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Technical Basis to Describe the Use of the Eberline E-600

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ACRONYMS

ANSI	American National Standards Institute
CFR	*Code of Federal Regulations*
cpm	counts per minute
cps	counts per second
DOE	U.S. Department of Energy
EPROM	erasable, programmable, read-only memory
ERC	Environmental Restoration Contractor
GM	Geiger-Mueller
HIEC	Hanford Instrument Evaluation Committee
HPIC	Health Physics Instrumentation Committee
NaI	sodium iodide
PNNL	Pacific Northwest National Laboratory

METRIC CONVERSION CHART

Into Metric Units			Out of Metric Units		
If You Know	*Multiply By*	*To Get*	*If You Know*	*Multiply By*	*To Get*
Length			**Length**		
inches	25.4	millimeters	millimeters	0.039	inches
inches	2.54	centimeters	centimeters	0.394	inches
feet	0.305	meters	meters	3.281	feet
yards	0.914	meters	meters	1.094	yards
miles	1.609	kilometers	kilometers	0.621	miles
Area			**Area**		
sq. inches	6.452	sq. centimeters	sq. centimeters	0.155	sq. inches
sq. feet	0.093	sq. meters	sq. meters	10.76	sq. feet
sq. yards	0.836	sq. meters	sq. meters	1.196	sq. yards
sq. miles	2.6	sq. kilometers	sq. kilometers	0.4	sq. miles
acres	0.405	hectares	hectares	2.47	acres
Mass (weight)			**Mass (weight)**		
ounces	28.35	grams	grams	0.035	ounces
pounds	0.454	kilograms	kilograms	2.205	pounds
ton	0.907	metric ton	metric ton	1.102	ton
Volume			**Volume**		
teaspoons	5	milliliters	milliliters	0.033	fluid ounces
tablespoons	15	milliliters	liters	2.1	pints
fluid ounces	30	milliliters	liters	1.057	quarts
cups	0.24	liters	liters	0.264	gallons
pints	0.47	liters	cubic meters	35.315	cubic feet
quarts	0.95	liters	cubic meters	1.308	cubic yards
gallons	3.8	liters			
cubic feet	0.028	cubic meters			
cubic yards	0.765	cubic meters			
Temperature			**Temperature**		
Fahrenheit	subtract 32, then multiply by 5/9	Celsius	Celsius	multiply by 9/5, then add 32	Fahrenheit
Radioactivity			**Radioactivity**		
picocuries	37	millibecquerel	millibecquerel	0.027	picocuries

1.0 PURPOSE

This technical basis document describes the parameters and conditions under which the Eberline™ E-600 rate meter and associated detectors can be operated to quantify ionizing radiation and radiological contamination.

2.0 EBERLINE E-600 RATE METER DESCRIPTION

The E-600 is a portable, programmable instrument that can be used as either a rate meter or scaler. It can be used with many different detector types (e.g., scintillation, ionization chamber, sodium iodide [NaI], and Geiger-Mueller [GM]). The instrument uses Eberline "Smart" programmable detectors, which allow the detectors to be interchanged without recalibration. The E-600 has three channels. Each channel can be programmed to perform a separate function for each detector.

The Eberline E-600 is powered by three "C" cell alkaline or nickel-cadmium batteries. Keep spare batteries handy when working on remote jobs. Replace the batteries when the battery low battery warning is displayed on the readout.

2.1 SPECIFICATIONS

Length:	22.9 cm (9 in.)
Width:	10.5 cm (4.1 in.)
Height:	15.3 cm (6.0 in.)
Weight:	1.53 kg (3.4 lb)
Batteries:	Three alkaline "C" cells
Radiation detected:	Alpha (α), beta (β), gamma (γ), x-ray, and neutron (η), depending on detector connected to the rate meter
Response time:	"Slow," "medium," and "fast"[1]
Count range:	0 to approximately 1.2 million cpm
Operating modes:	Rate meter, scaler
Temperature range:	-20°C to 50°C (-4°F to +122°F)
Humidity range:	0% to 95% (noncondensing)

™ Eberline is a tradename of Eberline Instruments, Santa Fe, New Mexico.

1 The response time setting for "fast," "medium," and "slow" are normally stored in the EPROM in the SHP-style detectors or Smart-Packs. Settings typically range between 2 seconds ("fast") and 20 seconds ("slow").

2.2 DISPLAY

The E-600 rate meter's display of the E-600 has analog and digital formats. Icons are located between the analog and digital displays that identify the type of radiation being measured. Special purpose icons along the left side of the display indicate abnormal conditions such as alarms, detector over-range conditions, low battery, and gross/net indicator. The lower right corner of the display screen contains a five-digit, numeric field, the meaning of which depends upon the selected mode (Table 1).

Table 1. E-600 Controls. (2 Pages)

Five-Digit Numeric Field	
Turned on	Probe model and serial numbers are displayed.
LOG feature	The data logging point serial number is displayed.
Check mode	Battery percentage left is displayed.
Integrate mode	The time over which the displayed dose has been integrated is displayed. Units of time are selected automatically.
Scaler mode	The remaining count time is displayed.
Background mode	The precision of the displayed background is presented as a percentage.
Dedicated Controls	
Mode selector	"On"/"Off," "Check," "Background," or one of the four operating modes (below).
Range up/down	Increases and decreases the full-scale range of the display by a factor of 10.
Gross/Net	Toggles display between gross and net, assuming that background rate data is available for the channel(s) being displayed.
Speaker	Audible "On"/"Off" does not affect audible alarms.
Light	Turns on light (approximately 6 seconds).
Channel	Changes channels programmed into the meter from the probe.
Log	Stores data in computer memory. Can be downloaded into the computer at a later time.
Response	Adjusts response time on the meter – "Slow," "Medium," or "Fast"
Control Switch Positions/Modes	
Off	Meter off.
Check	Performs diagnostics and indicates battery strength and the alarm setpoint.
Rate meter mode	Displays the results in the units specified by the probe. If multiple channels are defined in probe memory, use the channel button to switch among them.
Integrate mode	Used to display total counts for a preset time interval.
Scaler mode	Uses time averaging to calculate an activity rate based on counts per minute.
Peak hold mode	Indicates highest reading.
Background mode	Accumulates background for use with the background subtraction feature.

Table 1. E-600 Controls. (2 Pages)

✸Key Functions	
The ✸key button is located on the instrument handle, directly under the operator's thumb. The use of the ✸key is defined by the E-600's programming.	
All modes	Silences audible alarms. The "Alarm" icon on the display cannot be cancelled.
Check mode	Used to display alarm screens.
Rate meter mode	Resets display to zero or starts a scaler count cycle.[a]
Integrate mode	Resets display to zero.
Scaler mode	Resets display to zero and starts a scaler count cycle.
Peak hold mode	Resets the display to the currently measured rate value.
Background mode	Saves the current background value to be subtracted from future readings in other modes. Background may be captured as many times as desired. Only the last value captured will be retained in memory.

[a] Instruments set up for environmental surveys and automatic data logging equipment will normally have the ✸key set to start a scaler count cycle.

2.3 CALIBRATION

Portable radiation monitoring instruments are calibrated at established frequencies in accordance with 10 *Code of Federal Regulations* (CFR) 835, "Occupational Radiation Protection," Subpart E, "Monitoring of Individuals and Areas;" American National Standards Institute (ANSI) Standard N323A, *American National Standard Radiation Protection Instrumentation Test and Calibration, Portable Survey Instruments* (ANSI 1997); U.S. Department of Energy (DOE) Guide 441.1-7, *Portable Monitoring Instrument Calibration Guide*; and the manufacturer's instructions.

The Eberline E-600 rate meter and detectors are generally calibrated annually or when they fail daily operational checks. Minor repairs do not require recalibration, provided that the instrument successfully passes a response check following the repair. Minor repairs are defined as changing batteries, replacing cables, and repairing or replacing the polycarbonate windows.

Pacific Northwest National Laboratory (PNNL) performed receipt inspection tests and verified that the E-600 (when connected to a pulse generator pulser with an Eberline Smart-Pack calibration device) showed consistent readings between 12 E-600 rate meters (high-voltage and discriminator settings). This test and the manufacturer's data confirm that the instrument is capable of interchanging probes without requiring recalibration.

2.4 PERFORMANCE TESTING

Eberline performed tests to verify that the Eberline E-600 rate meter complies with the ANSI Standard N42.17A, *American National Standard Performance Specifications for Health Physics Instrumentation - Portable Instrumentation for Use in Normal Environmental Conditions* (ANSI 1989). During temperature tests, a maximum change of only 2% were noted over the range of 61.7°C to -27.7°C (143°F to -18°F). The DOE Health Physics Instrumentation Committee (HPIC) and the Hanford Instrument Evaluation Committee (HIEC) have approved the E-600 with the SHP-380AB for use at DOE sites.

2.5 INSTRUMENT USE WARNINGS

The following guidelines must be followed to ensure that the E-600 rate meter functions properly.

- Before changing detectors, the E-600 must be shut off and allowed to sit for a minimum of two minutes to allow the voltage to dissipate. If the voltage is not allowed to dissipate before the probe is connected, then the memory in the "Smart" detector may be scrambled rendering the detector unusable.

- Do not allow the batteries to completely run down because the E600's memory may be erased under low-voltage conditions.

- The instrument's audible response is not a direct function of individual events. The audible response is a computer-generated function that is independent of the selected instrument response time. Empirical tests indicate that the audible response appears to be close to a real-time response. However, the maximum audible count rate is approximately 4,500 counts per minute (cpm) or 75 counts per second (cps). Therefore, do not entirely rely on audible clicks to indicate the presence of high radiation fields.

- The E-600 electronics and photomultiplier tube equipped detectors are susceptible to interference from magnetic and high-voltage electric fields that may result in erratic and falsely high readings in both the alpha and beta channels. The E-600 rate meters have exhibited erratic performance when used near alternators, generators, magnetized metal (e.g., some bumpers), and machines that generate static electrical fields. Static electrical fields may also be present around drilling equipment and "guzzlers," and when large volumes of air are moved past plastic materials. If erratic and unusually high readings are observed while using the E-600 around magnetic and electric fields, it may be necessary to shut down the equipment that is generating the fields and to wait a few minutes before accurate readings can be obtained.

- The E-600 has the capability to operate up to three separate channels in the instrument body. These channels are primarily intended for conventional detectors. The settings available in the conventional channels are the same as those available for a "Smart" detector. Currently, most of the Environmental Restoration Contractor (ERC) E-600 rate meters are set up with

one conventional channel configured for a pancake GM and the other two channels disabled. This means that whenever a non-smart probe is connected to a standard Eberline E-600, it configures the display (cpm mode) and voltage (approximately 900 volts) for a pancake GM.

3.0 EBERLINE SHP DETECTOR PROBES

All SHP series probes used with the E-600 rate meter are equipped with erasable, programmable, read-only memory (EPROM) chips that contain all information related to the setup and calibration of that individual probe. The information stored in the EPROM is used by the instrument to set the operating parameters. Non-SHP probes can be adapted to operate in the same manner as the SHP probes through the addition of a "Smart-Pack"[1] that contains an EPROM of the same type as is in the SHP probes. The EPROM in the detector contains the calibration parameters for the probe. The stored parameters include the discriminator settings, high-voltage settings, scaler times, and the specific parameters for each channel. These parameters are downloaded into the E-600 when the instrument is turned on.

3.1 SHP-380 SERIES PROBES

The housing and photomultiplier tube are identical on all SHP-380 series probes and the probes have an active area of 100 cm^2. The SHP-380AB probe uses a plastic scintillator with a silver-activated, zinc-sulfide coating. When alpha particles interact with the zinc-sulfide coating on the SHP-380AB plastic scintillator, a tiny flash of light is produced. The amount of light produced is proportional to the amount of energy deposited in the zinc sulfide. Beta particles typically interact with the plastic scintillator, producing a flash of light that is proportional to the amount of energy deposited in the plastic detector. The light is converted to an electrical signal and amplified in the photomultiplier tube in the handle of the probe housing. The SHP-380AB can be used to detect beta-gamma and/or alpha radiation.

The SHP-380A is identical to the SHP-380AB with the exception that the zinc sulfide is coated on non-scintillating plastic and, therefore, the SHP-380A only detects alpha radiation. The SHP-380B is also identical to the SHP-380AB with the exception that plastic scintillator does not have a zinc sulfide coating, and therefore, the SHP-380B only detects beta-gamma radiation. The ERC's instrument inventory currently includes SHP-380AB and SHP-380A probes but does not include SHP-380B probes.

Some SHP-380ABs have an additional layer of Tyvek™-like material between the mylar and protective grid. These probes are designated SHP-380RW ("RW" represents ruggedized window) by the PNNL calibration facility. The Tyvek-like material renders the detector nearly insensitive to alpha radiation and slightly reduces the beta efficiency, but the material decreases

[1] "Smart-Pack" is a trademark of Eberline Instruments, Santa Fe, New Mexico.

™ Tyvek is a registered trademark of E.I. duPont de Nemours and Company, Wilmington, Delaware.

the probability of damaging the mylar window. The alpha channels are disabled on all SHP-380RWs.

3.2 CROSS-TALK

The Eberline E-600 uses pulse-height analysis to determine if a particular count is recorded as an alpha or beta particle. The amount of energy deposited by the alpha particles is higher than the energy deposited by beta particles, enabling the energy discrimination circuitry in the E-600 to differentiate between alpha and beta pulses. When the E-600 is connected to an alpha-beta detector, approximately 10% of the alpha scintillation events are recorded in the beta channel, and less than 1% of the beta events are recorded in the alpha channel. This phenomenon is known as "cross-talk" or crossover. The user must be aware of this phenomenon because high beta-contamination levels could cause the instrument to incorrectly report alpha contamination even though no alpha contamination is present (a false positive). The operating voltage of the instrument is adjusted in the calibration process to minimize the cross-talk.

The cross-talk phenomenon is not a significant concern with the SHP-380A because it has a low sensitivity to beta radiation. Similarly, the cross-talk phenomenon is not a significant concern with the SHP-380B because it has a low sensitivity to alpha radiation.

During routine contamination survey operations, the cross-talk phenomenon is not usually a significant concern because highly accurate, quantitative measurements are not required and it is acceptable to use the SHP-380AB in the presence of alpha and beta contamination. However, accurate, quantitative results are required when performing release surveys. Therefore, it is recommended that the SHP-380AB is not used to perform alpha and beta-gamma free-release surveys. When performing free-release surveys, it is recommended that separate alpha and beta/gamma detectors are used or to use the Eberline-380A for alpha surveys and an Eberline-380AB for beta-gamma surveys.

It is possible to operate the SHP-380AB at different voltages in the alpha and beta channels. This would greatly reduce, if not eliminate the beta to alpha cross-talk. However, it takes the instrument a significant amount of time (up to one minute) for a reduction from beta to the alpha plateau voltage. While the voltage is in transit, the "HV" icon flashes on the display and the instrument is unusable.

3.3 INSTRUMENT PARAMETERS

The SHP-380 detectors are normally set up to display alpha contamination data in channel 1, beta contamination data in channel 2, and alpha plus beta contamination data in channel 3. Note that channel 3 is normally disabled.

The response time for most instruments is set to 20 seconds ("fast," "medium," and "slow" response are all set the same) to dampen meter fluctuations. Instruments used for environmental release surveys may have the "fast" response-time setting as low as 2 seconds to allow for faster

scan speeds. Operating parameters for other detectors are specified in detector-specific technical basis documents or in project survey plans and instructions.

The response time is analogous but not quite the same as the response time settings on a purely analog instrument like the Eberline E-140 count rate meter. Nearly all ERC Eberline E-600 rate meters have the "fast", medium" and "slow" response times set at 20 seconds to dampen meter fluctuations. Instruments used for environmental release surveys may have the "fast" response-time setting as low as 2 seconds to allow for faster scan speeds. Operating parameters for other detectors are specified in detector-specific technical basis documents or in project survey plans and instructions.

Experience indicates that when the Eberline E-600 is in the alpha mode, the instrument seems to work better if the time constant is set to a shorter time (approximately 10 seconds). Also, the Eberline E-600 seems to work fine in the beta mode when the response time is set at 20 seconds. The ERC's Eberline E-600 rate meters are set up with response times fixed at 20 seconds because past experience indicates that it is too easy to accidentally reposition the switch without realizing the switch has been repositioned.

3.4 DETECTION CAPABILITIES

The Eberline E-600 with Eberline SHP-380 detectors is capable of detecting the 10 CFR 835, Appendix D, "Surface Contamination Values," limits for <u>total</u> contamination. Therefore, the Eberline E-600 with a SHP-380 series probe meets the requirements for conducting personnel surveys. The instrument is also capable of measuring the Appendix D limits for <u>removable</u> contamination when used in the scaler mode using a suitable counting time and an appropriate probe-to-sample geometry. Therefore, the instrument can be used to identify areas that require radiological posting according to 10 CFR 835, Subpart G, "Posting and Labeling." The SHP-380 series detectors are not capable of measuring radiation from the low-energy beta emitters (e.g., hydrogen-3 and nickel-63). Table 2 shows typical detection efficiencies for the SHP-380 series.

Table 2. Typical SHP-380 Detection Efficiencies.

Probe	^{239}Pu	^{90}Sr^{90}Y	^{99}Tc	^{137}Cs (beta)	^{137}Cs (gamma)
SHP-380AB	18%	22%	9%	18%	All probes < 1% or approximately 12,000 cpm per mR/hr
SHP-380A	21%	N/A	N/A	N/A	
SHP-380B	N/A	26%	14%	18%	

N/A = not applicable

The Eberline SHP-380 can be configured to operate in the cps and cpm modes. The cps mode can be used to count contamination that is approximately 60 times greater than can be counted in the cpm mode. The Eberline E-600 monitor displays an "over-range" error when the count rate

limit of the probe is exceeded. Therefore, if the Eberline E-600 over-ranges or approaches the over-range limit while using a probe in cpm mode, it is recommended to switch to a probe configured for cps mode to extend the count rate capability and to obtain more accurate readings.

NOTE: The SHP-380 probes can be changed between cpm and cps modes using the setup software without affecting the instrument calibration. However, this software is currently not available to field personnel.

NOTE: Due to small differences in hardware and software, the Eberline E-600 and SHP-380 detectors do not all give over-range errors at the same count rates.

4.0 OTHER DETECTORS USED WITH THE EBERLINE E-600 RATE METER

The E-600 is a versatile instrument that is capable of operating with a variety of detectors. Detector types include gas-proportional, ionization chamber, GM, and neutron-sensitive detectors. Some of the detectors used by ERC are listed below:

- **SSPA-3:** A 2-in. diameter by 2-in. thick NaI(Tl)-based detector intended for high-sensitivity gamma measurements. The response of the SSPA-3 is approximately 1.2×10^6 cpm per mR/hr (cesium-137).

- **SHP-360 and SHP-210T:** Pancake GM detectors used for beta/gamma surveys. Both probes have a circular mica window with an active area of 15.5 cm^2. The primary difference between the probes is that the SHP-210T has a titanium shield on the back of the detector that reduces background radiation levels to approximately one-third of the observed with the SHP-360.

- **NRD:** A 9-in. polyethylene sphere with a BF_3 detector. The detector is intended for neutron surveys and is designed to reject gamma radiation up to approximately 500 R/hr.

- **Smart Pole:** Includes two energy compensated GM detector tubes that provide a seamless range from 0.1 mR/hr to 1,000 R/hr. The detector tubes are located at the end of an aluminum telescoping pole that allows safe measurement of high dose rate fields from a distance. The pole extends from approximately 4 to 12 ft.

5.0 INSTRUMENT USE

The use of the instrument depends greatly on the needed or desired results of the radiological surveys performed. The choice of the detector and the method that it is used will vary from location to location, based on the radionuclides present and required detection levels. The location- or project-specific survey and/or sampling plan will contain the survey methodology (e.g., scan speeds, background rate limitations, and instrument set-up parameters). For a detailed discussion on counting statistics, refer to *Counting Statistics for Radiological Control* (BHI 2000).

6.0 CONCLUSIONS

The E-600 with the appropriate detector can detect the majority of the nuclides of concern at ERC projects at levels listed in 10 CFR 835, Appendix D. In the scaler mode with a suitable counting time, the E-600 with a SHP-380 series probe can reliably detect 20 dpm/100 cm^2 plutonium-239 (and similar transuranic isotopes) and 200 dpm/100 cm^2 strontium-90. However, scanning surveys using the E-600 with a SHP-380 series probe cannot reliably detect the removable contamination limits of 20 dpm/100 cm^2 for plutonium-239 (and similar transuranic isotopes) or 200 dpm/100 cm^2 values for strontium-90 (> 90%).

7.0 REFERENCES

10 CFR 835, "Occupational Radiation Protection," *Code of Federal Regulations*, as amended.

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