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*Evaluation of ANSI N42-17A by Investigating
the Effects of Temperature and Humidity on the
Response of Radiological Instruments*

Los Alamos
NATIONAL LABORATORY

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Response of Radiological Instruments*

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MASTER

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CONTENTS

CONTENTS	vii
LIST OF FIGURES	ix
LIST OF TABLES	xi
NOMENCLATURE	xiii
ABSTRACT	1
 1.0 INTRODUCTION	 2
1.1 ANSI N42.17A-1989 standard	2
1.1.1 Environmental factors—temperature	2
1.1.2 Environmental factors—humidity	3
1.2 Background	3
1.2.1 Ionization chambers, proportional counters, and GM detectors	4
1.2.2 Environmental dependence of detectors	5
 2.0 METHODS	 8
2.1 Environmental chamber system	8
2.2 Radiological instruments	9
2.2.1 Beta-gamma survey meters	9
2.2.2 Neutron rem meters	10
2.2.3 Alpha contamination monitors	11
2.2.4 Tritium-in-air monitors	11
2.3 Tests	12
2.4 Analysis	12
2.4.1 Descriptive statistics, correction factor, and normalized response	13
2.4.2 ANOVA estimates	14
2.4.3 Binomial frequency distribution	14
 3.0 RESULTS	 15
3.1 Beta-gamma survey meters	15
3.1.1 Eberline RO-2 ionization chamber	15
3.1.2 Eberline RO-3C ionization chamber	15
3.1.3 Eberline E-530 survey meter with the Model HP-177C stainless steel GM wall probe	16
3.1.4 Eberline PIC-6A ion chamber	16
3.1.5 Eberline PIC-6B ion chamber	17
3.1.6 Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector	17
3.1.7 Ludlum 3 survey meter with the Model 44-6 stainless steel GM wall probe	18

3.2	Neutron rem meters	19
3.2.1	Eberline ESP-1 survey meter with the NRD	19
3.2.2	Eberline ESP-2 survey meter with the NRD	19
3.2.3	Eberline PNR-4 survey meter with the NRD	20
3.2.4	HPI 2080 survey meter with the moderator detector	20
3.3	Alpha contamination monitors	21
3.3.1	Ludlum 139 survey meter with the Model 43-32 air-proportional alpha detector	21
3.4	Tritium-in-air monitors	22
3.4.1	Overhoff 394-C tritium monitor	22
3.4.2	Johnston J-111 tritium monitor	22
3.4.3	Johnston J-110 tritium monitor	23
4.0	DISCUSSION	24
5.0	CONCLUSION	26
	REFERENCES	30
	APPENDIX A: PROCEDURES	111
	APPENDIX B: WORK SHEETS	117
	APPENDIX C: DATA SPREADSHEETS	131

LIST OF FIGURES

Figure 1. Dry air density plotted as a function of ambient temperature and pressure.	31
Figure 2. The environmental chamber system.	32
Figure 3. Beta-gamma survey meters positioned inside the chamber for testing.	33
Figure 4. A neutron rem meter positioned inside the chamber for testing.	34
Figure 5. Alpha contamination monitors positioned inside the chamber for testing.	35
Figure 6. A tritium-in-air monitor positioned inside the chamber for testing.	36
Figure 7. Temperature test showing the exposure profile in accordance with the ANSI standard.	37
Figure 8. Humidity test showing the exposure profile in accordance with the ANSI standard. .	38
Figure 9. Eberline RO-2 ionization chamber temperature test (uncorrected response).	39
Figure 10. Eberline RO-2 ionization chamber temperature test (corrected response).	40
Figure 11. Eberline RO-2 ionization chamber humidity test.	41
Figure 12. Eberline RO-3C ionization chamber temperature test (uncorrected response).	42
Figure 13. Eberline RO-3C ionization chamber temperature test (corrected response).	43
Figure 14. Eberline RO-3C ionization chamber humidity test.	44
Figure 15. Eberline E-530 survey meter with the Model HP-177C stainless steel GM wall probe temperature test.	45
Figure 16. Eberline E-530 survey meter with the Model HP-177C stainless steel GM wall probe humidity test.	46
Figure 17. Eberline PIC-6A ion chamber temperature test.	47
Figure 18. Eberline PIC-6A ion chamber humidity test.	48
Figure 19. Eberline PIC-6B ion chamber temperature test.	49
Figure 20. Eberline PIC-6B ion chamber humidity test.	50
Figure 21. Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector temperature test.	51
Figure 22. Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector humidity test.	52
Figure 23. Ludlum 3 survey meter with the Model 44-6 stainless steel GM wall probe temperature test.	53
Figure 24. Ludlum 3 survey meter with the Model 44-6 stainless steel GM wall probe humidity test.	54
Figure 25. Eberline ESP-1 survey meter with the NRD temperature test.	55
Figure 26. Eberline ESP-1 survey meter with the NRD humidity test.	56
Figure 27. Eberline ESP-2 survey meter with the NRD temperature test.	57
Figure 28. Eberline ESP-2 survey meter with the NRD humidity test.	58
Figure 29. Eberline PNR-4 survey meter with the NRD temperature test.	59
Figure 30. Eberline PNR-4 survey meter with the NRD humidity test.	60
Figure 31. HPI 2080 survey meter with the moderator detector temperature test.	61
Figure 32. HPI 2080 survey meter with the moderator detector humidity test.	62

LIST OF FIGURES CONT'D

Figure 33. Ludlum 139 survey meter with the Model 43-32 alpha detector temperature test. . .	63
Figure 34. Ludlum 139 survey meter with the Model 43-32 alpha detector humidity test. . . .	64
Figure 35. Overhoff 394-C tritium monitor temperature test (corrected response).	65
Figure 36. Overhoff 394-C tritium monitor humidity test.	66
Figure 37. Johnston J-111 tritium monitor temperature test (corrected response).	67
Figure 38. Johnston J-111 tritium monitor humidity test.	68
Figure 39. Johnston J-110 tritium monitor temperature test (corrected response).	69
Figure 40. Johnston J-110 tritium monitor humidity test.	70

LIST OF TABLES

Table 1. Cross section of radiological instruments tested in accordance with the ANSI standard.	71
Table 2. Eberline RO-2 ionization chamber temperature test data and GLM summaries.	72
Table 3. Eberline RO-2 ionization chamber humidity test data and GLM summaries.	73
Table 4. Eberline RO-3C ionization chamber temperature test data and GLM summaries.	74
Table 5. Eberline RO-3C ionization chamber humidity test data and GLM summaries.	75
Table 6. Eberline E-530 survey meter with the Model HP-177C stainless steel GM wall probe temperature test data and GLM summaries.	76
Table 7. Eberline E-530 survey meter with the Model HP-177C stainless steel GM wall probe humidity test data and GLM summaries.	77
Table 8. Eberline PIC-6A ion chamber temperature test data and GLM summaries.	78
Table 9. Eberline PIC-6A ion chamber humidity test data and GLM summaries.	79
Table 10. Eberline PIC-6B ion chamber temperature test data and GLM summaries.	80
Table 11. Eberline PIC-6B ion chamber humidity test data and GLM summaries.	81
Table 12. Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector temperature test data and GLM summaries.	82
Table 13. Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector humidity test data and GLM summaries.	83
Table 14. Ludlum 3 survey meter with the Model 44-6 stainless steel GM wall probe temperature test data and GLM summaries.	84
Table 15. Ludlum 3 survey meter with the Model 44-6 stainless steel GM wall probe humidity test data and GLM summaries.	85
Table 16. Beta-gamma survey meters tested for temperature and humidity based on the ANSI standard's performance criteria and test methods.	86
Table 17. Beta-gamma survey meters tested for temperature based on the binomial frequency distribution.	87
Table 18. Beta-gamma survey meters tested for humidity based on the binomial frequency distribution.	88
Table 19. Eberline ESP-1 survey meter with the NRD temperature test data and GLM summaries.	89
Table 20. Eberline ESP-1 survey meter with the NRD humidity test data and GLM summaries.	90
Table 21. Eberline ESP-2 survey meter with the NRD temperature test data and GLM summaries.	91
Table 22. Eberline ESP-2 survey meter with the NRD humidity test data and GLM summaries.	92
Table 23. Eberline PNR-4 survey meter with the NRD temperature test data and GLM summaries.	93

LIST OF TABLES CONT'D

Table 24. Eberline PNR-4 survey meter with the NRD humidity test data and GLM summaries.	94
Table 25. HPI 2080 survey meter with the moderator detector temperature test data and GLM summaries.	95
Table 26. HPI 2080 survey meter with the moderator detector humidity test data and GLM summaries.	96
Table 27. Neutron rem meters tested for temperature and humidity based on the ANSI standard's performance criteria and test methods.	97
Table 28. Neutron rem meters tested for temperature based on the binomial frequency distribution.	98
Table 29. Neutron rem meters tested for humidity based on the binomial frequency distribution.	99
Table 30. Ludlum 139 survey meter with the Model 43-32 alpha detector temperature test data and GLM summaries.	100
Table 31. Ludlum 139 survey meter with the Model 43-32 alpha detector humidity test data and GLM summaries.	101
Table 32. Alpha contamination monitors tested for temperature and humidity based on the ANSI standard's performance criteria and test methods.	102
Table 33. Alpha contamination monitors tested for temperature based on the binomial frequency distribution.	103
Table 34. Alpha contamination monitors tested for humidity based on the binomial frequency distribution.	104
Table 35. Overhoff 394-C tritium monitor temperature test data and GLM summaries.	105
Table 36. Overhoff 394-C tritium monitor humidity test data and GLM summaries.	106
Table 37. Johnston J-111 tritium monitor temperature test data and GLM summaries.	107
Table 38. Johnston J-111 tritium monitor humidity test data and GLM summaries.	108
Table 39. Johnston J-110 tritium monitor temperature test data and GLM summaries.	109
Table 40. Johnston J-110 tritium monitor humidity test data and GLM summaries.	110
Table 41. Tritium-in-air monitors tested for temperature and humidity based on the ANSI standard's performance criteria and test methods.	111
Table 42. Tritium-in-air monitors tested for temperature based on the binomial frequency distribution.	112
Table 43. Tritium-in-air monitors tested for humidity based on the binomial frequency distribution.	113

NOMENCLATURE

- $\dot{D}_a$ $\equiv$ absorbed dose rate in dry air, rad h⁻¹
 $\dot{D}_t$ $\equiv$ absorbed dose rate in tissue, rad h⁻¹
 e $\equiv$ charge of an electron. 1 e = 1.602 $\times$ 10⁻¹⁹ Coul
 E_α $\equiv$ alpha emission energy, MeV
 E_γ $\equiv$ gamma emission energy, keV
 I $\equiv$ current, A
 ip $\equiv$ ion pair. 1 ip = 1.602 $\times$ 10⁻¹⁹ Coul
 m_a $\equiv$ mass of dry air. m_a = 28.96 g mole⁻¹ at 293.2 K, 760 mm Hg
 m_w $\equiv$ mass of water. m_w = 18.02 g mole⁻¹ at 293.2 K, 760 mm Hg
 Φ $\equiv$ electron fluence, # cm⁻² s⁻¹
 P $\equiv$ ambient (total) pressure, mm Hg
 P_0 $\equiv$ reference standard pressure. P_0 = 760 mm Hg
 P_s $\equiv$ saturation vapor pressure, mm Hg
 P_w $\equiv$ partial pressure of water vapor, mm Hg
 rad $\equiv$ radiation absorbed dose. 1 rad = 6.242 $\times$ 10⁷ MeV g⁻¹ = 100 ergs g⁻¹
 R $\equiv$ Roentgen. 1 R = 2.58 $\times$ 10⁻⁴ Coul kg⁻¹ = 2.082 $\times$ 10⁹ ip cm⁻³ at STP = 1 esu cm⁻³ at STP
 RH $\equiv$ relative humidity, %
 ρ $\equiv$ density, g cm⁻³
 ρ_a $\equiv$ density of air. ρ_a = 1.293 $\times$ 10⁻³ g cm⁻³ at STP
 ρ_h $\equiv$ density of humid air, g cm⁻³
 T $\equiv$ ambient temperature, K
 T_0 $\equiv$ reference standard temperature. T_0 = 273.2 K
 $T_{1/2}$ $\equiv$ half-life, y
 $(\mu_{en} \rho^{-1})_a$ $\equiv$ mass energy absorption coefficient for air, cm² g⁻¹
 $(\mu_{en} \rho^{-1})_t$ $\equiv$ mass energy absorption coefficient for tissue (muscle), cm² g⁻¹
 V $\equiv$ ambient air volume. 1 mole of gas occupies 2.4 $\times$ 10⁴ cm³ at 293.2 K, 760 mm Hg
 V_0 $\equiv$ air volume corrected to STP, cm³
 $(\bar{W} e^{-1})_a$ $\equiv$ mean energy expended by a slowing electron in air. $(\bar{W} e^{-1})_a$ = 33.97 J Coul⁻¹
 $\dot{X}$ $\equiv$ exposure rate, R h⁻¹

EVALUATION OF ANSI N42.17A BY INVESTIGATING THE EFFECTS OF TEMPERATURE AND HUMIDITY ON THE RESPONSE OF RADIOLOGICAL INSTRUMENTS

by

Richard S. Clement

ABSTRACT

The American National Standards Institute (ANSI) N42.17A-1989 standard's performance criteria and test methods has been evaluated by investigating the effects of temperature and humidity on the response of 105 portable direct-reading radiological instruments (45 beta-gamma survey meters, 32 neutron rem meters, 10 alpha contamination and 18 tritium-in-air monitors). The US Department of Energy (DOE) mandates the use of ANSI standards for the calibration and performance testing of radiological instruments, and requires that instruments be appropriate for existing environmental conditions. Random tests conducted in an environmental chamber determined the effects of temperatures ranging from -10°C to 50°C and humidity at levels of 40% RH and 95% RH on the response of a cross section of instruments used in routine health physics operations at Los Alamos. The following instruments were tested: Eberline RO-2 and RO-3C ionization chambers, Eberline E-530 survey meter with the Model HP-177C stainless steel Geiger-Mueller (GM) wall probe, Eberline PIC-6A and PIC-6B ion chambers, Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector, Ludlum 3 survey meter with the Model 44-6 stainless steel GM wall probe, Eberline ESP-1, ESP-2 and PNR-4 survey meters with the neutron rem detector, Health Physics Instruments 2080 survey meter with the moderator detector, Ludlum 139 survey meter with the Model 43-32 air-proportional alpha detector, and the Overhoff 394-C, Johnston J-111 and J-110 tritium monitors. Experimental results encompass 1128 temperature tests (1269-hours exposure in the chamber) and 735 humidity tests (1890-hours exposure in the chamber). The study shows the standard's test requirement for temperature at or near the extreme conditions, and the standard's test requirement for humidity at 95% RH may be too restrictive for instruments used in the work environment. This report also contains a discussion of the impact of the ANSI standard's performance criteria and test methods for temperature- and humidity-type testing at the Los Alamos National Laboratory, a DOE facility.

1.0 INTRODUCTION

Radiological instruments are used by health and safety professionals to protect workers from exposure to ionizing radiation, to monitor and control processes releasing radioactivity or external radiation to the environment, and to ensure compliance with federal and state regulations. Instruments are calibrated at a given temperature, pressure, and humidity but are used routinely outdoors or in work environments where the conditions can be dramatically different from those experienced at the time of the original calibration. Consequently, the influence of environmental factors on instrument response may compromise the accuracy and defensibility of measurements taken by workers in the field. Compliance with the American National Standards Institute (ANSI), ANSI N42.17A-1989 "Performance Specifications for Health Physics Instrumentation—Portable Instrumentation for Use in Normal Environmental Conditions" standard is voluntary with manufacturers; however, the US Department of Energy (DOE) mandates the use of ANSI standards for the calibration and performance testing of radiological instruments¹ and requires that instruments be appropriate for existing environmental conditions.²

Standards have been published to establish guidelines for test and calibrations³ and performance specifications^{4,5} for radiological instruments. The objective of the ANSI N42.17A standard is to provide basic performance criteria (requirements) and verification test methods for health physics instruments used in normal environmental conditions. The ANSI standard describes requirements and test methods for general characteristics, electronic and mechanical tests, radiation responses, interfering responses, and environmental factors. This report has evaluated a selection of the ANSI standard's performance criteria and test methods, described in environmental factors, by investigating the effects of temperature and humidity on the response of a cross section of portable direct-reading radiological instruments used in routine health physics operations at Los Alamos.

1.1 ANSI N42.17A-1989 standard

1.1.1 Environmental factors—temperature

Performance criteria. The ANSI standard's performance criteria states, "the temperature range over which the mean instrument response shall not vary more than 15% from the mean response at a nominal temperature of 22°C shall be stated by the manufacturer. The mean instrument response shall not vary more than 15% from the mean response at a nominal 22°C from 0°C to 40°C and shall not vary more than 20% from the mean response at a nominal 22°C from -10°C to 50°C. Corrections to instrument readings for air density changes shall be made when appropriate."⁵

Test method. The ANSI standard's test method states, "the instrument shall be exposed in a reproducible geometry in an environmental chamber to an acceptable source of sufficient energy to minimize the effect of the statistical fluctuations of the instrument readings, and to

produce a response at approximately midscale or middecade.... The temperature inside the environmental chamber shall be raised or lowered at a rate of approximately $10^{\circ}\text{C h}^{-1}$ until the temperature extremes have been reached.... Sufficient data shall be taken at approximately 10°C increments; the instrument shall be permitted to come to thermal equilibrium at each temperature level before the data are taken....”⁵

1.1.2 Environmental factors—humidity

Performance criterion. The ANSI standard’s performance criterion states, “the mean instrument response shall not vary more than 15% over the noncondensing relative humidity range of 40% to 95% RH and a nominal temperature of $22 \pm 2^{\circ}\text{C}$ from the mean instrument response at 40% RH and a nominal 22°C .”⁵

Test method. The ANSI standard’s test method states, “the instrument shall be exposed in a reproducible geometry in an environmental chamber to an acceptable source of sufficient energy to minimize the effect of the statistical fluctuations of the instrument readings, and to produce a response at approximately midscale or middecade. The mean instrument reading at $40 \pm 5\%$ RH and a temperature of $22 \pm 2^{\circ}\text{C}$ shall be determined... after a minimum exposure period in this atmosphere of four hours. The RH inside the chamber shall be increased to $95 \pm 4\%$ RH while the temperature is kept at $22 \pm 2^{\circ}\text{C}$ and maintained at that level for a minimum of eight hours, and the mean instrument reading shall be determined. The relative humidity shall be decreased to $40 \pm 5\%$ RH while the temperature is kept at $22 \pm 2^{\circ}\text{C}$ and then maintained at that level for a minimum of four hours, and the mean instrument reading shall be determined.”⁵

1.2 Background

The three main categories of gas-filled detectors based on ionization for instruments used in radiation detection and monitoring applications are: 1) ionization (ion) chambers (vented or sealed); 2) proportional counters (vented or sealed); and 3) Geiger-Mueller (GM) detectors (sealed). The majority of external radiation surveys performed in the work environment require the measurement of β - and γ -radiation. Exposure, measured in Roentgens, is defined in terms of the electrical charge due to ionization liberated by secondary electrons formed within a finite volume and mass of air. As radiation passes through the fill gas in a detector, ion pairs are formed along the particles path. Ions (charged particles) created by the ionization and excitation of the gas molecules are collected through an applied voltage (electric field) across the detector. If the detector is vented to the environment, the charge collected depends on the ambient temperature, pressure (more so), and humidity (to a lesser degree) which produces a mass change of the fill gas (air) being ionized. Other gas-filled detectors based on ionization are sealed and include pressurized (CH_4 gas) ion chambers, proportional (BF_3 gas) counters, and GM (He and Ar gas) detectors. Even though a permanently sealed detector is not directly dependent on ambient conditions, an instrument’s internal and electronic components (e.g., high voltage, microprocessor) can be affected if the instrument is not adequately protected against the environment.

1.2.1 Ionization chambers, proportional counters, and GM detectors

Ionization chambers operate at the range of applied voltages in which all primary ions created in the fill gas by radiation incident on the detector are collected. In the ionization region, the charge collected is proportional to the ions formed in the gas. Ion chambers are primarily used for the measurement of X-, γ -, and β -radiation in the work environment. Because gas inside a vented detector is sensitive to the environment, a correction factor to account for the change in air density must be applied for quantitative measurements when the instrument is used in conditions different from those experienced at the time of its original calibration. Ion chambers exhibit a relatively flat energy response and have a wide range of exposure rate measurements, but require a large detector volume for adequate sensitivity which, in turn, makes them more susceptible to inaccurate measurements due to partial irradiation from spatially localized radiation fields.

As the applied voltage across the detector is increased, the primary ions created in the fill gas are accelerated and strike other gas molecules with sufficient energy to cause secondary ionization and an increase in pulse amplitude. This condition where gas multiplication occurs is called the proportional region. In a proportional counter, the number of ion pairs collected in the observed pulse is proportional to the number produced by the primary charged particle and its secondaries incident on neutral gas molecules in the detector. Gas-flow "windowless" counters, routinely used for measuring α - and low energy X-radiation, which can be severely attenuated by window materials are especially dependent on ambient conditions because the sample is in direct contact with the active volume of the counting gas. Proportional counters also can be sealed and filled with a pressurized gas. A commonly used proportional counter using such a detector is the neutron rem meter with the neutron rem detector (NRD) filled with BF_3 gas. This instrument detects the α -particle produced by the thermal neutron capture in Boron and measures steady-state neutron radiation in mixed neutron/gamma fields.

In the GM region increased voltage accelerates primary electrons, which interact with the gas molecules in the detector and produce a sequence of ionizing events as they migrate to the anode. As the secondary ion pairs are collected even more ionization is produced in the detector. GM detectors employ gas multiplication but at a substantially higher applied voltage (compared to proportional counters) to increase the charge created in the fill gas by the primary ions. The higher electric field produced in the detector causes an electron avalanche (resulting in dead time of the counter), which subsequently triggers a cascading effect (chain reaction) of other avalanches associated with the original event that lead to a rapid increase in the counting rate (multiple pulsing) and breakdown of the counting gas. Quench gas added to the fill gas in the detector prevents the continuous discharge due to the release of electrons from the cathode wall as the slower positive ions are collected by the cathode. Because the observed pulse is characterized by the same amplitude and time profile regardless of the initial energy deposited in the gas, a detector operated in the GM region can not distinguish between different types of radiation incident on the detector. GM detectors are primarily used for the measurement of β - γ radiation in the work environment. Types of GM detectors include pancake detectors ("friskers"),

which use a thin mica window to measure α - and low energy β -radiation, and cylindrical stainless steel wall probes, which incorporate a rotary sliding window to measure low energy β -radiation. GM detectors are inexpensive, have a high sensitivity and fast response time, but are limited to low-counting rates and finite lifetimes (organic quench gas), exhibit a large dead time and are characterized by a strong dependence on energy. To compensate for energy dependence, a GM detector can be shielded with tin to flatten the energy response but with the trade-off of under-responding at the lower energies.

1.2.2 Environmental dependence of detectors

Exposure is defined by ICRU⁶ for X- and γ -radiation in units of the Roentgen in terms of the number of ion pairs liberated per kilogram of dry air. Instruments used for radiation detection and measurement are either vented to the environment or sealed. The mass of gas (mostly air) inside a vented detector is dependent on ambient temperature, pressure, and humidity, whereas sealed detectors are not as influenced by environmental changes.

The active volume of gas (assumed to be dry) varies with ambient temperature and pressure according to the Generalized Gas Law:

$$\frac{P_0 V_0}{T_0} = \frac{P V}{T} , \quad (1)$$

and solving for the air volume

$$V_0 = \frac{P V T_0}{T P_0} . \quad (2)$$

When air reaches thermal equilibrium and stabilizes with the environment, the density of dry air (Fig. 1) is

$$\rho_a = \frac{m_a}{V_0} = \frac{m_a T P_0}{P V T_0} , \quad (3)$$

and solving for the mass of dry air

$$m_a = \frac{\rho_a P V T_0}{T P_0} . \quad (4)$$

Air density is influenced to a small degree by humidity or water vapor in the air. The ratio of the partial pressure of water vapor to the saturation vapor pressure is defined as the relative humidity:

$$RH = \frac{P_w}{P_s} 100 \quad (5)$$

Relative humidity is the percentage of the saturated value of vapor pressure present in a system. For temperatures ranging from 0°C to 60°C, the saturation vapor pressure is expressed empirically by Hinds⁷ as

$$\log_{10} P_s = 8.11 - \frac{1750}{235 + T} \quad (6)$$

The partial pressure of water vapor in a system as a function of the relative humidity and temperature becomes

$$P_w = \frac{RH}{100} 10^{\left(8.11 - \frac{1750}{235 + T}\right)} \quad (7)$$

Most often the gas in a vented detector is humid air. The density of dry air is related to the density of humid air by

$$\rho_h = \rho_a \left[1 - \frac{P_w}{P} \left(1 - \frac{m_w}{m_a} \right) \right] \quad (8)$$

Therefore, ambient air containing moisture can be described according to the amount of relative humidity in the environment as

$$\rho_h = \rho_a \left[1 - \left(\frac{RH}{100} 10^{\left(8.11 - \frac{1750}{235 + T}\right)} \right) 0.378 \right] \quad (9)$$

Air density decreases by approximately 1% from dry to saturated conditions. Water vapor influences the number of ion pairs created in a given volume of gas, the air density, and the wall material of the detector if it has hygroscopic properties. Since the charge liberated per unit volume of humid air inside a vented detector is greater than in dry air, the correction factor applied to the mean instrument reading will be a value less than or equal to 1. For the range of humidities from 10% RH to 70% RH, the ICRU⁸ humidity correction factor is approximately a constant value of 0.997 ± 0.001 , which is too small to be of any consequence for instruments used in routine health physics measurements. More important, however, is the significant effect that humidity can have on the performance of electronic and internal components if the instrument is not adequately sealed against moisture.

The current or electrical charge collected depends on the mass and type of gas in the detector. Current (referenced at STP) produced in the volume of air in a vented detector (e.g.,

free air) exposed to incident radiation can be correlated to the ion pair density equivalent of the Roentgen and the exposure rate assuming energy spacial equilibrium:

$$I (A) = \frac{2.082 \times 10^9 \text{ ip}}{R \text{ cm}^3} \dot{X} \left(\frac{R}{h} \right) \frac{1.602 \times 10^{-19} \text{ Coul}}{\text{ip}} \frac{A \text{ s}}{\text{Coul}} \frac{h}{3600 \text{ s}} \quad (10)$$

$$\frac{P (\text{mm Hg}) V (\text{cm}^3) T_0 (273.2 \text{ K})}{T (\text{K}) P_0 (760 \text{ mm Hg})} \quad \text{or}$$

$$I = \frac{3.331 \times 10^{-14} \dot{X} P V}{T} \quad (11)$$

Alternatively, the exposure rate can be defined in terms of the current and mass of air in a detector vented to the environment:

$$\dot{X} (R \text{ h}^{-1}) = I (A) \frac{\text{Coul}}{A \text{ s}} \frac{1}{\rho} \left(\frac{\text{cm}^3}{1.293 \times 10^{-3} \text{ g}} \right) \frac{R \text{ kg}}{2.58 \times 10^{-4} \text{ Coul}} \frac{3600 \text{ s}}{h} \quad (12)$$

$$\frac{10^3 \text{ g}}{\text{kg}} \frac{T (\text{K}) P_0 (760 \text{ mm Hg})}{P (\text{mm Hg}) V (\text{cm}^3) T_0 (273.2 \text{ K})} \quad \text{or}$$

$$\dot{X} = \frac{3.002 \times 10^{13} I T}{P V} \quad (13)$$

Exposure rate in air, described by Attix⁹ at a point due to an energy fluence of monoenergetic photons:

$$\dot{X} = \Phi E_\gamma \left(\frac{\mu_{en}}{\rho} \right)_a \left(\frac{e}{W} \right)_a \quad (14)$$

can be related to the dose rate in air, also described by Attix⁹ at the same point:

$$\dot{D}_a = \Phi E_\gamma \left(\frac{\mu_{en}}{\rho} \right)_a \quad (15)$$

by equating the two relationships

$$\dot{D}_a = \dot{X} \left(\frac{\bar{W}}{e} \right)_a \quad (16)$$

and converting to consistent units:

$$\dot{D}_a \text{ (rad h}^{-1}\text{)} = \dot{X} \left(\frac{\text{R}}{\text{h}} \right) \frac{\bar{W}}{\text{e}} \left(\frac{33.97 \text{ eV}}{1.602 \times 10^{-19} \text{ Coul}} \right) \frac{2.58 \times 10^{-4} \text{ Coul}}{\text{R kg}} \quad (17)$$

$$\frac{\text{kg}}{10^3 \text{ g}} \frac{\text{g rad}}{6.242 \times 10^7 \text{ MeV}} \frac{\text{MeV}}{10^6 \text{ eV}} \quad \text{or}$$

$$\dot{D}_a = 0.876 \dot{X} \quad (18)$$

Since the ratio of the mass energy coefficients of the media (tissue and air) for the range of photon energies from 0.01 MeV to 10 MeV is shown by NBS¹⁰ as a relatively constant value of 1.1, the absorbed dose rate in tissue can be derived from the dose rate in air as

$$\dot{D}_t = \dot{D}_a = \left(\frac{\mu_{en}}{\rho} \right)_t \left(\frac{\mu_{en}}{\rho} \right)_a^{-1} = 0.876 \dot{X} \cdot 1.1 \quad \text{or} \quad (19)$$

$$\dot{D}_t = 0.964 \dot{X} \quad (20)$$

For routine external radiation surveys performed in the work environment, tissue dose is frequently used interchangeably (though incorrectly) with exposure, because the dose in tissue due to 1 R of exposure is close to the energy deposited in tissue (100 ergs g⁻¹) which is the definition of the rad.

2.0 METHODS

2.1 Environmental chamber system

An environmental chamber provides a wide range of controllable temperatures and humidity levels. The environmental chamber system used in this study included the chamber, digital controller, humidity transmitter, process chart recorder, video camera, and time-lapse video cassette recorder (Fig. 2). Interior dimensions of the chamber are 51 cm (W) × 50 cm (D) × 56 cm (H). The internally lined chamber is corrosive resistant with moisture resistant seals to protect internal parts from exposure to harsh conditions. Temperature inside the chamber could be varied from -20°C to 70°C. Noncondensing humidity levels were measured with a humidity transmitter. Both temperature and humidity were independently checked with an electronic digital thermohygrometer, traceable to the US National Institute of Standards and Technology. A programmable microprocessor-based digital controller regulated the temperature/humidity rates and soak intervals inside the chamber. The chamber used a R-502 refrigeration system and a five-gallon gravity-fed water reservoir for recycling water. A side access port on the side of the chamber allowed passage of electrical cords to permit testing of AC powered and fixed radiological instruments.

A 3 mCi Cs-137 radiation source ($E_\gamma = 662$ keV, $T_{1/2} = 30.2$ y) was used to produce a response on beta-gamma survey meters and on tritium-in-air monitors (the use of a β -emitting radioactive gas in an open system was not within the as-low-as-reasonably-achievable "ALARA" concept and the response of ion chambers using a gamma source is well known). The cesium source was installed in a lucite source holder that is permanently mounted to the back wall of the chamber. The holder also could be fitted with a 250 mCi Am-241/Be (AmBe) radiation source ($E_\alpha = 5.5$ MeV, $E_\gamma = 59.5$ keV, $T_{1/2} = 432.7$ y) to produce a response on neutron rem meters. A performance test calibrator containing a 700 nCi Pu-239 radiation source ($E_\alpha = 5.1$ MeV, $T_{1/2} = 2.41 \times 10^4$ y) was used to produce a response on alpha contamination monitors using an air-proportional alpha detector. The detector was inserted into the calibrator and tested in the chamber with the instrument.

Since the statistical uncertainty associated with the random nature of radioactive decay is related to the field strength, a source of sufficient activity is required to minimize the random fluctuations in response that occur when an instrument is exposed in a radiation field. The field established in the chamber by the cesium source was shown to produce an instrument response that was within 5% ($COV < 2\%$ for digital-display-type instruments) and within 10% using the AmBe source at reference conditions. The plutonium source was shown to produce an instrument response that was generally within 10% of the baseline at reference conditions.

2.2 Radiological instruments

2.2.1 Beta-gamma survey meters

Portable direct-reading beta-gamma survey meters tested include the Eberline RO-2 and RO-3C ionization chambers (Fig. 3), the Eberline E-530 survey meter with the Model HP-177C stainless steel GM wall probe, the Eberline PIC-6A and PIC-6B ion chambers, the Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector, and the Ludlum 3 survey meter with the Model 44-6 stainless steel GM wall probe. All beta-gamma survey meters tested are DC powered, use an analog-type meter display, and function in the rate mode (except for the ESP-1, which is a digital-display-type instrument, and functions in both rate and scaler modes).

The Eberline RO-2 and RO-3C ionization chambers measure and X-, γ -, and β -radiation on four linear ranges (0-5, 0-50, 0-500, and 0-5000) of exposure rate from 0 (0.2) mR h⁻¹ to 5000 mR h⁻¹ full scale. Both analog-display-type instruments use an internal air-filled ion chamber detector vented to the environment. The Eberline RO-2 ionization chamber is equipped with a window (7-mg cm² mylar) and sliding beta shield (400-mg cm² phenolic) on the bottom of the chamber to measure β -radiation, while the Eberline RO-3C ionization chamber is equipped with a window (3.5-mg cm² mylar) and β -shield on the front of the chamber. The Eberline E-530 survey meter also uses an analog-type meter display and measures exposure rate from γ -radiation on four linear range (scale) multipliers ($\times 0.01$, $\times 0.1$, $\times 1$, and $\times 10$) from 0 (0.01) mR h⁻¹ to 200 mR h⁻¹ full scale. Beta radiation is detected by opening the rotating stainless steel window covering the halogen-quenched GM tube inside the external hand probe.

The Eberline PIC-6A and PIC-6B ion chambers with analog-type meter displays measure exposure rate from X- or γ -radiation over six decades (two ranges of three decades each) of exposure rate from 1 mR h⁻¹ to 1000 R h⁻¹ full scale. Both ion chambers use an internal sealed pressurized detector that operates in the proportional region. These ion chambers are equipped with a window to measure β -radiation (not recommended for the Eberline PIC-6B ion chamber). The sealed detector prevents internal contamination from ambient radioactive gases and makes these instruments useful for monitoring in emergency response applications.

The Eberline ESP-1 survey meter is a microprocessor-based instrument, uses an auto-ranging digital-type liquid-crystal display (LCD) with bar graph display, and can be used with several different types of radiation probes and detectors (GM, scintillation, and proportional detectors). This instrument operates in the rate mode displaying a digital count or dose rate in addition to an analog (bar graph) format, or in the scaler mode, displaying total counts or dose. Gamma radiation is measured with the external "pancake" detector which incorporates a halogen-quenched GM tube. The large surface area of the thin mica window on the detector permits higher sensitivity for measuring α - and β -radiation.

The Ludlum 3 survey meter uses an analog-type meter display and measures exposure rate from γ -radiation on four linear range (scale) multipliers ($\times 0.1$, $\times 1$, $\times 10$, and $\times 100$) from 0 (0.1) mR h⁻¹ to 200 mR h⁻¹ full scale. Beta radiation is measured by opening the rotating stainless steel window covering the halogen-quenched GM tube inside the external hand probe.

2.2.2 Neutron rem meters

Portable direct-reading neutron rem meters tested include the Eberline ESP-1, Eberline ESP-2 (Fig. 4) and Eberline PNR-4 survey meters with the NRD, and the Health Physics Instruments (HPI) 2080 survey meter with the moderator detector. All neutron rem meters tested are DC powered (HPI 2080 survey meter is AC/DC), use a digital-type meter display, and function in the rate and scaler modes (except for the Eberline PNR-4 survey meter, which is an analog-display-type instrument and operates strictly as a rate meter, and the HPI 2080 survey meter, which also operates as a rate meter). Both the NRD and moderator can be detached from the instrument for remote monitoring.

The Eberline ESP-1 and ESP-2 survey meters are microprocessor-based instruments and use an auto-ranging digital-type LCD with a bar graph display. Both the Eberline ESP-1 and ESP-2 survey meters operate in the rate mode, displaying a digital count or dose rate equivalence, or in the scaler mode, displaying total counts or dose equivalence. The Eberline ESP-2 survey meter is similar in regard to the Eberline ESP-1 survey meter with the added capability of data logging via a RS-232 serial communications port and includes a feature that allows multidetector configurations. The Eberline PNR-4 survey meter measures neutron radiation using an auto-ranging analog (linear-logarithm)-type meter display on four decades (5, 50, 500, and 5000) of dose rate equivalence from 0 (0.5) mrem h⁻¹ to 5 K mrem h⁻¹ full scale. All three instruments are tested with the same model detector. The sealed pressurized proportional

detector (filled with BF_3 gas) allows gamma rejection in fields up to 500 R h^{-1} and is housed in the center of the 9-in-diameter cadmium-loaded polyethylene sphere.

The HPI 2080 survey meter is a microprocessor-based auto-ranging instrument and uses a digital-type LCD. Dose rate equivalence is measured on the basis of determining the average time between instrument readings ($15 \text{ s} \times 1, 2, 4, 6, 8, 16, \text{ or } 32$). Serial data communications are possible with the HPI 2080 via a RS-232 serial port. This instrument is designed to measure either pulsed or steady-state neutron dose rate equivalence in mixed neutron/gamma radiation fields and is typically used at accelerator facilities. The HPI 2080 survey meter is tested with the 25-cm-diameter polyethylene pseudosphere moderator detector. Two gain-matched sealed GM detectors are used in this instrument: 1) an Ag-wrapped GM tube to detect β -radiation; and 2) a Sn-wrapped GM tube to allow γ -radiation background subtraction.

2.2.3 Alpha contamination monitors

The portable direct-reading alpha contamination monitor tested was the Ludlum 139 survey meter with the Model 43-32 air-proportional alpha detector (Fig. 5). This instrument is DC powered, uses an analog-type meter display, and operates in the rate mode. Alpha radiation is measured on four linear range (scale) multipliers ($\times 1, \times 10, \times 100, \text{ and } \times 1000$) from 0 (50) counts s^{-1} to 10^6 counts s^{-1} full scale. The external hand held mylar-covered detector used with the instrument is vented to the environment.

2.2.4 Tritium-in-air monitors

Portable direct-reading tritium-in-air monitors tested include the Overhoff 394-C, Johnston J-111 and J-110 (Fig. 6) tritium monitors. These instruments are AC/DC powered, use a bar graph LCD (except for the Overhoff 394-C tritium monitor, which is an analog-display-type instrument), incorporate a brushless diaphragm-type pump to draw in ambient air contaminated with tritium gas/oxide, and read out in activity concentration units.

The Overhoff 394-C tritium monitor measures β - and γ -radiation on four linear ranges ($\times 100, \times 1 \text{ K}, \text{ and } \times 10 \text{ K}$) from 0 (1) $\mu\text{Ci m}^{-3}$ to $10^3 \mu\text{Ci m}^{-3}$ full scale, while the Johnston J-111 and J-110 tritium monitors measure β - and γ -radiation on ranges (50 $\mu\text{Ci m}^{-3}$ and 500 $\mu\text{Ci m}^{-3}$ linear, $10^3 \mu\text{Ci m}^{-3}$ and $10^5 \mu\text{Ci m}^{-3}$ logarithm) from 0 (1) $\mu\text{Ci m}^{-3}$ to $10^5 \mu\text{Ci m}^{-3}$ full scale. All three instruments are equipped with an air-flow ionization chamber (there are two sample ion chambers in the Johnston J-111 and J-110 tritium monitors) which are vented to the environment. The Johnston J-111 tritium monitor incorporates two additional ion chambers to compensate for external γ -radiation in fields up to 5 mR h^{-1} . These tritium-in-air monitors are used for monitoring open/closed-loop operations and controlled environments (e.g., glove boxes, environmental chambers). Measurement of other β -emitting radioactive gases is achieved by applying an appropriate calibration factor.

2.3 Tests

105 radiological instruments representing four major categories of portable direct-reading instruments used in routine health physics operations at Los Alamos were tested to evaluate the ANSI standard (Table 1). A minimum of four (maximum of ten) instruments of each model were randomly selected off the ready-for-issue shelf at the Los Alamos Radiation Inventory Pool for exposure in the chamber according to a laboratory procedure (APPENDIX A). All instruments were calibrated shortly before testing. Preliminary data were collected for each instrument in a work sheet (APPENDIX B) that includes an instrument identification number (HSN), detector type, battery voltages (DC-powered instruments only), instrument range (scale) tested, and test conditions, etc. Information on instrument age (inventory year) was also collected. Instruments were exposed in the chamber for a minimum of nine hours for temperature and a minimum of eighteen hours for humidity. Instrument readings were recorded on video tape using a video camera and time-lapse video recorder. Repeat (rep) tests for reproducibility were performed on at least two instruments of each model for the temperature test only.

Temperature. The temperature program test file (Fig. 7) programmed into the digital controller initially exposed the instrument for one hour at 20°C (reference temperature) and ambient humidity. Chamber temperature was increased at a rate of 10°C h⁻¹ until the maximum temperature limit of 50°C was reached. Within one hour, temperature was gradually decreased from 50°C to 20°C. After the temperature has been stabilized for one hour at 20°C, the test is repeated for an instrument taken down at a rate of -10°C h⁻¹ until the minimum temperature limit of -10°C was reached. The program then returned the temperature inside the chamber to reference temperature. Pass/fail was based on meeting two criteria: 1) maintaining a mean instrument reading within 15% from the temperature range of 0°C to 40°C; and 2) maintaining a mean instrument reading within 20% from the temperature range of -10°C to 50°C.

Humidity. The humidity program test file (Fig. 8) programmed into the digital controller initially exposed the instrument for four hours at 40% RH (reference humidity) and 20°C. Chamber humidity was increased to 95% RH for nine hours maintaining the same temperature. The program then returned the humidity level inside the chamber to reference humidity for five hours maintaining the same temperature. Pass/fail was based on maintaining a mean instrument reading within 15% from the extended humidity range of 40% to 95% to 40% RH.

2.4 Analysis

A video camera and time-lapse video recorder were used to record instrument readings. Readings were averaged over a thirty-second sampling interval during the last minute of each test hour. An "eye-ball" weighted average of the reading is determined for analog-display-type instruments, while descriptive statistics were applied for digital-display-type instruments. Instrument readings, collected by viewing the video tapes, were analyzed and compared using three methods: 1) descriptive statistics; 2) Analysis of Variance (ANOVA) estimates; and 3) the binomial frequency distribution.

2.4.1 Descriptive statistics, correction factor, and normalized response

Instrument readings were entered into a Borland Quattro Pro¹¹ spreadsheet which calculated the sample mean, sample standard deviation, coefficient of variation (digital-display-type instruments only), an air density correction factor, CF, for instruments using an air-filled or air-flow detector vented to the environment, and normalized the instrument response (APPENDIX C). A summary graph was plotted on the spreadsheet for quality assurance purposes. The CF was not applied to alpha contamination monitors (because these instruments operate in the pulse mode and not in the current mode where the charge collected depends on the mass of air in the detector) and in cases when the mean instrument reading did not differ from the baseline reading determined at reference conditions. The CF (referenced at 20°C) applied to the mean instrument reading is

$$CF = \left(\frac{P}{P + \Delta P} \right) \left(\frac{T}{T_0 + 20^\circ\text{C}} \right) , \quad (21)$$

where ΔP (same units as P) is the measured chamber pressure above ambient during the exposure profile. The pressure component of the CF equation was assumed to be unity, since the pressure increase in the chamber was small relative to the statistical variations observed in instrument response when the instrument was exposed in a radiation field. The shift in response for an instrument exposed in a gamma field using a vented detector can be 10% at the temperature extremes (50°C and -10°C) due to effect of temperature alone. A change in altitude, on the other hand, can affect an instruments reading by 30% (sea level to 7300 ft at constant temperature). The change in air density due to ambient humidity is insignificant compared to the normal fluctuations that can be observed in the response of an instrument exposed in a field.

The normalized response, NR, to include the correction factor for the change in air density during the temperature test, where R_T is the mean instrument reading at temperature T (°C) and R_{20} is the mean instrument reading at reference temperature is

$$NR = \left(\frac{R_T}{R_{20}} \right) CF . \quad (22)$$

Likewise, the NR for the humidity test, where R_H is the mean instrument reading at humidity RH (%) and R_{40} is the mean instrument reading at reference humidity (40% RH) is

$$NR = \left(\frac{R_H}{R_{40}} \right) CF . \quad (23)$$

2.4.2 ANOVA estimates

One-way and two-way structure ANOVA estimates were used to compare the differences in the NR for $NR \geq 0.500$ (50% under-response) and for $NR \leq 2.000$ (200% over-response) to estimate the associated uncertainties in the instrument response. For the temperature test, data were fit using the SAS¹² general linear models (GLM) procedure to the full model (two-way structure ANOVA): $y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \epsilon_{ijk}$, where y_{ijk} is the observed instrument response normalized to 20°C, μ is the y-intercept, α_i is the effect of i th level of instrument, β_j is the effect of the j th level of temperature, $\alpha\beta_{ij}$ is the interaction effect (measure of whether comparisons of instrument depends on temperature) for the i th level of instrument and the j th level of temperature, and ϵ_{ijk} is the random (experimental) error associated with individual observations. For the humidity test, data were fit using the GLM procedure to the full model (one-way structure ANOVA): $y_{ij} = \mu + \alpha_i + \beta_j + \epsilon_{ij}$, where y_{ij} is the observed instrument response normalized to 40% RH, μ is the y-intercept, α_i is the effect of i th level of instrument, β_j is the effect of the j th level of humidity or time sequence (time sequence is the elapsed time during the exposure profile), and ϵ_{ij} is the random (experimental) error associated with individual observations. An interaction effect was not defined in the full model for humidity since repeat tests were not performed. Error bars at the 95% confidence level (2σ) were calculated as twice the root mean square error (MSE) from the GLM procedure.

2.4.3 Binomial frequency distribution

Test performance of an instrument falls into one of only two classes or dichotomous outcomes (pass/fail); therefore, the distribution for calculating the probability of obtaining x events out of n samples is the binomial frequency distribution. The binomial frequency distribution for the interval estimation of the population parameter p was used to determine the lower and upper limits (bounds) and the estimated percentage of responses outside the standards performance criteria sampled in the population (denoted as a "Fail"). This parameter was reported at a 95% level of confidence. The estimation of the confidence interval on p given by Fryer¹³ are as follows:

$$L = \frac{x}{x + (n - x + 1) F_{\alpha/2} [2(n - x + 1), 2x]}, \quad (24)$$

for the lower limit L and

$$U = \frac{(x + 1) F_{\alpha/2} [2(x + 1), 2(n - x)]}{(n - x) + (x + 1) F_{\alpha/2} [2(x + 1), 2(n - x)]}, \quad (25)$$

for the upper limit U , where x is the number of observations outside the performance criterion, n is the sample size and α is the level of significance (0.05) using the F distribution.

3.0 RESULTS

3.1 Beta-gamma survey meters

Results for the beta-gamma survey meters tested based on the ANSI standard's performance criteria and test methods evaluated are given in Table 16. Results for estimating the percentage of observations sampled in the population outside the ANSI standard's performance criteria based on the binomial frequency distribution are summarized in Tables 17 and 18.

3.1.1 Eberline RO-2 ionization chamber

Temperature. Figures 9 and 10 show normalized response (uncorrected and corrected response for air density changes during the exposure profile) plotted as a function of temperature. All six instruments (with corrected responses) tested for temperature (including repeat tests) maintained a mean response within 15% from 0°C to 40°C and within 20% from -10°C to 50°C (Tables 2 and 16). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and the interaction effect between instrument and temperature (repeat tests) was statistically significant ($p = 0.0001$). The full model (two-way structure ANOVA) explained essentially 100% of the total variation in the normalized response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% and 20% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 7.4%) (Table 17).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Figure 11. All six instruments tested for humidity maintained a mean response within 15% over the noncondensing humidity range from 40% to 95% to 40% RH (Tables 3 and 16). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to time sequence was statistically significant ($p = 0.005$). The full model (one-way structure ANOVA) explained 58% of the total variation in the normalized response by the linear relationship to instrument and time sequence. The estimated percentage of observations sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 10.2%) (Table 18).

3.1.2 Eberline RO-3C ionization chamber

Temperature. Figures 12 and 13 show normalized response plotted as a function of temperature. All six instruments (with corrected normalized responses) tested for temperature (including repeat tests) maintained a mean response within 15% from 0°C to 40°C, but two instruments (including a repeat test) failed to maintain a mean response within 20% from -10°C to 50°C (Tables 4 and 16). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and the interaction effect between instrument and temperature (repeat tests) was statistically significant ($p = 0.0001$). The full model (two-way structure ANOVA) explained 99% of the total variation in the normalized

response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% and 20% based on the binomial frequency distribution was determined to be 4.2% (95% CI 0.5%, 14.4%) (Table 17).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Figure 14. Two of the six instruments tested for humidity failed to maintain a mean response within 15% over the noncondensing humidity range from 40% to 95% to 40% RH (Tables 5 and 16). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to time sequence was not statistically significant ($p = 0.20$). The full model (one-way structure ANOVA) explained 41% of the total variation in the normalized response by the linear relationship to instrument and time sequence. The estimated percentage of observations sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 16.7% (95% CI 6.4%, 32.9%) (Table 18).

3.1.3 Eberline E-530 survey meter with the Model HP-177C stainless steel GM wall probe

Temperature. Figure 15 shows normalized response plotted as a function of temperature. One of the six instruments tested for temperature (including a repeat test) failed to maintain a mean response within 15% from 0°C to 40°C and within 20% from -10°C to 50°C (Tables 6 and 16). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and the interaction effect between instrument and temperature (repeat tests) was not statistically significant ($p = 0.44$). The full model (two-way structure ANOVA) explained 78% of the total variation in the normalized response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% was determined to be 14.6% (95% CI 6.2%, 28.0%) and outside of 20% based on the binomial frequency distribution was 12.5% (95% CI 4.7%, 24.6%) (Table 17).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Figure 16. All six instruments tested for humidity maintained a mean response within 15% over the noncondensing humidity range from 40% to 95% to 40% RH (Tables 7 and 16). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to time sequence was statistically significant ($p = 0.0001$). The full model (one-way structure ANOVA) explained 84% of the total variation in the normalized response by the linear relationship to instrument and time sequence. The estimated percentage of observations sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 9.8%) (Table 18).

3.1.4 Eberline PIC-6A ion chamber

Temperature. Figure 17 shows normalized response plotted as a function of temperature. Two of the ten instruments tested for temperature (including a repeat test) failed to maintain a mean response within 15% from 0°C to 40°C, and six instruments (including repeat tests) failed

to maintain a mean response within 20% from -10°C to 50°C (Tables 8 and 16). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and the interaction effect between instrument and temperature (repeat tests) was statistically significant ($p = 0.0001$). The full model (two-way structure ANOVA) explained 98% of the total variation in the normalized response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% was determined to be 16.7% (95% CI 9.5%, 26.1%) and outside of 20% based on the binomial frequency distribution was 10.7% (95% CI 5.1%, 19.0%) (Table 17).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Figure 18. One of the ten instruments tested for humidity failed to maintain a mean response within 15% over the noncondensing humidity range from 40% to 95% to 40% RH (Tables 9 and 16). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to time sequence was statistically significant ($p = 0.0001$). The full model (one-way structure ANOVA) explained 61% of the total variation in the normalized response by the linear relationship to instrument and time sequence. The estimated percentage of observations sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 6.7% (95% CI 0.8%, 16.3%) (Table 18).

3.1.5 Eberline PIC-6B ion chamber

Temperature. Figure 19 shows normalized response plotted as a function of temperature. All four instruments tested for temperature (including repeat tests) maintained a mean response within 15% from 0°C to 40°C and within 20% from -10°C to 50°C (Tables 10 and 16). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and the interaction effect between instrument and temperature (repeat tests) was not statistically significant ($p = 0.99$). The full model (two-way structure ANOVA) explained 39% of the total variation in the normalized response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% was determined to be 5.6% (95% CI 0.7%, 18.8%) and outside of 20% based on the binomial frequency distribution was 0% (95% CI 0%, 5.8%) (Table 17).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Figure 20. All four instruments tested for humidity maintained a mean response within 15% over the noncondensing humidity range from 40% to 95% to 40% RH (Tables 11 and 16). The estimated percentage of responses sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 14.3%) inclusive of all observations (Table 18).

3.1.6 Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector

Temperature. Figure 21 shows normalized response plotted as a function of temperature. All seven instruments tested for temperature (including repeat tests) maintained a mean response

within 15% from 0°C to 40°C and within 20% from -10°C to 50°C (Tables 12 and 16). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and the interaction effect between instrument and temperature (repeat tests) was not statistically significant ($p = 0.78$). The full model (two-way structure ANOVA) explained 63% of the total variation in the normalized response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% and 20% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 6.0%) (Table 17).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Figure 22. All seven instruments tested for humidity maintained a mean response within 15% over the noncondensing humidity range from 40% to 95% to 40% RH (Tables 13 and 16). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to time sequence was statistically significant ($p = 0.0001$). The full model (one-way structure ANOVA) explained 73% of the total variation in the normalized response by the linear relationship to instrument and time sequence. The estimated percentage of observations sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 8.5%) (Table 18).

3.1.7 Ludlum 3 survey meter with the Model 44-6 stainless steel GM wall probe

Temperature. Figure 23 shows normalized response plotted as a function of temperature. All six instruments tested for temperature (including repeat test) maintained a mean response within 15% from 0°C to 40°C and within 20% from -10°C to 50°C (Tables 14 and 16). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and the interaction effect between instrument and temperature (repeat tests) was statistically significant ($p = 0.0001$). The full model (two-way structure ANOVA) explained 99% of the total variation in the normalized response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% and 20% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 7.4%) (Table 17).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Figure 24. All six instruments tested for humidity maintained a mean response within 15% over the noncondensing humidity range from 40% to 95% to 40% RH (Tables 15 and 16). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to time sequence was statistically significant ($p = 0.0001$). The full model (one-way structure ANOVA) explained 83% of the total variation in the normalized response by the linear relationship to instrument and time sequence. The estimated percentage of observations sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 9.8%) (Table 18).

3.2 Neutron rem meters

Results for the neutron rem meters tested based on the ANSI standard's performance criteria and test methods evaluated are given in Table 27. Results for estimating the percentage of observations sampled in the population outside the ANSI standard's performance criteria based on the binomial frequency distribution are summarized in Tables 28 and 29.

3.2.1 Eberline ESP-1 survey meter with the NRD

Temperature. Figure 25 shows normalized response plotted as a function of temperature. One of the eight instruments tested for temperature failed to maintain a mean response within 15% from 0°C to 40°C and within 20% from -10°C to 50°C (Tables 19 and 27). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and the interaction effect between instrument and temperature (repeat tests) was not statistically significant ($p = 0.08$). The full model (two-way structure ANOVA) explained 83% of the total variation in the normalized response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% was determined to be 4.5% (95% CI 0.9%, 12.7%) and outside of 20% based on the binomial frequency distribution was 3.0% (95% CI 0.4%, 10.5%) (Table 28).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Figure 26. All eight instruments tested for humidity maintained a mean response within 15% over the noncondensing range from 40% to 95% to 40% RH (Tables 20 and 27). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to time sequence was statistically significant ($p = 0.0001$). The full model (one-way structure ANOVA) explained 64% of the total variation in the normalized response by the linear relationship to instrument and time sequence. The estimated percentage of observations sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 7.3%) (Table 29).

3.2.2 Eberline ESP-2 survey meter with the NRD

Temperature. Figure 27 shows normalized response plotted as a function of temperature. All eight instruments tested for temperature (including repeat tests) maintained a mean response within 15% from 0°C to 40°C and within 20% from -10°C to 50°C (Tables 21 and 27). Two of these instruments, however, displayed error messages outside the test when the temperature was increased from -10°C to 20°C, but returned to normal after stabilizing at room temperature. GLM procedure results showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and repeat tests was not statistically significant ($p = 0.26$). The full model (two-way structure ANOVA) explained 78% of the total variation in the normalized response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% and 20% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 5.4%) (Table 28).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Figure 28. Four of the eight of the instruments tested for humidity failed to maintain a mean response within 15% over the noncondensing range from 40% to 95% to 40% RH (Tables 22 and 27). GLM procedure results showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to time sequence was not statistically significant ($p = 0.67$). The full model (one-way structure ANOVA) explained 23% of the total variation in the normalized response by the linear relationship to instrument and time sequence. The estimated percentage of observations sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 20.8% (95% CI 10.4%, 35.0%) (Table 29).

3.2.3 Eberline PNR-4 survey meter with the NRD

Temperature. Figure 29 shows normalized response plotted as a function of temperature. Two of the eight instruments tested for temperature (including a repeat test) failed to maintain a mean response within 15% from 0°C to 40°C, and three instruments (including a repeat test and another that failed the first criterion) failed to maintain a mean response within 20% from -10°C to 50°C (Tables 23 and 27). GLM procedure results showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and the interaction effect was not statistically significant ($p = 0.41$). The full model (two-way structure ANOVA) explained 75% of the total variation in the normalized response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% and 20% based on the binomial frequency distribution was determined to be 10.6% (95% CI 4.4%, 20.7%) (Table 28).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Figure 30. Three of the eight of the instruments tested for humidity failed to maintain a mean response within 15% over the noncondensing range from 40% to 95% to 40% RH (Tables 24 and 27). GLM procedure results showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to time sequence was not statistically significant ($p = 0.07$). The full model (one-way structure ANOVA) explained 44% of the total variation in the normalized response by the linear relationship to instrument and time sequence. The estimated percentage of observations sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 14.6% (95% CI 6.1%, 28.1%) (Table 29).

3.2.4 HPI 2080 survey meter with the moderator detector

Temperature. Figure 31 shows normalized response plotted as a function of temperature. Six out of the eight instruments tested for temperature failed to maintain a mean response within 15% from 0°C to 40°C and within 20% from -10°C to 50°C (Tables 25 and 27). Of the two instruments that passed, one failed both of the ANSI criteria on a repeat test. GLM procedure results showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and repeat tests was not statistically significant ($p = 0.30$). The full model (two-way structure ANOVA) explained 84% of the total variation in the normalized response by the linear

relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% was determined to be 35.0% (95% CI 23.2%, 48.8%) and outside of 20% based on the binomial frequency distribution was 13.3% (95% CI 5.9%, 24.8%) (Table 28).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Figure 32. Seven out of the eight instruments tested for humidity failed to maintain a mean response within 15% over the noncondensing range from 40% to 95% to 40% RH (Tables 26 and 27). GLM procedure results showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to time sequence was statistically significant ($p = 0.027$). The full model (one-way structure ANOVA) explained 54% of the total variation in the normalized response by the linear relationship to instrument and time sequence. The estimated percentage of observations sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 31.3% (95% CI 18.8%, 46.5%) (Table 29).

3.3 Alpha contamination monitors

Results for the alpha contamination monitors tested based on the ANSI standard's performance criteria and test methods evaluated are given in Table 32. Results for estimating the percentage of observations outside the ANSI standard's performance criteria based on the binomial frequency distribution are summarized in Tables 33 and 34.

3.3.1 Ludlum 139 survey meter with the Model 43-32 air-proportional alpha detector

Temperature. Figure 33 shows normalized response plotted as a function of temperature. Four of the ten instruments tested for temperature failed to maintain a mean response within 15% from 0°C to 40°C and within 20% from -10°C to 50°C. Of the six instruments that passed the first criterion, three failed to maintain a mean response within 20% from -10°C to 50°C (Tables 30 and 32). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and the interaction effect between instrument and temperature (repeat tests) was statistically significant ($p = 0.0001$). The full model (two-way structure ANOVA) explained essentially 100% of the total variation in the normalized response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% was determined to be 25.0% (95% CI 15.5%, 36.8%) and outside of 20% based on the binomial frequency distribution was 16.7% (95% CI 9.0%, 27.3%) (Table 33).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Figure 34. Eight out of ten instruments tested for humidity failed to maintain a mean response within 15% over the noncondensing range from 40% to 95% to 40% RH (Tables 31 and 32). In addition, the response of six instruments pegged full scale during the test at 95% RH. Results from the GLM procedure showed that the variability in the mean response ($0.500 \leq NR \leq 2.000$) due to time sequence was statistically significant ($p = 0.016$). The full model (one-way

structure ANOVA) explained 42% of the total variation in the normalized response by the linear relationship to instrument and time sequence. The estimated percentage of observations sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 38.3% (95% CI 25.8%, 52.9%) (Table 34).

3.4 Tritium-in-air monitors

Results for the tritium-in-air monitors tested based on the ANSI standard's performance criteria and test methods evaluated are given in Table 41. Results for estimating the percentage of observations sampled in the population outside the ANSI standard's performance criteria based on the binomial frequency distribution are summarized in Tables 42 and 43.

3.4.1 Overhoff 394-C tritium monitor

Temperature. Figure 35 shows normalized response plotted as a function of temperature. All six instruments tested for temperature (including repeat tests) maintained a mean response within 15% from 0°C to 40°C and within 20% from -10°C to 50°C (Tables 35 and 41). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and the interaction effect between instrument and temperature (repeat tests) was statistically significant ($p = 0.0001$). The full model (two-way structure ANOVA) explained 97% of the total variation in the normalized response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% and 20% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 7.4%) (Table 42).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Figure 36. All six instruments tested for humidity maintained a mean response within 15% over the noncondensing range from 40% to 95% to 40% RH (Tables 36 and 41). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to time sequence was statistically significant ($p = 0.0001$). The full model (one-way structure ANOVA) explained 77% of the total variation in the normalized response by the linear relationship to instrument and time sequence. The estimated percentage of observations sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 9.8%) (Table 43).

3.4.2 Johnston J-111 tritium monitor

Temperature. Figure 37 shows normalized response plotted as a function of temperature. One of the six instruments tested for temperature failed to maintain a mean response within 15% from 0°C to 40°C and within 20% from -10°C to 50°C, but passed on the repeat test (Tables 37 and 41). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and the interaction effect between instrument and temperature (repeat tests) was statistically significant ($p = 0.0001$). The full model (two-way

structure ANOVA) explained 97% of the total variation in the normalized response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% was determined to be 10.4% (95% CI 3.5%, 22.8%) and outside 20% based on the binomial frequency distribution was 2.1% (95% CI 0.1%, 11.1%) (Table 42).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Figure 38. All six instruments tested for humidity maintained a mean response within 15% over the noncondensing range from 40% to 95% to 40% RH (Tables 38 and 41). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to time sequence was statistically significant ($p = 0.0001$). Time sequence explained essentially 100% of the total variation in the normalized response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 9.8%) (Table 43).

3.4.3 Johnston J-110 tritium monitor

Temperature. Figure 39 shows normalized response plotted as a function of temperature. All six instruments tested for temperature (including repeat tests) maintained a mean response within 15% from 0°C to 40°C and within 20% from -10 to 50°C (Tables 39 and 41). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to temperature and the interaction effect between instrument and temperature (repeat tests) was statistically significant ($p = 0.005$). The full model (two-way structure ANOVA) explained 93% of the total variation in the normalized response by the linear relationship to instrument and the interaction term. The estimated percentage of observations sampled in the population outside of 15% and 20% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 7.4%) (Table 42).

Humidity. Normalized response plotted as a function of humidity (time sequence) is shown in Fig. 40. All six instruments tested for humidity maintained a mean response within 15% over the noncondensing range from 40% to 95% to 40% RH (Tables 40 and 41). Results from the GLM procedure showed that the variability in the normalized response ($0.500 \leq NR \leq 2.000$) due to time sequence was statistically significant ($p = 0.0001$). The full model (one-way structure ANOVA) explained 87% of the total variation in the normalized response by the linear relationship to instrument and time sequence. The estimated percentage of observations sampled in the population outside of 15% based on the binomial frequency distribution was determined to be 0% (95% CI 0%, 9.8%) (Table 43).

4.0 DISCUSSION

Uncertainties in the measurement of instrument response exist as errors that have a systematic or random effect. For example, systematic (bias) effects appears reproducibly: 1) in measurements from standards and procedures used to calibrate instruments; 2) from measurements in temperature and humidity; and 3) from the inability to control humidity levels at low temperatures in the chamber. Generally, the errors associated with calibration standards and procedures are relatively small in comparison to the random effects. Because the mean instrument reading at a given temperature, humidity, and time is normalized to the reference (baseline) reading, calibration accuracy is not an issue. Random effects, on the other hand, can result from variations in the experimental conditions or from the intrinsic statistical variations in the instrument response associated with the radiation field and the interaction processes.

The intent of maintaining a reproducible geometry, denoted as a requirement in the ANSI standard, for instruments tested in the chamber was achieved by not changing the source-to-detector distance. The instrument and detector were positioned adjacent to the radiation source in the chamber and the mean instrument reading determined at reference conditions was used as a baseline measurement for comparison purposes. Even though instrument readings may not have been reproducible within the same make and model instrument or between different instruments, the observed response when normalized to the reference (baseline) response becomes reproducible to itself providing the instrument, detector, and source remained in a fixed position during the test. The only instrument tested in which baseline readings could be compared between instruments was the Ludlum 139 survey meter with the Model 43-32 air-proportional alpha detector. For this alpha contamination monitor, the detector was inserted into a performance test calibrator containing a plutonium source. The instrument, detector, and calibrator were placed into the chamber and tested together. Unfortunately, the calibrator was designed only to accommodate this particular shape and size detector. For the other instruments, an alternative was to tape a radiation source to the detector in a reproducible location, however, this was not considered to be in good practice with the ALARA concept. Moreover, tests for temperature shock were not performed due to the elevated personal dose that would be received from handling the radiation sources.

The ANSI standard requires a test rate $\pm 10^{\circ}\text{C h}^{-1}$ starting from $22 \pm 2^{\circ}\text{C}$ until the temperature extremes of 50°C and -10°C are met. At each 10°C increment, sufficient data are to be taken when the instrument has reached thermal equilibrium. Several factors should be considered for achieving thermal equilibrium in an instrument. These factors depend on the wall thickness and material construction (e.g., hygroscopic properties) of the detector, whether the detector is vented to the environment, and also on instrument design (e.g., integrity of the utility enclosure housing the instrument's electronics, high voltage, and microprocessor). Instrument readings taken at 20°C from 20°C to 50°C were similar to those taken at 20°C from 20°C to -10°C ; therefore, the temperature test profile programmed into the chamber controller seemed adequate for use as the test method for the standard. Since temperature was increased at 10°C intervals beginning at 20°C , mean instrument readings at 35°C were not determined. Given the

same exposure profile, a requirement of maintaining a mean response within 15% for the temperature range from 10°C to 30°C would probably be more appropriate for testing existing laboratory conditions. If the exposure profile had begun at 22°C, a confidence interval around 35°C (e.g., $\pm 3^\circ\text{C}$) would have allowed this criterion to be looked at in more detail.

The ANSI standard provides guidance on the number of instrument readings required to detect, at the 95% confidence level, a true difference between two sets of readings on the same instrument given the percentage difference between the means and the coefficient of variation. In this study, the mean instrument reading for the test hour was determined by averaging readings over a preestablished thirty-second sampling interval (in the work environment, readings are typically averaged over ten seconds). Because a quantitative reading was easier to obtain with the digital-display-type instruments, the mean response and error were expressed using descriptive statistics.

Determining whether or not a particular instrument or group of instruments meet the ANSI standard's performance criteria, simply based on either pass or fail, may represent an overestimate of the percentage of instruments that fail. According to the standard, an instrument whose mean response is not maintained for the temperature criteria (within 15% from 0°C to 40°C and 10°C to 35°C, and within 20% from -10°C to 50°C) and for the humidity criterion (within 15% from 40% RH to 95% RH at $22 \pm 2^\circ\text{C}$) during the exposure profile constitutes complete failure of the test. In actuality, the ANSI standard's test method for temperature comprises six separate tests (a test at 30°C, 40°C, and 50°C, then a test at 10°C, 0°C, and -10°C) for the exposure profile (excluding two baseline readings at reference temperature). Likewise, for the humidity test (extended humidity range), a total of six tests were performed (excluding the initial baseline reading at reference humidity). It was observed in this study that an instrument could fail at one or more tests but pass the others during an exposure profile. Conversely, an instrument could fail even upon stabilization at reference conditions. Data analysis using the binomial frequency distribution with the latter method and larger number of tests produced more reliable statistics with smaller variances and confidence intervals to estimate the percentage of instruments that pass/fail in a given population.

The ANSI standard's temperature test requirement at or near the extreme conditions (e.g., 40°C, 50°C, 0°C, and -10°C) may be too restrictive for instruments using vented and sealed detectors. Failures at other test temperatures were also observed. Type testing at the extreme temperatures should only be considered for those instruments intended for use primarily in field applications (e.g., environmental monitoring).

The ANSI standard's humidity test method may be too restrictive for instruments not adequately sealed against moisture. In this case, improvements in the design of the instrument can include the effective use of weather-resistant seals and better fitting utility enclosures. Moreover, the test requirement at 95% RH and $22 \pm 2^\circ\text{C}$ is not a typical condition experienced in either ambient or work environments. Testing using a more qualitative method to include a range of values between 40% RH and 95% RH may not be cost effective due to the person-hours

required. Type testing at 95% RH with a higher temperature would probably result in more observed failures of the test and also for instruments with design problems. Even though valuable performance test information can be obtained by testing instruments for humidity in accordance with the standard, this test is not useful for instruments strictly used in semi-arid to arid-type environments.

The design of the ANSI standard's test method for temperature and humidity is such that measurements of instrument response cannot be independent, since the shift or change in response at any given time during a test can be affected by a previous environmental condition. None the less, repeated measurements are typically performed on the same instrument for testing due to convenience and for practical considerations. Therefore, the analyses and conclusions of this study were proceeded on the basis that the assumption of independence seemed reasonable.

5.0 CONCLUSION

The purpose of this study was to evaluate the ANSI standard's performance criteria and test methods by investigating the effect of environmental factors, such as temperature and humidity, on the response of a cross section of radiological instruments used in routine health physics operations at Los Alamos. By testing a variety of commercially available instruments in a wide range of environmental conditions the best performing instruments can be recommended. It is important to note that instruments were tested in a controlled environment and exposed to a radiation source which produced a response on only one scale or decade, which may be atypical of the normal operating conditions experienced in a work environment. Other important factors which can affect the response of an instrument such as energy dependence, angular dependence, and interference from radio frequency fields also require ANSI-type testing.

The main objective of performance testing is to improve the confidence in health physics measurements. Confidence is achieved by implementing a program which characterizes and documents the response of a broad range of instruments under various conditions or factors which may influence instrument response. More importantly, however, is that these tests are accomplished in guidance with performance criteria and test methods based on consensus standards. Through independent testing, consumers can insist upon more reliable, higher quality, easier serviceable, and more user-friendly instrumentation, upon which personal safety and protection of the environment greatly depend. The ANSI standard serves to provide a necessary and vital function in establishing guidelines, and in setting benchmarks for instrument design and performance testing. The ANSI standard's various performance criteria and test methods should be evaluated and considered on a case-by-case basis for issues concerning its practicality, usefulness, and cost effectiveness according to the users needs to promote a safe and productive work environment. Some conclusions observed from this study follow.

Beta-gamma survey meters

- The response of air-filled detectors vented to the environment is strongly dependent on ambient temperature and pressure (more so); therefore, a correction factor to account for the change in air density must be applied to the instrument reading when quantitative health physics measurements are required. The change in air density due to ambient humidity is insignificant compared the normal statistical fluctuations that can be observed in the response of an instrument exposed in a radiation field.
- The response of beta-gamma survey meters using a vented detector tends to under-respond as temperature is increased and over-respond as temperature is decreased. The effect of temperature on the response of beta-gamma survey meters using a sealed detector also can exhibit a similar behavior. The variance in the mean response between a group of instruments tends to increase as the temperature extremes are approached.
- The Eberline RO-2 ionization chamber resulted in the best overall performance for the two models of vented ionization chambers tested. Failures at the temperature extremes (50°C and -10°C) and at 95% RH (though statistically insignificant) were observed for the Eberline RO-3C ionization chamber.
- Both the Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector and the Ludlum 3 survey meter with the Model 44-6 stainless steel GM wall probe resulted in the best overall performance for both temperature and humidity for the three models of GM detector-based instruments tested. Failures at and near the temperature extremes (30°C, 40°C, 50°C, 0°C, and -10°C, though statistically insignificant) were observed for the Eberline E-530 survey meter with the Model HP-177C stainless steel GM wall probe.
- For the two models of sealed ion chambers tested, failures at and near the temperature extremes for the Eberline PIC-6A (40°C, 50°C, and -10°C) and the Eberline PIC-6B (0°C, though statistically insignificant) ion chambers were observed. Failures at 95% RH were observed for the Eberline PIC-6A ion chamber.

Neutron rem meters

- The humidity test at 95% RH was found to be too restrictive for the Eberline ESP-2 and Eberline PNR-4 survey meters with the NRD, and the HPI 2080 survey meter with the moderator detector. Even though the Eberline ESP-2 survey meter passed both temperature test criteria, instrument failure was observed outside the test at -10°C to 20°C. Failure at the lower temperatures (10°C, 0°C, and -10°C) was observed for the Eberline PNR-4 survey meter, while the HPI 2080 survey meter failed at all test temperatures (though statistically insignificant). Failures at the lower temperatures (0°C and -10°C, though statistically insignificant) were also observed for the Eberline ESP-1 survey meter, but this instrument resulted in the best overall performance for the four models of neutron rem meters tested.

Alpha contamination monitors

- The effect of temperature on the response of the alpha contamination monitors tested using the air-proportional alpha detector tends to under-respond for both an increase and decrease in temperature. Variance in the mean response between a group of instruments tends to increase as temperature is decreased. The effect of humidity on the response of these instruments may underestimate the true count rate at high-humidity levels.
- The Ludlum 139 survey meter with the Model 43-32 air-proportional alpha detector showed unsatisfactory performance for both temperature and humidity, but recovered following thermal equilibration at ambient conditions. Failures at and near the temperature extremes (40°C, 50°C, 10°C, 0°C, and -10°C) were observed. The test requirement for the humidity test at 95% RH was found to be too restrictive for the alpha contamination monitors tested.

Tritium-in-air monitors

- Both the Overhoff 394-C and Johnston J-110 tritium monitors resulted in the best overall performance for both temperature and humidity for the three models of tritium monitors tested. A failure at the lower temperature (0°C) was observed for the Johnston J-111 tritium monitor. Gamma compensation on the Johnston J-111 tritium monitor appeared to be angularly dependent when exposed in a radiation field.

General

- Performance can vary widely within the same make and model and between different instruments employing the same method of detection. Instrument performance is not always reproducible even when exposed under the same test conditions.
- The ANSI standard's performance criteria may overestimate the percentage of instruments that fail in a given population when failure of an instrument is considered as failure to maintain a mean response within the criteria at any time during a test. Data analysis using the binomial frequency distribution provides a better estimate of the instruments that pass/fail in a given population. Test performance of an instrument depends on how the data are interpreted and analyzed.
- The ANSI standard's temperature test at or near the extreme conditions (e.g., 40°C, 50°C, 0°C, and -10°C) may be too restrictive for instruments. Testing at the temperature extremes should only be considered for those instruments intended for use in field applications. Evaluations using the criterion of maintaining a mean instrument response within 15% from 10°C to 35°C are possible if a confidence interval around 35°C (e.g., $\pm 3^\circ\text{C}$) is established. Intervals around 0°C (e.g., $\pm 4^\circ\text{C}$), 10°C (e.g., $\pm 3^\circ\text{C}$), and 40°C (e.g., $\pm 4^\circ\text{C}$) also should be stated.
- The ANSI standard's humidity test at 95% RH may be too restrictive for instruments. Instrument failure is probably associated with its design such that moisture is allowed to affect electronic and internal components. In this case, design improvements can include the effective use of weather-resistant seals and better fitting utility enclosures. Moreover, the test requirement at 95% RH and $22 \pm 2^\circ\text{C}$ is not a typical condition experienced in either ambient or in work environments. Testing at this humidity level with a higher temperature would probably result in more observed failures of the test and also of the instrument. Type testing using a more qualitative method to include a range of values between 40% RH and 95% RH is probably not cost effective. The humidity test is not useful for instruments strictly used in semi-arid to arid-type environments.
- Performance specifications supplied by the manufacturer can be incomplete and inaccurate; therefore, a continued commitment in independent testing is essential. Type testing improves the confidence in health physics measurements by effectively identifying the strengths, weaknesses, and limitations inherent in radiological instrumentation.
- The ANSI standard provides a necessary and vital function for establishing guidelines and setting benchmarks for instrument design and type testing. Each performance criteria and test method should be evaluated on a case-by-case basis for issues concerning its practicality, usefulness, and cost effectiveness according to the needs of the user in order to promote a safe and productive work environment.

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Figure 1. Dry air density plotted as a function of ambient temperature and humidity.

Figure 2. The environmental chamber system.

Figure 3. Beta-gamma survey meters positioned inside the chamber for testing.

Figure 4. A neutron rem meter positioned inside the chamber for testing.

Figure 5. Alpha contamination monitors positioned inside the chamber for testing.

Figure 6. A tritium-in-air monitor positioned inside the chamber for testing.

Figure 8. Humidity test showing the exposure profile in accordance with the ANSI standard. Testing begins at the reference humidity of $40 \pm 5\%$ RH, ramps to $95 \pm 4\%$ RH, then ends at reference humidity. Chamber temperature is maintained at $22 \pm 2^\circ\text{C}$ throughout the exposure profile.

Eberline RO-2 ionization chamber temperature test (uncorrected response)

Figure 9. Eberline RO-2 ionization chamber temperature test (uncorrected response). Shown are instrument responses uncorrected for air density changes during the exposure profile, the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 10. Eberline RO-2 ionization chamber temperature test (corrected response). Shown are instrument responses corrected for air density changes during the exposure profile, the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 11. Eberline RO-2 ionization chamber humidity test. Shown are the ANSI standard's 15% (dotted line) performance criterion limit and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Eberline RO-3C ionization chamber temperature test (uncorrected response)

Figure 12. Eberline RO-3C ionization chamber temperature test (uncorrected response). Shown are instrument responses uncorrected for air density changes during the exposure profile, the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Eberline RO-3C ionization chamber temperature test (corrected response)

Figure 13. Eberline RO-3C ionization chamber temperature test (corrected response). Shown are instrument responses corrected for air density changes during the exposure profile, the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 14. Eberline RO-3C ionization chamber humidity test. Shown are the ANSI standard's 15% (dotted line) performance criterion limit and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Eberline E-530 survey meter with the Model HP-177C GM probe temperature test

Figure 15. Eberline E-530 survey meter with the Model HP-177C stainless steel GM wall probe temperature test. Shown are the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Eberline E-530 survey meter with the Model HP-177C GM probe humidity test

Figure 16. Eberline E-530 survey meter with the Model HP-177C stainless steel GM wall probe humidity test. Shown are the ANSI standard's 15% (dotted line) performance criterion limit and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 17. Eberline PIC-6A ion chamber temperature test. Shown are the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 18. Eberline PIC-6A ion chamber humidity test. Shown are the ANSI standard's 15% (dotted line) performance criterion limit and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 19. Eberline PIC-6B ion chamber temperature test. Shown are the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 20. Eberline PIC-6B ion chamber humidity test. Shown is the ANSI standard's 15% (dotted line) performance criterion limit.

Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector temperature test

Figure 21. Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector temperature test. Shown are the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector humidity test

Figure 22. Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector humidity test. Shown are the ANSI standard's 15% (dotted line) performance criterion limit and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Ludlum 3 survey meter with the Model 44-6 GM probe temperature test

Figure 23. Ludlum 3 survey meter with the Model 44-6 stainless steel GM wall probe temperature test. Shown are the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Ludlum 3 survey meter with the Model 44-6 GM probe humidity test

Figure 24. Ludlum 3 survey meter with the Model 44-6 stainless steel GM wall probe humidity test. Shown are the ANSI standard's 15% (dotted line) performance criterion limit and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Eberline ESP-1 survey meter with the NRD temperature test

Figure 25. Eberline ESP-1 survey meter with the NRD temperature test. Shown are the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 26. Eberline ESP-1 survey meter with the NRD humidity test. Shown are the ANSI standard's 15% (dotted line) performance criterion limit and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 27. Eberline ESP-2 survey meter with the NRD temperature test. Shown are the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 28. Eberline ESP-2 survey meter with the NRD humidity test. Shown are the ANSI standard's 15% (dotted line) performance criterion limit and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 29. Eberline PNR-4 survey meter with the NRD temperature test. Shown are the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 30. Eberline PNR-4 survey meter with the NRD humidity test. Shown are the ANSI standard's 15% (dotted line) performance criterion limit and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

HPI 2080 survey meter with the moderator detector temperature test

Figure 31. HPI 2080 survey meter with the moderator detector temperature test. Shown are the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

HPI 2080 survey meter with the moderator detector humidity test

Figure 32. HPI 2080 survey meter with the moderator detector humidity test. Shown are the ANSI standard's 15% (dotted line) performance criterion limit and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Ludlum 139 survey meter with the Model 43-32 alpha detector temperature test

Figure 33. Ludlum 139 survey meter with the Model 43-32 alpha detector temperature test. Shown are the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Ludlum 139 survey meter with the Model 43-32 alpha detector humidity test

Figure 34. Ludlum 139 survey meter with the Model 43-32 alpha detector humidity test. Shown are the ANSI standard's 15% (dotted line) performance criterion limit and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Overhoff 394-C tritium monitor temperature test (corrected response)

Figure 35. Overhoff 394-C tritium monitor temperature test (corrected response). Shown are instrument responses corrected for air density changes during the exposure profile, the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 36. Overhoff 394-C tritium monitor humidity test. Shown are the ANSI standard's 15% (dotted line) performance criterion limit and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 37. Johnston J-111 tritium monitor temperature test (corrected response). Shown are instrument responses corrected for air density changes during the exposure profile, the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 38. Johnston J-111 tritium monitor humidity test. Shown are the ANSI standard's 15% (dotted line) performance criterion limit and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 39. Johnston J-110 tritium monitor temperature test (corrected response). Shown are instrument responses corrected for air density changes during the exposure profile, the ANSI standard's 15% (dotted line) and 20% (solid line) performance criteria limits, and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Figure 40. Johnston J-110 tritium monitor humidity test. Shown are the ANSI standard's 15% (dotted line) performance criterion limit and error bars at the 95% confidence level determined by ANOVA estimates for $0.500 \leq NR \leq 2.000$.

Table 1. Cross section of radiological instruments tested in the chamber in accordance with the ANSI standard.

Category	Make	Model	Detector	No	Range tested	Temperature		Humidity	
						Tests	Hours	Tests	Hours
Beta-gamma survey meters	Eberline	RO-2	ionization chamber (vented)	6	0-500	64	72	42	108
	Eberline	RO-3C	ionization chamber (vented)	6	0-500	64	72	42	108
	Eberline	E-530	Model HP-177C GM probe	6	$\times 10$	64	72	42	108
	Eberline	PIC-6A	ion chamber	10	2nd, 3rd decade	112	126	70	180
	Eberline	PIC-6B	ion chamber	4	3rd decade	48	54	28	72
	Eberline	ESP-1	Model HP-260 pancake GM	7	---	80	90	49	126
	Ludlum	3	Model 44-6 GM probe	6	$\times 10$	64	72	42	108
Neutron rem meters	Eberline	ESP-1	NRD	8	---	88	99	56	144
	Eberline	ESP-2	NRD	8	---	88	99	56	144
	Eberline	PNR-4	NRD	8	---	88	99	56	144
	HPI	2080	moderator	8	3×15 s	80	90	56	144
Alpha contamination monitors	Ludlum	139	Model 43-32 alpha (vented)	10	$\times 100$	96	108	70	180
Tritium-in-air monitors	Overhoff	394-C	ion chamber (vented)	6	$\times 10$ K	64	72	42	108
	Johnston	J-111	ion chamber (vented)	6	$\times 10^3$ log	64	72	42	108
	Johnston	J-110	ion chamber (vented)	6	$\times 10^3$ log	64	72	42	108
Totals				105		1128	1269	735	1890

NOTE: GM and NRD are abbreviations for Geiger-Mueller and neutron rem detector. All detectors are sealed unless stated.

Table 2. Eberline RO-2 ionization chamber temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C) [‡]								Performance criteria	
	20°C 0:59 h	30°C 1:59 h	40°C 2:59 h	50°C 3:59 h	20°C 5:59 h	10°C 6:59 h	0°C 7:59 h	-10°C 8:59 h	0°C to 40°C (15%)	-10°C to 50°C (20%)
1	1.000	0.995	1.001	0.978	1.000	1.015	1.026	1.034	Pass	Pass
1, Rep 2	1.000	0.995	0.988	0.978	1.000	1.015	1.026	1.034	Pass	Pass
2	1.000	0.995	0.974	0.949	1.000	1.016	1.053	1.061	Pass	Pass
2, Rep 2	1.000	0.994	0.972	0.947	1.000	1.016	1.041	1.061	Pass	Pass
3	1.000	0.995	0.974	0.977	1.000	1.003	1.015	1.047	Pass	Pass
4	1.000	0.995	0.987	0.991	1.000	1.003	1.015	1.024	Pass	Pass
5	1.000	0.996	0.989	0.980	1.000	1.002	1.012	1.031	Pass	Pass
6	1.000	0.995	0.974	0.949	1.000	1.015	1.039	1.047	Pass	Pass
Mean inventory year = 1984.7 ± 1.6 (1 σ) df [†] = 47 R ^{2†} = 1.00 Root MSE [†] = 0.004 Pr > F [†] = 0.0001										

[†]ANOVA estimates for n = 48, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 20°C (0:59 h and 5:59 h)

[‡]Normalized response reflects correction for the air density change during the temperature exposure profile

Table 3. Eberline RO-2 ionization chamber humidity test data and GLM procedure summaries.

Instrument	Normalized response (40% RH)							Performance criterion
	40% RH 3:59 h	95% RH 4:59 h	95% RH 6:59 h	95% RH 8:59 h	95% RH 10:59 h	95% RH 12:59 h	40% RH 17:59 h	40% to 95% to 40% RH (15%)
1	1.000	1.000	1.000	1.000	1.013	1.013	1.013	Pass
2	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
3	1.000	1.000	0.987	1.000	1.000	1.000	1.000	Pass
4	1.000	0.988	0.988	1.000	1.000	0.988	1.000	Pass
5	1.000	0.988	0.988	0.988	1.000	0.988	0.988	Pass
6	1.000	1.000	1.000	1.000	0.988	1.000	0.988	Pass
Mean inventory year = 1984.7 ± 1.6 (1 σ) $df^\dagger = 35$ $R^{2\dagger} = 0.58$ Root MSE $^\dagger = 0.006$ $Pr > F^\dagger = 0.005$								

† ANOVA estimates for $n = 36$, $0.500 \leq NR \leq 2.000$, and excluding data referenced at 40% RH (3:59 h)

Table 4. Eberline RO-3C ionization chamber temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C) [‡]								Performance criteria	
	20°C	30°C	40°C	50°C	20°C	10°C	0°C	-10°C	0°C to 40°C	-10°C to 50°C
	0:59 h	1:59 h	2:59 h	3:59 h	5:59 h	6:59 h	7:59 h	8:59 h	(15%)	(20%)
1	1.000	1.003	0.971	0.969	1.000	0.995	1.016	1.034	Pass	Pass
1, Rep 2	1.000	1.003	1.003	1.002	1.000	1.024	1.016	0.006	Pass	Fail ⁶
2	1.000	1.001	0.965	0.960	1.000	1.028	1.052	1.071	Pass	Pass
2, Rep 2	1.000	0.969	0.935	0.930	1.000	1.028	1.052	1.100	Pass	Pass
3	1.000	1.004	0.974	0.940	1.000	1.023	1.041	1.030	Pass	Pass
4	1.000	0.971	0.939	0.902	1.000	1.056	1.106	1.150	Pass	Pass
5	1.000	0.975	0.946	0.945	1.000	1.023	1.041	1.082	Pass	Pass
6	1.000	1.005	0.977	0.567	1.000	1.023	1.069	1.109	Pass	Fail ³
Mean inventory year = 1985.3 ± 2.1 (1 σ) df [†] = 46 R ^{2†} = 0.99 Root MSE [†] = 0.017 Pr > F [†] = 0.0001										

³Failed @ 50°C (3:59 h)

⁶Failed @ -10°C (8:59 h)

[†]ANOVA estimates for n = 48, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 20°C (0:59 h and 5:59 h)

[‡]Normalized response reflects correction for the air density change during the temperature exposure profile

Table 5. Eberline RO-3C ionization chamber humidity test data and GLM procedure summaries.

Instrument	Normalized response (40% RH)							Performance criterion
	40% RH 3:59 h	95% RH 4:59 h	95% RH 6:59 h	95% RH 8:59 h	95% RH 10:59 h	95% RH 12:59 h	40% RH 17:59 h	40% to 95% to 40% RH (15%)
1	1.000	1.000	1.000	1.000	1.000	0.719	0.531	Fail ^{5,6}
2	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
3	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
4	1.000	1.000	0.970	0.576	0.424	0.333	0.303	Fail ^{3,4,5,6}
5	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
6	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
Mean inventory year = 1985.3 $\pm$ 2.1 (1 σ) df [†] = 32 R ^{2†} = 0.41 Root MSE [†] = 0.108 Pr > F [†] = 0.20								

³Failed @ 95% RH (8:59 h)

⁴Failed @ 95% RH (10:59 h)

⁵Failed @ 95% RH (12:59 h)

⁶Failed @ 40% RH (17:59 h)

[†]ANOVA estimates for n = 36, 0.500 $\leq$ NR $\leq$ 2.000, and excluding data referenced at 40% RH (3:59 h)

Table 6. Eberline E-530 survey meter with the Model HP-177C stainless steel GM wall probe temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C)								Performance criteria	
	20°C	30°C	40°C	50°C	20°C	10°C	0°C	-10°C	0°C to 40°C	-10°C to 50°C
	0:59 h	1:59 h	2:59 h	3:59 h	5:59 h	6:59 h	7:59 h	8:59 h	(15%)	(20%)
1	1.000	1.020	0.941	1.000	1.000	0.875	0.650	0.400	Fail ⁵	Fail ^{5,6}
1, Rep 1	1.000	1.158	1.289	1.316	1.000	0.976	0.634	0.415	Fail ^{1,2,5}	Fail ^{2,3,5,6}
2	1.000	0.957	1.000	0.957	1.000	1.021	1.064	1.043	Pass	Pass
2, Rep 2	1.000	1.000	1.022	0.978	1.000	1.044	1.044	1.089	Pass	Pass
3	1.000	1.071	1.071	1.095	1.000	0.957	0.870	1.087	Pass	Pass
4	1.000	0.980	1.000	1.000	1.000	1.039	1.059	1.078	Pass	Pass
5	1.000	1.000	0.978	0.933	1.000	1.023	1.023	1.023	Pass	Pass
6	1.000	1.000	0.971	0.971	1.000	1.030	1.030	1.030	Pass	Pass
Mean inventory year = 1983.0 ± 0 (1 σ) df† = 45 R ^{2†} = 0.78 Root MSE† = 0.108 Pr > F† = 0.44										

¹Failed @ 30°C (1:59 h)

²Failed @ 40°C (2:59 h)

⁵Failed @ 50°C (3:59 h)

⁴Failed @ 0°C (7:59 h)

⁶Failed @ -10°C (8:59 h)

†ANOVA estimates for n = 48, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 20°C (0:59 h and 5:59 h)

Table 7. Eberline E-530 survey meter with the Model HP-177C stainless steel GM wall probe humidity test data and GLM procedure summaries.

Instrument	Normalized response (40% RH)						Performance criterion	
	40% RH 3:59 h	95% RH 4:59 h	95% RH 6:59 h	95% RH 8:59 h	95% RH 10:59 h	95% RH 12:59 h	40% RH 17:59 h	40% to 95% to 40% RH (15%)
1	1.000	1.022	1.000	1.000	1.022	1.000	0.978	Pass
2	1.000	1.043	1.043	1.043	1.021	1.043	0.979	Pass
3	1.000	1.042	1.042	1.042	1.042	1.042	1.021	Pass
4	1.000	1.058	1.058	1.058	1.058	1.058	1.019	Pass
5	1.000	1.047	1.047	1.023	1.023	1.023	0.977	Pass
6	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
Mean inventory year = 1983.0 $\pm$ 0 (1 σ) df [†] = 35 R ^{2†} = 0.84 Root MSE [†] = 0.012 Pr > F [†] = 0.0001								

[†]ANOVA estimates for n = 36, 0.500 $\leq$ NR $\leq$ 2.000, and excluding data referenced at 40% RH (3:59 h)

Table 8. Eberline PIC-6A ion chamber temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C)								Performance criteria	
	20°C	30°C	40°C	50°C	20°C	10°C	0°C	-10°C	0°C to 40°C	-10°C to 50°C
	0:59 h	1:59 h	2:59 h	3:59 h	5:59 h	6:59 h	7:59 h	8:59 h	(15%)	(20%)
1	1.000	1.000	1.050	1.050	1.000	1.000	0.955	0.955	Pass	Pass
2	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass	Pass
3	1.000	0.944	0.889	0.778	1.000	1.056	1.111	1.111	Pass	Fail ³
3, Rep 2	1.000	0.944	0.889	0.833	1.000	1.056	1.111	1.111	Pass	Pass
4	1.000	0.950	0.850	0.800	1.000	1.000	1.000	1.000	Pass	Pass
4, Rep 2	1.000	0.947	0.842	0.737	1.000	1.059	1.059	1.059	Fail ²	Fail ³
5*	1.000	1.139	1.417	1.556	1.000	0.950	0.850	0.750	Fail ²	Fail ^{2,3,6}
5*, Rep 2	1.000	1.081	1.297	0.243	1.000	1.000	0.938	0.875	Fail ²	Fail ^{2,3}
6*	1.000	0.974	0.949	0.897	1.000	1.051	1.051	1.051	Pass	Pass
6*, Rep 2	1.000	0.976	0.951	0.878	1.000	1.025	1.025	1.025	Pass	Pass
7*	1.000	1.050	1.150	1.250	1.000	0.958	0.917	0.875	Pass	Fail ³
8*	1.000	0.947	0.895	0.842	1.000	1.056	1.111	1.222	Pass	Fail ⁶
9*	1.000	1.059	1.059	1.000	1.000	0.944	0.944	0.889	Pass	Pass
10*	1.000	0.944	0.889	0.833	1.000	1.053	1.105	1.158	Pass	Pass
Mean inventory year = 1968.8 ± 1.5 (1 σ) $df^\dagger = 82$ $R^{2\dagger} = 0.98$ Root MSE [†] = 0.037 Pr > F [†] = 0.0001										

²Failed @ 40°C (2:59 h)³Failed @ 50°C (3:59 h)⁶Failed @ -10°C (8:59 h)

*2nd decade tests

[†]ANOVA estimates for $n = 84$, $0.500 \leq NR \leq 2.000$, and excluding data referenced at 20°C (0:59 h and 5:59 h)

Table 9. Eberline PIC-6A ion chamber humidity test data and GLM procedure summaries.

Instrument	Normalized response (40% RH)						Performance criterion	
	40% RH 3:59 h	95% RH 4:59 h	95% RH 6:59 h	95% RH 8:59 h	95% RH 10:59 h	95% RH 12:59 h	40% RH 17:59 h	40% to 95% to 40% RH (15%)
1	1.000	1.000	1.000	1.000	0.952	0.952	0.952	Pass
2	1.000	1.000	1.000	0.005	0.550	0.650	0.700	Fail ^{3,4,5,6}
3	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
4	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
5*	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
6*	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
7*	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
8*	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
9*	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
10*	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
Mean inventory year = 1968.8 ± 1.5 (1 σ) df [†] = 58 R ^{2†} = 0.61 Root MSE [†] = 0.059 Pr > F [†] = 0.0001								

³Failed @ 95% RH (8:59 h)

⁴Failed @ 95% RH (10:59 h)

⁵Failed @ 95% RH (12:59 h)

⁶Failed @ 40% RH (17:59 h)

*2nd decade tests

[†]ANOVA estimates for n = 60, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 40% RH (3:59 h)

Table 10. Eberline PIC-6B ion chamber temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C)								Performance criteria	
	20°C	30°C	40°C	50°C	20°C	10°C	0°C	-10°C	0°C to 40°C	-10°C to 50°C
	0:59 h	1:59 h	2:59 h	3:59 h	5:59 h	6:59 h	7:59 h	8:59 h	(15%)	(20%)
1	1.000	1.000	1.000	1.000	1.000	1.083	1.167	0.833	Fail ⁵	Pass
1, Rep 2	1.000	1.000	0.923	0.923	1.000	0.923	1.077	1.154	Pass	Pass
2	1.000	1.000	1.000	1.000	1.000	0.917	0.833	1.083	Fail ⁵	Pass
2, Rep 2	1.000	1.000	1.000	1.000	1.000	1.077	1.077	1.077	Pass	Pass
3	1.000	1.000	1.000	1.042	1.000	1.000	0.960	0.960	Pass	Pass
4	1.000	0.923	0.923	0.923	1.000	1.000	1.000	1.000	Pass	Pass
Mean inventory year = 1989.0 ± 1.2 (1 σ) df [†] = 35 R ^{2†} = 0.39 Root MSE [†] = 0.099 Pr > F [†] = 0.99										

[†]ANOVA estimates for n = 36, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 20°C (0:59 h and 5:59 h)

⁵Failed @ 0°C (7:59 h)

Table 11. Eberline PIC-6B ion chamber humidity test data and GLM procedure summaries.

Instrument	Normalized response (40% RH)						Performance criterion	
	40% RH 3:59 h	95% RH 4:59 h	95% RH 6:59 h	95% RH 8:59 h	95% RH 10:59 h	95% RH 12:59 h	40% RH 17:59 h	40% to 95% to 40% RH (15%)
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
2	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
3	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
4	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
Mean inventory year = 1989.0 $\pm$ 1.2 (1 σ) df [†] = 23 R ^{2†} = 0 Root MSE [†] = 0 Pr > F [†] = ---								

[†]ANOVA estimates for n = 24, 0.500 $\leq$ NR $\leq$ 2.000, and excluding data referenced at 40% RH (3:59 h)

Table 12. Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C)								Performance criteria	
	20°C	30°C	40°C	50°C	20°C	10°C	0°C	-10°C	0°C to 40°C	-10°C to 50°C
	0:59 h	1:59 h	2:59 h	3:59 h	5:59 h	6:59 h	7:59 h	8:59 h	(15%)	(20%)
1	1.000	0.995	1.004	1.015	1.000	1.016	1.018	1.019	Pass	Pass
1, Rep 2	1.000	1.002	1.006	1.013	1.000	1.017	1.014	1.023	Pass	Pass
2	1.000	0.926	0.867	0.874	1.000	0.983	0.975	0.975	Pass	Pass
2, Rep 2	1.000	1.011	1.014	0.996	1.000	0.991	0.986	0.986	Pass	Pass
3	1.000	0.988	0.995	1.008	1.000	1.004	1.012	1.024	Pass	Pass
3, Rep 2	1.000	0.994	1.000	1.008	1.000	1.005	1.018	1.024	Pass	Pass
4	1.000	0.967	0.952	0.951	1.000	1.019	1.024	1.039	Pass	Pass
5	1.000	1.002	0.991	0.985	1.000	1.011	1.035	1.059	Pass	Pass
6	1.000	1.003	1.010	1.004	1.000	1.013	1.009	1.025	Pass	Pass
7	1.000	1.005	1.003	0.994	1.000	0.995	0.999	0.995	Pass	Pass
Mean inventory year = 1990.3 ± 1.3 (1 σ) $df^\dagger = 59$ $R^{2\dagger} = 0.63$ Root MSE $^\dagger = 0.035$ $Pr > F^\dagger = 0.78$										

† ANOVA estimates for $n = 60$, $0.500 \leq NR \leq 2.000$, and excluding data referenced at 20°C (0:59 h and 5:59 h)

Table 13. Eberline ESP-1 survey meter with the Model HP-260 pancake GM detector humidity test data and GLM procedure summaries.

Instrument	Normalized response (40% RH)						Performance criterion	
	40% RH 3:59 h	95% RH 4:59 h	95% RH 6:59 h	95% RH 8:59 h	95% RH 10:59 h	95% RH 12:59 h	40% RH 17:59 h	40% to 95% to 40% RH (15%)
1	1.000	1.006	1.000	1.013	1.004	1.001	1.004	Pass
2	1.000	1.006	1.002	1.004	1.004	1.002	1.004	Pass
3	1.000	1.034	1.036	1.038	1.034	1.038	0.999	Pass
4	1.000	1.011	1.012	1.003	1.006	1.004	0.976	Pass
5	1.000	1.033	1.031	1.031	1.028	1.029	0.995	Pass
6	1.000	1.016	1.014	1.016	1.016	1.022	0.995	Pass
7	1.000	1.064	1.021	1.018	1.022	1.011	0.993	Pass
Mean inventory year = 1990.3 ± 1.3 (1σ) $df^\dagger = 41$ $R^{2\dagger} = 0.73$ Root MSE $^\dagger = 0.010$ $Pr > F^\dagger = 0.0001$								

† ANOVA estimates for $n = 42$, $0.500 \leq NR \leq 2.000$, and excluding data referenced at 40% RH (3:59 h)

Table 14. Ludlum 3 survey meter with the Model 44-6 stainless steel GM wall probe temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C)								Performance criteria	
	20°C 0:59 h	30°C 1:59 h	40°C 2:59 h	50°C 3:59 h	20°C 5:59 h	10°C 6:59 h	0°C 7:59 h	-10°C 8:59 h	0°C to 40°C (15%)	-10°C to 50°C (20%)
1	1.000	1.007	0.985	0.985	1.000	1.007	1.007	1.000	Pass	Pass
1, Rep 2	1.000	1.007	0.993	0.985	1.000	0.993	1.007	1.022	Pass	Pass
2	1.000	0.970	0.933	0.896	1.000	1.000	1.015	1.053	Pass	Pass
2, Rep 2	1.000	0.969	0.962	0.938	1.000	1.015	1.023	1.077	Pass	Pass
3	1.000	0.967	0.933	0.920	1.000	1.027	1.053	1.100	Pass	Pass
4	1.000	0.986	0.950	0.929	1.000	1.021	1.071	1.129	Pass	Pass
5	1.000	0.979	0.951	0.930	1.000	1.049	1.070	1.119	Pass	Pass
6	1.000	0.973	0.953	0.933	1.000	1.040	1.100	1.120	Pass	Pass
Mean inventory year = 1987.5 ± 0.8 (1 σ) $df^\dagger = 47$ $R^{2\dagger} = 0.99$ Root MSE $^\dagger = 0.013$ $Pr > F^\dagger = 0.0001$										

† ANOVA estimates for $n = 48$, $0.500 \leq NR \leq 2.000$, and excluding data referenced at 20°C (0:59 h and 5:59 h)

Table 15. Ludlum 3 survey meter with the Model 44-6 stainless steel GM wall probe humidity test data and GLM procedure summaries.

Instrument	Normalized response (40% RH)						Performance criterion	
	40% RH 3:59 h	95% RH 4:59 h	95% RH 6:59 h	95% RH 8:59 h	95% RH 10:59 h	95% RH 12:59 h	40% RH 17:59 h	40% to 95% to 40% RH (15%)
1	1.000	1.000	1.000	1.000	1.021	1.000	1.007	Pass
2	1.000	1.000	1.000	1.014	1.014	1.014	1.000	Pass
3	1.000	1.013	1.000	1.000	1.013	1.013	1.000	Pass
4	1.000	0.993	0.979	0.979	0.979	0.986	0.986	Pass
5	1.000	1.000	1.000	1.000	1.000	1.000	0.987	Pass
6	1.000	0.968	0.975	0.987	0.968	0.968	0.975	Pass
Mean inventory year = 1987.5 ± 0.8 (1 σ) $df^\dagger = 35$ $R^{2\dagger} = 0.83$ Root MSE $^\dagger = 0.007$ $Pr > F^\dagger = 0.0001$								

† ANOVA estimates for $n = 36$, $0.500 \leq NR \leq 2.000$, and excluding data referenced at 40% RH (3:59 h)

Table 16. Beta-gamma survey meters tested for temperature and humidity based on the ANSI standard's performance criteria and test methods. Shown are the number of failures F / total number n tested.

Category	Make	Model	Detector	Temperature		Humidity ¹
				F / n	F / n ^a	F / n
Beta-gamma survey meters	Eberline	RO-2	ionization chamber (vented)	0 / 6	0 / 8	0 / 6
	Eberline	RO-3C	ionization chamber (vented)	1 / 6	2 / 8	2 / 6
	Eberline	E-530	Model HP-177C GM probe	1 / 6	2 / 8	0 / 6
	Eberline	PIC-6A	ion chamber	4 / 10	6 / 14	1 / 10
	Eberline	PIC-6B	ion chamber	2 / 4	2 / 6	0 / 4
	Eberline	ESP-1	Model HP-260 pancake GM	0 / 7	0 / 10	0 / 7
	Ludlum	3	Model 44-6 GM probe	0 / 6	0 / 8	0 / 6

NOTE: To pass the temperature test, all performance criteria evaluated must be satisfied. ¹Extended humidity range from 40% to 95% to 40% RH. ^aIncluding repeat tests.

Table 17. Beta-gamma survey meters tested for temperature based on the binomial frequency distribution. Shown are the interval estimations of the population parameter p for a 95% ($\alpha = 0.05$) level of confidence with v_1 and v_2 degrees of freedom, excluding data referenced at 20°C (0:59 h and 5:59 h).

Make	Model	Detector	Criterion	n	x	Variables for p				
						$x n^{-1}$	L	$F_{\alpha/2}(v_1, v_2)_L$	U	$F_{\alpha/2}(v_1, v_2)_U$
Eberline	RO-2	ionization chamber (vented)	15%	48	0	0	0	---	0.074	3.85
			20%	48	0	0	0	---	0.074	3.85
Eberline	RO-3C	ionization chamber (vented)	15%	48	2	0.042	0.005	8.33	0.144	2.57
			20%	48	2	0.042	0.005	8.33	0.144	2.57
Eberline	E-530	Model HP-177C GM probe	15%	48	7	0.146	0.062	2.58	0.280	2.00
			20%	48	6	0.125	0.047	2.82	0.246	2.05
Eberline	PIC-6A	ion chamber	15%	84	14	0.167	0.095	1.88	0.261	1.65
			20%	84	9	0.107	0.051	2.23	0.190	1.76
Eberline	PIC-6B	ion chamber	15%	36	2	0.056	0.007	8.35	0.188	2.62
			20%	36	0	0	0	---	0.058	3.90
Eberline	ESP-1	Model HP-260 pancake GM	15%	60	0	0	0	---	0.060	3.80
			20%	60	0	0	0	---	0.060	3.80
Ludlum	3	Model 44-6 GM probe	15%	48	0	0	0	---	0.074	3.85
			20%	48	0	0	0	---	0.074	3.85

Table 18. Beta-gamma survey meters tested for humidity based on the binomial frequency distribution. Shown are the interval estimations of the population parameter p for a 95% ($\alpha = 0.05$) level of confidence with v_1 and v_2 degrees of freedom, excluding data referenced at 40% RH (3:59 h).

Make	Model	Detector	Criterion	n	x	Variables for p				
						$x n^{-1}$	L	$F_{\alpha/2}(v_1, v_2)_L$	U	$F_{\alpha/2}(v_1, v_2)_U$
Eberline	RO-2	ionization chamber (vented)	15%	36	0	0.000	0.000	---	0.102	3.90
Eberline	RO-3C	ionization chamber (vented)	15%	36	6	0.167	0.064	2.85	0.329	2.10
Eberline	E-530	Model HP-177C GM probe	15%	36	0	0.000	0.000	---	0.098	3.90
Eberline	PIC-6A	ion chamber	15%	60	4	0.067	0.008	8.32	0.163	2.17
Eberline	PIC-6B	ion chamber	15%	24	0	0.000	0.000	---	0.143	4.00
Eberline	ESP-1	Model HP-260 pancake GM	15%	48	0	0.000	0.000	---	0.085	3.88
Ludlum	3	Model 44-6 GM probe	15%	36	0	0.000	0.000	---	0.098	3.90

Table 19. Eberline ESP-1 survey meter with the NRD temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C)								Performance criteria	
	20°C 0:59 h	30°C 1:59 h	40°C 2:59 h	50°C 3:59 h	20°C 5:59 h	10°C 6:59 h	0°C 7:59 h	-10°C 8:59 h	0°C to 40°C (15%)	-10°C to 50°C (20%)
1	1.000	0.961	0.959	0.938	1.000	0.997	1.077	1.031	Pass	Pass
1, Rep 2	1.000	0.970	0.953	0.984	1.000	1.021	0.987	1.010	Pass	Pass
2	1.000	1.027	1.014	1.114	1.000	0.968	0.943	0.962	Pass	Pass
2, Rep 2	1.000	0.949	0.986	0.938	1.000	1.022	0.994	1.038	Pass	Pass
3	1.000	1.032	1.043	1.051	1.000	0.981	0.967	0.993	Pass	Pass
4	1.000	0.986	0.994	1.040	1.000	1.022	0.992	1.008	Pass	Pass
5	1.000	0.929	0.947	1.000	1.000	0.989	0.994	0.908	Pass	Pass
6	1.000	1.012	0.984	0.865	1.000	1.032	1.048	1.053	Pass	Pass
6, Rep 2	1.000	0.991	1.091	0.949	1.000	1.039	1.015	1.018	Pass	Pass
7	1.000	1.025	0.986	1.026	1.000	0.976	0.968	0.971	Pass	Pass
8	1.000	1.071	1.007	1.151	1.000	0.951	0.805	0.760	Fail ⁵	Fail ⁶
Mean inventory year = 1990.5 ± 0.9 (1 σ) df [†] = 65 R ^{2†} = 0.83 Root MSE [†] = 0.048 Pr > F [†] = 0.08										

⁵Failed at 0°C (7:59 h)

⁶Failed at -10°C (8:59 h)

[†]ANOVA estimates for n = 66, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 20°C (0:59 h and 5:59 h)

Table 20. Eberline ESP-1 survey meter with the NRD humidity test data and GLM procedure summaries.

Instrument	Normalized response (40% RH)						Performance criterion	
	40% RH 3:59 h	95% RH 4:59 h	95% RH 6:59 h	95% RH 8:59 h	95% RH 10:59 h	95% RH 12:59 h	40% RH 17:59 h	40% to 95% to 40% RH (15%)
1	1.000	1.011	0.976	1.005	0.961	0.980	0.950	Pass
2	1.000	0.903	0.961	0.964	0.990	0.987	0.980	Pass
3	1.000	1.021	1.019	0.992	0.971	1.000	1.033	Pass
4	1.000	0.942	0.947	0.981	1.049	1.014	0.990	Pass
5	1.000	0.952	0.933	0.997	0.960	0.988	0.981	Pass
6	1.000	1.076	1.088	1.003	1.105	0.972	1.061	Pass
7	1.000	0.942	0.950	0.910	0.901	0.932	0.952	Pass
8	1.000	1.051	1.087	1.069	1.026	0.997	1.072	Pass
Mean inventory year = 1990.5 ± 0.9 (1σ) $df^\dagger = 47$ $R^{2\dagger} = 0.64$ Root MSE $^\dagger = 0.034$ $Pr > F^\dagger = 0.0001$								

† ANOVA estimates for $n = 48$, $0.500 \leq NR \leq 2.000$, and excluding data referenced at 40% RH (3:59 h).

Table 21. Eberline ESP-2 survey meter with the NRD temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C)								Performance criteria	
	20°C	30°C	40°C	50°C	20°C	10°C	0°C	-10°C	0°C to 40°C	-10°C to 50°C
	0:59 h	1:59 h	2:59 h	3:59 h	5:59 h	6:59 h	7:59 h	8:59 h	(15%)	(20%)
1	1.000	0.963	1.004	0.914	1.000	0.935	0.980	1.035	Pass	Pass
1, Rep 2	1.000	0.963	1.023	0.952	1.000	1.032	1.054	0.992	Pass	Pass
2	1.000	1.031	0.999	0.980	1.000	0.971	0.976	1.018	Pass	Pass
2, Rep 2	1.000	0.978	0.969	1.004	1.000	0.923	1.017	1.016	Pass	Pass
3	1.000	0.962	0.986	0.947	1.000	1.054	1.042	1.037	Pass	Pass
4	1.000	1.087	1.086	1.099	1.000	0.973	0.959	0.990	Pass	Pass
4, Rep 2	1.000	1.061	1.060	1.042	1.000	1.118	0.974	1.051	Pass	Pass
5	1.000	1.056	1.001	0.979	1.000	1.004	1.014	0.993	Pass	Pass
6	1.000	1.081	1.003	1.037	1.000	1.013	1.024	1.010	Pass	Pass
7	1.000	0.976	0.992	1.029	1.000	0.943	0.972	0.981	Pass	Pass
8	1.000	0.998	0.958	0.942	1.000	0.938	0.998	0.972	Pass	Pass
Mean inventory year = 1987.8 ± 0.5 (1 σ) df [†] = 65 R ^{2†} = 0.78 Root MSE [†] = 0.040 Pr > F [†] = 0.26										

NOTE: "COMPUTER LINK RESET WHEN DONE" then "ROM ERROR FOUND!" appeared in the display of Instrument 5 @ -10°C to 20°C (9:12 h). "H.V. Failed!" appeared in the display of Instrument 8 @ -10°C to 20°C (9:12 h).

[†]ANOVA estimates for n = 66, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 20°C (0:59 h and 5:59 h)

Table 22. Eberline ESP-2 survey meter with the NRD humidity test data and GLM procedure summaries.

		Normalized response (40% RH)						Performance criterion	
	40% RH	95% RH	95% RH	95% RH	95% RH	95% RH	40% RH	40% to 95% to 40% RH	
Instrument	3:59 h	4:59 h	6:59 h	8:59 h	10:59 h	12:59 h	17:59 h	(15%)	
1	1.000	0.949	1.021	0.988	1.273	3.881	0.988	Fail ^{4,5}	
2	1.000	0.979	0.994	0.975	1.021	1.041	1.061	Pass	
3	1.000	0.996	0.964	1.013	1.046	1.055	1.051	Pass	
4	1.000	1.061	1.027	0.957	1.030	0.913	1.056	Pass	
5	1.000	34.020	1.100	0.989	0.989	1.007	1.043	Fail ¹	
6	1.000	1.049	1.575	1.022	0.998	1.024	0.991	Fail ²	
7	1.000	1.002	1.016	1.074	1.113	0.978	1.073	Pass	
8	1.000	<----- see NOTE ----->						Fail ^{1,2,3,4,5,6}	
Mean inventory year = 1987.5 ± 0.5 (1 σ)									
df [†] = 39									
R ^{2†} = 0.23									
Root MSE [†] = 0.108									
Pr > F [†] = 0.67									

NOTE: "OVER RANGE" appeared in the display of Instrument 1 @ 95% RH (12:00 h). "H.V. Failed!" appeared in the display of Instrument 8 @ 95% RH (4:20 h).

¹Failed @ 95% RH (4:59 h)

²Failed @ 95% RH (6:59 h)

³Failed @ 95% RH (8:59 h)

⁴Failed @ 95% RH (10:59 h)

⁵Failed @ 95% RH (12:59 h)

⁶Failed @ 40% RH (17:59 h)

[†]ANOVA estimates for n = 40, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 20°C (0:59 h and 5:59 h)

Table 23. Eberline PNR-4 survey meter with the NRD temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C)								Performance criteria	
	20°C	30°C	40°C	50°C	20°C	10°C	0°C	-10°C	0°C to 40°C	-10°C to 50°C
	0:59 h	1:59 h	2:59 h	3:59 h	5:59 h	6:59 h	7:59 h	8:59 h	(15%)	(20%)
1	1.000	0.912	0.941	1.000	1.000	1.030	1.000	1.000	Pass	Pass
1, Rep 1	1.000	1.031	1.000	1.031	1.000	0.941	0.912	0.912	Pass	Pass
2	1.000	1.074	0.963	1.037	1.000	1.000	0.926	1.000	Pass	Pass
3	1.000	1.065	1.000	1.000	1.000	1.000	0.906	0.781	Pass	Fail ⁶
4	1.000	1.071	1.000	1.000	1.000	0.966	0.966	0.931	Pass	Pass
5	1.000	1.114	1.057	1.057	1.000	0.946	0.595	0.135	Fail ⁵	Fail ^{5,6}
6	1.000	0.952	1.024	1.000	1.000	1.000	1.024	1.000	Pass	Pass
7	1.000	1.000	1.074	1.037	1.000	0.966	0.966	1.034	Pass	Pass
7, Rep 2	1.000	1.000	1.000	0.964	1.000	0.964	0.964	0.964	Pass	Pass
8	1.000	1.065	1.065	1.065	1.000	1.259	0.963	0.185	Fail ⁴	Fail ^{4,6}
8, Rep 2	1.000	1.000	1.088	1.088	1.000	0.944	0.611	0.014	Fail ⁵	Fail ^{5,6}
Mean inventory year = 1976.0 ± 6.8 (1 σ) df [†] = 62 R ^{2†} = 0.75 Root MSE [†] = 0.092 Pr > F [†] = 0.41										

⁴Failed @ 10°C (6:59 h)

⁵Failed @ 0°C (7:59 h)

⁶Failed @ -10°C (8:59 h)

[†]ANOVA estimates for n = 63, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 20°C (0:59 h and 5:59 h)

Table 24. Eberline PNR-4 survey meter with the NRD humidity test data and GLM procedure summaries.

Instrument	Normalized response (40% RH)						Performance criterion	
	40% RH 3:59 h	95% RH 4:59 h	95% RH 6:59 h	95% RH 8:59 h	95% RH 10:59 h	95% RH 12:59 h	40% RH 17:59 h	40% to 95% to 40% RH (15%)
1	1.000	1.065	1.065	1.032	1.097	1.032	1.065	Pass
2	1.000	1.034	1.138	1.034	1.103	1.138	1.034	Pass
3	1.000	1.000	1.065	1.065	1.065	1.032	1.000	Pass
4	1.000	1.034	0.966	1.000	0.966	1.000	1.000	Pass
5	1.000	125.000	125.000	125.000	75.000	57.500	0.875	Fail ^{1,2,3,4,5}
6	1.000	0.977	1.000	1.000	0.977	1.000	0.977	Pass
7	1.000	1.000	1.037	1.037	1.037	1.519	1.074	Fail ⁵
8	1.000	1.048	1.048	1.024	6.905	1.071	0.976	Fail ⁴
Mean inventory year = 1976.0 ± 6.8 (1 σ) df [†] = 41 R ^{2†} = 0.44 Root MSE [†] = 0.080 Pr > F [†] = 0.07								

NOTE: Response for Instrument 5 pegged full scale @ 95% RH (4:49 h, 6:59 h, and 8:59 h).

¹Failed @ 95% RH (4:59 h)

²Failed @ 95% RH (6:59 h)

³Failed @ 95% RH (8:59 h)

⁴Failed @ 95% RH (10:59 h)

⁵Failed @ 95% RH (12:59 h)

[†]ANOVA estimates for n = 42, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 40% RH (3:59 h)

Table 25. HPI 2080 survey meter with the moderator detector temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C)								Performance criteria	
	20°C	30°C	40°C	50°C	20°C	10°C	0°C	-10°C	0°C to 40°C	-10°C to 50°C
	0:59 h	1:59 h	2:59 h	3:59 h	5:59 h	6:59 h	7:59 h	8:59 h	(15%)	(20%)
1	1.000	0.693	0.844	0.868	1.000	1.028	1.154	1.154	Fail ^{1,2,5}	Fail ¹
2	1.000	1.154	1.200	1.240	1.000	0.919	0.799	0.858	Fail ^{1,2,3,5}	Fail ³
3	1.000	0.892	1.000	0.719	1.000	1.024	0.920	0.973	Fail ³	Fail ³
4	1.000	1.104	1.294	1.187	1.000	1.047	0.952	0.838	Fail ²	Fail ²
4, Rep 2	1.000	1.180	1.344	1.000	1.000	1.178	1.072	0.841	Fail ^{1,2,4}	Fail ²
5	1.000	1.088	1.263	1.149	1.000	1.020	0.891	1.038	Fail ²	Fail ²
6	1.000	0.878	0.968	1.088	1.000	1.085	1.199	1.030	Fail ⁵	Pass
7	1.000	0.952	0.887	1.050	1.000	0.859	1.003	0.950	Pass	Pass
8	1.000	0.900	0.973	0.997	1.000	1.061	1.043	0.912	Pass	Pass
8, Rep 2	1.000	1.342	1.092	0.838	1.000	0.894	0.745	0.910	Fail ^{1,5}	Fail ^{1,5}
Mean inventory year = 1990.1 ± 1.6 (1 σ) df [†] = 59 R ^{2†} = 0.84 Root MSE [†] = 0.133 Pr > F [†] = 0.30										

NOTE: "FAST TRIP" appeared in the display of Instrument 7 @ 50°C (3:11 h).

¹Failed @ 30°C (1:59 h)

²Failed @ 40°C (2:59 h)

³Failed @ 50°C (3:59 h)

⁴Failed @ 10°C (6:59 h)

⁵Failed @ 0°C (7:59 h)

⁶Failed @ -10°C (8:59 h)

[†]ANOVA estimates for n = 60, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 20°C (0:59 h and 5:59 h)

Table 26. HPI 2080 survey meter with the moderator detector humidity test data and GLM procedure summaries.

Instrument	Normalized response (40% RH)						Performance criterion	
	40% RH 3:59 h	95% RH 4:59 h	95% RH 6:59 h	95% RH 8:59 h	95% RH 10:59 h	95% RH 12:59 h	40% RH 17:59 h	40% to 95% to 40% RH (15%)
1	1.000	<----- see NOTE ----->					1.074	Fail ^{1,2,3,4,5}
2	1.000	0.840	0.884	0.960	1.017	1.002	0.867	Fail ¹
3	1.000	1.086	1.081	1.172	0.927	1.122	0.992	Fail ³
4	1.000	1.091	<----- see NOTE ----->					Fail ^{2,3,4,5,6}
5	1.000	0.989	0.945	0.898	0.911	1.011	0.817	Fail ⁶
6	1.000	0.898	1.078	0.938	1.064	0.903	0.750	Fail ⁶
7	1.000	1.060	0.892	1.096	0.967	0.910	0.994	Pass
8	1.000	0.974	1.129	1.086	1.033	1.305	1.079	Fail ⁵
Mean inventory year = 1990.5 ± 0.9 (1 σ) df [†] = 37 R ^{2†} = 0.54 Root MSE [†] = 0.090 Pr > F [†] = 0.027								

NOTE: "FAIL" appeared in the display of Instrument 1 @ 95% RH (4:08 h) but recovered @ 40% RH (13:02 h). "FAIL" appeared in the display of Instrument 4 @ 95% RH (6:12 h) then "FAST TRIP" @ 95% RH (7:12 h).

¹Failed @ 95% RH (4:59 h)

²Failed @ 95% RH (6:59 h)

³Failed @ 95% RH (8:59 h)

⁴Failed @ 95% RH (10:59 h)

⁵Failed @ 95% RH (12:59 h)

⁶Failed @ 40% RH (17:59 h)

[†]ANOVA estimates for n = 38, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 20°C (0:59 h and 5:59 h)

Table 27. Neutron survey meters tested for temperature and humidity based on the ANSI standard's performance criteria and test methods. Shown are the number of failures F / total number n tested.

Category	Make	Model	Detector	Temperature		Humidity ¹
				F / n	F / n ^a	F / n
Neutron survey meters	Eberline	ESP-1	NRD	1 / 8	1 / 11	0 / 8
	Eberline	ESP-2	NRD	0 / 8	0 / 11 ^b	4 / 8
	Eberline	PNR-4	NRD	3 / 8	4 / 11	3 / 8
	HPI	2080	moderator	6 / 8	8 / 10	7 / 8

NOTE: To pass the temperature test, all performance criteria evaluated must be satisfied. ¹Extended humidity range from 40% to 95% to 40% RH. ^aIncluding repeat tests. ^bTwo instruments failed outside the test @ -10°C to 20°C.

Table 28. Neutron rem meters tested for temperature based on the binomial frequency distribution. Shown are the interval estimations of the population parameter p for a 95% ($\alpha = 0.05$) level of confidence with v_1 and v_2 degrees of freedom, excluding data referenced at 20°C (0:59 h and 5:59 h).

Make	Model	Detector	Criterion	n	x	Variables for p				
						$x n^{-1}$	L	$F_{\alpha/2}(v_1, v_2)_L$	U	$F_{\alpha/2}(v_1, v_2)_U$
Eberline	ESP-1	NRD	15%	66	3	0.045	0.009	4.89	0.127	2.29
			20%	66	2	0.030	0.004	8.30	0.105	2.51
Eberline	ESP-2	NRD	15%	66	0	0.000	0.000	---	0.054	3.77
			20%	66	0	0.000	0.000	---	0.054	3.77
Eberline	PNR-4	NRD	15%	66	7	0.106	0.044	2.55	0.207	1.92
			20%	66	7	0.106	0.044	2.55	0.207	1.92
HPI	2080	moderator	15%	66	21	0.350	0.232	1.74	0.488	1.69
			20%	66	8	0.133	0.059	3.77	0.248	1.90

Table 29. Neutron rem meters tested for humidity based on the binomial frequency distribution. Shown are the interval estimations of the population parameter p for a 95% ($\alpha = 0.05$) level of confidence with v_1 and v_2 degrees of freedom, excluding data referenced at 40% RH (3:59 h).

Make	Model	Detector	Criterion	n	x	Variables for p				
						x/n	L	$F_{\alpha/2}(v_1, v_2)_L$	U	$F_{\alpha/2}(v_1, v_2)_U$
Eberline	ESP-1	NRD	15%	48	0	0.000	0.000	---	0.073	3.85
Eberline	ESP-2	NRD	15%	48	10	0.208	0.104	2.20	0.350	1.88
Eberline	PNR-4	NRD	15%	48	7	0.146	0.061	2.59	0.281	2.00
HPI	2080	moderator	15%	48	15	0.313	0.188	1.90	0.465	1.79

Table 30. Ludlum 139 survey meter with the Model 43-32 alpha detector temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C)								Performance criteria	
	20°C	30°C	40°C	50°C	20°C	10°C	0°C	-10°C	0°C to 40°C	-10°C to 50°C
	0:59 h	1:59 h	2:59 h	3:59 h	5:59 h	6:59 h	7:59 h	8:59 h	(15%)	(20%)
1	1.000	1.028	0.958	0.887	1.000	0.958	0.847	0.819	Pass	Pass
1, Rep 2	1.000	1.029	0.971	0.914	1.000	0.958	0.901	0.803	Pass	Pass
2	1.000	0.973	0.905	0.784	1.000	0.986	0.903	0.847	Pass	Fail ³
2, Rep 2	1.000	0.971	0.942	0.841	1.000	0.985	0.956	0.882	Pass	Pass
3	1.000	1.000	0.954	0.831	1.000	0.897	0.838	0.735	Fail ⁵	Fail ⁶
4	1.000	1.017	1.000	0.883	1.000	0.933	0.917	0.900	Pass	Pass
5	1.000	1.089	1.589	1.786	1.000	0.897	0.724	0.586	Fail ^{2,3,5}	Fail ^{2,3,5,6}
6	1.000	1.000	0.922	0.813	1.000	0.984	0.855	0.790	Pass	Fail ⁶
7	1.000	1.000	0.953	0.906	1.000	0.938	0.859	0.813	Pass	Pass
8	1.000	0.930	0.877	0.895	1.000	0.756	0.444	0.267	Fail ^{4,5}	Fail ^{4,5,6}
9	1.000	1.000	0.957	0.829	1.000	0.972	0.845	0.775	Pass	Fail ⁶
10	1.000	1.027	1.000	0.890	1.000	0.905	0.797	0.662	Fail ⁵	Fail ⁶
Mean inventory year = 1990.0 ± 0 (1 σ) df [†] = 69 R ^{2†} = 1.00 Root MSE [†] = 0.023 Pr > F [†] = 0.0001										

NOTE: Response for Instrument 5 pegged full scale during the test @ 50°C (3:59 h).

²Failed @ 40°C (2:59 h)

³Failed @ 50°C (3:59 h)

⁴Failed @ 10°C (6:59 h)

⁵Failed @ 0°C (7:59 h)

⁶Failed @ -10°C (8:59 h)

[†]ANOVA estimates for n = 70, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 20°C (0:59 h and 5:59 h)

Table 31. Ludlum 139 survey meter with the Model 43-32 alpha detector humidity test data and GLM procedure summaries.

Instrument	Normalized response (40% RH)						Performance criterion	
	40% RH 3:59 h	95% RH 4:59 h	95% RH 6:59 h	95% RH 8:59 h	95% RH 10:59 h	95% RH 12:59 h	40% RH 17:59 h	40% to 95% to 40% RH (15%)
1	1.000	1.449	0.870	0.884	0.841	0.855	1.029	Fail ^{1,4}
2	1.000	0.866	0.866	0.851	0.851	0.821	1.000	Fail ⁵
3	1.000	0.841	0.810	0.810	0.825	0.810	0.968	Fail ^{1,2,3,4,5}
4	1.000	0.862	0.845	0.862	0.879	0.845	1.017	Pass
5	1.000	0.862	0.845	0.845	0.862	1.000	1.034	Pass
6	1.000	0.841	0.857	1.286	0.857	0.984	1.016	Fail ^{1,3,5}
7	1.000	0.820	0.820	0.902	0.852	0.852	1.033	Fail ^{1,2}
8	1.000	0.698	0.698	0.721	0.767	0.767	0.977	Fail ^{1,2,3,4,5}
9	1.000	1.171	0.857	0.843	0.857	0.829	0.986	Fail ^{1,3,5}
10	1.000	0.861	0.875	1.208	0.833	0.833	0.986	Fail ^{3,4,5}
Mean inventory year = 1990.0 $\pm$ 0 (1 σ) df [†] = 59 R ^{2†} = 0.42 Root MSE [†] = 0.115 Pr > F [†] = 0.016								

NOTE: Response for Instruments 1, 5, 6, 7, 9, and 10 pegged full scale during the test @ 95% RH.

¹Failed @ 95% RH (4:59 h)

²Failed @ 95% RH (6:59 h)

³Failed @ 95% RH (8:59 h)

⁴Failed @ 95% RH (10:59 h)

⁵Failed @ 95% RH (12:59 h)

⁶Failed @ 95% RH (17:59 h)

[†]ANOVA estimates for n = 60, 0.500 $\leq$ NR $\leq$ 2.000, and excluding data referenced at 40% RH (3:59 h)

Table 32. Alpha contamination monitors tested for temperature and humidity based on the ANSI standard's performance criteria and test methods. Shown are the number of failures F / number n tested.

Category	Make	Model	Detector	Temperature		Humidity ¹
				F / n	F / n ^a	F / n
Alpha contamination monitors	Ludlum	139	Model 43-32 alpha (vented)	7 / 10	7 / 12	8 / 10

NOTE: To pass the temperature test, all performance criteria evaluated must be satisfied. ¹Extended humidity range from 40% to 95% to 40% RH. ^aIncluding repeat tests.

Table 33. Alpha contamination monitors tested for temperature based on the binomial frequency distribution. Shown are the interval estimations of the population parameter p for a 95% ($\alpha = 0.05$) level of confidence with v_1 and v_2 degrees of freedom, excluding data referenced at 20°C (0:59 h and 5:59 h).

Make	Model	Detector	Criterion	n	x	Variables for p				
						$x n^{-1}$	L	$F_{\alpha/2}(v_1, v_2)_L$	U	$F_{\alpha/2}(v_1, v_2)_U$
Ludlum	139	Model 43-32 alpha (vented)	15%	72	18	0.25	0.155	1.79	0.368	1.66
			20%	72	12	0.167	0.090	2.00	0.273	1.74

Table 34. Alpha contamination monitors tested for humidity based on the binomial frequency distribution. Shown is the interval estimation of the population parameter p for a 95% ($\alpha = 0.05$) level of confidence with v_1 and v_2 degrees of freedom, excluding data referenced at 40% RH (3:59 h).

Make	Model	Detector	Criterion	n	x	Variables for p				
						$x n^{-1}$	L	$F_{\alpha/2}(v_1, v_2)_L$	U	$F_{\alpha/2}(v_1, v_2)_U$
Ludlum	139	Model 43-32 alpha (vented)	15%	60	23	0.383	0.258	1.74	0.529	1.73

Table 35. Overhoff 394-C tritium monitor temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C) [‡]								Performance criteria	
	20°C	30°C	40°C	50°C	20°C	10°C	0°C	-10°C	0°C to 40°C	-10°C to 50°C
	0:59 h	1:59 h	2:59 h	3:59 h	5:59 h	6:59 h	7:59 h	8:59 h	(15%)	(20%)
1	1.000	1.000	1.046	1.035	1.000	0.985	0.969	0.952	Pass	Pass
2	1.000	1.017	1.034	1.013	1.000	0.997	0.992	0.970	Pass	Pass
3	1.000	1.016	1.031	1.026	1.000	0.983	0.996	0.975	Pass	Pass
3, Rep 2	1.000	1.017	1.032	1.028	1.000	0.983	1.012	1.006	Pass	Pass
4	1.000	1.000	1.000	1.078	1.000	0.986	0.971	0.955	Pass	Pass
5	1.000	1.014	1.026	1.016	1.000	0.984	0.968	0.949	Pass	Pass
6	1.000	1.013	1.046	1.033	1.000	0.986	0.970	0.953	Pass	Pass
6, Rep 2	1.000	0.993	1.025	1.014	1.000	0.986	0.970	0.953	Pass	Pass
Mean inventory year = 1990.0 ± 0 (1 σ) df [†] = 47 R ^{2†} = 0.97 Root MSE [†] = 0.010 Pr > F [†] = 0.0001										

[†]ANOVA estimates for n = 48, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 20°C (0:59 h and 5:59 h)

[‡]Normalized response reflects correction for the air density change during the temperature exposure profile

Table 36. Overhoff 394-C tritium monitor humidity test data and GLM procedure summaries.

Instrument	Normalized response (40% RH)							Performance criterion
	40% RH 3:59 h	95% RH 4:59 h	95% RH 6:59 h	95% RH 8:59 h	95% RH 10:59 h	95% RH 12:59 h	40% RH 17:59 h	40% to 95% to 40% RH (15%)
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
2	1.000	1.014	1.014	1.014	1.014	1.014	1.014	Pass
3	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
4	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
5	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
6	1.000	0.980	0.980	1.000	1.000	1.000	1.000	Pass
Mean inventory year = 1990.0 ± 0 (1σ) $df^\dagger = 35$ $R^{2\dagger} = 0.77$ Root MSE $^\dagger = 0.004$ $Pr > F^\dagger = 0.0001$								

† ANOVA estimates for $n = 36$, $0.500 \leq NR \leq 2.000$, and excluding data referenced at 40% RH (3:59 h)

Table 37. Johnston J-111 tritium monitor temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C) [‡]								Performance criteria	
	20°C 0:59 h	30°C 1:59 h	40°C 2:59 h	50°C 3:59 h	20°C 5:59 h	10°C 6:59 h	0°C 7:59 h	-10°C 8:59 h	0°C to 40°C (15%)	-10°C to 50°C (20%)
1	1.000	1.000	0.961	0.882	1.000	1.050	1.053	1.171	Pass	Pass
2	1.000	1.000	1.000	1.000	1.000	1.000	0.969	1.077	Pass	Pass
3	1.000	0.891	0.921	0.950	1.000	1.005	1.118	1.077	Pass	Pass
4	1.000	0.993	0.983	0.882	1.000	1.050	1.215	1.171	Fail ⁵	Fail ⁵
4, Rep 2	1.000	1.000	0.929	0.863	1.000	1.050	1.094	1.171	Pass	Pass
5	1.000	1.000	0.926	0.955	1.000	1.000	1.056	1.017	Pass	Pass
5, Rep 2	1.000	1.000	0.926	0.955	1.000	1.000	1.056	1.017	Pass	Pass
6	1.000	0.879	0.908	0.827	1.000	1.023	1.096	1.056	Pass	Pass
Mean inventory year = 1982.5 ± 5.2 (1 σ) $df^\dagger = 47$ $R^{2\dagger} = 0.97$ Root MSE [†] = 0.027 $Pr > F^\dagger = 0.0001$										

⁵Failed @ 0°C (7:59 h)

[†]ANOVA estimates for $n = 48$, $0.500 \leq NR \leq 2.000$, and excluding data referenced at 20°C (0:59 h and 5:59 h)

[‡]Normalized response reflects correction for the air density change during the temperature exposure profile

Table 38. Johnston J-111 tritium monitor humidity test data and GLM procedure summaries.

Instrument	Normalized response (40% RH)						Performance criterion	
	40% RH 3:59 h	95% RH 4:59 h	95% RH 6:59 h	95% RH 8:59 h	95% RH 10:59 h	95% RH 12:59 h	40% RH 17:59 h	40% to 95% to 40% RH (15%)
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
2	1.000	0.806	0.806	0.806	0.806	0.806	0.806	Pass
3	1.000	1.029	1.029	1.000	1.029	1.029	1.029	Pass
4	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
5	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
6	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
Mean inventory year = 1982.5 ± 5.2 (1σ) $df^\dagger = 35$ $R^{2\dagger} = 1.00$ Root MSE $^\dagger = 0.005$ $Pr > F^\dagger = 0.0001$								

† ANOVA estimates for $n = 36$, $0.500 \leq NR \leq 2.000$, and excluding data referenced at 40% RH (3:59 h)

Table 39. Johnston J-110 tritium monitor temperature test data and GLM procedure summaries.

Instrument	Normalized response (20°C) [‡]								Performance criteria	
	20°C	30°C	40°C	50°C	20°C	10°C	0°C	-10°C	0°C to 40°C	-10°C to 50°C
	0:59 h	1:59 h	2:59 h	3:59 h	5:59 h	6:59 h	7:59 h	8:59 h	(15%)	(20%)
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass	Pass
2	1.000	1.000	1.000	1.000	1.000	0.950	0.901	0.853	Pass	Pass
3	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass	Pass
4	1.000	1.000	1.000	1.066	1.000	1.000	1.000	1.000	Pass	Pass
4, Rep 2	1.000	1.000	1.000	0.992	1.000	1.000	1.000	1.000	Pass	Pass
5	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass	Pass
5, Rep 2	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass	Pass
6	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass	Pass
Mean inventory year = 1979.0 ± 0 (1 σ) df [†] = 47 R ^{2†} = 0.93 Root MSE [†] = 0.015 Pr > F [†] = 0.005										

[†]ANOVA estimates for n = 48, 0.500 ≤ NR ≤ 2.000, and excluding data referenced at 20°C (0:59 h and 5:59 h)

[‡]Normalized response reflects correction for the air density change during the temperature exposure profile

Table 40. Johnston J-110 tritium monitor humidity test data and GLM procedure summaries.

Instrument	Normalized response (40% RH)						Performance criterion	
	40% RH 3:59 h	95% RH 4:59 h	95% RH 6:59 h	95% RH 8:59 h	95% RH 10:59 h	95% RH 12:59 h	40% RH 17:59 h	40% to 95% to 40% RH (15%)
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
2	1.000	0.950	0.950	0.933	0.950	0.983	1.000	Pass
3	1.000	1.026	1.026	1.051	1.051	1.051	1.051	Pass
4	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
5	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
6	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Pass
Mean inventory year = 1979.0 $\pm$ 0 (1 σ) df [†] = 35 R ^{2†} = 0.87 Root MSE [†] = 0.011 Pr > F [†] = 0.0001								

[†]ANOVA estimates for n = 36, 0.500 $\leq$ NR $\leq$ 2.000, and excluding data referenced at 40% RH (3:59 h)

Table 41. Tritium-in-air monitors tested for temperature and humidity based on the ANSI standard's performance criteria and test methods. Shown are the number of failures F / number n tested.

Category	Make	Model	Detector	Temperature		Humidity ¹
				F / n	F / n ^a	F / n
Tritium-in-air monitors	Overhoff	394-C	ion chamber (vented)	0 / 6	0 / 8	0 / 6
	Johnston	J-111	ion chamber (vented)	1 / 6	1 / 8	0 / 6
	Johnston	J-110	ion chamber (vented)	0 / 6	0 / 8	0 / 6

NOTE: To pass the temperature test, all performance criteria evaluated must be satisfied. ¹Extended humidity range from 40% to 95% to 40% RH. ^aIncluding repeat tests.

Table 42. Tritium-in-air monitors tested for temperature based on the binomial frequency distribution. Shown are the interval estimations of the population parameter p for a 95% ($\alpha = 0.05$) level of confidence with v_1 and v_2 degrees of freedom, excluding data referenced at 20°C (0:59 h and 5:59 h).

Make	Model	Detector	Criterion	n	x	Variables for p				
						$x n^{-1}$	L	$F_{\alpha/2}(v_1, v_2)_L$	U	$F_{\alpha/2}(v_1, v_2)_U$
Overhoff	394-C	ion chamber (vented)	15%	48	0	0.000	0.000	---	0.074	3.85
			20%	48	0	0.000	0.000	---	0.074	3.85
Johnston	J-111	ion chamber (vented)	15%	48	5	0.104	0.035	3.17	0.228	2.12
			20%	48	1	0.021	0.001	39.49	0.111	2.94
Johnston	J-110	ion chamber (vented)	15%	48	0	0.000	0.000	---	0.074	3.85
			20%	48	0	0.000	0.000	---	0.074	3.85

Table 43. Tritium-in-air monitors tested for humidity based on the binomial frequency distribution. Shown are the interval estimations of the population parameter p for a 95% ($\alpha = 0.05$) level of confidence with v_1 and v_2 degrees of freedom, excluding data referenced at 40% RH (3:59 h).

Make	Model	Detector	Criterion	n	x	Variables for p				
						$x n^{-1}$	L	$F_{\alpha/2}(v_1, v_2)_L$	U	$F_{\alpha/2}(v_1, v_2)_U$
Overhoff	394-C	ion chamber (vented)	15%	36	0	0.000	0.000	---	0.098	3.90
Johnston	J-111	ion chamber (vented)	15%	36	0	0.000	0.000	---	0.098	3.90
Johnston	J-110	ion chamber (vented)	15%	36	0	0.000	0.000	---	0.098	3.90

APPENDIX A: PROCEDURES

1.0 Setting up an instrument for a test

- 1.1 Log the instrument into a work sheet (Appendix B).
- 1.2 Check to see if the instrument has a valid calibration sticker. The instrument must NOT be tested if the calibration is void.
- 1.3 Visually inspect the instrument and detector for evidence of mechanical and electrical defects. If applicable, check the detector window for punctures or tears.
- 1.4 Turn the instrument on. Allow a MINIMUM of 30 seconds warm-up time.
- 1.5 Check the instruments battery response. AC/DC-powered instruments are tested on AC power for convenience.
- 1.6 Label the instrument close to the meter face. The label should contain the minimum information: 1) instrument make, 2) instrument model, 3) detector type, 4) HS number (HSN), 5) environmental test, and 6) test date.
- 1.7 Select the appropriate radiation source. For beta-gamma survey meters and tritium-in-air monitors, install the 3 mCi Cs-137 source into the lucite source holder inside the chamber. For neutron rem meters, install the 250 mCi AmBe source into the lucite source holder inside the chamber. Use ALARA techniques to the extent possible.
- 1.8 Select an instrument range to produce a reading at approximately midscale or middecade. Place the instrument inside the chamber. If applicable, use the appropriate lucite stand. The lucite stand is marked for the instrument model(s) to be used.
- 1.9 Position the instrument and camera so that a clear picture of the meter face can be recorded.

2.0 Setting up the VCR's time date generator for a test

- 2.1 Label a T-120 video tape. The label should contain the minimum information: 1) instrument make, 2) instrument model, 3) detector type, 4) environmental test, 5) HS number (HSN), and 6) test date.
- 2.2 Insert the labeled T-120 video tape into the VCR.

APPENDIX A

- 2.3 Open the VCR's front control panel.
- 2.4 Depress the CLOCK SET button to get a blinking month display on the monitor.
- 2.5 Depress the SET (-)/(+) button to reverse or forward to the correct display.
- 2.6 Depress the MEMORY button to store the blinking display into memory (this will also will blink the display to the next position).
- 2.7 Repeat Steps 2.5 and 2.6 to store the day-year-day of the month displays into memory.
- 2.8 Repeat Steps 2.5 and 2.6 to set and store the hour display to "0." Set the minute display to "00" (the second display can not be set). DO NOT depress the MEMORY button. The time display should read "0:00:00" with the minute display blinking.
- 2.9 Make sure the VCR recording speed is set to 24 hours. Depress the RECORD button on the VCR (this stops the minute display from blinking and starts the timer to count up from 0:00:00). "REC" should be indicated in the VCR display.

3.0 Starting a program

- 3.1 Programs must be executed from the SYSTEM Menu. If not in one of the three menus (SYSTEM, SETUP, or PROGRAM), depress the MODE key until "RETURN" appears in the display. Depress the ENTER key to get the SYSTEM Menu.
- 3.2 Depress the RUN/HOLD key to get "FILE?" followed by a file number. Use the UP/DOWN key to scroll the file number (program) you wish to run. Depress the ENTER key to select the file number into memory. The RUN/HOLD indicator light should be lit on HOLD.
- 3.3 Depress the ENTER key to get "START" followed by a flashing start number. A program should always start on "1," so depress the ENTER key again. The RUN/HOLD indicator light should be lit on RUN.
- 3.4 To stop or interrupt a program at any time, depress the RUN/HOLD key to get the SYSTEM Menu. "SYSTEM" will be displayed in the controller at the completion of the program.

APPENDIX A

- 3.5 At the completion of the test, depress the STOP button on the VCR to end recording. Open the chamber and remove the instrument and lucite stand (if used). Turn the instrument off. Place the source back into its storage container and proper location after use.

4.0 Analysis

4.1 Temperature test

- 4.1.1 Advance the VCR tape of the recorded instrument readings to just before the first sampling interval (0:59:01 h to 0:59:30 h). For analog-display-type instruments, determine the average ("eye-ball" weighted average) reading. For digital-display-type instruments, determine the sample mean reading, standard deviation (sigma), and coefficient of variation (COV).
- 4.1.2 Repeat 4.1.1 for the sampling intervals: 1:59:01 h to 1:59:30 h, 2:59:01 h to 2:59:30 h, 3:59:01 h to 3:59:30 h, 5:59:01 h to 5:59:30 h, 6:59:01 h to 6:59:30 h, 7:59:01 h to 7:59:30 h, and 8:59:01 h to 8:59:30 h.
- 4.1.3 Determine the NR for the instrument. NR is equal to the ratio of the mean instrument reading R_T determined at temperature T ($^{\circ}\text{C}$) and the mean instrument reading R_{20} determined at reference temperature (20°C) times an air density correction factor, CF (for air-filled and air-flow detectors vented to the environment). The mean instrument readings at 20°C (0:59 h), 30°C (1:59 h), 40°C (2:59 h), and 50°C (3:59 h) determined in 4.1.2 for the temperature test from 20°C to 50°C are normalized to the reference mean instrument reading determined at 20°C (0:59 h). The mean instrument readings at 20°C (5:59 h), 10°C (6:59 h), 0°C (7:59 h), and -10°C (8:59 h) determined in 4.1.2 for the temperature test from 20°C to -10°C are normalized to the reference mean instrument reading determined at 20°C (5:59 h).

4.2 Temperature rep test

- 4.2.1 Advance the VCR tape of the recorded instrument readings to just before the first sampling interval (0:59:01 h to 0:59:30 h). For analog-display-type instruments, determine the average ("eye-ball" weighted average) reading. For digital-display-type instruments, determine the sample mean reading, standard deviation (sigma), and coefficient of variation (COV).

APPENDIX A

- 4.2.2 Repeat 4.2.1 for the sampling intervals: 1:59:01 h to 1:59:30 h, 2:59:01 h to 2:59:30 h, 3:59:01 h to 3:59:30 h, 5:59:01 h to 5:59:30 h, 6:59:01 h to 6:59:30 h, 7:59:01 h to 7:59:30 h, and 8:59:01 h to 8:59:30 h.
- 4.2.3 Determine the NR for the instrument. NR is equal to the ratio of the mean instrument reading R_T determined at temperature T ($^{\circ}\text{C}$) and the mean instrument reading R_{20} determined at reference temperature (20°C) times an air density correction factor, CF (for air-filled and air-flow detectors vented to the environment). The mean instrument readings at 20°C (0:59 h), 30°C (1:59 h), 40°C (2:59 h), and 50°C (3:59 h) determined in 4.2.2 for the temperature test from 20°C to 50°C are normalized to the reference mean instrument reading determined at 20°C (0:59 h). The mean instrument readings at 20°C (5:59 h), 10°C (6:59 h), 0°C (7:59 h), and -10°C (8:59 h) determined in 4.2.2 for the temperature test from 20°C to -10°C are normalized to the reference mean instrument reading determined at 20°C (5:59 h).

4.3 Humidity test

- 4.3.1 Advance the VCR tape of the recorded instrument readings to just before the first sampling interval (3:59:01 h to 3:59:30 h). For analog-display-type instruments, determine the average ("eye-ball" weighted average) reading. For digital-display-type instruments, determine the sample mean reading, standard deviation (sigma), and coefficient of variation (COV).
- 4.3.2 Repeat 4.3.1 for the sampling intervals: 4:59:01 h to 4:59:30 h, 6:59:01 h to 6:59:30 h, 8:59:01 h to 8:59:30 h, 10:59:01 h to 10:59:30 h, 12:59:01 h to 12:59:30 h, and 17:59:01 h to 7:59:30 h.
- 4.3.3 Determine the NR for the instrument. The mean instrument readings at 40% RH (3:59 h), 95% RH (4:59 h), 95% RH (6:59 h), 95% RH (8:59 h), 95% (10:59 h), 95% RH (12:59 h), and 40% RH (17:59 h) determined in 4.3.2 for the humidity test from 40% to 95% to 40% RH are normalized to the reference mean instrument reading determined at 40% RH (3:59 h).

5.0 Manual operation of the controller

- 5.1 Manual commands are executed from the SYSTEM Menu. If not in one of the three menus (SYSTEM, SETUP, or PROGRAM), depress the MODE key until "RETURN" appears in the display. Depress the ENTER key to get the SYSTEM Menu.
- 5.2 At the SYSTEM Menu, depress the ENTER key to get "SP1" followed by a flashing temperature value in the display. Use the UP/DOWN keys to scroll the temperature setpoint you wish to enter. Depress the ENTER key to select the display into memory.
- 5.3 At the SYSTEM Menu, depress the ENTER key to get "SP2" followed by a flashing humidity value in the display. Use the UP/DOWN keys to scroll the humidity setpoint you wish to enter. Depress the ENTER key to select the display into memory.
- 5.4 For nonroutine tests, it is recommended that several variations of a program be run, video taped, and graphed to observe which version runs most efficiently and best represents the desired effect.

APPENDIX B: WORK SHEETS

APPENDIX B
Attachment 1

1.1 Temperature exposure profile

Date: _____
Comments: _____

Time interval (h)	0 → 1	1 → 2	2 → 3	3 → 4
t (h)	T / RH	T / RH	T / RH	T / RH
0.017				
0.033				
0.067				
0.100				
0.133				
0.167				
0.250				
0.333				
0.417				
0.500				
0.583				
0.667				
0.750				
0.833				
0.917				
0.933				
0.950				
0.967				
0.983				
1.000				

APPENDIX B
Attachment 1

1.1 Temperature exposure profile cont'd

Date: _____
 Comments: _____

Time interval (h)	5 → 6	6 → 7	7 → 8	8 → 9
t (h)	T / RH	T / RH	T / RH	T / RH
0.017				
0.033				
0.067				
0.100				
0.133				
0.167				
0.250				
0.333				
0.417				
0.500				
0.583				
0.667				
0.750				
0.833				
0.917				
0.933				
0.950				
0.967				
0.983				
1.000				

APPENDIX B
Attachment 1

1.2 Temperature rep exposure profile

Date: _____
 Comments: _____

Time interval (h)	0 → 1	1 → 2	2 → 3	3 → 4
t (h)	T / RH	T / RH	T / RH	T / RH
0.017				
0.033				
0.067				
0.100				
0.133				
0.167				
0.250				
0.333				
0.417				
0.500				
0.583				
0.667				
0.750				
0.833				
0.917				
0.933				
0.950				
0.967				
0.983				
1.000				

APPENDIX B
Attachment 1

1.2 Temperature rep exposure profile cont'd

Date: _____
Comments: _____

Time interval (h)	5 → 6	6 → 7	7 → 8	8 → 9
t (h)	T / RH	T / RH	T / RH	T / RH
0.017				
0.033				
0.067				
0.100				
0.133				
0.167				
0.250				
0.333				
0.417				
0.500				
0.583				
0.667				
0.750				
0.833				
0.917				
0.933				
0.950				
0.967				
0.983				
1.000				

APPENDIX B
Attachment 1

1.3 Humidity exposure profile

Date: _____
Comments: _____

Time interval (h)	0 → 1	1 → 2	2 → 3	3 → 4	4 → 5	5 → 6
t (h)	RH / T	RH / T	RH / T	RH / T	RH / T	RH / T
0.017						
0.033						
0.067						
0.100						
0.133						
0.167						
0.250						
0.333						
0.417						
0.500						
0.583						
0.667						
0.750						
0.833						
0.917						
0.933						
0.950						
0.967						
0.983						
1.000						

APPENDIX B
Attachment 1

1.3 Humidity exposure profile cont'd

Date: _____
Comments: _____

Time interval (h)	6 → 7	7 → 8	8 → 9	9 → 10	10 → 11	11 → 12
t (h)	RH / T	RH / T	RH / T	RH / T	RH / T	RH / T
0.017						
0.033						
0.067						
0.100						
0.133						
0.167						
0.250						
0.333						
0.417						
0.500						
0.583						
0.667						
0.750						
0.833						
0.917						
0.933						
0.950						
0.967						
0.983						
1.000						

APPENDIX B
Attachment 1

1.3 Humidity exposure profile cont'd

Date: _____
Comments: _____

Time interval (h)	12 → 13	13 → 14	14 → 15	15 → 16	16 → 17	17 → 18
t (h)	RH / T	RH / T	RH / T	RH / T	RH / T	RH / T
0.017						
0.033						
0.067						
0.100						
0.133						
0.167						
0.250						
0.333						
0.417						
0.500						
0.583						
0.667						
0.750						
0.833						
0.917						
0.933						
0.950						
0.967						
0.983						
1.000						

2.1 Temperature test

Test conditions

Date start: _____
Time start: _____
P (in Hg): _____
T (°C): (see Data)
RH (%): 40 ± 5 (20°C to 50°C)

Test source

Nuclide: _____
Activity: _____
Ref date: _____
SN: _____

Instrument under test

Type: _____
Make: _____
Model: _____
Detector: _____
HSN: _____
Ranges: _____
Range tested: _____
Comments: _____
DC voltages: (see table)

Instrument battery voltage table

n	V _i (VDC)	V _f (VDC)
1		
2		
3		
4		
5		
6		

Time stop: _____
Date stop: _____
Program file: _____
Test by: _____

APPENDIX B
Attachment 2

2.1 Temperature test cont'd

Data

T (°C)	20°C to 50°C				20°C to -10°C			
	20	30	40	50	20	10	0	-10
t (h)	0:59:()	1:59:()	2:59:()	3:59:()	5:59:()	6:59:()	7:59:()	8:59:()
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

Comments: _____

2.2 Temperature rep test

Test conditions

Date start: _____

Time start: _____

P (in Hg): _____

T (°C): (see Data)

RH (%): 40 ± 5 (20°C to 50°C)

Test source

Nuclide: _____

Activity: _____

Ref date: _____

SN: _____

Instrument under test

Type: _____

Make: _____

Model: _____

Detector: _____

HSN: _____

Ranges: _____

Range tested: _____

Comments: _____

DC voltages: (see table)

Instrument battery voltage table

n	V _i (VDC)	V _f (VDC)
1		
2		
3		
4		
5		
6		

Time stop: _____

Date stop: _____

Program file: _____

Test by: _____

APPENDIX B
Attachment 2

2.2 Temperature rep test cont'd

Data

T (°C)	20°C to 50°C				20°C to -10°C			
	20	30	40	50	20	10	0	-10
t (h)	0:59:()	1:59:()	2:59:()	3:59:()	5:59:()	6:59:()	7:59:()	8:59:()
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

Comments: _____

2.3 Humidity test

Test conditions

Date start: _____
 Time start: _____
 P (in Hg): _____
 T (°C): 22 ± 2°C
 RH (%): (see Data)

Test source

Nuclide: _____
 Activity: _____
 Ref date: _____
 SN: _____

Instrument under test

Type: _____
 Make: _____
 Model: _____
 Detector: _____
 HSN: _____
 Ranges: _____
 Range tested: _____
 Comments: _____
 DC voltages: (see table)

Instrument battery voltage table

n	V _i (VDC)	V _f (VDC)
1		
2		
3		
4		
5		
6		

Time stop: _____
 Date stop: _____
 Program file: _____
 Test by: _____

APPENDIX B
Attachment 2

2.3 Humidity test cont'd

Data

RH (%)	40% to 95% to 40 % RH						
	40	95	95	95	95	95	40
t (h)	3:59:()	4:59:()	6:59:()	8:59:()	10:59:()	12:59:()	17:59:()
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Comments: _____

APPENDIX C: DATA SPREADSHEETS

Data was collected by viewing the video-taped recordings of instrument readings when the instrument was exposed in the chamber during a test. Readings were then entered into a spreadsheet which performed descriptive statistics (for digital-display-type instruments), calculated a correction factor (for instruments using an air-filled or air-flow detector vented to the environment), normalized the response to reference conditions, and plotted a summary graph. For this report, 246 spreadsheets were generated from the 105 radiological instruments tested to evaluate the ANSI standard's performance criteria and test methods. Due to space limitations, only a sample of data spreadsheets from each category of radiological instruments are presented.

Instrument Type:	Beta-gamma survey	Environmental Test:	Temperature
Make:	Eberline	Temperature (C):	see below
Model:	RO-2	Pressure (in Hg):	22.64
Detector:	Ion chamber	Source:	Cs-137
HS Number:	003361	Source Number:	V-069
Units:	mrem/h	Test By:	R. Clement
Range Tested:	0-500	Test Date:	11/13/93

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data:	400	385	375	355	395	415	435	455
-------	------------	------------	------------	------------	------------	------------	------------	------------

Mean	400	385	375	355	395	415	435	455
------	-----	-----	-----	-----	-----	-----	-----	-----

Sigma
COV (%)

CF	1.000	1.034	1.068	1.102	1.000	0.966	0.932	0.898
----	-------	-------	-------	-------	-------	-------	-------	-------

NR	1.000	0.995	1.001	0.978	1.000	1.015	1.026	1.034
----	-------	-------	-------	-------	-------	-------	-------	-------

Summary:	T (C)	NR
	30	0.995
	40	1.001
	50	0.978
	10	1.015
	0	1.026
	-10	1.034

Comments: **Vented detector**

Instrument Type:	Beta-gamma survey	Environmental Test:	Temp, Rep 2
Make:	Eberline	Temperature (C):	see below
Model:	RO-2	Pressure (in Hg):	22.52
Detector:	Ion chamber	Source:	Cs-137
HS Number:	003361	Source Number:	V-069
Units:	mrem/h	Test By:	R. Clement
Range Tested:	0-500	Test Date:	11/13/93

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data:	400	385	370	355	395	415	435	455
-------	------------	------------	------------	------------	------------	------------	------------	------------

Mean	400	385	370	355	395	415	435	455
------	-----	-----	-----	-----	-----	-----	-----	-----

Sigma
COV (%)

CF	1.000	1.034	1.068	1.102	1.000	0.966	0.932	0.898
----	-------	-------	-------	-------	-------	-------	-------	-------

NR	1.000	0.995	0.988	0.978	1.000	1.015	1.026	1.034
----	-------	-------	-------	-------	-------	-------	-------	-------

Summary:	T (C)	NR
	30	0.995
	40	0.988
	50	0.978
	10	1.015
	0	1.026
	-10	1.034

Comments: **Vented detector**

Instrument Type:	Beta-gamma survey	Environmental Test:	Humidity
Make:	Eberline	Temperature (C):	20
Model:	RO-2	Pressure (in Hg):	22.70
Detector:	Ion chamber	Source:	Cs-137
HS Number:	003361	Source Number:	V-069
Units:	mrem/h	Test By:	R. Clement
Range Tested:	0-500	Test Date:	11/14/93

Tests: 1) 40% RH for 4 h, 2) 95% RH for 9 h, then 3) 40% RH for 5 h @ 20 C.

RH (%)	40	95	95	95	95	95	40
t (h)	3:59	4:59	6:59	8:59	10:59	12:59	17:59

Data:	395	395	395	395	400	400	400
-------	------------	------------	------------	------------	------------	------------	------------

Mean	395	395	395	395	400	400	400
------	-----	-----	-----	-----	-----	-----	-----

Sigma

COV (%)

CF	1.000	1.000	1.000	1.000	1.000	1.000	1.000
----	-------	-------	-------	-------	-------	-------	-------

NR	1.000	1.000	1.000	1.000	1.013	1.013	1.013
----	-------	-------	-------	-------	-------	-------	-------

Summary:	RH (%)	NR
	95	1.000
	95	1.000
	95	1.000
	95	1.013
	95	1.013
	40	1.013

Comments: **Vented detector**

Instrument Type:	Beta-gamma survey	Environmental Test:	Temperature
Make:	Eberline	Temperature (C):	see below
Model:	PIC-6A	Pressure (in Hg):	22.94
Detector:	Ion chamber	Source:	Cs-137
HS Number:	003161	Source Number:	V-069
Units:	mrem/h	Test By:	R. Clement
Range Tested:	2nd decade	Test Date:	11/08/93

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data:	36	41	51	56	40	38	34	30
-------	-----------	-----------	-----------	-----------	-----------	-----------	-----------	-----------

Mean	36	41	51	56	40	38	34	30
------	----	----	----	----	----	----	----	----

Sigma

COV (%)

CF

NR	1.000	1.139	1.417	1.556	1.000	0.950	0.850	0.750
----	-------	-------	-------	-------	-------	-------	-------	-------

Summary:	T (C)	NR
	30	1.139
	40	1.417
	50	1.556
	10	0.950
	0	0.850
	-10	0.750

Comments: **Sealed detector**

Instrument Type:	Beta-gamma survey	Environmental Test:	Temp, Rep 2
Make:	Eberline	Temperature (C):	see below
Model:	PIC-6A	Pressure (in Hg):	22.96
Detector:	ion chamber	Source:	Cs-137
HS Number:	003161	Source Number:	V-069
Units:	mrem/h	Test By:	R. Clement
Range Tested:	2nd decade	Test Date:	11/08/93

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data:	37	40	48	9	32	32	30	28
-------	-----------	-----------	-----------	----------	-----------	-----------	-----------	-----------

Mean	37	40	48	9	32	32	30	28
------	----	----	----	---	----	----	----	----

Sigma

COV (%)

CF

NR	1.000	1.081	1.297	0.243	1.000	1.000	0.938	0.875
----	-------	-------	-------	-------	-------	-------	-------	-------

Summary:	T (C)	NR
	30	1.081
	40	1.297
	50	0.243
	10	1.000
	0	0.938
	-10	0.875

Comments: **Sealed detector**

Instrument Type:	Beta-gamma survey	Environmental Test:	Humidity
Make:	Eberline	Temperature (C):	20
Model:	PIC-6A	Pressure (in Hg):	23.06
Detector:	ion chamber	Source:	Cs-137
HS Number:	003161	Source Number:	V-069
Units:	mrem/h	Test By:	R. Clement
Range Tested:	2nd decade	Test Date:	11/09/93

Tests: 1) 40% RH for 4 h, 2) 95% RH for 9 h, then 3) 40% RH for 5 h @ 20 C.

RH (%)	40	95	95	95	95	95	40
t (h)	3:59	4:59	6:59	8:59	10:59	12:59	17:59

Data:	38	38	38	38	38	38	38
-------	-----------	-----------	-----------	-----------	-----------	-----------	-----------

Mean	38	38	38	38	38	38	38
------	----	----	----	----	----	----	----

Sigma

COV (%)

CF

NR	1.000	1.000	1.000	1.000	1.000	1.000	1.000
----	-------	-------	-------	-------	-------	-------	-------

Summary: RH (%) NR

95 1.000

95 1.000

95 1.000

95 1.000

95 1.000

40 1.000

Comments: **Sealed detector**

Instrument Type: **Beta-gamma survey**
 Make: **Eberline**
 Model: **ESP-1**
 Detector: **GM pancake**
 HS Number: **007438**
 Units: **cpm**
 Range Tested: **NA**

Environmental Test: **Temperature**
 Temperature (C): **see below**
 Pressure (in Hg): **22.86**
 Source: **Cs-137**
 Source Number: **V-069**
 Test By: **R. Clement**
 Test Date: **11/30/93**

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data:	5.63E+05	5.53E+05	5.34E+05	5.08E+05	5.38E+05	5.51E+05	5.46E+05	5.61E+05
	5.73E+05	5.45E+05	5.45E+05	5.16E+05	5.39E+05	5.55E+05	5.62E+05	5.67E+05
	5.64E+05	5.53E+05	5.29E+05	5.18E+05	5.34E+05	5.51E+05	5.53E+05	5.65E+05
	5.80E+05	5.55E+05	5.35E+05	5.24E+05	5.47E+05	5.61E+05	5.42E+05	5.86E+05
	5.62E+05	5.33E+05	5.40E+05	5.19E+05	5.49E+05	5.54E+05	5.61E+05	5.57E+05
	5.57E+05	5.23E+05	5.46E+05	5.23E+05	5.36E+05	5.45E+05	5.50E+05	5.51E+05
	5.42E+05	5.46E+05	5.18E+05	5.02E+05	5.36E+05	5.56E+05	5.50E+05	5.59E+05
	5.68E+05	5.42E+05	5.40E+05	5.15E+05	5.45E+05	5.48E+05	5.44E+05	5.60E+05
	5.56E+05	5.50E+05	5.36E+05	5.21E+05	5.38E+05	5.55E+05	5.52E+05	5.50E+05
	5.66E+05	5.36E+05	5.22E+05	5.09E+05	5.46E+05	5.57E+05	5.80E+05	5.67E+05
	5.59E+05	5.45E+05	5.37E+05	5.10E+05	5.46E+05	5.47E+05	5.59E+05	5.66E+05
	5.63E+05	5.38E+05	5.26E+05	5.22E+05	5.45E+05	5.51E+05	5.52E+05	5.55E+05
	5.54E+05	5.36E+05	5.29E+05	5.24E+05	5.48E+05	5.62E+05	5.62E+05	5.65E+05
	5.47E+05	5.39E+05	5.39E+05	5.10E+05	5.44E+05	5.46E+05	5.68E+05	5.65E+05
	5.58E+05	5.44E+05	5.33E+05	5.20E+05	5.46E+05	5.49E+05	5.48E+05	5.79E+05

Mean	5.61E+05	5.43E+05	5.34E+05	5.16E+05	5.42E+05	5.53E+05	5.55E+05	5.64E+05
Sigma	9.47E+03	8.65E+03	7.98E+03	6.81E+03	5.03E+03	5.19E+03	1.01E+04	9.55E+03
COV (%)	1.7	1.6	1.5	1.3	0.9	0.9	1.8	1.7
CF								
NR	1.000	0.967	0.952	0.951	1.000	1.019	1.024	1.039

Summary:	T (C)	NR
	30	0.967
	40	0.952
	50	0.951
	10	1.019
	0	1.024
	-10	1.039

Comments: **Sealed detector**

Instrument Type: **Beta-gamma survey**
 Make: **Eberline**
 Model: **ESP-1**
 Detector: **GM pancake**
 HS Number: **007438**
 Units: **cpm**
 Range Tested: **NA**

Environmental Test: **Humidity**
 Temperature (C): **20**
 Pressure (in Hg): **22.92**
 Source: **Cs-137**
 Source Number: **V-069**
 Test By: **R. Clement**
 Test Date: **12/01/93**

Tests: 1) 40% RH for 4 h, 2) 95% RH for 9 h, then 3) 40% RH for 5 h @ 20 C.

RH (%)	40	95	95	95	95	95	40
t (h)	3:59	4:59	6:59	8:59	10:59	12:59	17:59

Data:	5.22E+05	5.18E+05	5.51E+05	5.24E+05	5.24E+05	5.38E+05	5.16E+05
	5.28E+05	5.26E+05	5.43E+05	5.25E+05	5.34E+05	5.36E+05	5.15E+05
	5.30E+05	5.44E+05	5.36E+05	5.36E+05	5.35E+05	5.39E+05	5.18E+05
	5.17E+05	5.37E+05	5.38E+05	5.25E+05	5.33E+05	5.29E+05	5.11E+05
	5.17E+05	5.34E+05	5.44E+05	5.28E+05	5.22E+05	5.14E+05	5.21E+05
	5.24E+05	5.37E+05	5.30E+05	5.26E+05	5.38E+05	5.32E+05	5.26E+05
	5.17E+05	5.27E+05	5.15E+05	5.39E+05	5.40E+05	5.32E+05	5.18E+05
	5.32E+05	5.28E+05	5.34E+05	5.36E+05	5.40E+05	5.36E+05	5.08E+05
	5.33E+05	5.28E+05	5.25E+05	5.21E+05	5.19E+05	5.33E+05	5.14E+05
	5.31E+05	5.44E+05	5.26E+05	5.25E+05	5.35E+05	5.31E+05	5.14E+05
	5.28E+05	5.35E+05	5.31E+05	5.56E+05	5.42E+05	5.43E+05	4.99E+05
	5.29E+05	5.44E+05	5.44E+05	5.30E+05	5.21E+05	5.23E+05	5.23E+05
	5.31E+05	5.43E+05	5.29E+05	5.25E+05	5.24E+05	5.13E+05	5.13E+05
	5.43E+05	5.38E+05	5.33E+05	5.21E+05	5.41E+05	5.37E+05	5.13E+05
	5.42E+05	5.31E+05	5.41E+05	5.32E+05	5.27E+05	5.22E+05	5.22E+05

Mean	5.28E+05	5.34E+05	5.35E+05	5.30E+05	5.32E+05	5.31E+05	5.15E+05
Sigma	8.01E+03	7.86E+03	9.22E+03	9.07E+03	8.06E+03	8.90E+03	6.64E+03
COV (%)	1.5	1.5	1.7	1.7	1.5	1.7	1.3
CF							
NR	1.000	1.011	1.012	1.003	1.006	1.004	0.976

Summary:	RH (%)	NR
	95	1.011
	95	1.012
	95	1.003
	95	1.006
	95	1.004
	40	0.976

Comments: **Sealed detector**

Instrument Type:	Neutron rem meter	Environmental Test:	Temperature
Make:	Eberline	Temperature (C):	see below
Model:	ESP-1	Pressure (in Hg):	23.00
Detector:	NRD	Source:	AmBe
HS Number:	008022	Source Number:	C-777
Units:	mrem/h	Test By:	R. Clement
Range Tested:	NA	Test Date:	07/16/93

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data:	42.2	44.7	46.3	39.6	43.9	47.6	44.9	47.9
	42.6	42.4	44.0	43.1	43.5	44.7	49.0	44.7
	42.7	46.7	45.9	43.2	43.9	45.6	45.9	46.2
	43.3	48.8	42.0	43.3	41.8	41.4	43.9	45.6
	46.9	45.2	43.4	46.2	41.8	40.2	43.8	41.6
	50.9	42.4	45.4	46.3	37.9	38.2	45.7	41.1
	55.6	40.6	41.8	45.0	38.8	39.1	50.8	39.6
	50.0	43.1	43.0	42.0	42.3	43.2	47.9	36.3
	43.0	44.1	42.5	41.4	40.6	44.8	43.8	39.4
	45.7	47.1	41.2	43.0	43.8	47.7	43.2	45.2
	46.5	48.8	45.2	45.0	42.0	44.3	44.8	50.7
	48.8	43.8	46.6	45.6	45.6	39.0	46.2	49.2
	48.7	44.1	47.7	41.2	43.1	37.4	46.2	45.4
	44.4	45.5	45.1	44.2	46.7	40.0	47.0	43.2
	45.5	42.2	48.3	44.7	42.4	43.3	44.0	41.5

Mean	46.5	44.6	44.6	43.6	42.5	42.4	45.8	43.8
Sigma	3.8	2.4	2.2	2.0	2.3	3.4	2.2	4.0
COV (%)	8.2	5.4	4.9	4.5	5.4	7.9	4.7	9.0
CF								
NR	1.000	0.961	0.959	0.938	1.000	0.997	1.077	1.031

Summary:	T (C)	NR
	30	0.961
	40	0.959
	50	0.938
	10	0.997
	0	1.077
	-10	1.031

Comments: **Sealed detector**

Instrument Type:	Neutron rem meter	Environmental Test:	Temp, Rep 2
Make:	Eberline	Temperature (C):	see below
Model:	ESP-1	Pressure (in Hg):	23.00
Detector:	NRD	Source:	AmBe
HS Number:	008022	Source Number:	C-777
Units:	mrem/h	Test By:	R. Clement
Range Tested:	NA	Test Date:	07/17/93

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data:	57.0	54.7	51.9	50.3	58.9	52.7	63.3	56.5
	54.6	53.0	55.1	52.7	57.8	52.9	60.9	56.5
	55.1	51.7	51.7	55.0	60.0	57.6	61.3	53.8
	55.1	57.2	51.3	57.6	56.3	54.4	58.5	53.8
	53.5	57.5	49.4	53.6	53.4	58.1	52.1	54.4
	58.4	53.0	52.0	55.6	52.3	56.0	55.7	54.3
	57.4	51.9	57.1	57.6	55.7	55.0	54.3	56.6
	56.7	56.6	58.5	55.5	57.4	58.0	57.1	59.5
	55.4	57.1	52.5	58.3	52.9	58.3	50.6	59.1
	59.4	55.6	55.9	57.7	52.1	59.1	49.6	56.8
	63.5	56.0	54.3	59.0	52.3	61.9	47.7	57.9
	62.5	55.6	59.9	61.4	52.0	60.5	51.5	55.1
	59.5	54.1	56.8	55.7	56.7	53.1	51.4	58.1
	58.8	59.3	56.9	58.0	57.6	56.8	54.0	54.7
	53.4	60.9	56.7	58.7	58.9	57.5	55.4	55.4

Mean	57.4	55.6	54.7	56.4	55.6	56.8	54.9	56.2
Sigma	3.0	2.6	3.1	2.8	2.9	2.8	4.6	1.9
COV (%)	5.3	4.7	5.6	5.0	5.1	4.9	8.4	3.3
CF								
NR	1.000	0.970	0.953	0.984	1.000	1.021	0.987	1.010

Summary:	T (C)	NR
	30	0.970
	40	0.953
	50	0.984
	10	1.021
	0	0.987
	-10	1.010

Comments: **Sealed detector**

Instrument Type:	Neutron rem meter	Environmental Test:	Humidity
Make:	Eberline	Temperature (C):	20
Model:	ESP-1	Pressure (in Hg):	23.00
Detector:	NRD	Source:	AmBe
HS Number:	008022	Source Number:	C-777
Units:	mrem/h	Test By:	R. Clement
Range Tested:	NA	Test Date:	07/18/93

Tests: 1) 40% RH for 4 h, 2) 95% RH for 9 h, then 3) 40% RH for 5 h @ 20 C.

RH (%)	40	95	95	95	95	95	40
t (h)	3:59	4:59	6:59	8:59	10:59	12:59	17:59

Data:	63.0	63.0	64.4	65.1	59.1	54.8	62.1
	58.8	63.0	59.6	64.9	63.8	55.7	64.8
	60.5	66.7	64.2	66.0	65.0	59.6	58.3
	61.3	72.4	66.0	63.6	62.8	59.1	66.1
	63.5	63.5	69.3	62.6	66.5	62.1	64.4
	64.9	64.6	70.2	62.3	63.3	60.7	63.0
	67.0	62.2	70.1	63.0	63.8	66.0	57.8
	64.5	65.2	69.3	61.9	62.7	61.5	59.7
	61.8	66.5	65.2	60.3	62.0	63.0	55.4
	63.5	63.1	56.6	61.1	58.1	65.0	56.5
	68.2	66.1	60.2	68.5	62.4	60.8	59.4
	68.0	66.1	62.1	69.7	60.6	67.2	63.9
	69.4	65.3	58.4	69.3	58.7	72.0	66.1
	68.6	69.0	58.0	70.2	60.3	71.5	62.1
	68.1	64.9	54.4	67.9	63.8	72.2	63.1

Mean	64.7	65.4	63.2	65.1	62.2	63.4	61.5
Sigma	3.3	2.6	5.2	3.3	2.4	5.5	3.5
COV (%)	5.1	4.0	8.2	5.1	3.9	8.7	5.6
CF							
NR	1.000	1.011	0.976	1.005	0.961	0.980	0.950

Summary:	RH (%)	NR
	95	1.011
	95	0.976
	95	1.005
	95	0.961
	95	0.980
	40	0.950

Comments: **Sealed detector**

Instrument Type:	Neutron rem meter	Environmental Test:	Temperature
Make:	Eberline	Temperature (C):	see below
Model:	ESP-2	Pressure (in Hg):	23.08
Detector:	NRD	Source:	AmBe
HS Number:	006089	Source Number:	C-777
Units:	mrem/h	Test By:	R. Clement
Range Tested:	NA	Test Date:	10/23/93

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data:	42.8	48.8	41.0	39.7	45.3	42.9	40.0	38.0
	41.7	45.3	42.6	40.5	43.9	41.0	42.4	37.3
	42.2	44.0	42.4	39.0	42.8	41.3	42.4	41.6
	42.3	49.7	43.2	38.4	42.2	42.1	42.8	38.4
	40.8	42.5	44.8	39.2	40.5	40.2	43.5	41.0
	42.8	43.7	45.0	40.3	38.4	42.1	46.1	44.0
	42.5	39.3	43.7	41.5	40.8	44.0	44.7	47.4
	42.9	41.4	41.8	42.3	41.6	41.1	43.5	40.5
	44.7	44.3	40.5	41.7	41.5	41.3	42.9	44.7
	40.4	43.3	40.4	41.3	45.1	44.0	41.1	42.0
	40.5	42.8	41.6	38.4	43.3	41.6	38.6	41.9
	40.8	43.5	44.6	39.7	42.6	41.4	39.2	38.6
	41.0	40.7	39.9	44.4	39.2	40.5	39.9	42.6
	41.4	44.3	37.6	43.3	40.4	42.7	44.7	41.9
	38.3	46.4	36.5	42.1	40.0	43.7	44.5	43.6

Mean	41.7	44.0	41.7	40.8	41.8	42.0	42.4	41.6
Sigma	1.5	2.8	2.5	1.8	2.0	1.2	2.2	2.8
COV (%)	3.6	6.3	6.0	4.4	4.9	2.9	5.3	6.6
CF								
NR	1.000	1.056	1.001	0.979	1.000	1.004	1.014	0.993

Summary:	T (C)	NR
	30	1.056
	40	1.001
	50	0.979
	10	1.004
	0	1.014
	-10	0.993

Comments: **Sealed detector. "COMPUTER LINK RESET WHEN DONE" followed by "ROM ERROR FOUND!" indicated in instrument display @ 9:12 h (-10 C to 20 C).**

Instrument Type:	Neutron rem meter	Environmental Test:	Humidity
Make:	Eberline	Temperature (C):	20
Model:	ESP-2	Pressure (in Hg):	23.00
Detector:	NRD	Source:	AmBe
HS Number:	006089	Source Number:	C-777
Units:	mrem/h	Test By:	R. Clement
Range Tested:	NA	Test Date:	10/25/93

Tests: 1) 40% RH for 4 h, 2) 95% RH for 9 h, then 3) 40% RH for 5 h @ 20 C.

RH (%)	40	95	95	95	95	95	40
t (h)	3:59	4:59	6:59	8:59	10:59	12:59	17:59

Data:	40.9	1660	40.3	38.6	37.8	42.9	44.2
	40.4	742	41.6	40.8	38.9	40.1	41.8
	36.9	1550	45.0	40.1	38.6	44.0	44.1
	39.5	1410	47.2	43.3	39.1	40.5	42.6
	41.8	684	47.2	41.2	38.3	41.6	44.4
	41.6	1710	45.6	39.2	45.4	39.2	44.7
	41.7	1160	42.6	39.1	41.3	37.4	41.8
	41.3	1570	43.1	40.9	41.1	36.1	41.3
	43.3	1870	44.3	39.5	38.9	39.9	40.6
	40.8	1040	48.3	38.0	37.0	40.0	40.0
	40.5	1580	46.2	40.7	38.4	42.4	41.9
	38.7	910	43.2	36.8	38.4	41.8	39.6
	39.7	1400	44.0	38.0	38.9	39.7	37.2
	38.1	1390	41.2	38.8	38.8	37.9	41.3
	35.8	1770	41.4	39.2	43.7	42.0	41.3

Mean	40.1	1363	44.1	39.6	39.6	40.4	41.8
Sigma	2.0	374	2.5	1.6	2.3	2.2	2.0
COV (%)	5.0	27	5.6	4.0	5.8	5.4	4.9
CF							
NR	1.000	34.020	1.100	0.989	0.989	1.007	1.043

Summary:	RH (%)	NR
	95	34.020
	95	1.100
	95	0.989
	95	0.989
	95	1.007
	40	1.043

Comments: **Sealed detector**

Instrument Type:	Neutron rem meter	Environmental Test:	Temperature
Make:	Eberline	Temperature (C):	see below
Model:	PNR-4	Pressure (in Hg):	23.15
Detector:	NRD	Source:	AmBe
HS Number:	005202	Source Number:	C-777
Units:	mrem/h	Test By:	R. Clement
Range Tested:	NA	Test Date:	08/01/93

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data:	35	39	37	37	37	35	22	5
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Mean	35	39	37	37	37	35	22	5
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Sigma

COV (%)

CF

NR	1.000	1.114	1.057	1.057	1.000	0.946	0.595	0.135
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Summary:	T (C)	NR
	30	1.114
	40	1.057
	50	1.057
	10	0.946
	0	0.595
	-10	0.135

Comments: **Sealed detector**

Instrument Type: **Neutron rem meter**
 Make: **Eberline**
 Model: **PNR-4**
 Detector: **NRD**
 HS Number: **005202**
 Units: **mrem/h**
 Range Tested: **NA**

Environmental Test: **Humidity**
 Temperature (C): **20**
 Pressure (in Hg): **23.04**
 Source: **AmBe**
 Source Number: **C-777**
 Test By: **R. Clement**
 Test Date: **08/03/93**

Tests: 1) 40% RH for 4 h, 2) 95% RH for 9 h, then 3) 40% RH for 5 h @ 20 C.

RH (%)	40	95	95	95	95	95	40
t (h)	3:59	4:59	6:59	8:59	10:59	12:59	17:59

Data:	40	>5000	>5000	>5000	3000	2300	35
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Mean	40	>5000	>5000	>5000	3000	2300	35
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Sigma

COV (%)

CF

NR	1.000	125.000	125.000	125.000	75.000	57.500	0.875
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Summary:

RH (%)	NR
95	125.000
95	125.000
95	125.000
95	75.000
95	57.500
40	0.875

Comments: **Sealed detector. Instrument response pegged full scale during three sampling intervals (95% RH). Full scale value used to calculate normalized response.**

Instrument Type:	Alpha contamination	Environmental Test:	Temperature
Make:	Ludlum	Temperature (C):	see below
Model:	139	Pressure (in Hg):	22.98
Detector:	air-proportional alpha	Source:	Pu-239
HS Number:	007637	Source Number:	92-4651
Units:	cpm	Test By:	R. Clement
Range Tested:	X100	Test Date:	10/30/93

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data: 71000 73000 68000 63000 72000 69000 61000 59000

Mean 71000 73000 68000 63000 72000 69000 61000 59000

Sigma

COV (%)

CF

NR 1.000 1.028 0.958 0.887 1.000 0.958 0.847 0.819

Summary:	T (C)	NR
	30	1.028
	40	0.958
	50	0.887
	10	0.958
	0	0.847
	-10	0.819

Comments: **Vented detector**

Instrument Type:	Alpha contamination	Environmental Test:	Temp, Rep 2
Make:	Ludlum	Temperature (C):	see below
Model:	139	Pressure (in Hg):	22.98
Detector:	air-proportional alpha	Source:	Pu-239
HS Number:	007637	Source Number:	92-4651
Units:	cpm	Test By:	R. Clement
Range Tested:	X100	Test Date:	10/30/93

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data: **70000 72000 68000 64000 71000 68000 64000 57000**

Mean **70000 72000 68000 64000 71000 68000 64000 57000**

Sigma

COV (%)

CF

NR **1.000 1.029 0.971 0.914 1.000 0.958 0.901 0.803**

Summary:	T (C)	NR
	30	1.029
	40	0.971
	50	0.914
	10	0.958
	0	0.901
	-10	0.803

Comments: **Vented detector**

Instrument Type:	Alpha contamination	Environmental Test:	Humidity
Make:	Ludlum	Temperature (C):	20
Model:	139	Pressure (in Hg):	23.00
Detector:	air-proportional alpha	Source:	Pu-239
HS Number:	007637	Source Number:	92-4651
Units:	cpm	Test By:	R. Clement
Range Tested:	X100	Test Date:	10/31/93

Tests: 1) 40% RH for 4 h, 2) 95% RH for 9 h, then 3) 40% RH for 5 h @ 20 C.

RH (%)	40	95	95	95	95	95	40
t (h)	3:59	4:59	6:59	8:59	10:59	12:59	17:59

Data:	69000	>100000	60000	61000	58000	59000	71000
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Mean	69000	>100000	60000	61000	58000	59000	71000
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Sigma

COV (%)

CF

NR	1.000	1.449	0.870	0.884	0.841	0.855	1.029
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Summary:	RH (%)	NR
	95	1.449
	95	0.870
	95	0.884
	95	0.841
	95	0.855
	40	1.029

Comments: **Vented detector. Instrument response pegged full scale during test @ 95% RH. Full scale value used to calculate normalized response.**

Instrument Type:	Alpha contamination	Environmental Test:	Temperature
Make:	Ludlum	Temperature (C):	see below
Model:	139	Pressure (in Hg):	22.82
Detector:	air-proportional alpha	Source:	Pu-239
HS Number:	008331	Source Number:	92-4633
Units:	cpm	Test By:	R. Clement
Range Tested:	X100	Test Date:	11/01/93

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data:	65000	65000	62000	54000	68000	61000	57000	50000
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Mean	65000	65000	62000	54000	68000	61000	57000	50000
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Sigma

COV (%)

CF

NR	1.000	1.000	0.954	0.831	1.000	0.897	0.838	0.735
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Summary:	T (C)	NR
	30	1.000
	40	0.954
	50	0.831
	10	0.897
	0	0.838
	-10	0.735

Comments: **Vented detector**

Instrument Type:	Alpha contamination	Environmental Test:	Humidity
Make:	Ludlum	Temperature (C):	20
Model:	139	Pressure (in Hg):	22.78
Detector:	air-proportional alpha	Source:	Pu-239
HS Number:	008331	Source Number:	92-4633
Units:	cpm	Test By:	R. Clement
Range Tested:	X100	Test Date:	11/01/93

Tests: 1) 40% RH for 4 h, 2) 95% RH for 9 h, then 3) 40% RH for 5 h @ 20 C.

RH (%)	40	95	95	95	95	95	40
t (h)	3:59	4:59	6:59	8:59	10:59	12:59	17:59

Data: **63000 53000 51000 51000 52000 51000 61000**

Mean **63000 53000 51000 51000 52000 51000 61000**

Sigma

COV (%)

CF

NR **1.000 0.841 0.810 0.810 0.825 0.810 0.968**

Summary:	RH (%)	NR
	95	0.841
	95	0.810
	95	0.810
	95	0.825
	95	0.810
	40	0.968

Comments: **Vented detector**

Instrument Type:	Tritium-in-air	Environmental Test:	Temperature
Make:	Overhoff	Temperature (C):	see below
Model:	394-C	Pressure (in Hg):	23.06
Detector:	Ion chamber	Source:	Cs-137
HS Number:	004748	Source Number:	V-069
Units:	uCi/m3	Test By:	R. Clement
Range Tested:	X10K	Test Date:	10/06/93

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data:	5100	5000	4900	4700	5200	5300	5400	5500
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Mean	5100	5000	4900	4700	5200	5300	5400	5500
Sigma								
COV (%)								
CF	1.000	1.034	1.068	1.102	1.000	0.966	0.932	0.898
NR	1.000	1.014	1.026	1.016	1.000	0.984	0.968	0.949

Summary:	T (C)	NR
	30	1.014
	40	1.026
	50	1.016
	10	0.984
	0	0.968
	-10	0.949

Comments: **Vented detector. Test on AC power and pump on.**

Instrument Type:	Tritium-In-air	Environmental Test:	Humidity
Make:	Overhoff	Temperature (C):	20
Model:	394-C	Pressure (in Hg):	22.87
Detector:	Ion chamber	Source:	Cs-137
HS Number:	004748	Source Number:	V-069
Units:	uCi/m3	Test By:	R. Clement
Range Tested:	X10K	Test Date:	10/07/93

Tests: 1) 40% RH for 4 h, 2) 95% RH for 9 h, then 3) 40% RH for 5 h @ 20 C.

RH (%)	40	95	95	95	95	95	40
t (h)	3:59	4:59	6:59	8:59	10:59	12:59	17:59

Data:	4800	4800	4800	4800	4800	4800	4800
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Mean	4800	4800	4800	4800	4800	4800	4800
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Sigma

COV (%)

CF	1.000	1.000	1.000	1.000	1.000	1.000	1.000
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NR	1.000	1.000	1.000	1.000	1.000	1.000	1.000
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Summary:	RH (%)	NR
	95	1.000
	95	1.000
	95	1.000
	95	1.000
	95	1.000
	40	1.000

Comments: Vented detector. Test on AC power and pump on.

Instrument Type:	Tritium-In-air	Environmental Test:	Temperature
Make:	Johnston	Temperature (C):	see below
Model:	J-110	Pressure (in Hg):	23.04
Detector:	Ion chamber	Source:	Cs-137
HS Number:	005163	Source Number:	V-069
Units:	uCi/m3	Test By:	R. Clement
Range Tested:	X1000 (log)	Test Date:	10/11/93

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data:	3000	3000	3000	2900	2700	2700	2700	2700
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Mean	3000	3000	3000	2900	2700	2700	2700	2700
Sigma								
COV (%)								
CF	1.000	1.000	1.000	1.102	1.000	1.000	1.000	1.000
NR	1.000	1.000	1.000	1.066	1.000	1.000	1.000	1.000

Summary:	T (C)	NR
	30	1.000
	40	1.000
	50	1.066
	10	1.000
	0	1.000
	-10	1.000

Comments: Vented detector. Test on AC power and pump on. No change in Instrument response from reference temperature at 30 C, 40 C, 10 C, 0 C, and -10 C (CF = 1.000).

Instrument Type:	Tritium-In-air	Environmental Test:	Temp, Rep 2
Make:	Johnston	Temperature (C):	see below
Model:	J-110	Pressure (in Hg):	22.98
Detector:	Ion chamber	Source:	Cs-137
HS Number:	005163	Source Number:	V-069
Units:	uCi/m3	Test By:	R. Clement
Range Tested:	X1000 (log)	Test Date:	10/11/93

Tests: 1) 20 C to 50 C @ 10 C/h, then 2) 20 C to -10 C @ -10 C/h.

T (C)	20	30	40	50	20	10	0	-10
t (h)	0:59	1:59	2:59	3:59	5:59	6:59	7:59	8:59

Data:	3000	3000	3000	2700	2700	2700	2700	2700
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Mean	3000	3000	3000	2700	2700	2700	2700	2700
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Sigma

COV (%)

CF	1.000	1.000	1.000	1.102	1.000	1.000	1.000	1.000
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NR	1.000	1.000	1.000	0.992	1.000	1.000	1.000	1.000
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Summary:	T (C)	NR
	30	1.000
	40	1.000
	50	0.992
	10	1.000
	0	1.000
	-10	1.000

Comments: **Vented detector. Test on AC power and pump on. No change in instrument response from reference temperature at 30 C, 40 C, 10 C, 0 C, and -10 C (CF = 1.000).**

Instrument Type: **Tritium-In-air**
 Make: **Johnston**
 Model: **J-110**
 Detector: **Ion chamber**
 HS Number: **005163**
 Units: **uCi/m3**
 Range Tested: **X1000 (log)**

Environmental Test: **Humidity**
 Temperature (C): **20**
 Pressure (in Hg): **23.00**
 Source: **Cs-137**
 Source Number: **V-069**
 Test By: **R. Clement**
 Test Date: **10/13/93**

Tests: 1) 40% RH for 4 h, 2) 95% RH for 9 h, then 3) 40% RH for 5 h @ 20 C.

RH (%)	40	95	95	95	95	95	40
t (h)	3:59	4:59	6:59	8:59	10:59	12:59	17:59

Data:	2700	2700	2700	2700	2700	2700	2700
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Mean	2700	2700	2700	2700	2700	2700	2700
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Sigma
COV (%)

CF	1.000	1.000	1.000	1.000	1.000	1.000	1.000
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NR	1.000	1.000	1.000	1.000	1.000	1.000	1.000
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Summary:	RH (%)	NR
	95	1.000
	95	1.000
	95	1.000
	95	1.000
	95	1.000
	40	1.000

Comments: **Vented detector. Test on AC power and pump on.**