments are inspected to make sure they are in good working order and inspected for physical damage. Damaged instruments are repaired before calibration. As-found readings at the unit (1.0) point of each decade are recorded before calibration. If the as-found readings are more than ±20% out of tolerance, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

The instruments are calibrated in uniform ^{137}Cs photon fields. If the instrument range exceeds 10 R/hr, uniform ^{60}Co photon fields are also used. The uniform fields are produced using source wells and the high-exposure facility (when needed). Each range is calibrated at the unit point of each decade. In addition, the EC4-X is exposed to a radiation field that is at least twice the full-scale reading to make sure it properly off scales. Instruments that do not properly off-scale, do not pass calibration.

Alarm and failure functions are checked. Alarm set points are returned to their as-found settings.

If the unit is equipped with 4-mA to 20-mA output relays, the 4-mA and 20-mA outputs are verified at the unit (1.0) position of the first decade and at full scale, respectively.

If a solenoid actuated check source is installed, the source reading is stated on the instrument.

The calibration is independent of cable length, up to 1,000 ft, provided the correct cable is used (Belden 8777 or Alpha 6010), except for the DA1-8CC detector, which has a limitation of 300 ft with this cable.

EC4s are calibrated annually and after any maintenance is performed that voids the existing calibration. The calibration is valid through midnight of the expiration date listed on the calibration sticker, or at midnight on the last day of the month for the mm/yy formatted expiration date.

For more detailed information on instrument calibration, refer to PNL-MA-563, Section 2.1.3.

22.5 Maintenance Instructions

Routine maintenance on the EC4-X is performed at the calibration laboratory. Routine maintenance includes checking the desiccant and, if it is turning pink, replacing the desiccant (ion chamber instruments only).

Common problems include panel lights or the alarm beacon lights burning out; failure of the audible alarm horn; the meter being broken by mishandling; and cable ends being pulled out of connectors.

Spent desiccant: The calibration laboratory recommends sending instruments for fresh desiccant when the desiccant is becoming clear or pink. However, as long as the instrument functions correctly (as evidenced by successful completion of periodic source checks) the instrument can be used in the field.

22.6 Instrument Specifications and Limitations

22.6.1 Temperature

The EC4-X temperature dependence is less than 20% across the range 10°C to 40°C (50°F to 120°F) for the control unit.

Operating temperatures for the detectors are as follows:

- DA1-1, DA1-6: - 40°C to 60°C (-40°F to 140°F).
- DA1-4: -23°C to 60°C (-10°F to 140°F).

22.6.2 Temperature Shock

No direct test data are available. No temperature shock dependence problems have been noted in records.

As a good practice, allow the EC4-X to reach a thermal equilibrium at the ambient temperature for at least an hour before making measurements.

22.6.3 Humidity and Pressure

The EC4-X is insensitive to changes in ambient humidity. If it is used in areas of high humidity for an extended period, the desiccant in the detector unit (ion chamber instruments only) may become saturated and the instrument may develop an erratic response. In this case, return the EC4-X to the calibration laboratory for maintenance.

The EC4-X detectors are sealed and response is not affected by changes in altitude because of the associated change in ambient pressure.

22.6.4 Radio Frequency/Electromagnetic Interference

No direct test data are available. Some radio frequency interference problems have been noted in the records. Sources of non-ionizing radiation fields include microwaves, portable radios, or cellular phones. Experience has indicated that portable and mobile communication transceivers may create instrument response if they are brought into proximity to an operational EC4-X. No electromagnetic interference problems have been noted in the records. High electromagnetic field sources include generators or ignition sources are welders or particle accelerators. As a precaution, sources of these fields that may affect the EC4-X should be turned off, shielded, or avoided when using near the EC4-X.

22.6.5 Energies and Types of Radiation

EC4-X responds to gamma radiation, as denoted in Section 22.1.2. High-energy beta radiation (e.g., ^{90}Sr/Y) is sufficiently energetic to penetrate the detector case and will be measured by the EC4-X when the source is close to the detector case.

22.6.6 Interfering Ionizing Radiation Response

The EC4-X will not respond to alpha or neutron radiation.

22.7 Applications

22.7.1 Area Radiation Monitoring

An EC4-X should be in use for personnel warning as follows:

- In occupied areas where permanently installed area radiation monitors are out of service.
- When required by a Radiological Work Permit or by Radiological Control.
- When required by a Facility Safety Analysis Report, Operational Safety Requirement, Hazards Identification and Evaluation, or at the discretion of the radiological control organization.

23.0 Ludlum Model 2200 Series Scaler Rate Meter

23.1 Instrument Description and Theory of Operation

The Ludlum 2200 series scaler rate meters are designed to accommodate scintillation, proportional, and GM detectors for measuring radioactive contamination and radiation. The various models (see Figure 23.1) have both digital and analog output. Two channels allow the 2200 series to perform pulse-height analysis and discriminate radiation based on incident energy. The 2200 is a desktop unit, whereas the 2224 and 2224-2 are portable.

Although the 2200 series support a wide variety of detectors, the most commonly paired combinations at Hanford are the 2200/Ludlum 43-10, 2224/NaI detector, and 2224-2/NE DP6BD.

The 43-10 sample counter is an alpha-only version of the 43-10-1 described in Section 17.0 of this manual. The DP6BD is a dual-phosphor alpha/beta detector described in Section 16.0 of this manual. The 2224 pairing with gamma-sensitive NaI detectors is referenced generically because there are many models in use (e.g., Ludlum 44-3, Eberline SPA3, and Bicron G1LE and G2LE). Specific models of NaI detectors are discussed in Section 18.0 of this manual.

2200 2224 2224-2

Figure 23.1. Ludlum 2200, 2224, and 2224-2 Scaler Rate Meters

More detailed technical information can be obtained by contacting the PNNL calibration laboratory at (509) 376-5624 or reviewing the referenced sections of this manual.

23.1.1 Physical Description

23.1.1.1 Ludlum 2200

The 2200 weighs about 3.6 kg (8 lb) without batteries and measures 22 cm (8.5 in.) high by 13 cm (5 in.) wide by 24 cm (9.3 in.) long. The front panel contains the following:

- three-function meter (cpm, detector high voltage, battery strength)
- high-voltage (HV) adjustment potentiometer (200 V to 2500 V)

- two-digit count time dial
- four-position count time range dial (X.1, X1, X10, external)
- power switch (LINE, BAT, CHarGe)
- six-digit LED scaler display
- count-and-hold push buttons
- red light, indicating counting status
- mega high-voltage connection
- four-digit range switch for analog meter (X1, X10, X100, X1K)
- two-position toggle switch for rate meter response time (F/S)
- adjusting knob for LED display intensity (DIM)
- window on/off toggle
- potentiometers for Window and Threshold
- discriminator set screw
- three-position switch for establishing meter function (Rate, HV, BAT)
- linear analog meter (0 cpm to 500 cpm, 0 kV to 2.5 kV detector HV, battery strength).

The rear panel includes a 1-amp fuse, 15-pin data output connector, battery access panel, and 115-V AC cable connector. Four internal potentiometers are used to calibrate the rate meter (one potentiometer for each range).

Response time varies from 2.2 seconds (fast) to 22 seconds (slow).

23.1.1.2 Ludlum 2224-2

The 2224-2 is approximately 22 cm long, 9 cm wide, and 11 cm high (8.5 in. by 3.5 in. by 4.2 in.) not including the handle and weighs 1.5 kg (3.3 lb) without batteries or attached detector. External instrument controls include:

- volume adjust knob
- six-digit LED display for scaler results
- analog logarithmic meter (0 to 1M cpm, 0 to 2 kV detector HV, BAT OK)
- mega high-voltage connection
- eight-position count time (min) switch (0.1, 0.5, 1, 2, 5, 10, 60, ∞)
- five-position rotary switch (Off, BAT, alpha, beta, alpha/beta)
- three-position toggle switch (Reset/Null/Read HV)
- headphone jack (1/8 in.)

- push button for starting scaler count (located in handle end).

Internal controls used during calibration include an HV adjustment potentiometer, audio divide DIP switch (beta tone only), tone DIP switch, potentiometer for meter calibration, alpha and beta discriminators, and beta window.

Response time is 4 seconds from 200 cpm to 200,000 cpm. Recovery time is considerably longer. The meter requires 18 seconds to drop from 200,000 cpm to 200 cpm in the absence of radiation.

23.1.1.3 Ludlum 2224

The 2224 is approximately 22 cm long, 9 cm wide, and 11 cm high (8.5 in. by 3.5 in. by 4.2 in.), not including the handle and weighs 1.36 kg (3 lb) without batteries or attached detector. External instrument controls include:

- volume adjust knob
- six-digit LED display for scaler results
- analog linear meter (0 to 500 cpm, 0 to 2 kV detector HV, BAT OK)
- series 'C' connection
- six position rotary switch (Off, BAT, X1000, X100, X10, X1)
- three position toggle switch (alpha, alpha/beta, beta)
- high voltage test push button
- reset push button (RES) for resetting meter reading (drives reading rapidly to zero)
- push button for starting scaler count (located in handle end).

Internal controls used during calibration include an HV adjustment potentiometer, audio divide DIP switch (beta tone only), tone DIP switch, potentiometers for meter calibration, alpha and beta discriminators, beta window, and internal DIP switch to set the scaler count time (6, 30, 60, or 120 seconds).

Response time is dependent upon the operating range as follows:

- X1 = 10 seconds
- X10 = 7 seconds
- X100 = 2 seconds
- X1000 = 1.5 seconds.

23.1.2 Radiation and Energy Response

Radiation response is dependent upon the attached detector. Refer to Section 16.1.2 for the DP6BD and Section 18.1.2 for NaI detectors.

The 43-10 detector responds to alpha radiation above ~3 MeV. Alpha response may be energy dependent but should be relatively consistent for ^{241}Am and ^{239}Pu. The 43-10 average ^{239}Pu efficiency is 40%.

The 43-10's construction and discriminator settings minimize response to beta radiation.

Detector response to neutron and gamma radiation is unknown. Based on detector type, neutron and gamma response should be slight at best.

23.1.3 Integral Sources

The 2224/2224-2 may have an alpha-emitting source attached to its side for performing response checks in the field. These sources are typically on the order of 0.85 nCi (~2000 dpm) ^{230}Th. See Section 5.0, Figure 5.1, of this manual for an example of these sources.

23.2 Operating Instructions

Before using a 2200 series instrument, perform the operational check to make sure the instrument is in good working condition (see Section 23.3.1). These checks should be performed each time the instrument is used.

Ensure that the appropriate detector is attached and commence with a radiological survey according to contractor-specific operating procedures.

23.2.1 Ludlum 2200/43-10

To count a contamination smear or air sample filter, rotate the sample drawer knob counter-clockwise, pull the sample drawer out, and place the sample in the tray. Planchets should be used to hold samples (minimizing handling and the potential for cross contamination). Slide the sample holder back beneath the detector, and lock the slide in position by rotating the locking knob clockwise. The sample holder must be pushed completely in to trip a microswitch, thereby activating the detector voltage.

Set the desired count time, and then press the COUNT button to start the count cycle. Count times between 0.1 minutes (6 seconds) and 990 minutes (16.5 hours) are possible.

General counting precautions include the following:

- The 43-10 is intended for counting dry technical smears and air sample filters. Placement of other types of materials into the counters may result in contamination of the instrument, inaccurate measurements, and/or detector damage.
- The sample drawer should be maintained clean. A cotton swab may be used to remove any residual debris.
- Bent technical smears and air sample filters require extra care because they may easily lodge inside the sample drawer. A thin layer of adhesive between the sample and its planchet may help bent samples lie flat.

- The potential for significant instrument contamination increases with the activity of the sample. Highly radioactive samples may contaminate counting instruments and should be handled with extreme care. Portable survey instruments should be used to survey samples before placing them into the sample drawer. Contact facility technical staff if questions arise regarding sample activity limitations.
- Samples that are wet or that will break apart should not be counted.
- The 43-10 does not discriminate radon or radon progeny.
- Use the efficiency values determined during calibration (normally ^{239}Pu), unless the radionuclide and the counting efficiency for another radionuclide of concern is known. Contact the calibration laboratory to request specific isotopic efficiency values.
- Sample counting times will vary to obtain desired MDA or MDC values. The longer a sample is counted, the lower the MDA/MDC value. Sample count times should be long enough to yield the required sensitivity (MDA/MDC).
- Sample count times should be less than or equal to the background count time.
- The 43-10 includes a sample holder, approximately 1 cm (3/8 in.) thick. This holder must be used for accurate analysis results.

23.2.2 Ludlum Model 224/2224-2

The speaker emits separate tones for alpha and beta radiation. Beta radiation is indicated by a lower pitch tone relative to the alpha radiation pitch tone. The beta radiation tone frequency may be independent of the actual count rate because the instrument has an internal click divider. For example, an instrument with a click divider of 100 will chirp once for every 100 counts.

Pressing the scaler count button, located in the end of the handle, during a count, zeroes the display and restarts the count. The count time is typically set at 1 minute on the 2224.

23.2.3 Correction Factors

23.2.3.1 Measurements with 2200/43-10

When using the scaler function to obtain the gross cpm, the displayed number must be divided by the number of minutes counted. When using the rate meter, the displayed value must be multiplied by the range setting (X1, X10, X100, X1K).

To obtain an activity in dpm, divide the net cpm (gross cpm-background cpm) by the detector efficiency.

If the sample is a smear, this activity is the dpm/100 cm^2, provided the area smeared is less than or equal to 100 cm^2. When the smeared area is greater than 100 cm^2, divide the measured activity by the ratio area smeared/100 to obtain the dpm/100 cm^2 (e.g., if the smear area 300 cm^2, then divide the measured activity by 300/100 or 3).

23.2.3.2 Measurements with 2224 or 2224-2 w/DP6BD

When using the scaler function to obtain the gross cpm, the displayed number must be divided by the number of minutes counted. When using the rate meter on the 2224, the displayed value must be multiplied by the range setting (X1, X10, X100, X1K).

Use the specific efficiency for the radionuclide being surveyed, if known. If the radionuclide mix is not known, then a default efficiency of 0.10 (10%) should be used for beta radioactivity levels and 0.14 (14%) should be used for alpha radioactivity levels.

23.2.3.3 Measurements with NaI Detectors

Sodium Iodide detectors used as qualitative surveying devices do not require applying correction factors.

23.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions in this section are provided as examples of acceptable methods.

23.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the instrument fails any of the first three operability checks, fill out an Instrument Service Tag to identify the problem, attach it to the instrument, and return it to the calibration laboratory for servicing.

1. Inspect the instrument for physical defects, such as broken meter face, loose knobs or switches, punctured probe windows, light leaks, or defective cables (if so equipped).
2. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) on the expiration date on the calibration sticker.
3. Verify that the HV reading shows an upscale value on the meter.
4. Verify that the initial source check has been completed.
5. Ensure that the instrument source check is current. Source checks are generally valid for the day performed and typically do not cover more than 24 hours.
6. Turn the count rate meter selector switch to BAT.
7. The meter will indicate battery level. If the needle does not rise above the BAT OK (2224-2 and 2224) or BAT TEST (2200), replace the batteries. Some Model 2200 instruments will not operate without batteries, even when connected to AC line voltage. Refer to Section 23.5 for specific information regarding battery changes.

23.3.2 Source Check

Instructions for DP6BD-equipped instruments are in Section 16.3.2 of this manual.

Instructions for 43-10-equipped instruments are located in Section 17.3.2 of this manual. The 2220/43-10 instrument combinations are typically managed according to bench-top mini-scaler protocols for performance testing.

23.3.2.1 Initial Source Check

Initial source checks should be performed immediately upon receiving the instrument from the calibration laboratory. Instruments should not be placed into storage until after performing the initial source check.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure the values are reasonable. The initial response is reasonable when it is within ±20% of the mean instrument response for that source.*

The acceptable range should allow for variations resulting from differing probe efficiency.

Center the detector over the check source. A jig or mark may be used to ensure reproducibility. Allow the reading to stabilize (rate meter), and note the instrument response. Alternatively, a scaler count may be performed. Multiply the instrument response by 0.8 and 1.2 to determine the acceptable range for that instrument/source combination.

23.3.2.2 Daily Source Check

NOTE: *The source used to perform the initial source check is used to perform the daily source check. To perform a daily source check with a source other than the one used for the initial source check, first perform the daily source check on the source used for the initial source check. If the instrument passes that daily source check, then perform a new initial source check using the new source to establish response limits for that source/instrument combination.*

Establish the source-to-detector geometry used during the initial source check. Allow the reading to stabilize (rate meter,) and note the instrument response. Alternatively, a scaler count may be performed. The instrument response should fall within the acceptable values determined during the initial source check.

If the instrument fails, tag it with a completed Instrument Service Tag, and return it to the calibration laboratory.

23.3.2.3 Response Checks

Periodically verify that the 2224 or 2224-2 responds to radiation during continuous use. Response check the instrument by placing the probe over the check source mounted on the instrument case and verify that the speaker (if so equipped) and meter respond to the source. Alternatively, background radiation may be used to response check the instrument when integral sources are not present.

23.4 Calibration Instructions

The 2200 series instruments are calibrated at the PNNL calibration laboratory in the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff.

Before calibration, instruments are inspected to make sure they are in good working order, to check the functionality of the switches and buttons, and to check the instrument for physical damage. Damaged instruments are repaired before they are calibrated. If the as-found readings are greater than ±20% out of tolerance, the calibration laboratory contacts the radiological control organization that last used the instrument to inform them of the problem.

The rate meter is calibrated electronically using a pulse generator. For the 2200 and 2224, instrument response is evaluated at two points in each decade up to 400,000 cpm (i.e., at 100 cpm, 400 cpm, 1,000 cpm, 4,000 cpm, 10,000 cpm, 40,000 cpm, 100,000 cpm, and 400,000 cpm). The off-scale meter response is also evaluated. The scaler function is then verified by performing a 1-minute count at 400,000 cpm (2200) or 40,000 cpm (2224). The 2224-2-rate meter is evaluated at one point within each decade of the logarithmic display (i.e., 100, 1,000, 10,000, 100,000, 1,000,000) and the scaler function evaluated at 100,000 cpm for 1 minute. The count rate meter must fall within ±5%, and the scaler response must be within ±2% of the delivered stimulus to pass calibration.

External potentiometers on the 2200 are locked during calibration. Adjusting these potentiometers voids the existing calibration.

These instruments are calibrated annually and after any maintenance is performed that voids the existing calibration. The calibration is valid through midnight of the expiration date listed on the calibration sticker.

For more detailed information on instrument calibration, refer to PNL-MA-563, Sections 4.1.11 (2200/NaI), 3.9.4 (2224), and 3.31 (2200/43-10).

23.4.1 Sodium Iodide Calibration

As-found efficiencies are recorded for an appropriate gamma-emitting radionuclide (e.g., ^{137}Cs, ^{129}I) and the background evaluated. When a ^{125}I efficiency is requested, the ^{129}I efficiency is used to determine the ^{125}I efficiency value.

Threshold and window settings are established and a high-voltage plateau is performed. After setting the HV, the efficiency of the requested radionuclide is measured. The alpha, beta, alpha/beta markings on the 2224-meter are covered and the beta channel is labeled gamma.

23.4.2 DP6BD Calibration

As-found efficiencies are recorded for ^{239}Pu, $^{90}Sr/Y$, and any other radionuclide(s) used during previous calibration (e.g., ^{137}Cs, ^{241}Am). Background is evaluated and the probes are checked for light leaks.

Threshold and window settings are established. If the calibration is intended to establish a beta-only probe, a high-voltage plateau is performed. If a dual alpha/beta probe is to be established, the high voltage is set to minimize probe cross talk. After the high voltage is established, the requested efficiencies are recorded (e.g., ^{137}Cs, ^{90}Sr/Y, ^{239}Pu, ^{241}Am).

To pass calibration, the ^{90}Sr(Y) efficiency must be at least 20% and the ^{239}Pu efficiency must be at least 10%. The evaluated efficiencies are stated in the limitations section of the calibration sticker. The beta-to-alpha crosstalk is limited to less than 1%.

In addition to efficiency limits, the detector background cannot exceed 350 cpm for the beta channel and 2 cpm for the alpha channel.

23.4.3 43-10 Calibration

The threshold is set and a voltage plateau is performed. High voltage is selected to minimize the background count rate while providing stable response. After setting the HV, the background and ^{239}Pu efficiency are measured.

23.5 Maintenance Instructions

Routine maintenance on the 2200 Series is performed at the calibration laboratory and in the field. Routine maintenance includes checking/replacing the batteries. Additionally, for the DP6BD and 43-10 detectors, maintenance includes checking the PMT for noise (DP6BD) and the window for light leaks. Common problems and causes are discussed below.

Low batteries: When the BAT mode indicates battery strength below the acceptable cutoff on the dial, the batteries should be changed. Batteries can be replaced in the field, excluding areas controlled for radiological contamination. Open the battery case (on the back of the 2200 and beneath the handle on the 2224), and replace the D cell batteries (2 in 2224 and 2224-2, 4 in 2200). Rechargeable nickel-cadmium or lead acid GEL CEL batteries must be used in the 2200. Batteries are charged in the 2200 using the charge (labeled CHG) position on the power switch. Do not use carbon zinc batteries in the 2200.

Light sensitivity - DP6BD: If the DP6BD exhibits a high-count rate when exposed to light, there are probably holes in the Mylar window. Even very small pinholes, too small to be seen with the naked eye, can cause the instrument to exhibit light sensitivity. To verify light sensitivity, expose the probe to a light source and verify an increased count rate. Then, cover the probe with a light shield (such as a dark cloth) and verify that the count rate drops. If the probe has a light leak, tag it with an Instrument Service Tag, and return it to the calibration laboratory for servicing.

Small light leaks on the DP6BD face can be repaired in the field. Locating a light leak involves placing the probe under a source of light that causes audible output and covering small sections of the probe face until a decrease in the count rate is observed. Using Testor brand (or equivalent) silver paint, cover the holes in the Mylar. The maximum area of the probe that is covered with paint should be limited to 1% (1 cm^2) of the total surface area.

Cable noise: Damaged cables may cause the 2224 and 2224-2 to exhibit a noisy response, especially when the cable is moved. Damaged cables can be replaced in the field. Make sure that the replacement cable has appropriate connections on both ends. The replacement cable must be the same length as the original.

Saturation: Very large light leaks will cause the DP6BD to saturate (i.e., not respond at all). To verify that a DP6BD is exhibiting saturation, place a dark shield over the probe. Slowly remove the shield while listening to the audible response. If the DP6BD has large light leaks, the audible response will first increases as the shield is removed and then decrease as the probe face is fully exposed to the light. If the probe is exhibiting saturation, tag it with an Instrument Service Tag, and return it to the calibration laboratory for servicing.

PMT noise: Faulty PMTs will cause the DP6BD to have a noisy response when the probe is shaken or moved. To determine if the PMT should be replaced, lightly tap the back of the probe several times against your hand. If tapping the detector causes an audible response, the PMT should be replaced. Tag the DP6BD with an Instrument Service Tag, and return it to the calibration laboratory.

Stuck sample: Occasionally a sample may become lodged inside the 43-10. To remove the sample, unplug the instrument (disconnect the AC-power cable and the signal cable from the 2200) and dismantle the sample tray assembly. Contact the calibration laboratory for assistance.

High background: A 43-10 that develops a high-background count rate may have a contaminated sample chamber/detector or a light leak. Contaminated instruments should be decontaminated as soon as possible. Instruments should be decontaminated before sending them to the calibration laboratory. After decontamination, if the instrument fails a source check, return the instrument to the calibration laboratory for recalibration.

A 43-10 detector with improperly adjusted sample trays or dislodged o-rings may respond to external light. If the instrument appears light sensitive (e.g., exhibits high background or fails the chi square test), tag it with an Instrument Service Tag, and return it to the calibration laboratory. The cause of high background should be evaluated to ensure that the counting chamber is not contaminated. Placing the instrument in a dark environment or covering it with a thick piece of cloth (e.g., coat) should reduce the background count rate if the cause is light leakage.

23.6 Instrument Specifications and Limitations

23.6.1 Temperature

Ludlum states temperatures range between -10°C (-14°F) and 50°C (122°F) for the 2224-2/2224 and -20°C (-4°F) to 50°C (122°F) for the 2200 and 43-10.

The temperature response of the 2224 paired with the DP6BD was evaluated by PNNL.[(a)] In the alpha mode, this instrument combination complied with the ANSI Standard N42.17C (instrument response fell within ±5% across the range of -20°C to 60°C) (ANSI 1989). In the beta mode, this

(a) Johnson 1996. Letter from ML Johnson, Pacific Northwest National Laboratory, to S.L. Jones, Martin-Marietta Energy Systems, “Results of ANSI N42.17A and N42.17C Testing of Ludlum 2224-1 and NE Technology DP6BD,” October 16, 1996.

instrument combination failed the ANSI N42.17C criteria across the -20°C to 60°C temperature range. ANSI N42.17C allows no more than a ±20% variation in response because of temperature changes.

23.6.2 Temperature Shock

When moving a 2200 series instrument from one area to another of different temperature, allow the instrument to reach equilibrium with the ambient temperature (usually about 1 hour) before use.

The temperature shock response of the 2224 paired with the DP6BD was evaluated by PNNL.[a] The instruments were subjected to shocks from 22°C to 70°C to 22°C and 22°C to -40°C to 22°C. In the alpha mode, this instrument combination complied with ANSI N42.17C (instrument response fell within ±5% for each shock). In the beta mode, this instrument combination failed the ANSI N42.17C temperature shock criteria. ANSI N42.17C allows no more than a ±20% variation in response because of temperature shocks.

23.6.3 Humidity and Pressure

No manufacturer data are available regarding 2200 Series scaler rate meters or the 43-10-detector response to varying humidity and pressure. Performance testing in the intended environment should ensure proper functionality.

The humidity response of the 2224 paired with the DP6BD was evaluated by PNNL.[a] The instruments were subjected to varying humidity across the range of 40% to 95% relative humidity. This instrument combination complied with ANSI N42.17A (ANSI N42.17A)(instrument response fell within ±5%) for both alpha and beta modes.

The 2200 Series with attached probe should not be used in condensing environments.

23.6.4 Electromagnetic Field Interference

No data are available regarding instrument response to external electromagnetic fields. However, the 43-10 and DP6BD may be sensitive to electromagnetic fields. Photomultiplier tubes, in general, are very sensitive to magnetic fields. Magnetic fields may cause the instrument to read high or low. A common source of fields that may affect response is video displays. If magnetic fields are a potential concern, response checks should be performed in the field at the distances from the magnetic field expected during use.

23.6.5 Radio Frequency Interference

No data are available regarding instrument response to external radio frequency fields. However, these instruments should be relatively insensitive to radio frequency fields.

(a) Johnson 1996. Letter from ML Johnson, Pacific Northwest National Laboratory, to S.L. Jones, Martin-Marietta Energy Systems, “Results of ANSI N42.17A and N42.17C Testing of Ludlum 2224-1 and NE Technology DP6BD,” October 16, 1996.

23.6.6 Energies and Types of Radiation

Radiation response is dependent upon the attached detector. Refer to Section 16.1.2 for the DP6BD and Section 18.1.2 for NaI detectors.

The 43-10 detector respond to alpha radiation. Specific information regarding this response is listed in Section 23.1.2.

23.6.7 Interfering Ionizing Radiation Response

Radiation response is dependent upon the attached detector. Refer to Section 16.1.2 for the DP6BD and Section 18.1.2 for NaI detectors.

The 43-10 detector response to neutron and gamma radiation is unknown. Based on detector type, neutron and gamma response should be slight at best.

23.6.8 Battery Life

Ludlum claims a battery life exceeding 350 hours for the 2224-2 and 20 hours for the 2200.

23.7 Applications

The 2200 Series instruments perform a number of measurements depending upon the attached probe. The DP6BD detector is used for direct and removable contamination surveys, the 43-10 is used for removable contamination and airborne radioactivity assessment, and NaI detector performs qualitative assessment of gamma radiation levels.

23.7.1 DP6BD Detector

Refer to Section 16.7 for DP6BD applications.

23.7.2 43-10 Detector

Section 17.7 for 43-10 applications.

23.7.3 Sodium Iodide Detector

Refer to contractor-specific operational procedures.

23.8 References

NOTE: *For information on technical manuals, see Bibliography.*

ANSI N42.17A-1989. 1989. *Performance Specifications for Health Physics Instrumentation - Portable Instrumentation for Use in Normal Environmental Conditions*. American National Standards Institute, New York.

ANSI N42.17C-1989. 1989. *Performance Specification for Health Physics Instrumentation - Occupational Airborne Radioactivity Monitoring Instrumentation*. American National Standards Institute, New York.

24.0 Xetex/Eberline Model 330A Telescan

24.1 Instrument Description and Theory of Operation

The Xetex/Eberline Model 330A Telescan is a gamma radiation exposure rate instrument with high-range capabilities and a telescopic probe that extends up to 4 m (13 ft) from the display unit. The instrument is microprocessor-based with an analog display. The Telescan uses two energy-compensated GM detectors to cover a wide range of exposure rates. The centerlines of the two detectors are indicated with scribed lines. The high-range detector is closest to the display (see Figure 24.1). The Telescan can not quantify non-penetrating radiation exposure rates.

Figure 24.1. Xetex Telescan Detector Assembly with Detector Position Indicators

Measurement data from the detector assembly are transmitted to the display unit via an infrared link.

More detailed technical information can be obtained by contacting PNNL calibration laboratory at (509) 376-5624.

24.1.1 Physical Description

The Telescan measures approximately 9.5 cm (3.75 in.) wide by 5.1 cm (2 in.) high by 109 cm (3.6 ft) long in the pole-retracted position. With the pole fully extended, its length increases to 429 cm (14.1 ft). The Telescan weighs 2.95 kg (6.5 lb). The instrument is commonly purchased as a Model 330A-C, which includes a carrying case, shoulder strap, and clear plastic sleeving. The carrying case also accommodates the batteries, battery holder, and technical manual (see Figure 24.2).

Figure 24.2. Xetex Telescan Model 330A-C (Typical Hanford Field Configuration)

The display unit has a nine-position rotary switch for selecting the meter range, battery check, and power off positions. Three membrane switches are located at the bottom of the unit to turn the internal speaker and meter light on and off and to reset the meter from an over-range condition or drive the response to zero. The display has a red LED above the membrane switches to alert the user to an instrument malfunction (see Figure 24.3 and Section 24.2).

The analog meter has a linear range from 0 to 10. The specific measurement range is determined by the rotary switch position. The low-range detector measurement range options are 0 mR/hr to 1 mR/hr, 0 mR/hr to 10 mR/hr, 0 mR/hr to 100 mR/hr, and 0 mR/hr to 1,000 mR/hr. The high-range detector options are 0 R/hr to 10 R/hr, 0 R/hr to 100 R/hr, and 0 R/hr to 1,000 R/hr. The meter is marked with a green bar to indicate acceptable battery strength.

The response time is established during calibration and varies between 1 and 4 seconds; depending on exposure rate and specific calibration adjustments.

The instrument uses two independent energy-compensated GM detectors; one for mR/hr exposure rates, and one for R/hr exposure rates. The detectors are housed in an aluminum casing that is sufficiently thick to prevent most beta radiation from being measured.

Figure 24.3. Xetex Telescan Display Unit

24.1.2 Radiation and Energy Response

The Telescan responds to gamma radiation from 70 keV to 1 MeV. Although photon response outside this range will vary as a function of energy, within this range, the Telescan energy response is within ±15%. Typical detector sensitivity is 1040 cpm/mR/hr (low range) and 21 cpm/mR/hr (high range).

These Telescan responds to high-energy beta radiation (e.g., ^{90}Sr/Y).

The Telescan does not respond to alpha or neutron radiation.

24.1.3 Integral Sources

There are no radioactive sources attached to, or inside, the Telescan.

24.2 Operating Instructions

WARNING: *The Telescan will not indicate an over range condition if it is turned on with the detector in a radiation field that exceeds the selected range or when the detector is quickly moved in to a field exceeding the selected range. To engage the latching over-range condition, the detector must be brought into the over-ranging, but non-saturating, field* ***after*** *it is turned on. Once the over-range condition is acknowledged, by pressing the RESET button, the Telescan will not indicate an over-range condition until the detector has been removed from the over range field.*

A continuously pegged meter indicates an over-range condition on the high-range detector. When an over-range condition occurs, remove the detector from the high-radiation field and either press RESET or turn the unit off and back on again to clear the over-range condition. If the range switch is set to read the low-range detector and the detector is brought into a field of 1.5 R/hr, or greater, the meter will off-scale high. If the range switch is then positioned to read the high-range detector, and the actual field strength is within the selected range, the over-range condition will automatically clear. If the instrument is switched back to any of the low-range detector positions, the meter will off scale high again. The high-range detector over-ranges when exposed to more than 1,300 R/hr.

Perform the operability check (see Section 24.3.1). Turn the instrument on and select the appropriate scale. Slowly move the instrument near radiation sources. When quantifying radiation levels, allow the instrument meter to stabilize for a few seconds before recording the instrument response.

Avoid hitting the telescoping pole or detector against other objects, such as walls, poles, or light fixtures. The extended pole can be easily bent, making it difficult to collapse.

A continuously glowing red malfunction LED and a series of beeps from the speaker indicates an instrument malfunction. The instrument should not be used while it is malfunctioning. The specific malfunction can be decoded by counting the number of consecutive beeps from the instrument, according to the following:

Table 24.1. Telescan Failure Codes

Number of Beeps	Failure
1	Remote (probe) battery failure
2	Remote HV failure
3	Serial communications failure
4	Not used
5	Low-range detector fail low
6	Not used
7	Remote battery failure and remote high-voltage (HV) failure
8	High-range detector fail low

24.2.1 Correction Factors

The instrument is calibrated in uniform gamma fields.

Temperature correction is needed when measuring at temperatures below 0°C (32°F). Correct the meter reading as indicated below:

- -10°C to 0°C (14°F to 32°F): Multiply reading by 1.2
- -18°C to -10°C (0°F to 14°F): Multiply reading by 1.3

24.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions below are provided as examples of acceptable methods.

24.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the instrument fails any of the checks listed below, other than battery test, return it to the calibration laboratory for servicing.

1. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) on the expiration date on the calibration sticker.
2. Verify that the instrument source check is current. Source checks are generally valid for the day performed and typically do not cover more than 24 hours.
3. Inspect the instrument for physical defects such as broken meter glass, loose knobs, or other observable defects.
4. Turn the control switch to Battery. The meter reading should be within the green Battery Check band. If not, go to Section 24.5.

NOTE: *When turned on, the instrument performs internal diagnostic protocols. Faults will be signaled by a flashing malfunction light and a series of tones (see Section 24.2). If the malfunction light remains on, tag the instrument with an Instrument Service Tag and return it to the calibration laboratory.*

5. Turn the selector switch to the lowest range (X.l), allow a 10-second warm-up, and verify that the malfunction LED does not illuminate.

24.3.2 Source Check

The Telescan may be source checked using a variety of sources, including ICCSs and linear beta sources. The source should provide an on-scale response at one point within the range of the low-range detector. Sources are not typically available to source check the high-range detector. When the high-range detector is not source checked, it should not be used to perform occupational monitoring.

A Quick Check can be requested from the calibration laboratory to verify that each instrument range is functioning, when source checks are not performed in the field.

24.3.2.1 Initial Source Check

Initial source checks should be performed immediately upon receiving the instrument from the calibration laboratory. Instruments should not be placed into storage until after performing the initial source check.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure the values are reasonable. Methods to determine whether the initial response is considered reasonable when the response is within ±20% of the mean instrument response for that source.*

The acceptable range should allow for variations resulting from differing instrument response.

Center the detector over the check source. A jig or mark may be used to ensure reproducibility. Allow the reading to stabilize and note the instrument response. Multiply the instrument response by 0.8 and 1.2 to determine the acceptable range for that instrument/source combination.

24.3.2.2 Daily Source Check

NOTE: *The source used to perform the initial source check is used to perform the daily source check. To perform a daily source check with a source other than the one used for the initial source check, first perform the daily source check on the source used for the initial source check. If the instrument passes that daily source check, then perform a new initial source check using the new source to establish response limits for that source/instrument combination.*

Establish the source-to-detector geometry used during the initial source check. Allow the reading to stabilize and note the instrument response. The instrument response should fall within the acceptable values determined during the initial source check. If the instrument fails, tag it with an Instrument Service Tag and return it to the calibration laboratory.

Source checks are generally valid for 24 hours after they are performed.

24.3.2.3 Response Checks

Response checks should be performed periodically during continuous use and each time the instrument is turned on. To response check the instrument, turn the instrument and speaker on. Verify that the instrument has an audible response and upscale meter deflection.

24.4 Calibration Instructions

The Telescan is calibrated at the PNNL calibration laboratory at the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff.

Before calibration, instruments are inspected to make sure they are in good working order. Batteries are checked, the meter is checked for oscillations, and the instrument is inspected for physical damage. Damaged instruments are repaired before calibration.

Before calibration, as-found readings are recorded at one point on each decade. If the as-found readings are more than ±20% out of tolerance from the conventionally true value, the calibration laboratory notifies the radiological control organization that last used the instrument.

Extendable survey instruments are calibrated in uniform ^{137}Cs and ^{60}Co radiation fields. Each detector has two calibration adjustments (linear calibration and dead time). The linear calibration is performed at the midpoint of one range for each detector (i.e., 5 mR/hr for the low-range detector and 5 R/hr for the high-range detector). After the linear calibration adjustment, the dead time is checked and adjusted at 80% of full scale for each detector (i.e., 800 mR/hr for the low-range detector and 800 R/hr for the high-range detector). After adjustment, the response at 20% and 80% of each decade is measured. The instrument response at each point has to be within ±10% of the conventionally true value for the instrument to pass calibration. Each detector is also exposed to a field that is at least twice the full-scale response to verify that the instrument properly off scales.

The Telescan is calibrated annually and after any maintenance is performed (other than battery changes). The calibration is valid through midnight on the expiration date listed on the calibration sticker.

For more information on calibrating extendable survey instruments, refer to PNL-MA-563, Section 3.13.2.

24.5 Maintenance Instructions

Routine maintenance on the Telescan is performed at the calibration laboratory and in the field. Typical maintenance includes cleaning the instrument and replacing batteries. Common problems include low, no, or sporadic response (described below).

Low batteries: If the instrument has low batteries, the batteries may be replaced in the field (excluding Contamination, High Contamination Area, or Airborne Radioactivity Areas). Remove the handle from the display unit, and replace all batteries with fresh 1.5-V C cell alkaline batteries. Install batteries with the positive terminal up (toward remote display). Correct battery orientation is indicated by a decal on the battery holder.

Do not attempt to replace the batteries in the remote probe. If the Telescan indicates loss of communication or (toward remote display) low batteries, tag the instrument with an Instrument Service Tag, and return it to the calibration laboratory.

The instrument should be source checked following a battery change.

Low, no, or sporadic response: The instrument may have a degraded response because the infrared communication between the detector assembly and display unit has been degraded. If the instrument does not properly respond to radiation, tag it with an Instrument Service Tag and return it to the calibration laboratory.

24.6 Instrument Specifications and Limitations

24.6.1 Temperature

The Telescan may be used without correction over the temperature range of 0°C to 40°C (32°F to104°F). Corrections are applied when the instrument is used at temperatures below 0°C (see Section 24.2.1).

24.6.2 Temperature Shock

The Telescan should not be not affected by temperature shocks. However, it is good practice to allow the instrument temperature to equalize with ambient temperature before using it to perform surveys.

24.6.3 Humidity and Pressure

The Telescan can be used within that range 0% to 95% relative humidity. If the instrument will be used in a damp or condensing environment, the probe should be sleeved in plastic.

Condensation (beads of water) may form on the instrument when moving a cold instrument to a warm, humid, environment. The instrument should be allowed to equalize with the ambient temperature and condensation should be removed.

The Telescan is not affected by changes in ambient pressure typically encountered on the Hanford Site.

24.6.4 Radio Frequency/Electromagnetic Interference

The Telescan is not affected by external electromagnetic or radio frequency fields.

24.6.5 Energies and Types of Radiation

Both detectors (high- and low-range) respond to photons within ±15% of the true exposure rate from 70 keV to 1 MeV. Although the Telescan does not measure non-penetrating exposure rates, high-energy beta radiation interferes with measured penetrating exposure rates.

24.6.6 Interfering Ionizing Radiation Response

The Telescan responds to high-energy beta radiation (e.g., ^{90}Sr/Y).

The Telescan does not respond to neutron or alpha radiations.

24.6.7 Battery Life

The 4C cell batteries, housed in the display unit handle, provide approximately 400 hours of operation.

The batteries in the detector assembly provide 80 hours of operation in a 100-R/hr field. These batteries will last for roughly 350 hours of operation when measuring no radiation.

24.7 Applications

The Telescan is used to measure penetrating radiation exposure rates. The instrument does not evaluate non-penetrating radiation exposure rates, but is influenced by high-energy beta radiation.

The high-range detector should not be used for occupational monitoring unless it has been source checked (see Section 24.3.2).

25.0 WB Johnson Model 1000W & 2000W Extender

25.1 Instrument Description and Theory of Operation

The WB Johnson Extender, Models 1000W and 2000W, are beta- and gamma-radiation exposure rate instruments with high-range capabilities and telescoping probes extending up to 3.7 m (12 ft) from the display unit.

The Extender uses two energy-compensated GM detectors to cover a wide range of exposure rates. The centerlines of the two detectors are indicated on the probe with colored lines. The high-range detector is marked with yellow and is closest to the display (see Figure 25.1).

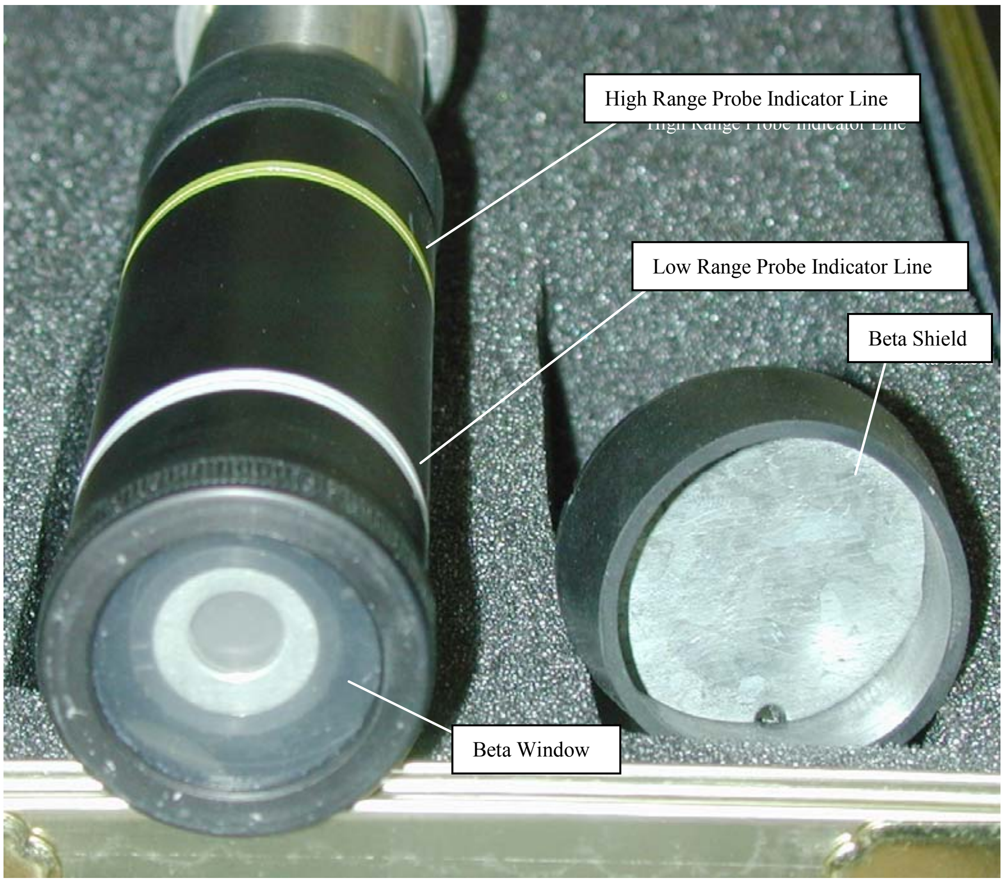

Figure 25.1. Extender Detector Assembly with Detector Position Indicators and Beta Window/Shield

Measurement data from the detector assembly are transmitted to the display unit via a four-conductor flat ribbon cable.

More detailed technical information can be obtained by contacting the PNNL calibration laboratory at (509) 376-5624.

25.1.1 Physical Description

The Extender measures approximately 12 cm (4.7 in.) wide by 9 cm (3.5 in.) high by 98 cm (3.2 ft) long in the pole-retracted position. With the pole fully extended, length increases to 370 cm (12 ft). The Extender weighs 3.2 kg (7 lb). The instrument is commonly purchased with a carrying case, which includes shoulder strap and clear plastic sleeving. The carrying case also accommodates the batteries, battery holder, and technical manual (see Figure 25.2).

Figure 25.2. WB Johnson Extender (Typical Hanford Field Configuration)

The display unit has a side-mounted, 10-position, rotary switch for selecting the meter range, battery check, and power off positions. A second four-position rotary switch is located on the display unit, below the meter, for turning the internal speaker and meter light on and off (see Figure 25.3).

The instrument has a single analog meter. The 10-position rotary dial changes the meter range, display, and switches between the low- and high-range detectors. The display backdrop is color-coded to indicate which detector is used (i.e., yellow display indicates high-range detector, white display indicates low-range detector). Each range is a combination linear/log display (this effect is most pronounced on the high-range scales). The low-range detector measurement range selections are 0 μR/hr to 1000 μR/hr, 0 mR/hr to 10 mR/hr, and 0 mR/hr to 100 mR/hr. The high-range detector options are 0 to 1000 mR/hr, 0 R/hr to 10 R/hr, 0 R/hr to 100 R/hr, and 0 R/hr to 1,000 R/hr. The meter includes two battery check positions, marked with a BK bar, indicating acceptable battery strength.

The response time varies between 1.5 and 4 seconds, depending on selected range.

The instrument uses two independent energy-compensated GM detectors. The detectors are housed in an aluminum casing that is sufficiently thick to prevent most beta radiation from being measured. The low-range detector has a removable beta shield (see Figure 25.1). With the beta shield removed, the low-range detector beta response broadens to include lower-energy beta radiation.

Figure 25.3. Extender 2000W Display Unit

25.1.2 Radiation and Energy Response

The Extender's low-range detector responds within ±15% of the true exposure rate to photons from 65 keV to 2 MeV. The high-range detector responds within ±15% of the true exposure rate for photons from 83 keV to 2 MeV.

With the beta shield removed, the low-range detector responds to beta radiation above roughly 150 keV (e.g., ^{14}C).

Both detectors respond to high-energy beta radiation (e.g., $^{90}Sr/Y$), regardless of the beta shield position.

The Extender does not respond to alpha or neutron radiation.

25.1.3 Integral Sources

There are no radioactive sources attached to, or inside, the Extender.

25.2 Operating Instructions

Perform the operability check (Section 25.3.1) before using the Extender. Turn the instrument on and select the appropriate scale. Slowly move the instrument near radiation sources. When quantifying radiation levels, allow the instrument meter to stabilize for a few seconds before recording the instrument response.

Avoid hitting the telescoping pole or detector against other objects, such as walls, poles, or light fixtures. The extended pole is easily bent making it difficult to collapse.

NOTE: *When making measurements with the beta shield removed, an off-scale high response can be obtained on the low-range detector and no response obtained on the high-range detector when the field is predominantly beta radiation.*

Compare field strength measurements, using the low-range detector, with the beta shield on and off to determine if the radiation field contains a significant beta-emitting component.

NOTE: *Avoid twisting the probe. Twisting the probe can damage the communication cable. Also, do not collapse extended probe quickly because the communication cable take-up spool can become tangled if the probe is collapsed abruptly.*

25.2.1 Correction Factors

The instrument is calibrated in uniform gamma fields.

25.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions below are provided as examples of acceptable methods.

25.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. If the instrument fails any of the checks listed below, other than battery test, return it to the calibration laboratory for servicing.

1. Verify that the calibration of the instrument is current. The calibration expires at midnight (11:59 p.m.) on the expiration date on the calibration sticker.

2. Verify that the instrument source check is current. Source checks are generally valid for the day performed and typically do not cover more than 24 hours.
3. Inspect the instrument for physical defects such as broken meter glass, loose knobs, or other observable defects.
4. Turn the control switch to BK. The meter reading should be within the BK band. If not, go to Section 25.5.

25.3.2 Source Check

The WB Johnson Extender may be source checked using a variety of sources including ICCSs and linear beta sources. The source should provide an on-scale response at one point within the range of the low-range detector. Sources are not typically available to source check the high-range detector. When the high-range detector is not source checked, it should not be used to perform occupational monitoring.

A Quick Check can be requested from the calibration laboratory to verify that each instrument range is functioning, when source checks are not performed in the field.

25.3.2.1 Initial Source Check

Initial source checks should be performed immediately upon receiving the instrument from the calibration laboratory. Instruments should not be placed into storage until after performing the initial source check.

NOTE: *Instrument response observed during the initial source check should be evaluated to ensure the values are reasonable. The initial response is reasonable when the response is within ±20% of the mean instrument response for that source.*

The acceptable range should allow for variations resulting from differing instrument response.

Center the detector over the check source. Remove the beta shield, if desired. A jig or mark may be used to ensure reproducibility. Allow the reading to stabilize and note the instrument response. Multiply the instrument response by 0.8 and 1.2 to determine the acceptable range for that instrument/source combination.

25.3.2.2 Daily Source Check

NOTE: *The source used to perform the initial source check is used to perform the daily source check. To perform a daily source check with a source other than the one used for the initial source check, first perform the daily source check on the source used for the initial source check. If the instrument passes that daily source check, then perform a new initial source check using the new source to establish response limits for that source/instrument combination.*

Establish the source-to-detector geometry used during the initial source check including the presence, or absence, of the beta shield. Allow the reading to stabilize and note the instrument response. The instrument response should fall within the acceptable values determined during the initial source check. If the instrument fails, tag it with an Instrument Service Tag, and return it to the calibration laboratory.

Source checks are generally valid for 24 hours after they are performed.

25.3.2.3 Response Checks

Response checks should be performed periodically during continuous use and each time the instrument is turned on. To response check the instrument, turn the instrument and speaker on. Verify that the instrument has an audible response and upscale meter deflection.

25.4 Calibration Instructions

The WB Johnson Extender is calibrated at the PNNL calibration laboratory at the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff.

Before calibration, instruments are inspected to make sure they are in good working order. Batteries are checked, the meter is checked for oscillations, and the instrument is inspected for physical damage. Damaged instruments are repaired before calibration.

Before calibration, as-found readings are recorded at one point on each decade. If the as-found readings are greater than ±20% from the conventionally true value, the calibration laboratory notifies the radiological control organization that used the instrument last.

Extendable survey instruments are calibrated in uniform ^{137}Cs and ^{60}Co radiation fields. Each range setting has a single calibration adjustment. After adjustment, the response at 20% and 80% of each decade is measured. The instrument's response at each point has to be within ±10% of the conventionally true value for the instrument to pass calibration. Each detector is also exposed to a field that is at least twice the full-scale response to verify that the instrument properly off scales.

The Extender is calibrated annually and after any maintenance is performed (other than battery changes). The calibration is valid through midnight of the expiration date listed on the calibration sticker.

For more information on calibrating extendable survey instruments, refer to PNL-MA-563, Section 3.13.4.

25.5 Maintenance Instructions

Routine maintenance on the Extender is performed at the calibration laboratory and in the field. Typical maintenance includes cleaning the instrument and replacing batteries.

Low batteries: If the instrument has low batteries, the batteries may be replaced in the field (excluding Contamination, High Contamination, or Airborne Radioactivity Areas). Remove the handle from the display unit and replace both batteries with fresh 1.5-V D cell, alkaline batteries.

The instrument should be source checked following a battery change.

25.6 Instrument Specifications and Limitations

25.6.1 Temperature

The 2000W Extender may be used over the temperature range from -20°C to 60°C (-4°F to 140°F).

The 1000W Extender may be used over the temperature range -8°C to 50°C (18°F to 120°F).

25.6.2 Temperature Shock

The Extender should not be not affected by temperature shocks. However, it is good practice to allow the instrument temperature to equalize with ambient temperature before using it to perform surveys.

25.6.3 Humidity and Pressure

The 2000W Extender can be used within that range of 0% to 95% relative humidity. The manufacturer has not identified an appropriate range for the 1000W extender.

If the instrument will be used in a damp or condensing environment, the probe should be sleeved in plastic.

Condensation (beads of water) may form on the instrument when moving a cold instrument to a warm, humid, environment. The instrument should be allowed to equalize with the ambient temperature and condensation should be removed.

The Extender is not affected by changes in ambient pressure typically encountered on the Hanford Site.

25.6.4 Radio Frequency/Electromagnetic Interference

The Extender is not affected by external electromagnetic or radio frequency fields.

25.6.5 Energies and Types of Radiation

The low-range detector responds to photons within ±15% of the true exposure rate from 65 keV to 2 MeV. The high-range detector responds to photons within ±15% of the true exposure rate from 83 keV to 2 MeV.

With the beta shield removed, the low-range detector responds to beta radiation above roughly 150 keV (e.g., ^{14}C).

25.6.6 Interfering Ionizing Radiation Response

The WB Johnson Extender responds to high-energy beta radiation (e.g., $^{90}Sr/Y$) with the beta shield installed.

The Extender does not respond to neutron or alpha radiation.

25.6.7 Battery Life

The two D cell batteries, housed in the display unit handle, provide approximately 300 hours of operation in the 2000W and 130 hours in the 1000W.

25.7 Applications

The Extender is used to measure penetrating radiation exposure rates.

The instrument does not evaluate non-penetrating radiation exposure rates, but can be used to determine if beta radiation represents a significant portion of a radiation field.

High-energy beta radiation (e.g., ^{90}Sr/Y) interferes with penetrating radiation measurements.

The high-range detector should not be used for occupational monitoring unless it has been source checked (see Section 25.3.2).

26.0 Canberra Alpha Sentry Continuous Air Monitor

26.1 Instrument Description and Theory of Operation

The Canberra Alpha Sentry CAM is a semi-portable device designed to monitor alpha radioactivity in the air. The Alpha Sentry CAM consists of two components; a sampling head, and controller. Two different sampling heads are used at Hanford; the AS1700 and AS1700R. Both use a 1700-mm^2 Canberra passivated implanted planar silicon (PIPS) detector with a diameter of 4.7 cm (1.8 in.). The AS1700R is a compliant version of the AS1700 that complies with ANSI N42.17B-1989. From the outside, the two models are indistinguishable. Up to eight sampling heads are controlled from a single controlling unit which may be a model ASM1000 for 110V applications or a ASM1001 for 220V applications (see Figure 26.1). For the purposes of this document, the ASM1000 and the ASM1001 are referred to generically as an ASM. An in-line adapter is available for the sampling head to allow for direct connection to a pipe or duct (see Figure 26.2).

The Alpha Sentry uses a 256-channel multi-channel analyzer (MCA) and performs radon rejection protocols based on peak-fitting/ stripping methods.

Figure 26.1. Canberra Alpha Sentry (Sampling Head and Controller)

Figure 26.2. Sampling Head and Optional In-Line Adapter

More detailed technical information can be obtained by contacting PNNL calibration laboratory at (509) 376-5624.

26.1.1 Physical Description

The Alpha Sentry sampling head measures approximately 31 cm (12 in.) high and 18 cm (7 in.) in diameter. The head weighs approximately 3.6 kg (8 lb). The head requires 24-V AC, 50/60-Hz, and < 15 W power supplied by the ASM. The ASM measures roughly 32 cm (13 in.) high by 22 cm (8.7 in) wide by 9 cm (3.5 in.) deep. The ASM requires 115 ±10 VAC, or 230 ±20 VAC depending on specific model, 50/60 Hz, and < 15 W supplied power.

The air inlet on the sampling head is covered with a diffusion screen that removes more than 95% of the unattached radon and radon progeny. This screen is most effective in laboratory environments with treated air (e.g., downstream of a high-efficiency particulate air filter). The unattached fraction in typical Hanford environments is small compared to the attached radon and radon progeny.

Both the ASM and sampling head provide alarm signals to indicate elevated levels of alpha-emitting airborne radioactivity. The alarm signals include audible and visual alarms, and actuating remote alarm relays. The instrument also provides a series of fault alarms, including high background, low or high airflow, detector bias power supply failure, door open, no data acquisition, excessive energy calibration shift, and communication failure between ASM and sampling head. Instrument alarms may be latching or non-latching, depending upon facility configuration. To clear latching alarms, press STOP ALARM on the ASM. By default, if the alarm condition remains, pressing STOP ALARM silences the audible alarm, leaving the visual alarm active. This feature can be disabled using Canberra's Alpha Sentry CAM software.

Personnel interact with the CAM using the ASM. The ASM's detailed display screen provides specific information regarding measured radioactivity for an attached head. The measured DAC-hr, activity concentration, sample flow rate, and measured cpm are listed. The ASM also lists active alarms. The ASM can display the energy spectrum and maintains history logs for review.

Alpha Sentry CAMs are equipped with mass flow meters to measure flow rate. The unit typically reads out in cubic feet per minute (cfm); however, other flow units are available.

Filter papers are placed in a filter pack assembly that is set in the filter drawer of the sampling head (see Figure 26.3).

Figure 26.3. Sampling Head with Open Filter Drawer

26.1.1.1 CAM Controls

The ASM includes many controlling features. These features commonly used by CAM operators (e.g., health physics technicians) are discussed below. Controls are accessed by pressing a soft key switch on the ASM.

Stop alarm: The red button acknowledges posted alarms and clears latching alarms after the alarm condition has been eliminated.

Filter change (F1): Press this button before changing the filter paper assembly. Two options follow; Date/Time and Filter Change. Date/Time is used to update the head’s internal date and time before changing the filter paper. Pressing Filter Change primes the head for changing the filter assembly.

Perf check (F2): Press this button before source checking the CAM. Pressing Perf Check primes the head for removing the filter paper and placing the check source puck into the head.

Data review (F3): Press this button to access three review options—Hist Trends (F1), Alarm Log (F2), and View Spectrum (F3). Hist Trends displays an electronic strip chart and View Spectrum displays the energy spectrum for the selected head.

System setup (F4): Press this button to access a series of control features including the following:

- Source Info: Used to enter specific activity information for the check source.
- Parameter Setup: Used to adjust alarm set point, units, and miscellaneous CAM settings.

Network display: Press this button to display the heads currently attached to an ASM. From the network display, the user selects the head they wish to access for further information.

Detailed display: Press this button to access detailed information for the selected head, including air flow rate, cpm, concentration, DAC-hr exposure, active alarms, and date of the last efficiency and airflow calibration.

26.1.1.2 CAM Alarms

There are four different classes of alarms—acute, chronic, instrument fault, and high background.

The Acute Alarm calculation is performed at every user preset Acute Alarm Counting Interval (default value is 30 seconds) in the sampling head based on the counts collected during the previous Acute Alarm Counting Interval. An Acute Alarm occurs if the number of counts in the region of interest (e.g., ^{239}Pu) exceeds the acute alarm set point *and* the ratio of the average counts per channel in the region of interest to the 6.05 MeV radon progeny peak exceeds 2. By default, the acute alarm set point is set at the factory to 80 cpm. This value can be changed by connecting to a remote computer and using the Alpha Sentry Software program. If communication is lost between the ASM and head, the Acute Alarm remains active.

The Chronic Alarm calculation is performed by the ASM and relayed to the head. The chronic alarm has two modes—DAC and DAC-hr. A Chronic Alarm occurs when the selected set point has been exceeded and the region of interest has collected at least 25 counts in the current counting interval. For DAC-hr alarms, the time since the last filter change is used to determine the exposure. If communication is lost between the ASM and head, the Chronic Alarm is disabled.

The ASM also performs diagnostics, continuously verifying functionality, including communications between the ASM and attached heads. Errors discovered during these diagnostics trigger the Fault Alarm.

Alarms trigger a combination of audible and visual alarms. Tables 26.1 and 26.2 identify the default settings for ASM and sample head alarm indications, respectively. Contact facility staff regarding deviations from these tables. The Fast Tone is an intermittent loud tone with a period of one-half second. The Slow Tone is an intermittent soft tone with a period of two seconds. Loud tones are 90 dB, soft tones are 85 dB.

Table 26.1. Default ASM Alarm Indicators

Alarm Condition	Red Lamp	Amber Light	Horn	Exposure Relay	Troubl e Relay	Screen	Alarm Log Entry
Acute Release	X		Fast	X		X	X
Chronic Release	X		Fast	X		X	X
Instrument Fault		X	Slow		X	X	X
High Background						X	
Stop Alarm Button			X				N/A
High background	Reverse video for the CAM display box						

Table 26.2. Default Alpha Sentry CAM-Sample Head Alarm Indicators

Alarm Condition	Strobe	Horn	Exposure Relay	Trouble Relay
Acute Release	X	Fast	X	
Chronic Release	X	Fast	X	
Instrument Fault	X	Slow		X

26.1.2 Radiation and Energy Response

The Alpha Sentry CAM responds to alpha radiation exclusively. Alpha particles with energies from approximately 3 MeV to 10 Mev are measured. The Alpha Sentry CAM has an average efficiency of 29% for electroplated ^{241}Am sources (47 mm diameter).

The instrument does not respond to neutron or beta radiation.

The Alpha Sentry CAM responds to naturally occurring alpha-emitting, airborne particulate such as radon progeny. The Alpha Sentry CAM uses a radon-rejection screen to prevent up to 95%, or more, of the unattached radon progeny from reaching the filter paper and being measured by the detector. For radon progeny collected on the filter, the CAM uses an alpha-peak, tail-stripping algorithm to remove interfering radon progeny data from the region of interest, differentiating between naturally occurring alpha-emitting activity and radionuclides of interest (e.g., ^{239}Pu, ^{241}Am).

26.1.3 Integral Sources

There are no radioactive sources attached to, or inside, these instruments.

26.2 Operating Instructions

Placing an Alpha Sentry CAM in service requires power (115 or 220 VAC, depending on ASM model) supplied to the ASM and vacuum-source utilities, supplied to the CAM head. Depending on the location and application, remote signal and/or alarm cables may be connected to the electronic output terminal strip located on the back of the CAM head and/or ASM.

Prior to use, ensure that the performance test protocols of Section 26.3 are complete. Operating a CAM requires establishing air flow to a specific rate or range, installing a membrane filter paper, and setting the alarm set point. The Millipore Fluoropore membrane filter is recommended. Glass fiber filters are discouraged because of self-absorption characteristics that can cause false alarms.

26.2.1 Correction Factors

Correction factors are not used to operate these instruments.

26.3 Performance Test Instructions

Refer to contractor-specific procedures for performance test instructions. The instructions below are provided as examples of acceptable methods.

26.3.1 Operability Check

Prior to using an instrument, an operability check is typically performed to verify that an instrument is functional and is in calibration. Operability checks are typically performed and documented daily. Although the following steps are not a procedure, these steps are typically considered when writing operability check procedures.

Check everything listed below. When in service, operability checks are typically performed and documented daily. Daily checks typically include the following steps:

1. Verify that the calibration of the instrument is current.
2. Verify that positive airflow is within the recommended range of 48.1 lpm - 65.1 lpm (1.7 cfm - 2.3 cfm) for 1700 mm^2 detector.
3. Verify that the response to background is greater than zero.
4. Verify that the electronic chart recorder is operational.
5. Verify that the vacuum lines are secure.
6. Remove any debris/obstructions present on the CAM.
7. Verify that the sample head's green Count LED is on.
8. Verify that the sample head's red Alarm LED is off.
9. Verify that the ASM's amber Instrument Failure light is off.
10. Verify that the sample door shut and latched.
11. Verify CAM control settings as follows:
    a. Proper Analysis Window setting: 2.7 MeV for ^{239}Pu, 2.8 MeV for ^{241}Am
    b. Proper Upper Energy Limit setting: 5.7 MeV for ^{239}Pu, 5.8 MeV for ^{241}Am
    c. Proper Confidence Level setting: Typically 1.65
    d. Chronic Alarm set point appropriately set: Typically 8 DAC-hr, or less.

26.3.2 Source Check

The Alpha Sentry CAM is source checked with an electroplated, or anodized, alpha-emitting source, typically ^{241}Am. The radionuclide used for source checking should match the radionuclide to which the CAM was calibrated. A special puck is necessary to hold the source and allow for placing the source in the proper geometry. The source puck is typically red in color.

Source checks should be performed with sources calibrated within the source puck. This calibration is available from the calibration laboratory.

26.3.2.1 Initial Source Check

If the source check is performed with a calibrated source, no special initial source check protocols are required. Otherwise, the initial efficiency should be measured, establishing acceptable limits for subsequent source checks at ±20% of the initial response. Regardless, CAMs should be source checked upon installation, and periodically thereafter.

26.3.2.2 Periodic Source Check (Performance Check)

CAM source checks are typically performed weekly and often coordinated with filter paper exchange. The source activity and energy should be entered through the ASM (System Setup…Source Info) before performing a source check. Alpha energies are typically 5.486 MeV (^{241}Am) or 5.155 MeV (^{239}Pu).

1. Select the desired CAM head using the network display, and then select Detailed Display.
2. Press F2 (Perf Check) and wait for the ASM to indicate the CAM head is Primed for performance check.
3. Verify that the source activity matches the source that will be used for source checking.
4. Remove the filter cartridge and replace it with the check source assembly.
5. Close and latch the door to initiate source counting.

The ASM performs a source count and compares the measured efficiency against the calibration efficiency. The measured efficiency must fall within a certain percentage of the calibration efficiency (default value is ±10%) to pass the source check. The ASM also compares the location of the alpha peak against the energy calibration and determines if the peak has shifted. If errors are encountered, the ASM posts a fault message. If the system passes the source check, the ASM indicates Pass in the Status block of the Performance Check screen. Depending upon the specific ASM configuration, source and alarm tests may be performed during this test and the ASM indicates Perf + Acute Test. If a fault message occurs, tag the instrument out of service and include the fault message on the service tag. Return the tagged instrument to the calibration laboratory for repair and/or calibration.

26.3.2.3 Alarm Function Test

Periodically, an in-service CAM should be tested to ensure properly operating alarm capabilities. CAM alarms are initiated by replacing the filter paper housing with the check source housing and verifying that audible and visual alarms occur.

Alarm function tests are typically performed monthly. Depending upon specific ASM configuration, source and alarm tests may be performed during periodic source checks (Section 26.3.2.2).

26.4 Calibration Instructions

The Alpha CAM is calibrated at the PNNL calibration laboratory at the 318 Building in the 300 Area. The calibration described in this section is performed by PNNL staff. Only the CAM heads are sent in for calibration (i.e., ASMs are not calibrated).

Before calibration, instruments are inspected to make sure they are in good working order. The detector background is measured and maintained to 5 cpm or less. In certain instances, higher background count rates may be accepted by the customer. Before calibration, the as-found efficiency and flow rate are evaluated. If the as-found efficiency reading varies more than ±20% from the previous calibration, or the measured airflow rate varies more than ±15% from the conventionally true value, the calibration laboratory notifies the radiological control organization that last used the instrument.

Calibration involves verifying and setting electronic parameters and performing efficiency and flow rate calibrations with standards that are traceable to the NIST. The minimum acceptable efficiency is 20%. Airflow is calibrated across the range from 1.5 cfm to 2.5 cfm. Verified parameters include the DAC-hr alarm set point (8), flow out of tolerance criteria (0.5 cfm and 2.5 cfm), confidence level (1.65), DAC factor (2.00E-12), upper energy limit (5.700), analysis window (2.700), count cycle (30), airflow units (cfm), activity units (μCi), and volume units (cm^3). The CAM head is checked for in-leakage by placing a blocked puck into the sample holder and verifying that the flow rate drops to 0 cfm. The horn, lights, and relays are verified as being operable.

Unless otherwise specified, the Alpha CAM is calibrated annually or after any maintenance/activity that voids the existing calibration. The calibration is valid until midnight of the last day of the month, as indicated on the calibration sticker.

For more detailed information on Alpha CAM calibration, refer to PNL-MA-563, Section 4.2.24.

26.5 Preventive Maintenance

Routine maintenance on the Alpha Sentry CAM is performed at the calibration laboratory and in the field. Routine maintenance includes changing filter papers, cleaning detectors and radon rejection screens, and inspecting and replacing o-rings.

Change filter paper: The filter exchange frequency is dependent upon the concentration of suspended particulate (e.g., dust and radioactive material). Common practice is to exchange CAM filters weekly. Because the Alpha CAM is susceptible to filter-loading effects (self absorption), the exchange frequency should be adjusted when attenuation causes operational problems such as spurious alarms. The Alpha CAM should use a Millipore Fluoropor membrane filter.

High background: If the CAM background becomes elevated, the detector may be cleaned according to manufacturer recommendations. It is easy to damage the detector during cleaning.

O-rings: O-rings should be inspected for cracks, seating, and dirt at each filter exchange. Special attention is necessary to ensure that the lower seal is present, because this seal is frequently dislodged. During calibration, o-rings are inspected, lubricated, or replaced if they are excessively dirty, do not fit properly, or are cracked.

Cleaning radon rejection screen: When used in dusty environments, the screen may become clogged and dirty. The screen can be removed from the head and cleaned using a variety of solvents.

26.6 Instrument Specifications and Limitations

26.6.1 Temperature

The operational temperature of CAM head is 0°C (32°F) to 55°C (131°F).

The ASM shares the temperature range of the head. However, the liquid crystal display may not function above 35°C (95°F).

26.6.2 Temperature Shock

Alpha Sentry CAMs are typically operated indoors and not exposed to temperature shocks. However, it is good practice to allow an instrument's temperature to equalize with the ambient temperature before placing it in service.

26.6.3 Humidity and Pressure

The CAM head and ASM are appropriate for the ambient humidity (0 %to 95) and pressure encountered on the Hanford Site. The instrument should not be used in condensing environments.

26.6.4 Radio Frequency/Electromagnetic Interference

The AS1700 is influenced by electromagnetic and radio frequency fields.

Field strengths of 5 V/m (140 MHz) will interfere with the CAM head. The AS1700R withstands fields exceeding 100 V/m at this frequency.

Field strengths of 20 V/m between 30 and 35 MHz will interfere with the CAM head. The AS1700R withstands fields exceeding 100 V/m within this frequency range.

The AS1700 is influenced by microwave fields. Field strengths of 50 V/m (915 MHz) and 100 V/m (2450 MHz) will interfere with the CAM head. The AS1700R withstands fields exceeding 200 V/m at both frequencies.

The AS1700 is sensitive to electrostatic shock. 5000-V shocks caused the measured background to increase by more than a factor of 15. The AS1700R was insensitive to the same electrostatic stimulus.

26.6.5 Energies and Types of Radiation

The Alpha CAM is sensitive to alpha radiation. The PIPS detector exhibits uniform energy response to alpha particles in the MeV range. The average efficiency for electroplated ^{241}Am sources (47 mm diameter) is 29%.

The calibration determines the energy range of interest. For example, an Alpha CAM calibrated for ^{239}Pu (Analysis Window = 2.7 MeV, Upper Energy Limit = 5.7 MeV) monitors alpha radiation between 3 MeV and 5.7 MeV as the region of interest.

26.6.6 Interfering Ionizing Radiation Response

The Alpha CAM does not respond to gamma, beta, or neutron radiation.

Alpha CAM detectors are sensitive to visible light. Light leaks will generate spurious counts within the spectrum. These counts typically register across the entire spectrum. Instruments are particularly susceptible to strobe lights.

26.6.7 Particle Transport Efficiency

Texas A&M University Mechanical Engineering Department's Aerosol Technology Laboratory tested the particle transport capabilities of the Alpha CAM sampling head (Kurz design) (McFarland, Ortiz, and Rodgers, 1989). Table 26.3 summarizes their test results.

Table 26.3. Particle Transport Efficiency

Particulate Penetration Percentages (per particle size and air speed)					
Flow Rate	**3 μm @ 1 m/s**	**7 μm @ 1 m/s**	**7 μm @ 0.3 m/s**	**14.8 μm @ 1 m/s**	**14.8 μm @ 0.3 m/s**
2 cfm	97.7%	103%	97.3%	85.7%	81.5%

26.7 Applications

The Alpha CAM is designed to selectively measure airborne concentrations of man-made alpha-emitters in the presence of natural occurring radon and their progeny. These instruments provide both visual and audible alarms, if so equipped, if airborne concentrations of the isotope being monitored exceed a predetermined, user-selectable value (e.g., DAC-h alarm set point). This instrument is most often applied as a workplace monitor although it may be applied to stack, duct, or plenum exhaust monitoring.

The manufacturer claims, under non-laboratory conditions (~1 pCi/l radon background, most attached) and a constant 1 DAC plutonium concentration, a sensitivity of ~ 3.5 DAC-hr (for the 1700-mm^2 detector) or ~4 DAC-hr (for the 450-mm^2 detector).

26.8 References

NOTE: *For information on technical manuals, see Bibliography.*

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Ludlum Model 2929 Dual-Channel Scaler Instruction Manual, January 1999.

Ludlum Model 43-10-1 Alpha-Beta Sample Counter Instruction Manual, February 2002.

Ludlum Model 43-78-5 Alpha-Beta Sample Counter Instruction Manual, July 1999.

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Operation and Instruction Manual for Johnson Model 2000W Extender, WmB. Johnson and Associates, Inc., date not available.

Operating Manual for Model 1000W Extender, WmB Johnson and Associates, Inc., date not available.

XETEX, Telescan Model 330A Instruction Manual, Revision B, October 1993.

Technical manuals can be obtained by contacting the manufacturer. Contact information for obtaining copies of manuals is provided below.

Bicron ◆NE
6801 Cochran Road
Solon, OH 44139

Canberra Industries, Inc.
800 Research Parkway
Meriden, CT 06450
(A subsidiary of Thermo Instrument Systems, Inc.)

Eberline
P.O. Box 2108
Santa Fe, NM, 87504-2108

Ludlum Measurements, Inc.
501 Oak Street /P.O. Box 810
Sweetwater, TX 79556

NE Technology Limited
Bath Road, Beenham, Reading
Berkshire. RG7 5PR.. England

Nuclear Research Corporation
125 Titus Avenue/P.O. Box H
Warrington, PA 18976

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