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Technological Considerations in Emergency Instrumentation Preparedness

Phase II-D - Evaluation Testing and
Calibration Methodology for Emergency
Radiological Instrumentation

September 1976

Prepared for the Energy Research
and Development Administration
under Contract E(45-1)-1830

Battelle
Pacific Northwest Laboratories

MASTER

BNWL-1991

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PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Under Contract E(45-1)-1830

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy \$9.00; Microfiche \$2.25

TECHNOLOGICAL CONSIDERATIONS IN
EMERGENCY INSTRUMENTATION PREPAREDNESS

Phase II-D - Evaluation Testing and
Calibration Methodology for Emergency
Radiological Instrumentation

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September 1976

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FOREWORD

The Energy Research and Development Administration, through its Division of Operational Safety, has contracted with Battelle, Pacific Northwest Laboratories, to conduct a study and develop technical criteria for determining the adequacy of instrumentation for use in radiological emergencies, abnormal occurrences and accidents. The program is responsive to the recommendations of the Advisory Committee on Reactor Safeguards regarding accidents involving the release of radioactivity. The work has been progressing in close collaboration with the Nuclear Regulatory Commission. A technical steering committee was established comprising representation from the Operational Safety Division, The Reactor Research and Development Division, The Nuclear Regulatory Commission, ERDA-RL, Environmental and Laboratory Programs Division, and the Environmental Protection Agency. This committee provides surveillance and technical direction and assures that the overall needs of the program and associated objectives are met. As a first step, the current practices at a number of ERDA and licensed facilities were reviewed. Results of the review were approved and reported in BNWL-1552, "Technological Considerations in Emergency Instrument Preparedness, Phase I - Current Capabilities Survey". A summary of emergency instrumentation criteria for reactors was presented in the Phase II-A report, BNWL-1635. BNWL-1742 provided a summary of emergency instrumentation criteria for mixed oxide fuel fabrication facilities and BNWL-1857 reviewed emergency instrumentation criteria for fuel reprocessing facilities to conclude the II-B and II-C portions of the Phase II study. This report, BNWL-1991 provides methodology for calibration and for testing conformance with the criteria established in Phases II-A, B, and C.

E. J. Vallario, Chairman
ERDA Headquarters
Battelle-Northwest Project
Steering Committee

M. B. Biles, Director
Division of Operational Safety

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TECHNOLOGICAL CONSIDERATIONS
IN EMERGENCY INSTRUMENTATION PREPAREDNESS

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I. INTRODUCTION

In response to recommendations from the Advisory Committee on Reactor Safeguards, the Division of Operational Safety, U.S. ERDA, has contracted with Battelle, Pacific Northwest Laboratories, to survey the adequacy of existing instrumentation at nuclear fuel cycle facilities to meet emergency requirements, and to develop technical criteria for instrumentation systems to be used in assessment of environmental conditions following plant emergencies.

This report, the fifth in a series, provides: 1) calibration methods to assure the quality of radiological measurements and 2) testing procedures for determining whether an emergency radiological instrument meets the performance specifications. Three previous reports in this series identified the emergency instrumentation needs for power reactors,⁽¹⁾ mixed oxide fuel plants,⁽²⁾ and fuel reprocessing facilities.⁽³⁾ Each of these three reports contains a Section VI, which sets forth applicable radiological instrument performance criteria and calibration requirements. Testing and calibration procedures in this report have been formatted in two parts: IV and V, each divided into three subsections: 1) Power Reactors, 2) Mixed Oxide Fuel Plants, and 3) Fuel Reprocessing Facilities. The three performance criteria subsections directly coincide with the performance criteria sections of the previous reports. These performance criteria sections have been reproduced in this report as Part III with references of "required action" added.

II. SCOPE AND OBJECTIVES

Various investigations and studies have shown that emergency radiological instrumentation should be capable of functioning under the most stressful conditions of environmental extremes and high dose rates. Reliability needs to be assured even following long periods of storage, exposure to very high radiation fields, radiofrequency fields, temperature and humidity extremes, rough handling and other factors outlined in previous reports. Although radiological emergency preparedness programs of ERDA contractors depend upon a high degree of reliability, it is known that some instruments now in use show evidence of deficiencies. The ability of other emergency instrumentation and instrument systems to meet even minimum performance criteria is unknown, having never been examined or fully evaluated even for the most commonly used portable instruments.

Not only is reliability important, but also the accuracy of emergency instrumentation is critical since radiological accidents or emergency situations can produce exposure levels sufficiently high as to be dangerous to health or even fatal. If routine dosimetry devices were in error by 50% the exposure record would be affected but probably no serious health consequences would result. On the other hand, a 50% error at the 200 rem level incurred during rescue operations or during the evaluation of a high level release can lead to serious "action-decision" errors.

While the accuracies and reliabilities specified in the referenced criteria were developed for Regulatory functions they are in general expected to be applicable and adaptable for contractor needs. In addition to the establishment of reliability and accuracy, techniques will be specified or developed for calibrations, particularly for the high ranges that preclude the use of normal procedures. Initially, these calibration methods, some of which employ analog techniques, will be responsive to the general and any unique requirements of the ERDA contractors. The objectives are to standardize the techniques, make them safe for high range application, practical for measurements of activities released to the environment and adaptable for application by users and manufacturers.

III. EMERGENCY INSTRUMENTATION PERFORMANCE CRITERIA

Several types of emergency instruments or instrumentation systems should be provided to characterize the severity and extent of a radiation accident and to aid in the protection of operating personnel and inhabitants of the local environs. The instruments should be capable of characterizing the release to the containment vessel or buildings and the radiological problem associated with re-entry. Instrumentation also should be available to estimate the amount of radioactive material released to the environs either via normal effluent channels or unanticipated breach of the containment. Meteorological instrumentation should provide necessary data to determine the direction the cloud will follow as well as the necessary parameters to permit rapid calculation of the consequences within a 10 mile radius of the plant using a diffusion model appropriate to the site. Additionally, instrumentation may be needed to aid in early direct assessment of the environmental consequences in the same area. Finally, survey instrumentation is necessary to supplement fixed instrument systems, to make radiological measurements at locations not covered by fixed instrumentation, and to aid in protection of operating personnel during their efforts to stabilize the emergency.

In this section primarily performance criteria are presented. Specific instrument systems, components or individual instruments which should meet these criteria are discussed in References 1-3. Throughout these criteria four verbs are used to indicate the degree of rigor intended by the specific criterion. "Shall" and "Will" indicate that strict application of the criterion is possible and is considered necessary to assure the instrumentation or systems will perform as needed during an emergency. "Should" or "Would" indicate that the application of the criterion is desirable.

The column "Required Action" suggests or references the appropriate level of testing or calibration effort. The phrase "Inspection/Engineering Review" indicates that the performance criterion is subjective. A professional engineer or technician should decide whether or not the criterion is met. Where a test or calibration procedure is referenced, that test or an equivalent one must be performed to demonstrate that the instrument meets the criteria.

III.1 EMERGENCY INSTRUMENTATION CRITERIA FOR POWER REACTORS⁽¹⁾

A number of radiation measurements may be necessary in a reactor radiological emergency:

- Direct measurement of the airborne radioactive material in the containment vessel to evaluate the nature and amount of airborne material potentially available for leakage to the environs.
- Ambient dose rates in the containment vessel and building.
- Radioactive material released to the environs via the building ventilation or liquid effluent systems.
- Radiological measurements in the environs.
- Ambient radiation and contamination surveys.

III.1.1 RADIOLOGICAL INSTRUMENTATION SYSTEMS

III.1.1.1 General Criteria for Installed Radiological Systems

	<u>Required Action</u>
• The system shall have an internal electronic calibration check, which shall check operation of all circuitry other than the detector.	Inspection/
Engineering
Review
• The system shall be fail-safe; in the event of a malfunction or failure, an internal audit circuit shall be activated and transmit an appropriate signal to a central manned location.	Test:
V.2.12.1
• The system shall be capable of operation on 117 V 60 Hz AC, and shall be unaffected by voltage or frequency changes of $\pm 20\%$. Emergency power capability shall be included in the design and installation, and shall be automatically implemented when required, with no more than a six second delay.	Test:
V.3.6.2
Inspection/
Engineering
Review
• When responding to levels in excess of the maximum specified range, the instrument should not paralyze and the readout signal shall remain full upscale.	Test:
V.4.10
• Switches and other controls shall be protected to prevent inadvertent deactivation or operation of system.	Inspection/
Engineering
Review

Criteria

Required Action

- Overall system accuracy shall be $\pm 40\%$ at the 95% confidence level over the entire operating range, with precision $\pm 10\%$ for any single measurement level. Test: V.4.5, V.4.6
- Overall system response time from 0 to 90% of full reading shall be ≤ 2 seconds. Test: V.4.9
- There shall be no deleterious effect to the system from:
 - 1) radiofrequency, V.3.7.8
 - 2) microwave exposure to 10 mW/cm^2 , V.3.7.9
 - 3) photon exposure to $5 \times 10^5 \text{ R}$, referenced to the energy range between 0.8 - 1.2 MeV, V.4.14.3
 - 4) electrostatic charges with potentials to 10,000 volts. V.3.7.1
- The operating temperature range of the system shall encompass the extremes anticipated. Where the instrumentation may be exposed directly to ambient outside temperatures, the 50 year extremes shall be applied. Test: V.2.7
- For the operating temperature range the temperature coefficient shall be $\leq 0.5\%$ per $^{\circ}\text{C}$ and it should be $\pm 15\%$ over the entire range. Test: V.2.7.7
- The instrument system shall be unaffected by relative humidities from 5% to 95% over the designated temperature range. Test: V.2.8
- The system shall be able to withstand mechanical stress equivalent to a peak overpressure of 15 psi. If located within the containment facility, the system shall be able to withstand mechanical stress equivalent to a peak overpressure of 50 psi. Test: V.2.11.1

Criteria

Required Action

• Logarithmic or digital readout should be employed. If multiple ranges are used, automatic range changing shall be provided. Manual adjustment of range shall be unnecessary.	Inspection/
Engineering
Review
• Readout capability shall be provided in the control room and at least two other physically separate locations, one of which shall be the emergency operations center, and the other at or near the detector.	Inspection/
Engineering
Review
• All units of similar function, including detectors, electronic modules, readout and display devices and power supplies, shall be wholly interchangeable within type.	Inspection/
Engineering
Review
• Except as noted, the electronics shall meet the specifications for and be compatible with the AEC standard nuclear instrument modules,⁽⁴⁾ thus ensuring a basic standard, ease of maintenance, and providing interchangeability and compatibility.	Inspection/
Engineering
Review
• Electronic and other supporting components should reflect the latest technology with solid state (i.e., transistorized) circuitry incorporated throughout, as practicable. The use of integrated circuits should be considered.	Inspection/
Engineering
Review
• All modules shall be accessible for test without removal from the circuit. Plug-in type units should be considered.	Inspection/
Engineering
Review
• The instrument system shall be equipped with an alarm capable of being externally set to alarm at any point over the stated range. The alarm should be both audible and visible, and should be capable of reset without removing the instrument from service.	Test:
V.4.1.2

III.1.1.2 General Criteria for Gaseous and Particulate Sampling

	<u>Required Action</u>
• The system shall be designed to remove on a continuous basis, a representative sample. ⁽⁵⁾	Inspection/ Engineering Review
• The location for sampling should be close to the point of release.	Inspection/ Engineering Review
• Particulate-generating gas phase reactions, corrosion, or release of contaminants, should be absent downstream of the sampling point.	Inspection/ Engineering Review
• When sampling a stack, the sampling point shall be no less than five duct diameters and preferably should be at least 10 duct diameters downstream from any injection point or point of turbulence or transition. A multi-entry probe shall be used for sampling in the duct or stack. ⁽⁵⁾	Inspection/ Engineering Review
• Sampling conditions should approach isokinetic. The inlet velocity to duct velocity should be 1.0 ± 0.2 .	Test: V.2.12.3
• Sampling lines shall be kept short. The distance from sample point to collector should be less than 10 feet. Sample line bend radii shall exceed five sampling line diameters.	Inspection/ Engineering Review
• The sample delivery system shall be corrosion resistant and designed for streamline flow with no right angles or sharp bends. ⁽⁵⁾ Stainless steel should be used for construction and plate out of radioactive material should be less than 5%.	Inspection/ Engineering Review
• A constant sample flow rate shall be used and a constant displacement pump should be used as the air mover. An appropriately calibrated airflow meter shall continuously verify flow rate, and shall be accurate to within $\pm 20\%$.	Test: V.2.12.5

Criteria

Required Action

- Particulate radioactive material shall be removed by membrane filters with pore size $\leq 5 \mu\text{m}$, having an efficiency of $\geq 99.5\%$ for particles with diameters $\geq 0.3 \mu\text{m}$.⁽⁶⁾
Inspection/
Engineering
Review
Test:
V.2.12.2
- Charcoal impregnated with potassium iodide shall be used to sample airborne radioiodines. A minimum of 99.5% removal shall be required with a minimum 24 hour retention at the maximum concentrations expected. The charcoal medium should follow the particulate filter in the same sample stream.⁽⁸⁾
Inspection/
Engineering
Review

III.1.1.3 Specific Criteria for Radiological Instrumentation Systems

III.1.1.3.1 Criteria for Plume Detection Instrumentation

The criteria listed below are in addition to those presented in Section III.1.1.1.

- The detector system shall consist of six NaI(Tl) crystals placed in circular array at ground level 60° of arc apart 100 meters from the reactor.
Inspection/
Engineering
Review
- The detectors should be hermetically sealed NaI(Tl) crystals, typically 3" x 3". The photomultiplier tubes shall be an integral part of detector assembly.
Inspection/
Engineering
Review
- The photomultiplier tube shall be shielded from rf and magnetic fields.
Test:
V.3.5,
V.3.7
- The detection range for fission gases shall be 10^{-2} to 10^3 Ci per meter of plume length, based on detection of photons above 2.0 MeV.
Test:
V.4.1.2
- The detector resolution shall be $\leq 10\%$ FWHM at 2.5 MeV.
Test:
V.4.13
- The coincidence sum peak from ^{60}Co shall be used to calibrate the system. Each detector shall be checked quarterly with a source, and calibration or maintenance shall be performed when indicated.
Calibration:
IV.2.1.1

III.1.1.3.2 Criteria for Containment Vessel
Noble Gas Monitor

Required
Action

The criteria listed below are in addition to those presented in Section III.1.1.1

- The detector shall be a hermetically sealed NaI(Tl) crystal. The photomultiplier tube shall be an integral part of detector assembly. Inspection/Engineering Review
- The photomultiplier tube shall be shielded from rf and magnetic fields. Test:
V.3.5
V.3.7
- The detection range for noble gases shall be 10^{-9} to 10^{-2} Ci/cm³ assuming detector immersion in a semi-infinite sphere and based upon detection of photons above 2.0 MeV. Test:
V.4.1.3
- Detector resolution shall be $\leq 10\%$ FWHM at 2.5 MeV. Test:
V.4.13
- The coincidence sum peak from ⁶⁰Co shall be used to calibrate the system. The system shall be checked quarterly with a source, and calibration or maintenance shall be performed when indicated. Calibration:
IV.2.1.2

III.1.1.3.3 Criteria for Containment Vessel Radioiodine and
Particulate Monitor

The criteria listed below are in addition to those presented in Sections III.1.1.1 and III.1.1.2

- Detection of particulate radioactivity should be on the basis of beta counting and iodine radioactivity should be on the basis of gamma counting. Inspection/Engineering Review
- For particulate radioactivity the detection range shall be 10^{-10} to 10^{-3} Ci/cm³ referenced to betas from ⁹⁰Sr-Y. Test:
V.4.1.4
- For radioiodine, the detection capability shall be 10^{-10} to 10^{-3} Ci/cm³ referenced to gammas from ¹³¹I. Test:
V.4.1.5
- The entire system operation shall be checked at least quarterly and calibrated and maintained when indicated. Calibration:
IV.2.1.3

III.1.1.3.4 Criteria for Stack Effluent Monitor

Required Action

The criteria listed below are in addition to those presented in Section III.1.1.1 and III.1.1.2

- The detection capability for particulate radioactivity shall have a minimum range of 10^{-10} to 10^{-3} Ci/cm³ referenced to ⁹⁰Sr-Y, and based on gross beta detection. This range shall overlap the range of stack monitoring instrumentation used for routine or nonemergency monitoring. Inspection/Engineering Review
Test: V.4.1.4
- For radioiodines, the detection capability shall be 10^{-10} to 10^{-3} Ci/cm³ referenced to ¹³¹I, and based on detection of the gamma energy of interest. This range shall overlap the range of nonemergency instrumentation used for monitoring radioiodine in stack releases. Inspection/Engineering Review
Test: V.4.1.5
- For the gaseous fraction, detection capability shall be 10^{-9} to 10^{-2} Ci/cm³. A flow-through ion chamber for gross beta radioactivity should be used for the detector system. Test: V.4.1.17
- The detectors shall be suitably shielded from external radiation from the reactor operation or a release into the containment vessel. If a flow-through ionization chamber is used for detecting gaseous radioactive material, approximately 15 cm (6 inches) of lead should be used if the detector is within the containment vessel. For beta detectors, electronic discrimination should be used, but if this is not feasible, shielding may be used. Inspection/Engineering Review
Test: V.4.15.3
- The entire system operation shall be checked at least quarterly and calibrated and maintained when indicated. Calibration: IV.2.1.4

III.1.1.3.5 Criteria for Environmental Air Monitor

The criteria listed below are in addition to those general criteria presented in Sections III.1.1.1 and III.1.1.2

- The system shall be designed to take on a continuous basis a representative sample of the ambient air. The preferred Inspection/Engineering Review

Criteria

Required Action

sampling location is at one meter above ground level, in a location free from unusual micrometeorological or other conditions (e.g., proximity of large buildings, vehicular traffic) which could result in artificially high or low air concentrations.⁽⁵⁾

- Direct sampling with no lines upstream of the sample medium is greatly preferred. Inspection/
Engineering
Review
- The sample collector shall be easily readable in place with portable monitoring instruments and removable for subsequent laboratory analysis. Inspection/
Engineering
Review
- The measurement capability for particulate activity shall have a minimum range of 10^{-6} to 10^{-1} Ci/cm³ gross beta referenced to ⁹⁰Sr-Y. This range shall overlap the range of instrumentation used for routine or nonemergency monitoring. Test:
V.4.1.4
- For radioiodines, the measurement capability shall be 10^{-7} to 10^{-2} Ci/cm³ referenced to ¹³¹I. This range shall overlap the range of routine or nonemergency instrumentation used for monitoring radioiodine in the environs. Test:
V.4.1.5
- The instrument system shall be protected from the external environment, and shall be housed in a locked facility to afford a measure of security from accidental or willful damage or tampering. Test:
V.2.6
V.2.9
- The entire system operation shall be checked at least quarterly and calibrated and maintained when indicated. Calibration:
IV.2.1.5

III.1.1.3.6 Criteria for Liquid Effluent Monitor

The criteria listed below are in addition to those general criteria presented in Section III.1.1.1

- | | <u>Required
Action</u> |
|---|--------------------------------------|
| • The detector system should consist of a small (typically a 0.5 x 0.5 in. right cylindrical) NaI(Tl) crystal. | Inspection/
Engineering
Review |
| • The detector and photomultiplier shall be optically coupled and hermetically sealed into an integral container. | Inspection/
Engineering
Review |
| • The minimum thickness of the material around the detector shall be at least 400 mg/cm ² ; preferred thickness is 1000 mg/cm ² . | Inspection/
Engineering
Review |
| • The detector resolution shall be $\pm 12\%$ FWHM or better for the 1.17 MeV photon peak associated with ⁶⁰ Co decay | Test:
V.4.13 |
| • The photomultiplier tube shall be provided with mu metal or other shielding to obviate the effects of magnetic fields. | Test:
V.3.7 |
| • The detector shall be capable of operating completely submerged. | Test:
V.2.9 |
| • The system shall be capable of detecting gross radioactivity in aqueous liquids over the range 10 ⁻⁹ to 10 ⁻⁴ Ci/cm ³ , referenced to photons with energies greater than 0.6 MeV, and assuming 0.5 photons per disintegration. | Test:
V.4.1.7 |
| • If the system is used to monitor a liquid stream, a flow meter, accurate to within $\pm 20\%$, shall be provided. This flow meter should also have remote readout capability; integrating capability should be considered. | Inspection/
Engineering
Review |
| • If the system is used to monitor a static or nearly static volume of liquid, provision shall be made to accurately monitor liquid volume, or alternatively, liquid level. | Inspection/
Engineering
Review |
| • The photon peak at 1.17 MeV from ⁶⁰ Co shall be used to ∞ calibrate the system. The system shall be checked quarterly with a source and calibration and maintenance performed when indicated. | Calibration:
IV.2.1.6 |

III.1.1.3.7 Criteria for Ambient Radiation Monitoring Instrumentation

Required Action

The criteria listed below are in addition to those presented in Section III.1.1.1

- The system shall be capable of detecting separately dose contribution from beta and low energy photon radiation, and the high energy photon radiation. Test: V.4.15.4
- Photon energy dependence shall be $\pm 20\%$ over the range 30 keV to 3 MeV. Test: V.4.7
- Beta energy dependence shall be $\pm 30\%$ over the range 0.1 to 3 MeV. Test: V.4.7
- The system shall have an internal electronic calibration check and an internal radioactive check source for the detector. These shall be capable of remote operation, i.e., the check shall be capable of being made from the Emergency Control Center. Calibration and operating checks shall be made monthly and recalibration and repair accomplished when indicated. If integrating capability is provided, this feature shall be reset at the time of calibration check. Inspection/Engineering Review Calibration: IV.2.1.7
- Detector placement shall be such that a representative measurement of the ambient field is obtained. The detector shall therefore be protected from fallout accumulations, shadow shielding, and similar effects. The recommended detector height is one meter above ground level in the environs. Inspection/Engineering Review
- If the ambient radiation monitor is to be used in the containment vessel the following shall apply:
 - 1) The detection range for photons shall be 1 to 10^6 R/hr. Test: V.4.1.1
 - 2) The detection range for beta radiation shall be 10 to 10^6 rad/hr. Test: V.4.1.1

Criteria

Required Action

- 3) Extracameral response shall be undetectable in photon fields to 10^6 R/hr referenced to 1 MeV energy, beta fields providing an air dose rate of 10^6 rad/hr referenced to 2 MeV, either singly or concomitantly. Test: V.4.11
- If the ambient radiation monitor is to be used in the reactor building or environs the following shall apply:
 - 1) The instrument system shall have a measurement range for photons of 10^{-3} to 10^4 R/hr. If an integration mode is provided, its operation should be simultaneous with the rate mode and its range should be 10^{-2} to 10^4 R. Test: V.4.1
 - 2) The measurement range for beta radiation shall be 10^{-2} to 10^4 rad/hr. If a simultaneous integration mode is provided, its range should be 10^{-2} to 10^4 rad. Test: V.4.1
 - 3) Extracameral response shall be absent in photon fields to 10^4 R/hr referenced to 1 MeV energy, and beta fields providing an air dose rate of 10^4 rad/hr referenced to 2 MeV E_β maximum either singly or concurrently. Test: V.4.11

III.1.2 CRITERIA FOR AMBIENT RADIATION AND CONTAMINATION SURVEY INSTRUMENTS

III.1.2.1 Dose Rate and Contamination Survey Instruments

- The system shall be capable of detecting beta and photon radiation, and separating the contribution from each. To accomplish this, a detector system which can be operated bare or which can be shielded with 1 gm/cm^2 of polyethylene or similar low Z plastic, should be used. Inspection/Engineering Review
 - The detection ranges shall be as shown:
 - Photon Exposure Rate: 0.1 mR/hr to 10^4 R/hr Test: V.4.1.1
 - Beta Dose Rate: 0.1 mrad/hr to 10^4 rad/hr . Test: V.4.1.1
- In recognition of the difficulties in design and construction of a single detector and/or instrument with such a breadth or range, two detectors or instruments are permissible, assuming

Criteria

Required Action

that all the other criteria specified in this section are met, and that a one decade overlap is provided.

- Photon energy dependence shall be $\pm 15\%$ over the range 30 keV to 3 MeV. Test: V.4.7
- Detection capability shall be provided for beta particles with energies greater than 100 keV. The beta energy dependence shall be $\pm 30\%$ over the range 0.1 to 3 MeV. Test: V.4.7
- Detectors and associated electronic circuitry, readout and display devices, and power supplies shall be wholly interchangeable. Inspection/Engineering Review
- Overall system accuracy shall be $\pm 40\%$ at the 95% confidence level for any level over the entire operating range, with precision of $\pm 10\%$ for any single measurement level. Test: V.4.5
- Overall system response (0 to 90% of full reading) time shall be ≤ 2 seconds after a warm-up time of one minute. This does not preclude the inclusion of variable response time capability. When the radiation field is removed, the instrument shall indicate within 2 seconds not more than 10% of the total reading in the field. Test: V.4.9
- Minimum battery lifetime shall be 200 hours of continuous duty operation at an exposure level of 10% the maximum full scale reading, at temperatures above 0°C . At temperatures below 0°C , alkaline batteries shall be used and the minimum battery lifetime shall be 100 hours of continuous operation. Test: V.3.8
- Geotropism, or change in reading with special orientation, shall be $\leq 2\%$ of full scale reading. Test: V.2.1
- Response to noise and vibration shall be undetectable at sound pressure levels ≤ 100 db, and vibration frequencies of 10 to 100 Hz, with a total excursion of 0.5 mm. Test: V.2.3
V.2.4

Criteria

Required Action

- Sensitivity shall be $\leq 5\%$ of mid-scale or decade, where sensitivity is defined as the minimum detectable change in response. Test:
V.4.3
- Angular dependence shall be $\leq 15\%$ in a 2π steradian frontal direction, referenced to photons with energies in the region 1 ± 0.2 MeV. Test:
V.4.8
- The instrument shall be equipped with a battery check switch and indicator of battery condition. Low or dead battery indication shall be positive - i.e., the instrument shall read upscale, and zeroing shall be rendered impossible. Inspection/
Engineering
Review
Test:
V.3.8.5
- Readout shall be direct and in units of dose or exposure per hour. However, high range instruments intended exclusively for rescue work may be calibrated in units of R/min or rad/min, and if so, the instrument and readout should be clearly and distinctively marked. The readout shall be such that multipliers (e.g., X10, X100) shall be included. Inspection/
Engineering
Review
- The readout shall be lighted to permit use in darkness; self-illumination should be considered. Inspection/
Engineering
Review
- The instruments, whether used routinely or not, shall be checked for operation on a quarterly basis, and recalibrated and repaired as indicated. In no case shall more than 18 months elapse between calibrations. Calibration:
IV.2.1.8
IV.2.1.9
- Overall instrument response shall not change by more than $\pm 10\%$ from the previous calibration when batteries are changed. Test:
V.3.8.3
V.3.8.4
- A 10 mV or mA recorder output shall be provided for instruments which are to be used with a recorder. Inspection/
Engineering
Review

Criteria

Required Action

- The total weight of the fully assembled survey meter, including batteries, should not exceed 3 kg (6.6 lbs). Inspection/Engineering Review
- If the survey instrument is to be operated while carried (portable) the following shall apply:
 - 1) The instrument is capable of and designed for, convenient transportability by a single person. This criterion does not preclude the use of back packs, neck or shoulder straps, belts, or other means of attachment to the body. Inspection/Engineering Review
 - 2) The weight of the total instrument, including power source, does not exceed 22.5 kg (50 lbs). Inspection Engineering Review
- If the survey instrument is to be operated while mounted in an airplane, motor vehicle or boat (mobile) the following shall apply:
 - 1) Any of the instrumentation that may be used in an airplane shall be designed to operate properly at an altitude of 5000 feet over the surrounding terrain. Test: V.2.2
 - 2) Mobile instrumentation shall be designed to provide a readout using a strip chart recorder. Inspection/Engineering Review
 - 3) Each separate portion of the mobile instrument system shall weigh less than 50 pounds. Inspection Engineering Review
- If an integrating capability is provided the following shall apply:
 - 1) Portable radiological instruments with integrating capability should have integrating ranges as shown:
 - Photon Exposure 0.1 to 10^3 R Test: V.4.1.15
 - Beta Dose 0.1 to 10^3 rad Test: V.4.1.15

Criteria

Required Action

- 2) Integrating units shall be equipped with an audible alarm having a continuous or intermittent warbling tone with a frequency in the region 2 to 7 kHz and a sound level of 85 dbA at a distance of 50 cm from the instrument.
- 3) The alarm shall be presettable to any level by an external switch. External reset capability shall also be provided.
- 4) An alarm test position or switch shall be provided.

Test:
V.2.10

Test:
V.4.1.2

Inspection/
Engineering
Review

III.1.2.2 Portable Air Samplers

- The sampler shall be designed for use with the portable survey meter described in III.1.2.1
- To simplify calibration, operation, and interpretation, a fixed sampling rate of 10-30 liters per minute should be used. Sampling rate shall remain constant to within $\pm 25\%$ during normal operation.
- The unit shall be compatible with standard glass fiber, cellulose fiber, and charcoal loaded filters commonly used for air sampling. The size of the filter used is dependent upon the size of the detector, but a 47 mm diameter should be considered. Filter diameter should not exceed 100 mm.
- The filter material used shall have an efficiency of 99.5% for particles 0.3 μm in diameter.
- Power should be provided by wet cells, and these shall conform to the specifications put forth by the National Bureau of Standards.⁽⁷⁴⁾

Inspection
Engineering
Review

Test:
V.2.12.6
Calibration:
IV.2.1.3(c)

Inspection/
Engineering
Review

Test:
V.2.12.2

Inspection/
Engineering
Review

Criteria

Required Action

- Battery lifetime shall be greater than eight hours under load. Test:
V.3.8
- The sampling unit shall be provided with a battery test or other indicator of battery condition. Inspection/
Engineering
Review
- Air flow shall be continuously indicated by an appropriate clearly marked gage having an accuracy of $\pm 20\%$. Test:
V.2.12.5

III.1.2 Direct Reading Dosimeters

- The pocket ion chamber shall have a range of 0 to 200 R if it is to be used for personnel involved in rescue work in which exposures to 100 R may be incurred.⁽⁸⁾ If used for other purposes, such as protection of property, the range shall be appropriate to the maximum permitted exposure. The maximum permitted exposure shall be in the range of 40 to 70% of full scale of the pocket ionization chamber used. Test:
V.4.1.16
- The instrument shall be provided with an optical system to permit direct readout. Major scale divisions shall be indicated by heavy lines at 0, 50, and 100% of scale; the scale should be further subdivided into tenths and twentieths by progressively shorter and/or less bold lines. Inspection/
Engineering
Review
- Leakage shall be $\leq 2\%$ of full scale in a 24 hour period. Test:
V.3.9.1
- Accuracy shall be $\pm 25\%$ of the true exposure at the 95% confidence level, referenced to 20 to 80% of full scale exposure. Precision at any level shall be $\pm 10\%$. Test:
V.4.8,
V.4.6
Calibration:
IV.2.1.10
- Energy dependence shall be $\pm 20\%$ for photons in the energy range 35 keV to 2 MeV. Test:
V.4.7

Criteria

Required Action

- The instrument system shall be unaffected by relative humidities from 5% to 95%, over the designated temperature range. Test: V.2.8.7
- For the operating temperature range the temperature coefficient shall be $\pm 0.5\%$ per $^{\circ}\text{C}$ and it should be $\pm 15\%$ over the entire range. V.2.7.9
- The unit shall be rate independent to 10^6 R/sec. Test: V.4.12.1
- There shall be no deleterious effect to the dosimeter from:
 - 1) radiofrequency Test: V.3.7.8
 - 2) microwave exposure to 10 mW/cm^2 , V.3.7.9
 - 3) photon exposure to 5×10^5 R referenced to the energy range between 0.05 - 1.2 MeV, V.4.14.1
 - 4) electrostatic charges with potentials to 10,000 volts. V.3.7.1
V.3.7.7
- The unit shall be unaffected by magnetic fields with intensities of 10 oersteds. Test: V.3.7
- The unit shall be able to withstand mechanical stress or shock equivalent to a drop from a height of three feet onto a hard surface and such a shock or stress shall not change or alter any reading more than $\pm 10\%$ of full scale. Test: V.2.5
- Change in reading with spatial orientation shall be $\leq 2\%$ of full scale. Test: V.2.1
- Angular dependence shall be $\leq 15\%$ over the energy range 35 keV to 2 MeV. Test: V.4.8
- Sensitivity shall be $\leq 5\%$ of midscale. Test: V.4.3

CriteriaRequired
Action

- The unit shall:
 - 1) be nonresponsive to beta radiations with energies ≤ 2 MeV,
or
 - 2) be accurate to within $\pm 30\%$ for beta radiations with
energies from 100 keV to 2 MeV. The scale shall be
calibrated in rads, and for photons 1 R can be taken
to equal 1 rad.

Test:
V.4.15.2

V.4.5.3
V.4.7.4

III.1.2.4 Personal Alarm Dosimeters

- The criteria established for the integrating survey meters in
Section III.1.2.1 shall apply.
- The personal alarm dosimeter shall have a range from 0 to 200 R.
- A meter, digital register or other readout shall continually
register the accumulated dose.
- The instrument shall weigh no more than 425 grams (8 oz).
- The instrument should be powered by any single or combination
of commercially available alkaline type dry cells. Mercury
cells, while acceptable, are discouraged.

Test:
V.4.1
Calibration:
IV.2.1.11

Inspection/
Engineering
Review

Inspection
Engineering
Review

III.2 PERFORMANCE CRITERIA FOR EMERGENCY INSTRUMENTATION FOR FUEL FABRICATION FACILITIES⁽²⁾

The discussions in this section are divided according to the type of instrumentation being considered, i.e., criticality detection and alarm, radiological instrumentation, both fixed and transportable, and meteorological instrumentation. A general discussion of design considerations, followed by a set of more specific performance criteria, is presented for each of the types of instrumentation given above.

III.2.1 CRITICALITY DETECTION AND ALARM SYSTEM

The primary purpose of the criticality alarm system is to initiate immediate evacuation of people in the event of accidental criticality. The system should be designed to 1) detect a criticality event by the attendant high radiation, 2) signal evacuation, 3) summon help, and 4) establish the time of the event for analysis. In order to reduce the frequency of false alarms, the criticality detectors should be operated such that two or more detectors must be tripped in order to sound the alarm. This will require that two or more detectors be located sufficiently close to each quantity of fissile material to respond to the minimum foreseeable burst with consideration of the trip point and intervening shielding.

Criticality Detection System Criteria

	<u>Required Action</u>
• The detection system shall be designed primarily to act as an alarm trigger.	Inspection/ Engineering Review
• If detectors serve as a post-alarm dose-rate monitoring system, remote switching shall be used to switch to the other mode after the alarm.	Inspection/ Engineering Review
• The system response time (i.e., the interval between the detection threshold and the time the alarm sounds) shall be less than 500 ms.	Test: V.4.9
• A minimum of two out of n detectors in alarm mode shall be required to sound the alarm signal.	Inspection/ Engineering Review

Criteria

Required Action

• If the detectors fail to the alarm mode then at least two detectors ($n \geq 2$) shall be located so as to respond to a minimum burst. If the detectors do not fail to the alarm mode then at least three detectors ($n \geq 3$) shall be located so as to respond to a minimum burst.	Inspection/
Engineering
Review
• An annunciator shall signal both visually and audibly any failure or alarm condition of any detector in the building.	Inspection/
Engineering
Review
• An annunciator which will signal power loss to the criticality alarm system shall be installed in the facility at a location which is normally occupied during normal building use.	Inspection/
Engineering
Review
• A central panel which contains a readout of all alarm system conditions should be provided.	Inspection/
Engineering
Review
• The criticality alarm system in the facility shall be connected to emergency power.	Inspection/
Engineering
Review
• The wiring for the criticality detection and alarm system shall be insensitive to power transients in the facility including the loss of and reestablishment of power.	Test:
V.3.5,
V.3.6
• The wiring for the system should be placed in conduits which are used only for the system.	Inspection/
Engineering
Review
• The system shall be designed for the alarm to sound continuously until reset. Consideration should be given to remote reset to facilitate reentry into the facility.	Inspection/
Engineering
Review
Test:
V.2.10.2
V.2.10.3

Detector Criteria

Required Action

- Neutron detection with low gamma sensitivity should be considered. Test:
V.4.3
V.4.15.1
- The detector system design should be based on integrated dose detection (i.e., should function as a dose-operated alarm trigger) coupled with low dose-rate rejection. Inspection/
Engineering
Review
- The criticality detection system should be designed to be operated by excursions of any foreseeable size whether or not those excursions are themselves directly attended by unacceptable hazard to man. Inspection/
Engineering
Review
- The detection threshold should be the minimum foreseeable spike yield over any duration within the range of foreseeable durations of delivery of that yield. The minimum foreseeable spike yield should be set at 10^{15} fissions unless the process involves considerable quantities of solid plutonium metals, when it should be set at 10^{14} fissions. For foreseeable durations, a range of 1 ms to 3 s should be considered. Test:
V.4.14
Calibration:
IV.2.1.12
- The largest foreseeable yield should be 10^{19} fissions, except where fissile solutions are processed and the presence of 100 gallon capacities (whether or not intended to receive fissile solution) cannot be considered to be improbable, in which case the yield should be increased to a maximum of 3×10^{19} fissions. Test:
V.4.1.14
Calibration:
IV.2.1.12
- Detectors should not be located in the immediate area of magnetic fields of high flux density.

Audible Alarms Criteria

- The criticality alarm signal shall be unique and shall not be used for any purposes other than to signal immediate evacuation in the event of accidental criticality. Inspection/
Engineering
Review

Criteria

Required Action

- The criticality alarm signal shall be a complex sound wave with a modulating frequency of 4 to 5 hertz as specified in ANSI N2.3. Inspection/
Engineering
Review
- The alarm signal shall be audible within a maximum of one-half second after activation of the radiation detector. Test:
V.2.10.2
- After initiation, the alarm signal shall continue to sound even though the radiation level falls below the alarm point. Test:
V.2.10.3
- Sufficient alarm howlers shall be installed to achieve a sound level of at least 10 decibels above the maximum background noise and not less than 75 decibels in all locations in the facility which may be occupied (except for areas with very high background noise levels). The alarm shall not subject any personnel to sound intensities greater than 130 db. Test:
V.2.10.1
- Areas with very high background noise levels may require that the audible signal be supplemented with visual signals, such as beacons. Instructions shall be posted at the entrance to these areas defining the meaning of the beacon. Inspection/
Engineering
Review

III.2.2 RADIOLOGICAL INSTRUMENTATION

Radiological instrumentation intended for use during emergencies must necessarily exhibit a high degree of reliability and be capable of operation under a variety of severe ambient conditions.

III.2.2.1 Installed Radiological Instrumentation

Insofar as is practicable, criteria stated below refer to the overall system including the detector, rather than a specific component or unit. The criteria are not intended for portable radiation instruments or meteorological instrumentation. Generalization will allow for some choice of modules, units and components, and minimize "locking in" on specific designs. The entire system should be unaffected by power

surges, external rf or magnetic fields, and AC induced fields, and transients, and to best achieve this independence, a separate instrument power circuit is recommended. Isolation transformers, while effective in many instances, can be adversely affected or even rendered inoperative by extra-ordinary demands of a major accident.

Systems Performance Criteria

	<u>Required Action</u>
<ul style="list-style-type: none"> • Except as noted, the electronics shall meet the specifications for and be compatible with the AEC standard nuclear instrument modules⁽⁴⁾ thus ensuring a basic standard and providing ease of maintenance through interchangeability and compatibility. 	Inspection/ Engineering Review
<ul style="list-style-type: none"> • All modules shall be accessible for test without removal from the circuit. Plug-in type units should be used if available, other considerations being equal. 	Inspection/ Engineering Review
<ul style="list-style-type: none"> • Switches and other controls shall be protected to prevent inadvertent deactivation or operation of system. 	Inspection/ Engineering Review
<ul style="list-style-type: none"> • The system shall have an internal electronic calibration check, which shall check operation of all circuitry other than the detector. 	Inspection Engineering Review
<ul style="list-style-type: none"> • The system shall be fail-safe; in the event of a malfunction or failure, an internal audit circuit shall be activated and transmit an appropriate signal to a central manned location. 	Inspection/ Engineering Review V.2.12.1
<ul style="list-style-type: none"> • The system should be capable of operation on 117 V 60 Hz AC, and should be unaffected by voltage or frequency changes of ± 20 percent. Emergency power capability should be included in the design and installation, and should be automatically implemented when required, with no delay which will cause a malfunction in the system. 	Test: V.3.6

Systems Performance Criteria

Required Action

- The entire system should be unaffected by power surges external rf or magnetic fields, and AC induced fields and transients, and to best achieve this independence, a separate instrument power circuit is recommended. Isolation transformers, while effective in many instances, can be adversely affected or even rendered inoperative by extraordinary demands of a major accident. Test:
V.3.5,
V.3.6,
V.3.7
- There shall be no deleterious effect to the system from: Test:
 - 1) radiofrequency field intensity of 1000 V/m V.3.7.8,
 - 2) microwave exposure to 10 mW/cm² V.3.7.9,
 - 3) photon exposure to 5×10^5 R referenced to the energy range between 0.6-1.25 MeV V.4.14.3
 - 4) external electrostatic fields of 500 V/cm. V.3.7.1
- The operating temperature and relative humidity ranges of the system shall encompass the extremes anticipated. Where the instrumentation may be exposed directly to ambient outside temperatures, the 50 year extremes shall be applied. Test:
V.2.7
- The instrument system shall be unaffected by relative humidities from 40 percent to 95 percent over the temperature range of 60°F and 120°F and shall be splashproof. Test:
V.2.8,
V.2.9
- The instrument system shall be able to withstand mechanical stress equivalent to a peak overpressure of 5 psi. Test:
V.2.11.1

Performance Criteria for Radiation or Air Concentration Level Instrumentation

In addition to the general criteria above, the following criteria shall apply to radiation and air concentration level instrumentation systems.

- Overall system accuracy shall be ± 40 percent over the entire operating range, with precision of ± 10 percent at the 95 percent confidence level for any single measurement level. Test:
V.4.5,
V.4.6

Criteria

Required Action

- Overall system response (0 to 90 percent of full reading) time, after a one minute warm-up, shall be ≤ 10 seconds on the most sensitive ranges and ≤ 2 seconds on full scale ranges of 100 mrad/hr, 100 mR/hr or 5000 d/m/100 cm² and higher. This does not preclude the inclusion of variable response time capability. Response time to a decreasing field (full reading to 10 percent of original reading) shall be no greater than response times to increasing fields
Test:
V.4.9
Calibration:
IV.2.1.7
- For the operating temperature range the temperature coefficient shall be ≤ 0.5 percent per °C and it should be ± 15 percent over the entire range.
Test:
V.2.7.7
- The instrument system shall be equipped with an alarm capable of being externally set to alarm at any point over the stated range. The alarm should be both audible and visible, and should be capable of reset without removing the instrument from service.
Test:
V.4.1.2
- Logarithmic or digital readout should be employed. If multiple ranges are used, automatic range changing shall be provided. Manual adjustment of range shall be unnecessary.
Inspection/
Engineering
Review
Test:
V.4.1.8
- Readout capability shall be provided at a central process control station designated as the emergency control center and at or near the instrument.
Inspection/
Engineering
Review

III.2.2.2 Transportable Radiation and Contamination Measurement Instrumentation

Contamination and ambient radiation survey instrument measurements are intended to supplement those obtained from fixed instrument systems and to aid in the protection of operating personnel during efforts to stabilize the emergency. In the case of plutonium releases, the measurements may be the primary method of determining the magnitude of release when an unusual route of release is

possible. Characteristically, these instruments need to be highly flexible and yet rugged in order to function as desired and withstand the rough treatment they may receive.

Monitoring on an emergency basis following a fuel fabrication plant accident will normally be for alpha and low energy photon radiation from ambient air and surface contamination. Only in the criticality accident will neutrons and fission over shadow the alpha contamination.

Performance Criteria for Transportable Dose Rate and Contamination Survey Instrument

Required Action

- The instrumentation shall be capable of detecting alpha, beta and photon radiation, and separating the contribution from each. To accomplish this, a detector system which can be operated bare or which can be shielded with 1 gm/cm² of polyethylene or similar low Z plastic should be used.

Inspection/
Engineering
Review

- The detection ranges shall be as shown:

Test

Photon Exposure Rate: 0.1 mR/hr to 10⁴ R/hr

V.4.1.1

Beta Dose Rate: 0.1 mrad/hr to 10⁴ rad/hr

V.4.1.1

Alpha Contamination: 500 d/m/100 cm² to

V.4.1.1

In recognition of the difficulties in design and construction of a single detector and/or instrument with such a breadth or range, two detectors or instruments are permissible, assuming that all the other criteria specified in this section are met, and that a one decade overlap is provided. Linear scales are preferred for ease of readout and reduction of error in calibration.

- Photon energy dependence shall be ±15 percent over the range 7 keV to 2.75 MeV. (more than one detector permissible)
- Detection capability shall be provided for beta particles with energies greater than 100 keV. The beta energy dependence shall be 30 percent over the range 0.1 to 2 MeV E_B maximum.

Test

V.4.7.1

Test:

V.4.7.4

Criteria

Required Action

- Photon energy dependence shall be ± 15 percent over the range 7 keV to 2.75 MeV. (more than one detector permissible) Test: V.4.7.1
- Detection capability shall be provided for beta particles with energies greater than 100 keV. The beta energy dependence shall be ± 30 percent over the range 0.1 to 2 MeV E_B maximum. Test: V.4.7.4
- Angular dependence for photon measurement shall be ≤ 15 percent in a 2π steradian frontal direction, referenced to photons with energies in the region 0.6 to 1.25 MeV. Test: V.4.8.4
- Readout for photon and beta instrumentation shall be direct and in units of dose or exposure per hour. However, high range instruments intended exclusively for rescue work may be calibrated in units of R/min or rad/min, and if so, the instrument and readout should be clearly and distinctively marked. The readout shall be such that multipliers (e.g., X10, X100) shall be included. Inspection/Engineering Review
- Readout for alpha instrumentation shall be direct and in disintegrations per minute. The readout shall be such that multipliers (e.g., X10, X100) shall be included. Inspection/Engineering Review
- Overall instrument accuracy shall be ± 20 percent over the entire operating range, with precision of ± 10 percent at the 95 percent confidence level for any single measurement level. Test: V.4.5, V.4.6 Calibration: IV.2.1.8
- Overall instrument response (0 to 90 percent of full reading) time, after a one minute warm-up, shall be ≤ 10 seconds on the most sensitive ranges and ≤ 2 seconds on full scale ranges of 100 mrad/hr, 100 mR/hr and 5000 d/m/100 cm² and higher. This does not preclude the inclusion of variable response time capability. Response time to a decreasing field (full

Criteria

Required Action

reading to 10 percent of original reading) shall be no greater than response times to increasing fields.

- Stability shall be evidenced by the ability of the instrument to maintain accuracy and precision for at least 24 hours after initial warm-up. Test: V.3.3
- Resolution (readout capability) is defined as the minimum detectable change in meter response. Resolution shall be ≤ 4 percent of full scale for a linear scale or ≤ 8 percent of a reading for log scale with a maximum of two decades per 90° of meter movement. Test: V.4.3
- Detectors and associated electronic circuitry, readout and display devices, and power supplies shall be wholly interchangeable between instruments of a given type. With the exception of the detector and display, solid state electronics should be used throughout. Inspection/Engineering Review
- The readout shall be lighted to permit use in darkness; self-illumination should be considered. Inspection/Engineering Review
Test: V.2.12.4
- A 10 mV or 1 mA recorder output shall be provided for instruments which are to be used with a recorder. Inspection/Engineering Review
- The instrument should be designed to be powered by readily available cells or batteries such as AA, C, or D cells or 9-volt batteries meeting specifications published by the U.S. National Bureau of Standards. Compatibility with alkaline, Ni-Cd, or mercury cells should be considered. Provision for operation from a standard automobile 12 volt system and 117 volt, 60 Hz, alternating current, also should be considered. Inspection/Engineering Review

Criteria

Required Action

- Minimum battery lifetime shall be 200 hours of continuous duty operation at an exposure level of 10 percent the maximum full scale reading, at temperatures above 0°C. At temperatures below 0°C, alkaline batteries shall be used and the minimum battery lifetime shall be 100 hours of continuous operation.
Test:
V.3.8.4
- The instrument shall be equipped with a battery check switch and indicator of battery condition. Low or dead battery indication shall be positive - i.e., the instrument shall read upscale, and zeroing shall be rendered impossible.
Inspection/
Engineering
Review
Test:
V.3.8.5
- When responding to levels in excess of the maximum range, the readout shall remain full upscale.
Test:
V.4.10
- Overall instrument response shall not change by more than ± 10 percent from the previous calibration when batteries are changed.
Test:
V.3.8.3
- The total weight of the fully assembled survey meter, including batteries, should not exceed 3 kg (6.6 lbs).
Inspection/
Engineering
Review
- For the operating temperature range the temperature coefficient shall be ≤ 0.5 percent per °C and it should be ± 15 percent over the entire range.
Test:
V.2.7.7
- The operating temperature range of the system shall encompass the extremes anticipated. Where the instrumentation may be exposed directly to ambient outside temperatures, the 50 year extreme shall be applied.
Test:
V.2.7
- The instruments shall be splashproofed. The instrument system shall be unaffected by relative humidities from 40 percent to 95 percent over the temperature range of 60°F to 120°F.
Test:
V.2.9,
V.2.8

Criteria

Required Action

- Response to noise shall be undetectable at noise pressure ≤ 100 dbA (referenced to 0.0002μ bar) in the frequency range of 1 to 1000 Hz. Test:
V.2.3
- Extracameral responses should be undetectable in photon field to 10 R/hr referenced to 1 MeV energy, and to beta fields providing an air dose of 10 rad/hr referenced to 2 MeV E_B maximum. Test:
V.4.11
- The system shall be unaffected by magnetic fields with intensity to 10 oersteds. Test:
V.3.7
- The system shall be capable of withstanding harmonic g loadings applied in each of three mutually orthogonal axes in the frequency range of 1 to 33 Hz with no lasting detrimental effects. The magnitude of the g loading shall be the larger of 1 g or the maximum g forces anticipated in the individual project siting specifications. Test:
V.2.4
- There shall be no deleterious effect to the system from:
 - 1) radiofrequency field intensity of 1000 V/m Test:
V.3.7.8
 - 2) microwave exposure to 10 mW/cm^2 Test:
V.3.7.9
 - 3) photon exposure to 5×10^5 R referenced to the energy range between 0.8-1.2 MeV Test:
V.4.14.3
 - 4) external electrostatic fields of 500 V/cm Test:
V.3.7.1
- Geotropism. The change in reading with spatial orientation, shall be percent of full scale reading. Test:
V.2.1
- If an integrating capability is provided the following shall apply:
- Portable radiological instruments with integrating capability should have integrating ranges as shown: Calibration
IV.2.1.9

Criteria

Required Action

Photon Exposure 0.1 to 10^4 R
Beta Dose 0.1 to 10^4 rad

Test:
V.4.1.15

Integrating units shall be equipped with an audible alarm having a continuous or intermittent warbling tone with a frequency in the region of 2 to 7 kHz and a sound level of 85 dbA at a distance of 50 cm from the instrument.

Test:
V.4.1
V.2.10.1

- The alarm shall be presettable to any level by an external switch. External reset capability shall also be provided.
- An alarm test position or switch shall be provided.

Test:
V.4.1.2

Inspection/
Engineering
Review

If the survey instrument is to be combined with recorders or air samplers and operated while carried (semi-portable) the following shall apply:

- The instrument is capable of and designed for convenient transportability by a single person. This criterion does not preclude the use of back packs, neck or shoulder straps, belts, or other means of attachment to the body.
- The weight of the total instrument, including power source, does not exceed 22.5 kg (50 lbs).

Inspection/
Engineering
Review

Inspection/
Engineering
Review

If the survey instrument is to be operated while mounted in an airplane, motor vehicle or boat (mobile) the following shall apply:

- Any of the instrumentation that may be used in an airplane shall be designed to operate properly at an altitude of 5000 feet over the surrounding terrain.
- Mobile instrumentation shall be designed to provide a readout using a strip chart recorder.

Test:
V.2.2

Inspection/
Engineering
Review

Criteria

Required Action

- Each separate portion of the mobile instrument system shall weight less than 50 pounds.

Inspection/
Engineering
Review

III.2.2.3 Performance Criteria for Airborne Particulate Monitoring

An important element of preparation for an emergency is to establish in advance the instruments and procedures to be used: 1) to quickly assess the seriousness of the event from the moment of recognition as an accident involving release; 2) to determine airborne levels which will permit decisions and action regarding people downwind and; 3) after the fact, reconstruct the event for the record and further assess the consequences of the release. All these activities are directed at preventing and mitigating human exposure. Because in the early stages of such an event the immediate concern is airborne concentrations, means should be available, if reasonably possible, to sample and measure plutonium near the ground at points to be designated from the real-time meteorology and the knowledge concerning the gross nature of the accident. This would include knowledge of integrity of the physical plant, whether fire criticality event or transuranium release had occurred or not, apparent integrity of air cleaning, etc.

Collection of a representative sample of an aerosol requires appropriate consideration of many factors influencing the behavior of particles in air. The paramount consideration in air sampling for emergency instrumentation is the ability to detect significant concentrations of airborne radioactive materials rapidly and reliably.

Stack Monitor performance Criteria

Required Action

- Particulate radioactive material shall be removed by filters with effective pore size ≤ 5 m, having an efficiency of ≤ 99.5 percent for particles with diameters $\leq 0.3 \mu\text{m}$.⁽⁶⁾
- A constant sample flow rate shall be used and a constant displacement pump should be used as the air mover. An appropriately calibrated airflow meter shall continuously verify sample flow rate, and shall be accurate to within 20 percent.

Test:
V.2.12.2

Test:
V.2.12.5

Criteria

Required Action

- The system shall be designed to remove, on a continuous basis a representative sample. (5) Inspection/Engineering Review
- Particulate-generating gas phase reactions, corrosion, or release of contaminants, should be absent downstream of the sampling point. Inspection/Engineering Review
- When sampling a stack, the sample point shall be no less than eight duct diameters and preferably should be at least 10 duct diameters downstream from any injection point or point of transition. A multientry probe shall be used for sampling in the duct or stack, unless prior tests have shown concentrations to be uniform to ± 10 percent across the stack. (5) Inspection/Engineering Review
- Sampling conditions should approach isokinetic. The sampler inlet velocity to duct velocity ratio should be 1.0 ± 0.2 . Test: V.2.12.3
- Sampling lines shall be kept short. Where possible the distance from sample point to collector should be less than 10 feet. Sample line bend radii shall exceed five sampling line diameters. (5) Inspection/Engineering Review
- The sample delivery system shall be corrosion resistant and designed for streamline flow with no right angles or sharp bends. Stainless steel should be used for construction and plate out of radioactive materials should be less than 5 percent. (5) Inspection/Engineering Review
- System shall be capable of detecting within 30 minutes an increase of plutonium in airborne effluents representing a release of 10 mg over an 8 hour period. Test: V.4.1.11
- System shall indicate largest postulated plutonium release from stack. Test: V.4.1.13

Criteria

Required Action

- Stack monitor shall remain functional when challenged by the release of 1.0 gram plutonium in 1 minute via the stack. Test:
V.4.1.12
- Stack monitor should be based upon rate of increase of activity rather than pre-set count. Inspection/
Engineering
Review
- The range of detection capability shall overlap the range of stack monitoring instrumentation used for routine or non-emergency monitoring. (The emergency instrumentation and routine instrumentation may be the same.) Inspection/
Engineering
Review
- The entire system operation shall be put on routine maintenance, checked at least quarterly, and calibrated and maintained when indicated. Calibration:
IV.2.1.4

III.2.2.4 Environmental Air Monitoring

A sample/monitor can provide an early warning at a point of interest. The alarm is necessarily delayed by the amount of time required for the material to travel from the release point to the instrument. However, it provides only a measure of the concentration at the point of interest and not an easily relatable estimate of the total amount released. This type of instrumentation could be of benefit for isolated points where atmospheric conditions, distance to the plant boundary, population mass, etc., warrant additional measurements.

Environmental Air Monitor Performance Criteria

Required Action

The criteria listed below are in addition to those general criteria presented above.

- The system shall be designed to take a representative sample of the ambient air on a continuous basis. The preferred sampling location is at one meter above ground level, in a location free from unusual micrometeorological or other conditions (e.g., proximity of large buildings, vehicular traffic) which could result in artificially high or low air concentrations. (5)
Inspection/
Engineering
Review
- The sample collector should be easily measurable in place with portable monitoring instruments and removable for subsequent laboratory analysis.
Inspection/
Engineering
Review
- The measurement capability for particulate activity shall have a minimum range of 10^{-1} to 10^{-5} $\mu\text{Ci}/\text{cm}^3$ gross alpha referenced to ^{239}Pu for 30 minute sample. This range shall overlap the range of instrumentation used for routine or non-emergency monitoring.
Test:
V.4.1.9
- The instrument system shall be protected from the external environment, and should be housed in a locked facility to afford a measure of security from accidental or willful damage or tampering.
Test:
V.2.8,
V.2.9
- The entire system operation shall be checked at least quarterly and calibrated and maintained when indicated.
Calibration:
IV.2.1.5
- To simplify calibration, operation and interpretation, a fixed sampling rate of 10-30 liters per minute should be used. Sampling rate shall remain constant to within ± 25 percent during normal operation.
Test:
V.2.12.6

Criteria

Required Action

- The unit shall be compatible with membrane, glass fiber, cellulose fiber, and charcoal loaded filters commonly used for air sampling. The size of the filter used is dependent upon the size of the detector, but a 47 mm diameter should be considered. Filter diameter should not exceed 100 mm. Inspection/Engineering Review
- The filter material used shall have an efficiency of 99.5 percent or greater for particles 0.3 μ m in diameter. (6) Test: V.2.12.2
- Power should be provided by wet cells, and these shall conform to the specifications put forth by the National Bureau of Standards. Inspection/Engineering Review
- Battery lifetime should be greater than 8 hours under load. Test: V.3.8.4
- The sampling unit shall be provided with a battery test or other indicator of battery condition. Inspection/Engineering Review
- Air flow shall be continuously indicated by an appropriate clearly marked gage having an accuracy of ± 20 percent. Test: V.2.15.5

III.2.2.5 Personnel Dosimeters

The determination of personnel external exposure or dose is of prime importance in a fuel fabrication plant only when a criticality incident is the accident.

There are a wide variety of devices which integrate external exposure. For emergency purposes only those devices which provide for a direct, instantaneous readout without disturbing the operation of the device or the accumulation of information will be considered. Hence, for all practical purposes, photographic and luminescent devices are excluded, since these require special readout equipment and, in addition, readout may erase or terminate the usefulness of the device.

Personal (or, alternatively) pocket alarm dosimeters are a hybrid pocket dosimeter and integrating survey meter. Several have been described in the open literature over the past few years.⁽⁹⁻¹⁴⁾ These have been made available primarily as a result of the development of miniature components. Although in many respects these have not yet been developed to their full potential, they may be superior to either the pocket ionization chamber or integrating survey meter for rescue purposes. In general, these should meet the requirements described for integrating survey meters.

Direct reading pocket ionization chambers would appear to be the least suitable for the emergency situation in general and rescue work in particular, because of the absence of an alarm capability. Pocket ionization chambers should generally conform to the standards and criteria put forth by the American Standards Institute.⁽¹⁵⁾

Personnel Dosimeters Performance Criteria

Required Action

- The pocket ion chamber shall have a range of 0 to 200 R if it is to be used for personnel involved in rescue work in which exposures to 100 R may be incurred. If used for other purposes, such as protection of property, the range shall be appropriate to the maximum permitted exposure. The maximum permitted exposure shall be in the range of 40 to 70 percent of full scale of the pocket ionization chamber used.
- The instrument shall be provided with an optical system to permit direct readout. Major scale divisions shall be indicated by heavy lines at 0, 50 and 100 percent of scale; the scale should be further subdivided into tenths and twentieths by progressively shorter and/or less bold lines.

Test:
V.4.1.16

Inspection/
Engineering
Review

Criteria

Required Action

- Leakage shall be ≤ 2 percent of full scale in a 24 hour period. Test:
V.3.9.1
- Accuracy shall be ± 25 percent of the true exposure referenced to 20 to 80 percent of full scale exposure. Precision any any level shall be ± 10 percent at the 95 percent confidence level. Test:
V.4.5,
V.4.6
Calibration:
IV.2.1.10
- Energy dependence shall be ± 10 percent for photons in the energy range 35 keV to 1.3 MeV. Test:
V.4.7
- The instrument system shall be unaffected by relative humidities from 40 percent to 95 percent over the temperature range of 60°F to 120°F. Test:
V.2.8.1
- For the operating temperature range the temperature coefficient shall be ± 0.5 percent per °C and it should be ± 15 percent over the entire range. Test:
V.2.7.9
- The unit shall be rate independent to 10^4 R/hr. Test:
V.4.12.1
- There shall be no deleterious effect to the system from:
1) radiofrequency field intensity of 1000 V/m Test:
V.3.7.8
2) microwave exposure to 10 mW/cm^2 Test:
V.3.7.9
3) photon exposure to 5×10^5 referenced to the energy range between 0.8-1.2 MeV Test:
V.4.14.1
4) external electrostatic fields of 500 V/cm Test:
V.3.7.1
V.3.7.7
- The unit shall be unaffected by magnetic fields with intensities of 10 oersteds. Test:
V.3.7
- The unit shall be able to withstand mechanical stress or shock equivalent to a drop from a height of 4 feet onto a hard surface and such a shock or stress shall not change or alter any reading more than ± 10 percent of full scale. Test:
V.2.5

Criteria

Required Action

- Change in reading with spatial orientation shall be ≤ 3 percent of full scale.
- Angular dependence or isotropism shall be such that a reading result of not less than 70 percent of the reading obtained at that energy when measuring energy dependence.
- Sensitivity shall be ≤ 5 percent at midscale.
- The unit shall:
 - 1) be nonresponsive to beta radiations with energies ≤ 2 MeV, or
 - 3) be accurate to within $\pm 30\%$ for beta radiations with energies from 100 keV to 2 MeV.

Test:
V.2.1

Test:
V.4.8

Test:
V.4.3

Test
V.4.15.2

V.4.5.3
V.4.7.4

The scale shall be calibrated in rads, and for photons 1 R can be taken to equal 1 rad.

Alarming Dosimeters

Required Action

- A meter, digital register or other readout shall continually register the accumulated dose.
- The instrument shall weigh no more than 300 grams (~ 10.5 oz).
- The instrument should be powered by any single or combination of commercially available alkaline type dry cells. Mercury cells, while acceptable, are discouraged.

Test
4.1.15

Inspection/
Engineering
Review

Inspection/
Engineering
Review
Calibration:
IV.2.1.11

III.3 PERFORMANCE CRITERIA FOR EMERGENCY INSTRUMENTATION FOR FUEL REPROCESSING FACILITIES⁽³⁾

The discussions in this section are divided according to the type of instrumentation being considered, e.i., criticality detection and alarm, radiological instrumentation, both fixed and transportable, and meteorological instrumentation. Specific performance criteria are presented for each type of instrumentation.

III.3.1 CRITICALITY DETECTION AND ALARM SYSTEM

The primary purpose of the criticality alarm system is to initiate immediate evacuation of people in the event of accidental criticality. The system should be designed to 1) detect a criticality event by the attendant high radiation, 2) signal evacuation, 3) summon help, and 4) establish the time of event for analysis.

In order to reduce the frequency of false alarms, the criticality detectors should be operated such that two or more detectors must be tripped in order to sound the alarm. This will require that two or more detectors be located sufficiently close to each quantity of fissile material to respond to the minimum foreseeable burst with consideration of the trip point and intervening shielding.

III.3.1.1 Criticality Detection and Alarm System Performance Criteria

- The detection system shall be designed primarily to act as an alarm trigger.
- If detectors serve as a post-alarm dose-rate monitoring system, remote switching shall be used to switch to the other mode after the alarm.
- The system response time (i.e., the interval between the detection threshold and the time the alarm sounds) shall be less than 500 ms.
- A minimum of two out of n detectors in alarm mode shall be required to sound the alarm signal.

Required Action

Inspection/
Engineering
Review

Inspection/
Engineering
Review

Test:
V.4.9

Inspection/
Engineering
Review

Criteria

Required Action

- If the detectors fail to the alarm mode, then at least two detectors ($n \geq 2$) shall be located so as to respond to a minimum burst. If the detectors do not fail to the alarm mode, then at least three detectors ($n \geq 3$) shall be located so as to respond to a minimum burst. Inspection/Engineering Review
- An annunciator shall signal both visually and audibly any failure or alarm condition of any detector in the building. Inspection/Engineering Review
- An annunciator which will signal power loss to the criticality alarm system shall be installed in the facility at a location which is normally occupied during normal building use. Inspection/Engineering Review
- A central panel which contains a readout of all alarm system conditions should be provided. Inspection/Engineering Review
- The criticality alarm system in the facility shall be connected to emergency power. Inspection/Engineering Review
- The wiring for the criticality detection and alarm system shall be insensitive to power transients in the facility including the loss of and reestablishment of power. Test:
V.3.5,
V.3.6
- The wiring for the system should be placed in conduits which are used only for the system. Inspection/Engineering Review
- The system shall be designed for the alarm to sound continuously until reset. Consideration should be given to remote reset to facilitate reentry into the facility. Inspection/Engineering Review
Test:
V.2.10.3
- Neutron detection with low gamma sensitivity should be considered. (50 R per hour gamma ray field should not cause an alarm trip.) Test:
V.4.15.1
- The detector system design should be based on integrated dose detection (i.e., should function as a dose-operated alarm trigger) coupled with low dose-rate rejection. Inspection/Engineering Review

Criteria

Required Action

- The criticality detection system should be designed to be operated by excursions of any foreseeable size whether or not those excursions are themselves directly attended by unacceptable hazard to man. Inspection/
Engineering
Review
- The detection threshold should be the minimum foreseeable spike yield over any duration within the range of foreseeable durations of delivery of that yield. The minimum foreseeable spike yield should be set at 10^{15} fissions unless the process involves considerable quantities of solid plutonium metals, when it should be set at 10^{14} fissions. For foreseeable durations, a range of 1 ms to 3 s should be considered. Test:
V.4.1.14
Calibration:
IV.2.1.12
- The largest foreseeable yield should be 10^{19} fissions, except where fissile solutions are processed and the presence of 100 gallon capacities (whether or not intended to receive fissile solution) cannot be considered to be improbable, in which case the yield should be increased to a maximum of 4×10^{19} fissions. Test:
V.4.1.14
Calibration:
IV.2.1.12
- Detectors should not be located in the immediate area of magnetic fields of high flux density Inspection/
Engineering
Review
- The criticality alarm signal shall be unique and shall not be used for any purposes other than to signal immediate evacuation in the event of accidental criticality. Inspection/
Engineering
Review
- The criticality alarm signal shall be a complex sound wave with a fundamental frequency between 450-500 hertz, and with a modulating frequency of 4 to 5 hertz as specified in ANSI N2.3. Inspection/
Engineering
Review
- The alarm signal shall be audible within a maximum of one-half second after activation of the radiation detector. Test:
V.2.10.2
- After initiation, the alarm signal shall continue to sound even though the radiation level falls below the alarm point. Test:
V.2.10.3

Criteria

Required Action

- Sufficient alarm howlers shall be installed to achieve a sound level of at least 10 decibels above the maximum background noise and not less than 75 decibels in all locations in the facility which may be occupied (except for areas with very high background noise levels). The alarm shall not subject any personnel to sound intensities greater than 130 db.
- Areas with very high background noise levels may require that the audible signal be supplemented with visual signals, such as beacons. Instructions shall be posted at the entrance to these areas defining the meaning of the beacon.

Test:
V.2.10.1

Inspection/
Engineering
Review

III.3.2 RADIOLOGICAL INSTRUMENTATION

Radiological instrumentation intended for use during emergencies must necessarily be completely reliable and be capable of operation under a variety of severe ambient conditions.

III.3.2.1 Installed Radiological Instrumentation

Insofar as is practicable, criteria stated in this subsection refer to an overall system including the detector, rather than a specific component or unit. The criteria are not intended for portable radiation instruments or meteorological instrumentation. Generalization will allow for some choice of modules, units and components, and minimize "locking in" on specific designs. The entire system should be unaffected by power surges, external rf or magnetic fields, and AC induced fields and transients. To best achieve this independence, a separate instrument power circuit is recommended. Isolation transformers, while effective in many instances, can be adversely affected or even rendered inoperative by extraordinary demands of a major accident.

Installed Radiological Systems Performance Criteria

Required Action

Except as noted, the electronics shall meet the specifications for and be compatible with the AEC standard nuclear instrument modules, ⁽⁴⁾ thus ensuring a basic standard and providing ease of maintenance through interchangeability and compatibility.

- All modules shall be accessible for test without removal from the circuit. Plug-in type units should be used if available, other considerations being equal. Inspection/
Engineering
Review
- Switches and other controls shall be protected to prevent inadvertent deactivation or operation of system. Inspection/
Engineering
Review
- The system shall have an internal electronic calibration check which shall check operation of all circuitry other than the detector. Inspection
Engineering
Review
- The system shall be fail-safe; in the event of a malfunction or failure, an internal audit circuit shall be activated and transmit an appropriate signal to a central manned location. Inspection/
Engineering
Review
Test:
V.2.12.1
- The system should be capable of operation on 117 V 60 Hz AC and should be unaffected by voltage or frequency changes of $\pm 20\%$. Emergency power capability should be included in the design and installation and should be automatically implemented when required, with no delay which would cause a malfunction in the system. Test:
V.3.6
V.3.5
- The entire system should be unaffected by power surges, external rf or magnetic fields, and AC induced fields and transients. To best achieve this independence, a separate instrument power circuit is recommended. Test:
V.3.5
V.3.7
Isolation transformers, while effective in many instances, can be adversely affected or even rendered inoperative by extraordinary demands of a major accident.

Criteria

Required Action

- There shall be no deleterious effect to the system from:
 - 1) radiofrequency field intensity of 100 V/m, V.3.7.8
 - 2) microwave exposure to 10 mW/cm², V.3.7.9
 - 3) photon exposure to 5×10^5 R referenced to the energy range between 0.6-1.25 MeV, V.4.14.3
 - 4) external electrostatic fields of 500 V/cm. V.3.7.1
- The operating temperature and relative humidity ranges of the system shall encompass the extremes anticipated. Where the instrumentation may be exposed directly to ambient outside temperatures, the 50 yr extremes shall be applied. Test: V.2.7
- The instrument system shall be unaffected by relative humidities from 40% to 95% over the temperature range of 60°F to 120°F and shall be splashproof. Test: V.2.8 V.2.9
- The instrument system shall be able to withstand mechanical stress equivalent to a peak overpressure of 5 psi. Test: V.2.11.1

Performance Criteria for Air Concentration Level Instrumentation

In addition to the general criteria in the above section, the following criteria shall apply:

- Detection of particulate radioactivity should be on the basis of beta-gamma counting. Inspection/Engineering Review
- For particulate radioactivity, the minimum detection range shall be 10^{-5} μ Ci/cc to 10^1 μ Ci/cm³, referenced to ¹³⁷Cs, for work and process areas. Test: V.4.1.10
- For particulate radioactivity, the minimum detection range shall be 10^{-6} to 10^0 μ Ci/cc, referenced to ¹³⁷Cs, in the plant environs. Test: V.4.1.10
- Overall system accuracy shall be $\pm 40\%$ over the entire operating range, with precision of $\pm 10\%$ at the 95% confidence level for any single measurement level. Test: V.4.5 Calibration: IV.2.1.7

Criteria

Required Action

- Overall electronic system response (0 to 90% of full reading) time shall be ≤ 2 seconds on all ranges. Test:
V.4.9
- For the operating temperature range, the temperature coefficient shall be $\leq 0.5\%$ per $^{\circ}\text{C}$ and it should be within $\pm 15\%$ over the entire range. Test:
V.2.7.8
- The instrument system shall be equipped with an alarm capable of being externally set to alarm at any point over the stated range. Test:
V.4.1.2
- The alarm should be both audible and visible and should be capable of reset without removing the instrument from service. Inspection/
Engineering
Review
- The alarm shall sound at the emergency control center and at the instrument for in-facility locations, whereas instrumentation located in the environs need only alarm at the emergency control center. Inspection/
Engineering
Review
- Logarithmic or digital readout should be employed. Inspection/
Engineering
Review
Test:
V.4.1.8
- Readout capability shall be provided at a central process control station designated as the emergency control center and at or near the instrument. Inspection/
Engineering
Review

Performance Criteria for Ambient Radiation Instrumentation

In addition to the general criteria given above the following criteria shall apply to ambient radiation instrumentation systems.

- Detection of ambient radiation should be on the basis of unpressurized air ionization chambers. Inspection/
Engineering
Review
- The instrument system shall operate within the range of 10^{-1} to mR/hr whether located within the facility or in the environs. Test:
V.4.1

Criteria

Required Action

- Overall system accuracy shall be $\pm 40\%$ over the entire operating range, with precision of $\pm 10\%$ at the 95% confidence level for any single measurement level.
Test:
V.4.5
V.4.6
Calibration:
IV.2.1.7
- Overall system response (0 to 90% of full reading) time, after a 1 minute warm-up, shall be ≤ 10 seconds on the most sensitive ranges and ≤ 2 seconds on the 10^4 mR/hr full scale range. Variable response time capability may be included. Response time to a decreasing field (full reading to 10% of original reading) shall be no greater than response times to increasing fields.
Test:
V.4.9
- For the operating temperature range, the temperature coefficient shall be $\leq 0.5\%$ per $^{\circ}\text{C}$ and it should be $\pm 15\%$ over the entire range.
Test:
V.2.7.7
- The instrument system shall be equipped with an alarm capable of being externally set to alarm at any point over the stated range. The alarm should be both audible and visible and should be capable of reset without removing the instrument from service. The alarm shall sound at the emergency control center and at the instrument for in-facility locations, whereas instrumentations located in the environs need only alarm at the emergency control center.
Inspection/
Engineering
Review
Test:
V.4.1.2
- Logarithmic or digital readout should be employed.
Inspection/
Engineering
Review
Test:
V.4.1.8
- Readout capability shall be provided at a central process control station designated as the emergency control center at or near the instrument.

III.3.2.2 Transportable Radiation and Contamination Measurement Instrumentation

Contamination and ambient radiation survey instrument measurements are intended to supplement those obtained from fixed instrument systems and to aid in the protection of operating personnel during efforts to stabilize the emergency. It is prohibitively expensive to have a fixed instrument system in the environs that will provide a complete coverage for all releases considering all possible meteorological conditions. Characteristically, these instruments need to be highly flexible and yet rugged in order to function as desired and withstand the rough treatment they may receive.

Monitoring on an emergency basis following a fuel reprocessing plant accident will normally be for beta-gamma medium energy radiation from ambient air and surface contamination. Releases involving only alpha emitters may become more important as facilities to convert the plutonium product from the nitrate to the oxide are added to permit transportation of the plutonium to a fuel fabrication plant.

Performance Criteria for Transportable Dose Rate and Contamination Survey Instruments

Required Action

• The instrumentation shall be capable of detecting alpha, beta and photon radiation, and of separating the contribution from each. To accomplish this, a detector system which can be operated bare or which can be shielded with 1 gm/cm² of polyethylene or similar low Z plastic should be used. • The detection ranges shall be as shown: <table border="0" style="margin-left: 20px;"> <tr> <td>Photon Exposure Rate:</td> <td>0.1 mR/hr to 10⁴ R/hr</td> <td style="vertical-align: top;">Inspection/
Engineering
Review</td> </tr> <tr> <td>Beta Dose Rate:</td> <td>0.1 mrad/hr to 10⁴ rad/hr</td> <td style="vertical-align: top;">Test:</td> </tr> <tr> <td>Alpha Contamination:</td> <td>500 d/m/100 cm² to 10⁷ d/m/100 cm²</td> <td style="vertical-align: top;">V.4.1.1</td> </tr> <tr> <td></td> <td></td> <td style="vertical-align: top;">V.4.1.17</td> </tr> <tr> <td></td> <td></td> <td style="vertical-align: top;">V.4.1.18</td> </tr> </table>	Photon Exposure Rate:	0.1 mR/hr to 10 ⁴ R/hr	Inspection/
Engineering
Review	Beta Dose Rate:	0.1 mrad/hr to 10 ⁴ rad/hr	Test:	Alpha Contamination:	500 d/m/100 cm ² to 10 ⁷ d/m/100 cm ²	V.4.1.1			V.4.1.17			V.4.1.18
Photon Exposure Rate:	0.1 mR/hr to 10 ⁴ R/hr	Inspection/
Engineering
Review													
Beta Dose Rate:	0.1 mrad/hr to 10 ⁴ rad/hr	Test:													
Alpha Contamination:	500 d/m/100 cm ² to 10 ⁷ d/m/100 cm ²	V.4.1.1													
		V.4.1.17													
		V.4.1.18													

In recognition of the difficulties in design and construction of a single detector and/or instrument with such a breadth or range, two detectors or instruments are permissible, assuming

Criteria

Required Action

- that all the other criteria specified in this section are met and that a one decade overlap is provided. Linear scales are preferred for ease of readout and reduction of error in calibration.
- Photon energy dependence shall be $\pm 15\%$ over the range 7 keV to 2.75 MeV (more than one detector permissible). Test: V.4.7
 - Detection capability shall be provided for beta particles with energies greater than 100 keV. The beta energy dependence shall be $\pm 30\%$ over the range 0.2 to 2 MeV E_β maximum. Test: V.4.7
 - Angular dependence for photon measurement shall be $\leq 15\%$ in a 2π steradian frontal direction, referenced to photons with energies in the region 0.6 to 1.25 MeV. Test: V.4.8
 - Readout for photon and beta instrumentation shall be direct and in units of dose or exposure per hour. However, high range instruments intended exclusively for rescue work may be calibrated in units of R/min or rad/min, and if so, the instrument and readout should be clearly and distinctively marked. The readout shall be such that multipliers (e.g., X10, X100) shall be included. Inspection/Engineering Review
 - Readout for alpha instrumentation shall be direct. The readout shall be such that multipliers (e.g., X10, X100) shall be included. Inspection/Engineering Review
 - Overall instrument accuracy shall be $\pm 20\%$ over the entire operating range, with precision of $\pm 10\%$ at the 95% confidence level for any single measurement level. Test: V.4.5
Calibration: IV.2.1.8
 - Overall instrument response (0 to 90% of full reading) time, after a one minute warm-up, shall be ≤ 10 seconds on the most sensitive ranges and ≤ 2 seconds on full scale ranges of 100 mrad/hr, 100 mR/hr and 5000 d/m/100 cm² and higher. Variable Test: V.4.9

Criteria

Required Action

- response time capability may be included. Response time to a decreasing field (full reading to 10% of original reading) shall be no greater than response times to increasing fields.
- Stability shall be evidenced by the ability of the instrument to maintain accuracy and precision for at least 24 hours after initial warm-up. Test: V.3.3
 - Resolution (readout capability) is defined as the minimum detectable change in meter response. Resolution shall be $\leq 4\%$ of full scale for a linear scale or $\leq 8\%$ of a reading for log scale with a maximum of two decades per 90° of meter movement. Test: V.4.3
 - Detectors and associated electronic circuitry, readout and display devices, and power supplies shall be wholly interchangeable between instruments of a given type. With the exception of the detector and display, solid state electronics should be used throughout. Inspection/Engineering Review
 - The readout shall be lighted to permit use in darkness; self-illumination should be considered. Inspection/Engineering Review
 - A 10 mV or 1 mA recorder output shall be provided for instruments which are to be used with a recorder. Inspection/Engineering Review
 - The instrument should be designed to be powered by readily available cells or batteries such as AA, C or D cells or 9-volt batteries meeting specifications published by the U.S. National Bureau of Standards. Compatibility with alkaline, Ni-Cd, or mercury cells should be considered. Provision for operation from a standard automobile 12 volt system and 117 volt, 60 Hz, AC, also should be considered. Inspection/Engineering Review

Criteria

Required Action

- Minimum battery lifetime shall be 200 hours of continuous duty operation at an exposure level of 10% the maximum full scale reading, at temperatures above 0°C. At temperatures below 0°C, alkaline batteries shall be used and the minimum battery lifetime shall be 100 hours of continuous operation.
Test:
V.3.8.3
- The instrument shall be equipped with a battery check switch and indicator of battery condition. Low or dead battery indication shall be positive, i.e., the instrument shall read up-scale, and zeroing shall be rendered impossible.
Test:
V.3.8.5
- When responding to levels in excess of the maximum range, the readout shall remain full upscale.
Test:
V.4.10
- Overall instrument response shall not change by more than $\pm 10\%$ from the previous calibration when batteries are changed.
Test:
V.3.8.4
- The total weight of the fully assembled survey meter, including batteries, should not exceed 3 kg (6.6 lbs).
Inspection/
Engineering
Review
- For the operating temperature range the temperature coefficient shall be $< 5\%$ per °C, and it should be $\pm 15\%$ over the entire range.
Test:
V.2.7.7
- The operating temperature range of the system shall encompass the extremes anticipated. Where the instrumentation may be exposed directly to ambient outside temperatures, the 50 year extreme shall be applied.
Test:
V.2.7
- The instruments shall be splashproofed. The instrument system shall be unaffected by relative humidities from 40% to 95% over the temperature range of 60°F to 120°F.
Test:
V.2.9,
V.2.8

Criteria

Required Action

- Response to noise shall be undetectable at noise pressure ≤ 100 dbA (referenced to 0.0002μ bar) in the frequency range of 1 to 1000 Hz. Test: V.2.3
- Extracameral responses should be undetectable in photon field to 10 R/hr, referenced to 1 MeV energy, and to beta fields providing an air dose of 10 rad/hr, referenced to 2 MeV E_B maximum. Test: V.4.11
- The system shall be unaffected by magnetic fields with intensity to 10 oersteds. Test: V.3.7
- The system shall be capable of withstanding harmonic g loadings applied in each of three mutually orthogonal axis in the frequency range of 1 to 33 Hz with no lasting detrimental effects. The magnitude of the g loading shall be the larger of 1 g or the maximum g forces anticipated in the individual project siting specifications. Test: V.2.4
- There shall be no deleterious effect to the system from:
 - 1) radiofrequency field intensity of 1000 V/m, Test: V.3.7.8
 - 2) microwave exposure to 10 mW/cm^2 , Test: V.3.7.9
 - 3) photon exposure to 5×10^5 R referenced to the energy range between 0.8-1.2 MeV, Test: V.4.14.3
 - 4) external electrostatic fields of 500 V/cm Test: V.3.7.1
- Geotropism: The change in reading with spatial orientation shall be $\leq 5\%$ of full scale reading. Test: V.2.1

If an integrating capability is provided the following shall apply:
- Portable radiological instruments with integrating capability should have integrating ranges as shown: Test: V.4.1.15
 - Photon Exposure 0.1 to 10^4 R Calibration: IV.2.1.9
 - Beta Dose: 0.1 to 10^4 rad

Criteria

Required Action

Integrating units shall be equipped with an audible alarm having a continuous or intermittent warbling tone with a frequency in the region of 2 to 7 kHz and a sound level of 85 dbA at a distance of 50 cm from the instrument.

Test:
V.4.1,
V.2.10

- The alarm shall be pre-settable to any level by an external switch. External reset capability shall also be provided.
- An alarm test position or switch shall be provided.

Test:
V.4.1.2

Inspection/
Engineering
Review

If the survey instrument is to be combined with recorders or air samplers and operated while carried (semi-portable), the following shall apply:

- The instrument will be capable of and designed for convenient transportability by a single person. This criterion does not preclude the use of back packs, neck or shoulder straps, belts, or other means of attachment to the body.
- The weight of the total instrument, including power source, will not exceed 22.5 kg (50 lbs).

Inspection/
Engineering
Review

Inspection/
Engineering
Review

If the survey instrument is to be operated while mounted in an airplane, motor vehicle or boat (mobile), the following shall apply:

- Any of the instrumentation that may be used in an airplane shall be designed to operate properly at an altitude of 5000 feet and 100 feet over the surrounding terrain.
- Mobile instrumentation shall be designed to provide a readout using a strip chart recorder.
- Each separate portion of the mobile instrument system shall weigh less than 22.5 kg (50 lbs)

Test:
V.2.2

Inspection/
Engineering
Review

Inspection/
Engineering
Review

III.3.2.3 Airborne Particulate Monitoring

An important element of preparation for an emergency is to establish in advance the instruments and procedures to be used:

1) to quickly assess the seriousness of the event from the moment an accident involving release is recognized, 2) to determine airborne levels which will permit decisions and action regarding people downwind and, 3) after the fact, to reconstruct the event for the record and further assess the consequences of the release. All these activities are directed at preventing and mitigating human exposure.

In the early stages of an accidental release the immediate concern is airborne concentrations in the environs. Monitoring stations will provide some information when suitably located for fission product releases. In the case of plutonium only releases, means should be available to sample and measure plutonium near the ground at points to be designated from the real-time meteorology and the knowledge concerning the gross nature of the accident. This would include knowledge of integrity of the physical plant, whether fire criticality event or transuranium release had occurred or not, apparent integrity of air cleaning, etc.

Stack Monitor Performance Criteria

Required Action

- Particulate radioactive material shall be removed by filters with effective pore size $\leq 5 \mu\text{m}$, having an efficiency of $\geq 99.5\%$ for particles with diameters $\leq 0.3 \mu\text{m}$. (6)
- A constant sample flow rate shall be used and a constant displacement pump should be used as the air mover. An appropriately calibrated airflow meter shall continuously verify sample flow rate, and shall be accurate to within $\pm 20\%$.

Test:
V.2.12.2

Test:
V.2.12.5

Criteria

Required Action

- The system shall be designed to remove, on a continuous basis, a representative sample. (5) Inspection/Engineering Review
- Particulate-generating gas phase reactions, corrosion, or release of contaminants should be absent downstream of the sampling point. Inspection/Engineering Review
- When sampling a stack, the sample point shall be no less than 8 duct diameters and preferably should be at least 10 duct diameters downstream from any injection point or point of transition. A multientry probe shall be used for sampling in the duct or stack unless prior tests have shown concentrations to be uniform to $\pm 10\%$ across the stack. (5) Inspection/Engineering Review
- Sampling conditions should approach isokinetic. The sampler inlet velocity to duct velocity ratio should be 1.0 ± 0.2 . Test: V.2.12.3
- Sampling lines shall be kept short. Where possible, the distance from sample point to collector should be less than 10 feet. Sample line bend radii shall exceed five sampling line diameters. (5) Inspection/Engineering Review
- The sample delivery system shall be corrosion resistant and designed for streamline flow with no right angles or sharp bends. Stainless steel should be used for construction, and plate out of radioactive materials should be less than 5%. Inspection/Engineering Review
- Stack monitor should be based upon rate of increase of activity rather than pre-set count. Inspection/Engineering Review
- The range of detection capability shall overlap the range of stack monitoring instrumentation used for routine or non-emergency monitoring. (The emergency instrumentation and routine instrumentation may be the same.) Inspection/Engineering Review

Criteria

Required Action

- The entire system operation shall be put on routine maintenance, checked at least quarterly, and calibrated and maintained when indicated.

Calibration:
IV.2.1.4

Environmental Air Monitor Performance Criteria

The criteria listed here are in addition to those general criteria just presented.

- The system shall be designed to take a representative sample of the ambient air on a continuous basis.⁽⁵⁾ The preferred sampling location is at one meter above ground level in a location free from unusual micrometeorological or other conditions (e.g., proximity of large buildings, vehicular traffic) which could result in artificially high or low air concentrations.
- The sample collected should be easily measurable in place with portable monitoring instruments and removable for subsequent laboratory analysis.
- The measurement capability for particulate activity shall have a minimum range of 10^{-3} to 10^{-7} $\mu\text{Ci}/\text{cm}^3$ gross alpha referenced to ^{239}Pu for 30 minute sample. This range shall overlap the range of instrumentation used for routine or nonemergency monitoring.
- The measurement capability for particulate activity shall have a minimum range of 10^{-1} to 10^{-6} $\mu\text{Ci}/\text{cm}^3$ gross beta-gamma referenced to ^{137}Cs for a 10 minute sample. This range shall overlap the range of instrumentation used for routine or nonemergency monitoring.
- The instrument systems shall be protected from the external environment and should be housed in a locked facility to afford a measure of security from accidental or willful damage or tampering.

Inspection/
Engineering
Review

Inspection/
Engineering
Review

Test:
V.4.1.9

Test:
V.4.1.9

Test:
V.2.8,
V.2.9

Criteria

Required Action

- The entire system operation shall be checked at least quarterly and calibrated and maintained when indicated.
- To simplify calibration, operation and interpretation, a fixed sampling rate of 10 to 30 liters per minute should be used. Sampling rate shall remain constant to within $\pm 25\%$ during normal operation.
- The unit shall be compatible with membrane, glass fiber, cellulose fiber, and charcoal loaded filters commonly used for air sampling. The size of the filter used is dependent upon the size of the detector, but a 47 mm diameter should be considered. Filter diameter should not exceed 100 mm.
- Air flow shall be continuously indicated by an appropriate clearly marked gage having an accuracy of $\pm 20\%$.

Calibration:
IV.2.1.5

Test:
V.2.12.6

Inspection/
Engineering
Review

Test:
V.2.12.5

If a portable or mobile system, the following criteria apply:

- Power should be provided by wet cells which conform to the specifications put forth by the National Bureau of Standards.
- Battery lifetime should be greater than 8 hours under load.
- The sampling unit shall be provided with a battery test or other indicator of battery condition.

Inspection/
Engineering
Review

Test:
V.3.8.3

Inspection/
Engineering
Review

If a stationary fixed station, the following criterion applies:

- The system should be capable of operation on 117 V 60 Hz AC and should be unaffected by voltage or frequency changes of $\pm 20\%$.

Test:
V.3.6

III.3.2.4 Personnel Dosimeters

The determination of personnel external exposure or dose is of prime importance in a fuel reprocessing plant. A wide variety of devices integrate external exposure. For emergency purposes

only those devices which provide for a direct, instantaneous readout without disturbing the operation of the device or the accumulation of information will be considered. Hence, for all practical purposes, photographic and luminescent devices are excluded since these require special readout equipment and readout may erase or terminate the usefulness of the device.

Personnel Dosimeters Performance Criteria

Required Action

• The pocket ion chamber shall have a range of 0 to 200 R if it is to be used for personnel involved in rescue work in which exposures to 100 R may be incurred. If used for other purposes, such as protection of property, the range shall be appropriate to the maximum permitted exposure. The maximum permitted exposure shall be in the range of 40 to 70% of full scale of the pocket ionization chamber used.	Test:
V.4.1.16
• The instrument shall be provided with an optical system to permit direct readout. Major scale divisions shall be indicated by heavy lines at 0, 50 and 100% of scale; the scale should be further subdivided into tenths and twentieths by progressively shorter and/or less bold lines.	Inspection/
Engineering
Review
• Leakage shall be $\leq 2\%$ of full scale in a 24 hour period.	Test:
V.3.9.1
• Accuracy shall be $\pm 25\%$ of the true exposure referenced to 20 to 80% of full scale exposure. Precision at any level shall be $\pm 10\%$ at the 95% confidence level.	Test:
V.4.5,
V.4.6
Calibration:
IV.2.1.10
• Energy dependence shall be $\pm 10\%$ for photons in the energy range 35 keV to 1.3 MeV.	Test:
V.4.7
• The instrument system shall be unaffected by relative humidities from 40% to 95% over the temperature range of 60°F to 120°F.	Test:
V.2.8.7
• For the operating temperature range, the temperature coefficient shall be $\pm 0.5\%$ per °C and it should be $\pm 15\%$ over the entire range.	Test:
V.2.7.9

Criteria

Required Action

- The unit shall be rate independent to 10^4 R/hr. Test:
V.4.12.1
 - There shall be no deleterious effect to the system from:
 - 1) radiofrequency field intensity of 1000 V/m, V.3.7.8
 - 2) microwave exposure to 10 mW/cm^2 , V.3.7.9
 - 3) photon exposure to 5×10^5 referenced to the energy range between 0.8 to 1.2 MeV, V.4.14.1
 - 4) external electrostatic fields of 500 V/cm. V.3.7.1
V.3.7.7
 - The unit shall be unaffected by magnetic fields with intensities of 10 oersteds. Test:
V.3.7
 - The unit shall be able to withstand mechanical stress or shock equivalent to a drop from a height of 4 feet onto a hard surface; such a shock or stress shall not change or alter any reading more than $\pm 10\%$ of full scale. Test:
V.2.5
 - Change in reading with spatial orientation shall be $\leq 3\%$ of full scale. Test:
V.2.1
 - Angular dependence shall result in a reading of not less than 70% of the true reading for a specified energy when energy dependence is being evaluated. Test:
V.4.8
 - Sensitivity shall be $\leq 5\%$ at midscale. Test:
V.4.3
 - The unit shall:
 - 1) be nonresponsive to beta radiations with energies ≤ 2 MeV, or Test:
V.4.15.2
 - 2) be accurate to within $\pm 30\%$ for beta radiations with energies from 100 keV to 2 MeV. V.4.5.3
V.4.7.4
- The scale shall be calibrated in rads; for photons, 1R can be taken to equal 1 rad.

Alarming Dosimeters

- A meter, digital register or other readout shall continually register the accumulated dose.
- The instrument shall weigh no more than 300 grams (~10.5 oz)
- The instrument should be powered by any single or combination of commercially available alkaline type dry cells. Mercury cells, while acceptable, are discouraged.

Required Action

Test:
V.4.1.15

Inspection/
Engineering
Review

Inspection/
Engineering
Review
Calibration:
IV.2.1.11

IV. CALIBRATION

All radiation instruments should be adequately calibrated so that their readings may be properly interpreted. The detailed calibration procedures to be used depend upon the types of instruments available and their use in the field. A proposed ANSI standard⁽¹⁶⁾ has been devoted to the subject of calibration of portable radiological instruments and is generally applicable to emergency radiological instruments. Calibration is divided into the following sub-categories:

- Precalibration

The following conditions shall be established prior to exposing the instrument to a source for adjustment and calibration:

1. The instrument should be free of significant radioactive contamination.
2. The meter shall be adjusted to zero or the point specified by the manufacturer using the adjustment(s) provided.
3. The batteries or power supply shall comply with the instrument manufacturer's specifications.
4. The instrument shall be turned on and allowed to warm up for the time period specified by the manufacturer.
5. Electronic adjustments such as high voltage shall be set, as applicable, to the manufacturer's specifications.
6. Geotropism shall be known for orientation of the instrument in the three mutually perpendicular planes, and this effect shall be taken into account during calibration.
7. The performance of any internal sampling time base in digital readout instruments should be verified as being within the manufacturer's specifications.

- Primary Calibration

1. General

The reproducibility (precision) of the instrument should be known prior to making calibration adjustments. This is particularly important

if the instrument failed to pass a performance field check or if repairs have been made. To check reproducibility, the instrument should be exposed to a radiation field three or more times under identical conditions. The readings obtained should normally not deviate from the mean value by more than $\pm 10\%$.

The response of an instrument may vary as a function of such parameters as energy, temperature, pressure, humidity, and source/detector geometry. The Primary Calibration should be accomplished with known values of these parameters. The calibration should be performed under the conditions specified by the manufacturer. Alternatively, any of these parameters may be fixed to the condition in which the instrument is to be used routinely, and notation made of these values. Described below are the steps that constitute the Primary Calibration when taken in conjunction with precalibration above.

2. Readout Scale and Linearity Calibration and Adjustment

a. Linear Readout Instruments

Linear instruments usually have a scale selection switch. If controls are provided for each scale, adjustment of each shall be made according to the manufacturer's specifications or at the midpoint of each scale. If only one control is provided, adjustment shall be made either 1) at the point specified by the manufacturer, 2) near the midpoint of the middle scale, or 3) near the midpoint of a scale that is particularly important to the user's requirements. After adjustment, calibration shall be checked near the ends of each scale (approximately 20% and 80% of full scale).

b. Logarithmic Readout Instruments

Logarithmic readout instruments commonly have a single readout scale spanning several decades with two or more adjustments. The instrument should be adjusted for each scale according to the manufacturer's specifications or, alternatively, at points of particular importance to

the user. After adjustment, calibration shall be performed at a minimum of one point near the midpoint of each decade.

c. Digital Readout Instruments

Digital instruments may have manual scale switching, automatic scale switching (auto ranging) or no scale switching. For instruments with either manual or automatic scale switching, the calibration shall be performed as in 2(a) above. For instruments without scale switching, the calibration shall be performed as in section 2(b) above.

- Calibration for Special Conditions

1. General

If the instrument is to be used under conditions (i.e., radiation energy, temperature and pressure, or source/detector geometry) which vary significantly from those for which the instrument is designed, the instrument should be adjusted, calibrated and used only for the special conditions. When an instrument is calibrated for special conditions, a special condition identification label shall be attached (in addition to any required calibration labels) to indicate its applicability for this special use only. However, if the instrument is also to be used within its design limits, the adjustments made during Primary Calibration shall remain the same, and instrument readings for the special conditions shall be corrected using correction factors obtained from appropriate tables or graphs. Only one parameter should be varied at a time during calibration for the special conditions, but the interrelationships of the variables should be known.

2. Radiation Energy

Calibration shall be performed with a standard source(s) providing radiation fields similar to those in which the instrument will be used. Where instruments will be used in radiation fields of widely differing energies, the response of the instrument at several energies over the range shall be determined.

3. Temperature, Pressure and Humidity

Instruments to be used outside the manufacturer's recommended temperature range or at temperatures which differ by more than 30°C from the calibration temperature shall be calibrated over the temperature range at which they will be used. Care should be taken to ensure that instruments are not exposed to temperatures that will damage detector or electronic components. In addition, instruments shall be calibrated at the approximate humidity or pressure expected to be encountered in use. Care should be taken to ensure that an instrument is not damaged by exceeding its pressure or humidity limits.

4. Detector Directional Dependence

If an instrument is to be used in a detector orientation relative to the source which is different from that used during Primary Calibration, correction factors should be developed.

5. Calibration Frequency for Special Conditions

Calibration for special conditions need be performed only once unless 1) the instrument is modified or physically altered, 2) the special conditions are changed, or 3) the Primary Calibration is altered.

- Periodic Recalibration

Periodic recalibration includes a precalibration check followed by adjustment and primary calibration and perhaps a recheck of response, if any, to unwanted radiations. During the precalibration check, the instrument is tested to assure that certain operating requirements, specified by the manufacturer, are met. Thus, the instrument is determined to be in proper working order prior to calibration and adjustment.

Recalibration shall be scheduled after any maintenance or adjustment of any kind has been performed on the instrument. For this requirement, battery change is not normally considered maintenance.

- Performance Field Checks

To assure proper operation of the instrument between calibrations, reference readings shall be obtained on each instrument when exposed to a check source in a constant and reproducible manner at the time of or promptly after Primary Calibration. If at any time the instrument response to the check source differs from the reference reading by more than $\pm 20\%$, the instrument shall be returned for calibration or for maintenance, repair and recalibration, as required. Reference readings should be obtained for one point on each scale or decade normally used. The check source should accompany the instrument if it is specific to that instrument.

- Performance Check Frequency

A performance check shall be made prior to each use, during intermittent use conditions and several times a day during continuous use.

IV.1 CALIBRATION EQUIPMENT, FACILITIES AND CAPABILITIES

IV.1.1 CALIBRATION STANDARDS

A number of calibration standards may be used for calibrating radiation instruments. The more commonly used standards are calibrated radionuclide sources, secondary instruments, free air ionization chambers, precision long counters, calorimeters and chemical dosimeters. Calibrated sources are easily used and maintained. Some nationally recognized group should provide primary calibrations to assure consistency for all radiation calibrations.

Cobalt-60, cesium-137 and radium sources may be calibrated with an accuracy of a few percent or better. These sources may then be used in low-scatter radiation positions to calibrate other sources or instruments. Primary calibrations may be provided with specially designed condenser ionization chambers, commonly known as R meters, or any of several similar systems now commercially available. Normally these

standardizing instruments are calibrated against some primary source prior to their actual use. They offer many advantages to a calibration laboratory because they are small and convenient to use in establishing dose rates at locations within the calibration facility. Laboratory jigs, such as radiation source wells, may be calibrated with these instruments and subsequently the source wells may be used in the routine monitoring instrument calibration program. For energies below about 100 keV, a simple free air ionization chamber or specially calibrated R meter may be used for primary calibrations. The fundamental electrical measurements and the physical dimensions of the free air ionization chamber provide data for direct calculation of the radiation dose. For calibration of low-energy X rays, this instrument is highly recommended.

A precision long counter or manganese sulphate bath provides a neutron moderating assembly for the accurate calibration of neutron flux. Calorimetry is a straightforward and fundamental method for calibrating all types of radiation sources--photon, beta and neutron. Calorimeters are normally not simple devices and are used primarily as precision control instruments for laboratory type measurements and fundamental calibrations.

IV.1.2 CALIBRATION SOURCES

Radiation fields used for calibration must be thoroughly understood in terms of quality, quantity, and reproducibility. Radiation sources and standard instruments that may be used in calibration are discussed in Reference 1b. Such problems as charged particle equilibrium, scattered or unwanted radiations from the source, and ambient background radiation must be taken into account quantitatively.

IV.1.2.1 Photon Calibration

For photon calibrations three types of radiation source are commonly used--radionuclides, filtered X rays and K-fluorescent X rays. Radiation sources may be used in scatter-free conditions for direct exposure of monitoring instruments or dosimeters, or in source wells or special jigs which have themselves been calibrated with appropriate secondary

standards. Source wells permit the positioning of a radiation source vertically within a long, properly shielded tube, and are frequently used when many instruments of the same design require repeated calibrations. Collimated beams with or without special shielding are similarly used.

Heavily filter X rays may be used to provide calibrations at specific effective energies. Details of filtered X-ray beams are given in Table 1. These beams are normally calibrated with standard condenser ionization chambers (R meters). A schematic diagram of a suitable layout of the apparatus for calibrations with an X-ray machine is shown in Figure 1.

K-fluorescent X rays may be used to provide energy response studies in the region of 8 keV to 100 keV and are usually calibrated with free air ionization chambers or R meters. A list of suitable radiation materials is shown in Table 2⁽¹⁷⁾. Special jigs or calibration equipment may be designed to position monitoring instruments or dosimeters about the filtered X rays and K-fluorescent sources as shown in Figure 2.

IV.1.2.2 Beta-Particle Calibrations

Beta-particle calibrations are usually provided by means of radioactive sources or, less frequently, by accelerators. Sources commonly used are strontium-90 and natural uranium in equilibrium with its daughters. Considerable discussion has centered on the surface dose rate of equilibrium uranium, but a value of 225 millirad/h is generally accepted for a well-aged and smoothly polished natural uranium surface. Fundamental extrapolation chamber measurement may be performed to verify the surface dose rate of each slab of uranium used for calibration purposes. In providing beta calibrations, the geometry of the exposures may become an important factor in the use and interpretation of the instruments. If beta calibrations are provided from point sources, correction factors for proper interpretations will clearly be required when the instruments are used to monitor large area beta sources at short distances.

TABLE 1. Details of Heavily Filtered X-Ray Sources⁽¹⁸⁾

Part A

Additional filtration other than inherent (mm)				Tube potential	Mean energy	Width	Effective energy	HVT
Pb	Sn	Cu	Al	(kV _{cp})	(keV)	(keV)	(keV)	(mm)
-	-	0.25	1.0	32	29	4	29	2.23 Al
-	-	1.0	1.0	53	46	8	46	0.245 Cu
-	-	2.5	1.0	67	59	12	59	0.49 Cu
-	2.0	0.53	1.0	97	85	16	87	1.33 Cu
-	4.0	1.05	1.0	129	111	21	110	2.23 Cu
2.0	3.0	0.53	1.0	171	152	22	154	3.90 Cu
3.5	2.0	0.53	1.0	203	181	28	188	4.95 Cu
5.5	2.0	0.53	1.0	224	203	29	209	5.54 Cu

Inherent filtration of X-ray machine 2 mm Al at 250 kV

Part B

Tube potential (kV _{cp})	E _{mean} ^a (keV)	Width at half height (ΔE)	σ ^b (keV)	Δ ^c (%)	Exposure rate at 1 m (mR/h.mA)	Filter (mm)
40	29	12	5.1	30	360	0.1 Cu + 4.0 Al
60	48	17	7.6	29	1320	0.6 Cu + 4.0 Al
80	66	20	9.0	26	240	2.0 Cu + 4.0 Al
100	83	23	11.0	23	138	5.0 Cu + 4.0 Al
120	99	27	12.7	22	210	1.0 Sn + 5.0 Cu + 4.0 Al
150	119	43	16.5	29	1000	2.5 Sn + 4.0 Al
200	157	50	20.4	25	210	1.0 Pb + 3.0 Sn + 2.0 Cu + 4.0 Al
250	205	62	28.5	25	252	3.0 Pb + 2.0 Sn + 4.0 Al
300	248	84	31.8	28	240	5.0 Pb + 3.0 Sn + 4.0 Al

^aE_{mean} = the energy at the maximum of the spectrum

^bσ = standard deviation of the Gauss distribution

^cΔ = ΔE/kV_{cp} in % ("resolving power")

TABLE 1. (contd)

Part C

Tube potential (kV _{cp})	X-ray current (mA)	Primary filter ^a (g/cm ²)	Effective energy (keV)	Spectral peak (keV)	Spectral width at half-height (keV)	Exposure rate at 50 cm (mR/min)
100	15	2.0 Mo	84	86	24	70
130	15	4.0 Mo	108	108	30	67
170	15	8.0 Mo	135	140	36	95
200	15	9.0 Sn	162	164	39	72
250	10	15.0 Sn	205	205	46	73
300	10	8.0 Pb	242	247	60	68

^aFilters placed between two 0.8-mm-thick aluminum sheetsPart D

kV setting	Filter materials and thickness (cm)	Average theoretical energy (keV)	Experimental effective energy (keV)
100	0.0137 Al + 0.0457 Pb + 0.196 Cu	85	88- 92
150	0.254 U + 0.0368 Cd	115	100-127
200	0.2208 Cd + 0.0254 Pt	156	149-164
236	0.0254 U + 0.0457 Pb + 0.0254 Pt + 0.0368 Cd	185	187

FIGURE 1. Equipment Used for Calibration with Filtered X-rays⁽¹⁸⁾

FIGURE 2. Fluorescent X-Ray Exposure Assembly⁽¹⁸⁾

TABLE 2. Details of Fluorescent X-ray Sources⁽¹⁸⁾

Atomic number	Radiator material	Radiator ^a thickness (g/cm ²)	K α_1 (keV)	K α_2 (keV)	K β_1 (keV)	K β_2 (keV)	Weighted average energy (keV) ^b	Al. L-line filter thickness (g/cm ²)	Scattered radiation in fluorescent source (%)	Exposure ^c rate mR/min at 50 cm
29	Cu	0.014	8.047	8.027	8.904	8.976	8.19	0.006	4	18
40	Zr	0.045	15.774	15.690	17.666	17.969	16.07	0.055	2	47
47	Ag	0.074	22.162	21.988	24.942	25.454	22.59	0.103	2	60
56	Ba	0.13	32.191	31.815	36.376	37.255	32.81	0.103	4	55
64	Gd ₂ • O ₃	0.23	42.983	42.280	48.718	49.961	43.78	0.103	4	43
66	Dy ₂ • O ₃	0.26	45.985	45.193	52.178	53.491	46.83	0.215	4	38
68	Er ₂ • O ₃	0.30	49.099	48.205	55.690	57.088	49.99	0.215	5	35
70	Yb ₂ • O ₃	0.35	52.360	51.326	59.352	60.959	53.28	0.441	7	24
72	Hf • O ₂	0.40	55.757	54.579	63.209	64.936	56.79	0.441	7	22
77	Ir	0.55	64.886	63.278	73.549	75.605	65.94	0.441	12	19
82	Pb	0.72	74.957	72.794	84.922	87.343	76.08	0.441	13	18
90	Th	1.50	93.334	89.942	105.592	108.67	94.52	1.446	~15	12
92	U	1.50	98.428	94.648	111.289	114.549	99.61	1.446	~15	12

^aFor oxides only the mass of rare earth is included

^bAssuming relative intensities of 1.0, 0.5, 0.25 and 0.05 for K α_1 , K α_2 , K β_1 , K β_2 , respectively

^cPrimary source 300 kV and 15 mA

IV.1.2.3 Alpha-Particle Calibrations

Most alpha-particle calibrations are provided by using radionuclide sources. Plutonium, uranium, polonium and other alpha emitters are used as small area sources, not point sources, for the calibration of detection type instrumentation. Alpha-particle calibrations and interpretations are usually not difficult because most energies are in the four to five MeV range and the calibrations can easily simulate the energies and geometries to be monitored in the field.

IV.1.2.4 Neutron Calibrations

Neutron calibrations may be accomplished with both isotopic neutron sources and neutron generating equipment. Frequently used neutron sources include radium beryllium, polonium beryllium, americium beryllium, plutonium beryllium, antimony beryllium and occasionally plutonium fluoride. These sources produce a broad spectrum of neutron energies, but generally give rise to relatively low dose rates so that high dose-rate monitoring equipment cannot be calibrated by this approach. Neutrons from accelerator targets are usually required for dose rates greater than a few rem per hour. Short duration pulsed neutrons for calibration of criticality alarms are best obtained from small pulsed reactor configurations.

IV.1.2.5 Electronic Calibrations

In some circumstances it may be desirable and even necessary to perform electronic simulations of radiation calibrations. This may result from lack of sources of appropriate size (particularly for high contamination levels or dose rates) or to minimize radiation exposures to personnel performing the calibrations. Properly done, the electronic simulation will provide adequate calibration. The basic technique consists of 1) establishing a reference point on the instrument being calibrated using an appropriate radiation source, 2) matching the reference point with a nuclear pulse generator or current source as applicable and 3) varying the pulse rate or current value to provide calibration check points for other scales or decades over the instrument range.

IV.1.2.6 Calibration Equipment

To carry out the calibration program, a laboratory requires properly designed and instrumented assemblies (sometimes called jigs or rigs) to position the instruments and sources in proper relationship to one another. The number, size and complexity of the laboratory assemblies will depend on the types of irradiations, instruments and dosimeters needed, and on the amount of calibration carried out. In designing the calibration assemblies the objectives are to:

1. Ensure accurate and reproducible positioning of test instruments and radiation sources;
2. Accommodate instruments of various sizes and shapes;
3. Provide shielding for calibration personnel and of the radiation source when not in use. A system should be used where necessary for remote reading of instrument scales, i.e., mirrors, TV, etc.;
4. Provide a method of moving the radiation source quickly into the desired exposure position, and into the shielded position when the radiation source is not in use;
5. Supply known radiation fields at the calibration position.

Examples of calibration assemblies are shown in Figures 3 to 8.

For laboratories that calibrate large numbers of the same type of beta-gamma survey instruments, calibration wells⁽¹⁹⁾ (Fig. 9) have the advantages of low exposure to the operators, of utilizing less floor space and of very little handling of the source. The requirements of such an installation are:

1. A well lined with a steel pipe starting from a point about 140 cm above floor level (eye level) and extending down for a total length of 600 cm (the dimensions depend on the size of source and the range of dose-rates required);
2. A rail inside this pipe carrying a light trolley for the source;
3. A source trolley which can be moved vertically within the pipe by means of a surveyor's metal tape;

FIGURE 3. Calibration Stands and Equipment for Routine Gamma Calibration - Photo of Stand(18)

FIGURE 4. Calibration Stands and Equipment for Routine Gamma Calibration - Outdoor System(18)

FIGURE 5. Calibration Stands and Equipment for Routine Gamma Calibration - Diagram of Equipment⁽¹⁸⁾

FIGURE 6. Gamma Radiation Exposure Assembly for Personnel Dosimeters⁽¹⁸⁾

FIGURE 7. Beta Radiation Exposure Assembly - Point Source⁽¹⁸⁾

FIGURE 8. Fast-neutron Exposure Assembly⁽¹⁸⁾

FIGURE 9. Diagram of Calibration Well⁽¹⁸⁾

4. A reel device for taking up this tape and controlling the source height;
5. Massive shielding above and below the floor level equivalent to 8 cm lead plus 45 cm of concrete;
6. The thickness of the lead shield should be increased to 14 cm for a distance of 20 cm below the top of the well. The 8 cm-thick lead shield should extend 75 cm below floor level decreasing to 40-50 cm;
7. A light trolley which moves across the opening of the well and carries the instrument so that it can be removed from the beam without exposing the operator's hands to the radiation;
8. A device for arresting the rapid downward movement of the source trolley in the event of tape failure, e.g., a dashpot or spring arrangement;

9. A remote handling device for removing the source from the bottom of the well;
10. A stop to prevent the source from being moved nearer than 20 cm from the top edge of the well;
11. A switch to operate a warning light when the source is raised from the bottom of the well.

Because of the problems of increased scattering, the radiation field from the radium source can no longer be standardized in terms of its specific gamma-ray emission constant. Standard cavity ionization chambers with accuracies of one to two percent are available for this type of calibration. Of course other sources, e.g., ^{60}Co , ^{137}Cs , ^{122}Ir , or neutron sources may be used in the vertical wells.

IV.1.3 CALIBRATION FACILITIES

The building space, methods and staff necessary to properly operate a calibration laboratory depend on the volume and type of work undertaken. Calibration facilities exist that employ from a fraction of one employee's time up to tens of people. The amount of building space needed depends on such diverse factors as volume of business, land and building costs, shielding, scatter, required accuracy, types of radioactive sources and instruments, and energy and strength of sources. Several types of rooms may be necessary including irradiation rooms, storage vaults and offices. The methods for proper, efficient and safe operation of the laboratory must be correctly established and should include such functions as receiving and handling instruments, calibration of test irradiation systems, calibration of instruments, return of calibrated instruments, reporting of results, keeping records of laboratory activities, maintenance and development of calibration procedures. The number of laboratory staff, of course, would depend on the volume of business. In any case, the technical integrity of the laboratory should be above reproach. Typical laboratory buildings, staffing requirements, and laboratory facilities have been described in the literature and can be adapted to most needs⁽¹⁸⁾.

IV.1.4 CALIBRATION QUALITY CONTROL

Any calibration facility will require a well organized and detailed internal quality control program. This program should provide a system of checks on all calibration jigs and assemblies and a schedule of recalibrations to assure top-quality control in the calibration operations. The use of monitoring instrumentation to signal abnormal conditions should be a fundamental part of each calibration jig assembly. Of equal importance is the training and assignment of fully qualified staff to the calibration function. One should select individuals who clearly possess traits of good organization and attention to detail. A calibration facility should not be operated by an inexperienced staff in training for other radiation protection assignments, although it can provide good training and background for staff members assigned to assist in the calibration functions. Trainees should always be under the supervision of an experienced and competently trained calibration staff member.

IV.1.5 REQUIRED CALIBRATION ACCURACIES

Calibration accuracies may be identified at five levels of performance: primary standards, secondary standards, laboratory standards, field standards and emergency standards. Primary standards are those established within a country or group of countries and utilized to assure consistency in interpretation and measurement of radiation quantities. Secondary standards are those standards utilized by the individual laboratories in providing their calibrations of field instrumentation and laboratory special-studies equipment. Laboratory standards are those standards utilized in precision radiochemistry and physics work. They generally incorporate precise instruments under environmental controls not normally available in radiation monitoring and dosimetry in the field. Field standards indicate the degree of performance that is required and that can be obtained in routine operational radiation protection programs. Emergency standards are relaxed somewhat from the other standards because they will be used only infrequently. One should, of course, not hesitate to use the best measurement instruments available

meeting the total demands of an emergency program. For most instruments, accuracies better than those listed in Table 3 will be provided by the instrumentation selected. Typical standards for photon, beta, and neutron radiations for each of these five calibration categories are summarized in Table 3.

TABLE 3. Suggested Radiological Standards

<u>Standard Category</u>	<u>Radiation Type</u>	<u>Radiation Quantity</u>	<u>Allowable Error (%)</u>
1. Primary	All	All	State of the Art
2. Secondary	Photon	Exposure	±2
	Beta	Dose	±5
	Neutron	Dose	±5
3. Laboratory	Photon	Exposure	±5
	Beta	Dose	±10
	Neutron	Dose	±10
4. Field	Photon	Exposure	±20
	Beta	Dose	±25
	Neutron	Dose	±25
5. Emergency	Photon	Exposure	±40
	Beta	Dose	±40
	Neutron	Dose	±40

IV.1.6 CALIBRATION RECORDS

A record shall be maintained of all calibration, maintenance, repair, and modification data for each instrument. The record shall be dated and shall identify the individual performing the work. The record shall be filed with previous records on the same instrument in accordance with American National Standard N13.6-1966 (R1972).⁽²²⁾

Each instrument shall be labeled with the following information:

- Date of most recent calibration.

- Initials or other specific identifying mark of calibrator.
- Energy correction factors, where required.
- A graph or table of calibration factors, where necessary, for each type of radiation for which the instrument may be used. This should relate the scale reading to the units required if units are not provided on the scale.
- Instrument response to an identified check source (to be provided either by calibrator or user).
- Unusual or special use conditions or limitations.
- The date that Primary Calibration is again required.
- Special condition identification label (if applicable).

IV.2 PROCEDURES FOR RADIOLOGICAL CALIBRATION

Calibration of radiological instruments have typically included many of the procedures which for purposes of this documentation have been included under section V, Performance Testing and Evaluation. An instrument offered up for "calibration" will be considered to have been tested and found in conformance with the performance criteria. Therefore, calibration will consist of making simple adjustments of electronic variables which result in the instrument responding appropriately (statistically) to a limited number of radiation sources or electronic input signals.

IV.2.1 CALIBRATION OF INSTRUMENTATION FOR NUCLEAR FACILITIES

IV.2.1.1 Plume Detection Calibration

Equipment

^{60}Co source
 ^{137}Cs source
Pulse Generator
Calibration Jig
Voltmeter

Procedure

1. Turn on plume detector and allow appropriate warmup time.
2. Check and adjust photomultiplier and other critical voltages to specifications.
3. Check and adjust zero.
4. Introduce a ^{60}Co source and adjust the plume detector so that only the ^{60}Co photon sum peak (~ 2.5 MeV) is registered.

NOTE: Maintain sufficient source to detector distance to assure the detector is in a uniform field.

5. Introduce a ^{137}Cs source and observe that there is no change in plume detector response. If there is response to the ^{137}Cs source, repeat step 4. Remove the ^{137}Cs source.
6. Adjust the ^{60}Co photon flux at the detector to 1750 sum peak events per second and adjust the plume detector to read 5×10^{-2} Ci/m. Remove the ^{60}Co source.
7. Disconnect the photomultiplier signal lead from the plume detector and attach the signal lead from the pulse generator to the plume detector.
8. Adjust the pulse generator output pulse to approximate the ^{60}Co sum peak pulse shape and size. Adjust the pulser pulse rate so that the plume detector reads 5×10^{-2} Ci/m (midrange) on the appropriate scale.
9. Increase the pulser rate by an order of magnitude ($\times 10$) and adjust the plume detector to read an order of magnitude higher (midrange) on the appropriate scale.
10. Repeat step 9 for each additional available scale or range decode.

IV.2.1.2 Containment Vessel Noble Gas Monitor Calibration

Equipment

^{60}Co source
 ^{137}Cs source
Pulse Generator
Calibration Jig
Voltmeter

Procedure

1. Turn on monitor and allow appropriate warmup time.
2. Check and adjust photomultiplier and other critical voltages to specifications.
3. Check and adjust zero.

4. Introduce a ^{60}Co source and adjust the monitor so that only the ^{60}Co photon sum peak (~ 2.5 MeV) is registered.

NOTE: Maintain sufficient source to detector distance to assure the detector is in a uniform field.

5. Introduce a ^{137}Cs source and observe that there is no change in monitor response. If there is response to the ^{137}Cs source, repeat step 4. Remove the ^{137}Cs source.

Monitor calibration depends upon the location of the detector within the containment vessel.

- A. For a detector at the approximate center of the containment volume (21):

$$GS = \frac{Ci/cm^3 (1 - e^{-4.5 \times 10^{-5} r})}{3.4 \times 10^{-15}}$$

Where

- G = geometry factor for test item = photon/count
 - S = count rate in counts per second
 - Ci/cm^3 = specified noble gas concentration in containment
 - r = radius of containment vessel in cm
 - GS = photons/count x counts/sec = photon/sec passing through the detector
6. Calculate GS for the known r and for a noble gas concentration of $5 \times 10^{-9} Ci/cm^3$.
 7. Expose the test item detector to ^{60}Co photon flux calculated in step 6 and adjust the monitor to read $5 \times 10^{-9} Ci/cm^3$ (midrange) on the appropriate scale.
 8. Disconnect the photomultiplier signal lead from the monitor and attach the signal lead from the pulse generator to the monitor.
 9. Adjust the pulse generator output pulse to approximate the ^{60}Co sum peak pulse shape and size. Adjust the pulser pulse rate so that the monitor reads $5 \times 10^{-9} Ci/m$ (midrange) on the appropriate scale.

10. Increase the pulser rate by an order of magnitude ($\times 10$) and adjust the monitor to read an order of magnitude higher (midrange) on the appropriate scale.
11. Repeat step 10 for each additional available scale or range decode.
- B. For a detector on the containment vessel wall⁽²¹⁾:

$$GS = \text{Ci/cm}^3 \left(\frac{1 - \frac{1}{9 \times 10^{-5} r} + \frac{e^{-9 \times 10^{-5} r}}{9 \times 10^{-5} r}}{6.8 \times 10^{-15}} \right)$$

See Part A for explanation of symbols.

12. Perform steps 12 through 11 of Part A using the equation above to calculate GS.

IV.2.1.3 Containment Vessel--Radioiodine and Particulate Calibration

Equipment

⁹⁰Sr-Y source

Mock ¹³¹I* source

Sources should be of such geometry (diameter, thickness, material, etc.) that they may be put in place of the filter media in the monitor.

Current Source

Pulse Generator

Voltmeter

Calibration Rotameter

Procedure

a. Beta Particulates

1. Disconnect and do not operate vacuum pumps during this calibration.
2. Turn on monitor and allow appropriate warmup time.

* Mock Iodine-131 is produced by the combination of ¹³³Ba and ¹³⁷Cs as follows:
 $1.2 \times 10^5 \text{ d/min } ^{133}\text{Ba} + 9.4 \times 10^4 \text{ d/min } ^{137}\text{Cs} \approx 1.0 \times 10^5 \text{ d/min } ^{131}\text{I}.$

3. Check and adjust detector and other critical voltages to specifications.
 4. Check and adjust zero.
 5. Place a $^{90}\text{Sr-Y}$ source of such size as to give a particulate monitor reading of $5 \times 10^{-10} \text{ Ci/cm}^3$ in the filter holder.
 6. Adjust the particulate readout of the monitor to read $5 \times 10^{-10} \text{ Ci/cm}^3$ (midscale on the appropriate range or decode).
 7. Remove the $^{90}\text{Sr-Y}$ source and connect the pulser or current source (depending upon the type of detector employed) to the particulate detector signal cable and adjust the pulser, pulse shape and size or current level to simulate the source.
 8. Adjust the pulser frequency or current level so that the monitor reads $5 \times 10^{-10} \text{ Ci/cm}^3$ on the appropriate scale.
 9. Increase the pulser rate or current level by an order of magnitude ($\times 10$) and adjust the monitor to read an order of magnitude higher on the appropriate scale.
 10. Repeat step 9 for each additional available scale on range decode.
- b. Radioiodine
11. Repeat steps 5-10 using a mock ^{131}I source and the iodine readout adjustments on the monitor.
- c. Flowrate Calibration
12. Connect the calibration rotameter in series with the monitor flowmeter.
 13. Place appropriate particulate and radioiodine filters in the monitor.
 14. Turn on monitor vacuum system and adjust the flowrate to the required value as indicated by the rotameter.
 15. Check the monitor flowmeter. It should indicate a flowrate within $\pm 20\%$ of the rotameter. If it does not, replace the flowmeter and repeat steps 14 and 15.

IV.2.1.4 Stack Effluent Monitor Calibration

a. Beta Particulates, Radioiodine, Air Flow Rate

Use applicable parts of procedure IV.2.1.3

b. Flow Through Ion Chamber

Equipment

^{90}Sr -Y source(s) of point or other geometry which may be introduced into the ion chamber to give about 50% of first scale reading.

Current Source

Voltmeter

Procedure

1. Disconnect and do not operate vacuum pump during the radiation calibration.
2. Turn on monitor and allow appropriate warm up time.
3. Check and adjust detector and other critical voltages to specifications.
4. Check and adjust zero.
5. Calculate simulated volume source strength of source to be employed.

$$S(\text{Ci}/\text{cm}^3) = \frac{A(\mu\text{Ci})}{V \text{ cm}^3}$$

where S = simulated volumetric activity

A = source activity

V = ion chamber volume

Example: $A = 5 \times 10^{-6} \text{ Ci}$

$V = 10^3 \text{ cm}^3$

$$S = \frac{5 \times 10^{-6}}{10^3} = 5 \times 10^{-9} \text{ Ci}/\text{cm}^3$$

6. Insert the source into the ion chamber (near the geometric center).
7. Adjust the monitor to indicate the calculated, S, value.
8. If ^{90}Sr -Y sources are available which will provide appropriate calibration points on other scales or decades, repeat steps 5-7 for each source.
9. For scale or decade calibration for which sources are not available or impractical, disconnect the signal lead from the ion chamber. Connect the output from the high impedance current source to the signal lead.
10. Adjust the current flow to match the monitor indication of step 7.
11. Use multiples or fractions of the step 10 current value to provide appropriate calibration values for scale or decades not calibrated in steps 5-8.

c. Alpha Particulates

Equipment

^{239}Pu alpha source(s) (at least one of about 1 nCi)

Pulse Generator (optional)

Oscilloscope

Voltmeter

Procedure

1. Disconnect and do not operate vacuum pump during the radiation calibration.
2. Turn on monitor and allow appropriate warm up time.
3. Check and adjust detector and other critical voltages to specifications.
4. Check and adjust zero.
5. Connect oscilloscope input to detector signal output and observe the pulse height distribution of any background pulses.

6. Place the ^{239}Pu source in the sample holder and observe the predominant pulse height associated with ^{239}Pu on the oscilloscope.
7. Adjust the monitor discriminator(s) to reject as much of the background as possible while passing most of the ^{239}Pu pulses.
8. Record the source counting rate C_S . Remove the ^{239}Pu source and record the background counting rate C_B .
9. Calculate the monitor counting efficiency.

$$\text{eff} = \frac{C_S - C_B}{A}$$

$$\text{Example: } C_{\text{eff}} = \frac{225 \text{ cpm} - 5 \text{ cpm}}{1 \text{ nCi} \times 2200 \text{ dpm/nCi}} = \frac{220 \text{ cpm}}{2200 \text{ dpm}} = 0.1$$

10. If ^{239}Pu sources are available which will provide appropriate calibration points on other scales or decodes, repeat steps 8 and 9 for each source. See note, IV.2.1.7, step 12. If the monitor has individual scale or decode adjustments, make adjustments to give appropriate monitor indications.
11. Scales or decodes for which sources are not available can be checked with the pulse generator. Disconnect the detector signal output and connect the pulse generator to the monitor signal lead. Adjust the pulse generator output shape and height to simulate the ^{239}Pu alpha pulses observed in step 6.
12. Adjust the pulse frequency to give the monitor net count rate ($C_S - C_B$) observed in step 8. Note the pulser output frequency (F) to give the desired net count rate.
13. Using appropriate multiples or fractions of F, observe the indicated monitor count rate on scales or decodes not checked in step 10. If the monitor has individual scale or decode adjustments make adjustments to give appropriate monitor indications.

14. Overall deviations of steps 10 and 13 (after adjustments) must fall within the accuracy criteria or repair is required.

d. Beta-Gamma Particulates

Use procedure IV.2.1.7c

IV.2.1.5 Environmental Air Monitor Calibration

a. Beta Particulates, Radioiodine, Alpha Particulates, Air Flow Rate

Use applicable parts of procedure IV.2.1.4 with appropriate source sizes for the different ranges involved.

b. Beta-Gamma Particulates

Use procedure IV.2.1.7.c

IV.2.1.6 Liquid Effluent Monitor Calibration

Equipment

^{60}Co source

Pulse Generator

Voltmeter

Procedure

1. Turn on monitor and allow appropriate warmup time.
2. Check and adjust detector and other critical voltages to specifications.
3. Check and adjust zero.
4. From the geometry in which the detector is operated, calculate the photon flux incident on the detector for a liquid concentration of $5 \times 10^{-9} \text{ Ci/cm}^3$ of ^{60}Co .
5. Expose the monitor detector to a ^{137}Cs photon flux of numerical value as calculated in step 4.

NOTE: Maintain sufficient source to detector distance to assure the detector is in a uniform field.

6. Adjust the monitor to read 5×10^{-9} Ci/cm³ (midrange) on the appropriate scale.
7. Remove the ¹³⁷Cs source and connect the pulser to the detector signal cable and adjust the pulse slope and size to simulate the ¹³⁷Cs source.
8. Adjust the pulser frequency so that the monitor indicates 5×10^{-9} Ci/cm³ on the appropriate scale.
9. Increase the pulse rate by an order of magnitude ($\times 10$) the monitor to read an order of magnitude higher on the appropriate scale.
10. Repeat step 9 for each additional scale or decode.

IV.2.1.7 Ambient Radiation Monitoring Instrumentation

Equipment

Photon Source ($E > 500$ keV)

Beta Source ($E > 100$ keV)

Procedure

a. Photons

1. Turn on instrument and allow appropriate warmup time.
2. Check and adjust detector and other critical voltages to specifications.
3. Check and adjust zero.
4. Introduce a photon source exposure rate of midrange on the first scale or decode and adjust the high energy photon indicator to the appropriate reading.
5. Increase the exposure rate to the value of midrange on the next higher scale or decode and observe the indicated exposure rate. If the instrument has independently adjustable scales, adjust the indication to the appropriate reading. If range adjustments are not independent for each range record the reading, calculate the percent deviation from the actual exposure rate and compare with the accuracy criteria.

NOTE: Maintain sufficient source to detector distance to assure the detector is in a uniform field.

6. Repeat step 5 for each range or decade of required response.

NOTE: At anytime the instrument cannot be adjusted to the appropriate reading (for independently adjustable scales) or the reading falls outside the stated accuracy criteria (non-independent scales) discontinue the calibration and submit the instrument for repair.

7. At the maximum calibration exposure rate of step 6, observe any response of the low energy photon/beta dose rate indicator (on the most sensitive scale). No response should be observed.

b. Beta Radiation

8. Open the beta shield
9. Repeat steps 4, 5 and 6 using the $^{90}\text{Sr-Y}$ source in place of the ^{60}Co source and adjusting the beta/low energy photon dose rate indicator.
10. Repeat step 7 using the $^{90}\text{Sr-Y}$ source and observing the high energy photon dose rate indicator.

c. Air Concentration Beta-Gamma Particulates

Equipment

^{137}Cs source(s)
Pulse Generator
Voltmeter

Procedure

Use procedures IV.2.1.3a and c substituting the ^{137}Cs source for the $^{90}\text{Sr-Y}$.

IV.2.1.8 Transportable Dose Rate and Contamination Survey Instruments

Equipment

Photon Source ($E > 500$ keV)

Beta Source ($E > 100$ keV)

Procedure

a. Beta/Gamma Instruments

1. Turn on instrument and allow appropriate warmup time.
2. Check and adjust zero.
3. Close the beta shield
4. For instruments with separate calibration adjustments for each scale or decode, introduce a photon exposure rate of 50% of the first range or decode. See step 8.
5. Adjust the instrument to indicate the true exposure rate.
Reduce the exposure rate to 20% of full scale and record the instrument indication. Increase the exposure rate to 80% of full scale and record the instrument indication.
6. Compare the instrument indications with the true exposure rate.
Deviations should be within the accuracy criteria. If not, maintenance or repair service is required.
7. Repeat steps 4-6 for each scale or decode.
8. For instruments with one calibration adjustment, perform steps 5 and 6 on a scale at or near the middle of the instrument range.
9. Adjust the exposure rate to 20 and 80% of each remaining scale or decode recording the instrument indications.
10. Compare the instrument indications with the true exposure rate.
Deviations should be within the accuracy criteria. If not, maintenance or repair service is required.
11. Open the beta shield.
12. Introduce a beta dose rate of 50% of the first range or decode.
13. Compare the instrument indication with the true beta dose rate.
Deviations should be within the beta accuracy criteria. If not, maintenance or repair service is required.

b. Alpha Contamination

14. Place a 500 dpm/100 cm² ²³⁹Pu source in contact with the alpha detector and adjust the meter to indicate appropriately.
15. Repeat step 11 in decade increments of source strength of each range or decade.

NOTE: Adjustment of apparent source strength may be accomplished by insertion of "screen" absorber material between the alpha source and the detector. An absorber with 50% holes would reduce the alpha transmission by a like amount. This method is practical over a range of two orders of magnitude per source.

IV.2.1.9 Integrating Survey Instruments

Equipment

Photon Source (E > 500 keV)

Beta Source (E > 100 keV)

Procedure

1. Calibrate the instrument according to IV.2.1.8.
2. Set the integrator alarm point at about 10% of full range or some other convenient value.
3. Introduce the appropriate photon or beta source and adjust the exposure/dose rate to a convenient value.
4. Reset the integrator to zero and accumulate exposure/dose until the alarm sounds. Record the actual exposure/dose required to trigger the alarm.
5. Calculate the percent difference between the integrator alarm set point (step 2) and the actual exposure/dose delivered and compare with the accuracy criteria.

IV.2.1.10 Direct Reading Dosimeters

Equipment

Photon Source (E ≥ 100 keV)

Procedure

1. Expose the dosimeter to the photon radiation for the period of time required to accumulate an exposure of 20% of full scale.
2. Observe the dosimeter exposure indication and compare any deviation from the true exposure with the accuracy criteria.
3. Reset the dosimeter to zero and repeat steps 1 and 2 at 50 and 80% of full scale resetting the dosimeter between exposures.
4. Reset the dosimeter to zero and allow to stand 24 hours in a low background radiation area. Observe the reading and compare with the leakage criteria.

IV.2.1.11 Alarming Dosimeters

Equipment

Photon Source ($E \geq 100$ keV)

Stopwatch

Procedure

1. Set the alarm point at 20% of full scale.
2. Expose the dosimeter to the photon radiation until the alarm trips. Record the exposure duration required to trip the alarm and calculate the true exposure. Record the exposure indicated on the integrator.
3. Compare the true exposure with the alarm set point and integrator indication for conformance with the accuracy criteria.
4. Reset the dosimeter and repeat steps 1-3 for exposures of 50 and 80% of full scale.

IV.2.1.12 Criticality Alarm

a. Neutron Sensitive Detector

Equipment

Neutron source, i.e.; PuBe, PuF, PoBe or Cf

Photon source ($E > 500$ keV)

Stopwatch

Procedure

1. Turn on instrument and allow appropriate warmup time.
2. Check and adjust critical voltages to specifications.
3. Introduce the minimum neutron dose rate which should trip the alarm and note whether the alarm trips within one half second. If the alarm trips, go to 5. If alarm does not trip within one half second, go to 4.
4. Remove or shield the neutron source, reset and adjust the alarm to a more sensitive condition and repeat step 3.
5. Reduce the neutron dose rate the maximum rate which should not trip the alarm. Reset the alarm and note whether an alarm trip occurs within an appropriate time period. If alarm trips, go to step 3. If alarm does not trip go to 6.
6. Remove the neutron source and introduce a photon source exposure rate of 1 R/hr. No alarm trip should occur. If alarm trip occurs, gamma discriminator should be adjusted.
7. If the detector serves as a post-alarm monitoring system, switch to the monitoring mode.
8. Introduce a neutron dose rate equal to midrange on the middle monitoring scale or decode. Adjust the monitor to give the appropriate indicated dose rate.
9. Change the dose rate to the midrange value of the next higher or lower scale or decode and if independent adjustment is provided for this scale or decode, adjust the monitor to the appropriate indication. If independent adjustment is not provided, note the dose rate indicated and calculate the correction factor to be applied to that scale or decode.
10. Repeat step 9 for all scales or decodes of interest. For single calibration adjustment instruments, provide a table of correction factors derived.

b. Photon Sensitive Detector

Procedure

The neutron procedure, excluding step 6, above, may be used replacing the neutron source with a high energy photon source.

V. PERFORMANCE TESTING AND EVALUATION

A review of the literature (see reference list and bibliography) was conducted to determine the availability of acceptable or adaptable testing procedures. Although virtually every manufacturer and user of radiological monitoring instrumentation performs some sort of calibration and evaluation of performance, there is a paucity of published information regarding such procedures. No textbook compendium, or similar document was revealed by the search that could provide procedures to verify or to otherwise measure instrument performance or, in other words, to determine how well an instrument might meet the performance criteria of section III. Thus a general compendium of procedures, techniques and instrumentation systems for the performance evaluation of radiological instruments is apparently lacking. The literature applicable to emergency radiological instrument performance testing techniques was sparse and often specific to a particular instrument system rather than of general applicability. Occasionally pertinent methodology appears as an ancillary part of a document with a different major emphasis or thesis.

This section contains a collection of pertinent tests which resulted from the literature search and a number of methods which were formulated for use where published methodology was lacking. The testing methodology has been divided into three parts: V.2 Mechanical; V.3 Electronic and V.4 Radiological.

V.1 TESTING CONCEPTS AND EQUIPMENT

The intent of testing is to subject the test item to controlled stresses which equal those which may be encountered in service and to determine whether the item continues to function satisfactorily under the stress. The type and range of testing required to certify the performance of emergency radiological instrumentation is generally

outside that for "routine" instruments. The very concept of emergency implies that the instrumentation may be subjected to unusual stress and abnormal radiation levels. Thus, a different level of testing capability is required for emergency instruments than for routine instruments. Stronger sources will be needed to provide orders of magnitude higher radiation levels than commonly utilized in calibration/testing laboratories. Some of the radiological tests can be performed by establishing a radiation reference point and then simulating the other test points with a pulse generator or current source. The use of stronger sources may lead to personnel exposure problems requiring improved personnel protection. Such measures as remote handling capabilities and additional radiation shielding may be needed. New or modified equipment including environmental control chambers, vibration and shock machines and electromagnetic interference generators may be required.

In the following sections, testing methods have been grouped in subsections according to the performance feature being tested. For each performance criteria statement in section III, an appropriate test subsection or specific test within the subsection has been referenced. Where the subsection, for example V.r.5 is referenced, any one of the listed test methods or an equivalent unlisted test is acceptable. If a specific test, for example V.3.7.1 is referenced, it is preferred (of the listed tests) but another listed test, or equivalent unlisted test may be acceptable. Unless otherwise directed, all tests should be conducted under the following standard conditions:

Temperature Range	20°C to 30°C
Relative Humidity	45% to 75%
Air Pressure	650 mm Hg to 800 mm Hg
Line Voltage	115 ± 5 V AC
Line Frequency	60 ± 1 Hz

V.2. MECHANICAL EVALUATION

V.2.1 GEOTROPISM

Geotropism is observed as the fiber-image shift when the instrument is held horizontally and rotated about its optical axis. Geotropic or position dependence effects are related to capacitance effects. In an ideal instrument the meter reading will not change regardless of the position in which the instrument is operated. Generally there is some position dependence due to gravity effects on the meter.

V.2.1.1 Geotropism

Equipment

Nuclear precision pulse generator

Procedure

1. Connect the pulse generator to the test pulse input. Turn on the instrument and pulser.
2. Adjust the pulse generator repetition rate for midscale needle deflection on the most sensitive range.
3. Rotate the instrument through a full 360° in each of two planes normal to each other and perpendicular to the ground. Note the amount of meter deviation from the midscale position. Compare to performance criteria for compliance.
4. Repeat for all sensitivity ranges.
5. Turn off power to pulser and instrument. Remove pulser connection from test pulse input.

V.2.1.2 Geotropism⁽²²⁾

Equipment

None required

Procedure

1. Incline the equipment at the rate of 5 to 7 cycles per minute in one plane to angles of 45 degrees on either side of the vertical for a period sufficiently long to determine its characteristics under such motion or for a minimum of 30 minutes.

2. Repeat step 1 with equipment reoriented 90 degrees to plane of initial test.
3. At the conclusion of the specified cyclic tests, stop the cyclic motion and adjust the inclination to any angle or angles within 45 degrees of the vertical for a sufficient time to investigate the electrical characteristics of the equipment.

V.2.1.3 Geotropism(18,23)

Equipment

Dosimeter Charger

Procedure

With the dosimeter charged to midscale and held horizontally, read the dosimeter:

- with the scale upright and horizontal
- with the dosimeter rotated 90 degrees in each direction
- with the scale inverted.

V.2.2 LOW PRESSURE

The altitude test is conducted to determine the effects of reduced pressure on equipment. Under low pressure conditions, low density materials change their physical and chemical properties. Damaging effects of low pressure include leakage of gases or fluids from gasket-sealed enclosures and rupture of pressurized containers. Erratic operation or malfunction of equipment may result from arcing or corona. Greatly decreased efficiency of convection and conduction as heat transfer mechanisms are encountered under low pressure conditions. Damage due to low pressure may be augmented or accelerated by the contraction, embrittlement and fluid congealing induced by low temperature.

V.2.2.1 Low Pressure (24)

Equipment

Temperature - altitude chamber.

Procedure

1. Place the test item in the test chamber.
2. Reduce the chamber internal temperature to -54°C (-65°F), unless otherwise specified, and maintain until the test item is stabilized.

NOTE: The rate of temperature change (steps 2 and 6) may be the maximum attainable by the chamber, but shall not exceed 10°C (18°F) per minute.

3. Reduce the chamber internal pressure (the rate of pressure change may be the maximum obtainable by the chamber) to the lowest pressure condition for which the test item is designed to operate while maintaining the specified temperature.
4. Maintain the above pressure and temperature for a period of not less than 1 hour.
5. At the conclusion of the time period and while at the same pressure and temperature, operate the test item and compare the data with the data obtained under standard temperature and pressure conditions.
6. With the test item still operating, increase the chamber internal pressure and temperature to standard ambient conditions, stabilize and compare the results with the data obtained previously under standard temperature and pressure condition. During this period, special attention shall be given to electrical and electronic test items for erratic operation or malfunction resulting from arcing or corona.
7. Inspect the test item for evidence of physical damage.

V.2.3 ACOUSTICAL PRESSURE

Some equipment is insensitive to acoustic stimulation even at very high levels. Other equipment may respond in a manner that will modify or disrupt the equipment function. In extreme cases mechanical failure may result. Equipment that is sensitive to vibration is usually sensitive to sound field exposure. For this reason a suitable vibration test is often a good indicator of acoustic sensitivity. However, it is possible that high frequency resonances of some responding equipment elements may be overlooked during the vibration test due to the high frequency limitations of the shaker and vibration attenuation of the test jig and the equipment under test.

V.2.3.1 Acoustical Pressure

Equipment

Acoustical test apparatus
Nuclear precision pulse generator
Test chart recorder

Procedure

1. Suspend the instrument with elastic cords at the center of an equilateral tetrahedron, six feet to the edge, defined by the position of the four speakers.
2. Lower the four microphones into the test area at a distance of 10 inches from each vertical edge of the instrument.
3. Connect the test output voltage of the instrument to the strip chart recorder, turn on the recorder and set the pen to zero.
4. Connect the pulse generator to the test pulse input. Turn on the instrument and pulser.
5. Adjust the pulse generator repetition rate for midscale needle deflection on the most sensitive range.
6. Adjust the strip chart recorder pen sensitivity for midscale pen deflection. Set the chart speed for about 10 cm/hr, carefully note the initial pen position and turn on the chart drive motor.

7. At a constant sound pressure of 90 dB increase the frequency from 1 to 1000 Hz at the rate of 50 Hz/min.
8. Increase the sound pressure to 100 dB, reset the frequency to 1 Hz and repeat the increase to 1000 Hz.
9. Increase the sound pressure to 110 dB, reset the frequency to 1 Hz and repeat the increase to 1000 Hz.
10. Apply a source of random noise, such as an electric drill motor, through the speakers at sound pressures ranging from 80 to 120 dB in 5 dB steps.
11. Turn off power to the acoustical apparatus, pulser, strip chart recorder, and instrument under test. Remove all connections.
12. Measure the various percentage deflections from midscale recorded on the strip chart and note the test conditions which existed at the time of each deviation. Compare test results with performance criteria for compliance.

V.2.3.2 Acoustic Pressure⁽²⁴⁾

Equipment

Reverberation test chamber (pentagonal configuration)

Acoustical generation reproduction and measuring equipment

Procedure

1. Use a microphone (several if desired) to define the sound pressure field within the test volume (central 10% of the chamber volume).
2. Establish the overall sound pressure level desired in the test chamber.
3. Suspend the test item in the test chamber with elastic cord as specified in V.2.3.1. (The natural frequency of all modes of suspension shall be less than 25 cps.)

4. Expose the test item on every surface to the sound field by centrally locating it in the test chamber. (The test item volume should be no more than 10% of the test chamber volume. When the test chamber is a rectanguloid, no major surface of the test item shall be installed parallel to a chamber wall).
5. Monitor at least three microphones located in proximity to each major dissimilar test item surface, at least 18 inches from the test item surface or one-half the distance to the nearest chamber wall, whichever is less.
6. Use test times as specified in Table 1.

TABLE 1. Sound Test Schedule

<u>Category</u>	<u>Test Overall Sound Pressure Level (dB)(a)(b)</u>	<u>Exposure Time</u>
A	140	30 minutes
B	150	30 minutes
C	160	30 minutes
D	165	30 minutes

(a) The average overall sound pressure distribution around the test item should be uniform within -2 and +4 dB of the desired value.

(b) Ref. 2×10^4 dynes/cm².

7. Compare measurements made during or following the test with data obtained under normal operation conditions.
8. Inspect test item for damage.
9. If the test item malfunctions during the test, but performs satisfactorily afterwards, perform a single frequency sound or vibration test to determine whether the malfunction can be duplicated. If duplication occurs, record and compare with results obtained from the continuous spectrum tests.

V.2.4 VIBRATION

The vibration test is used to determine the effects on component parts of vibration within the predominant frequency ranges and magnitudes that may be encountered during field service. Most vibration encountered in field service is not of a simple harmonic nature, but tests based on vibrations of this type have proved satisfactory for determining critical frequencies, modes of vibration and other data necessary for planning protective steps against the effects of undue vibration. Vibration, by causing loosening of parts or relative motion between parts in the specimen, can produce objectionable operating characteristics, noise, wear, and physical distortion, and often results in fatigue and failure of mechanical parts.

V.2.4.1 Vibration⁽²⁵⁾

Equipment

The vibration system, consisting of the vibration machine, together with its auxiliary equipment shall be capable of generating vibration frequencies and magnitudes specified below.

Procedure

Prior to vibration test, proper operation shall be demonstrated. The specimen shall be mounted as specified using suitable mounting apparatus to assure that mounting is free from resonances over the test frequency range. The specimen shall be subjected to a simple harmonic motion having an amplitude of 0.03 inch (0.06-inch maximum total excursion), the frequency being varied uniformly between the approximate limits of 10 and 55 hertz (Hz). The entire frequency range, from 10 to 55 Hz and return to 10 Hz, shall be traversed in approximately 1 minute. Unless otherwise specified, this motion shall be applied for a period of 2 hours in each of 3 mutually perpendicular directions (total of 6 hours). If applicable, this test shall be made under electrical-load conditions.

V.2.4.2 Vibration

Equipment

Nuclear precision pulse generator

Strip chart recorder

Vibration test stand

Procedure

1. Secure the instrument to the vibration test stand in its normal service installation orientation.
2. Connect the test output voltage of the instrument to the strip chart recorder, turn on the recorder and set the pen to zero.
3. Connect the pulse generator to the test pulse input. Turn on the instrument and pulser.
4. Adjust the pulse generator repetition rate for midscale needle deflection on the most sensitive range.
5. Adjust the strip chart recorder pen sensitivity for midscale pen deflection. Set the chart speed for about 100 cm/hr, carefully note the initial pen position and turn on the chart drive motor.
6. With a constant sinusoidal amplitude of 0.1 mm, peak-to-peak, increase the frequency of oscillation from 1 hz to 10 khz at the rate of 1/4 decade per minute.
7. Repeat the same frequency increase at a constant sinusoidal amplitude of 0.1 mm, peak-to-peak.
8. Stop the source of vibrations and the strip chart advance motor.
9. Note the points of maximum pen deflection and determine the corresponding frequencies.
10. Set the chart advance speed to about 10 cm/hr, set the vibrational peak-to-peak amplitude for 1.0 mm. Turn on the chart drive motor and vibrator.

11. Observe the response of each of the points to the exciting frequency found in (9) for a period of 30 minutes.
12. Turn off electrical power to the vibrating test stand, pulser, strip chart recorder and instrument under test. Remove all connections.
13. Measure the various percentage deflections from midscale recorded on the strip chart and note the test frequencies which existed at the time of each deviation.

V.2.4.3 Vibration

Equipment

Vibration generator

Procedure

1. Mounting

The specimen shall be mechanically connected to the vibration generator either directly or by means of a fixture as specified below.

Mounting fixtures shall be such as to enable the specimen to be vibrated along the various axes specified for conditioning. The relevant specification should state, if significant, the maximum level of magnetic interference to which the specimen under test may be subjected. Equipment intended for use with vibration isolators should normally be tested with its isolators.

2. Initial measurements

The specimen shall be electrically and mechanically checked as required by the relevant specification.

3. Conditioning

Unless otherwise stated in the relevant specification, the specimen shall be vibrated in three mutually perpendicular axes in turn, which should be so chosen that faults are most likely to be revealed. Vibrational frequencies which are appropriate are listed in Table 2.

The three test stages (parts 3, 4 and 5) shall be performed in sequence in the same direction and repeated for the other directions. If necessary, the sequence may be varied by the relevant specification, so as to allow resonance search to be carried out in more than one direction before starting the endurance conditioning.

The relevant specification should state the circumstances in which electrical and/or mechanical functioning of the specimen is required.

4. Initial resonance search

A complete sweep of the frequency range shall be carried out in order to study the behaviour of the specimen under vibration, to determine resonance frequencies and to obtain information for final resonance search. Endurance conditioning, if applicable, is carried out on these resonance frequencies. Normally, the initial resonance search shall be carried out at the same amplitude as for the endurance conditioning, but the vibration amplitude may be decreased below this full value if thereby more precise determination of the resonance characteristics can be obtained.

During this procedure, the specimen shall be examined in order to determine frequencies at which:

- a) specimen malfunctioning and/or deterioration of performance are exhibited which are dependent on vibration;
- b) mechanical resonances occur.

All frequencies and amplitudes at which these effects occur shall be noted for comparison with those found in the final search specified in part 6.

The specimen shall be functioning during this resonance search if appropriate. Where the mechanical vibrational characteristics cannot be assessed because the unit is functioning, an additional resonance search with the specimen not functioning shall be carried out.

Any arrangements made to detect the effect upon internal parts shall not substantially change the dynamic behaviour of the specimen as a whole.

5. Endurance conditioning by sweeping

The frequency shall be continuously varied as stated in part 5.1. If necessary, the frequency range may be subdivided. When called for by the relevant specification, the specimen shall be functioning and checked during this test and for such a proportion of the total time as may be specified.

5.1 Sweep method

A sweep is defined as a traverse of the specified frequency range once in each direction, for example 10-150-10 Hz (c/s).

The sweeping shall be continuous and logarithmic, and the sweep rate shall be approximately one octave per minute. A linear sweeping approximation may be used, provided the actual sweep rate does not exceed one octave per minute at any time and the duration of passage through each octave above 60 Hz (c/s) is approximately the same as with the logarithmic sweep. Whilst resonance search testing, the sweep rate may be decreased or stopped temporarily if necessary, but undue swell time should be avoided.

6. Final resonance search

The final resonance search shall be performed in the same manner as the initial resonance search and at the same vibration amplitudes. The relevant specification may state what action should be taken if any change of resonance frequency occurs.

It may be necessary to provide a period of time after the conditioning in which to allow the specimen to attain the same condition as existed at the commencement of the initial resonance search, e.g. as regards temperature.

7. Final measurements

The specimen shall be electrically and mechanically checked as required by the relevant specification.

TABLE 2

<div>Amplitude</div> <div>Frequency range Hz</div>	Duration			Examples of application
	0.15 mm or 19.6 m/s ² (2 g)	0.35 mm or 49 m/s ² (5 g)	0.75 mm or 98 m/s ² (10 g)	
5 - 35	—	150 h	30 h	Equipment exposed to the less severe conditions on shipboard or mounted adjacent to heavy rotating machinery
10 - 55	1.5 h	6 h	—	Equipment intended for large power plants, for transport by railway or road and for general industrial use
10 - 150	6 h	6 h	—	Equipment intended for large power plants, for transport by railway or road and for general industrial use, where it has been found that appreciable vibration components exist beyond 55 Hz
10 - 500	6 h	6 h	—	Equipment for general aircraft use and equipment for land transport under special conditions
10 - 2 000	—	6 h	6 h	Equipment for high-speed aircraft

V.2.5 MECHANICAL SHOCK

The shock test is conducted to determine that structural integrity and performance of equipment are satisfactory with respect to the mechanical shock environment expected in handling, transportation, and service use.

V.2.5.1 Mechanical Shock

Equipment

Nuclear precision pulse generator
Strip chart recorder
4-inch thick flat concrete surface

Procedure

NOTE: The test procedure places increasing levels of stress on the instrument as it progresses. Tests which exceed the degree of shock resistance required by the criteria should not be conducted.

1. With a cable length of at least eight feet, connect the test output voltage of the instrument to the strip chart recorder, turn on the recorder and set the pen to zero.
2. With a cable length of at least eight feet, connect the pulse generator to the test pulse input. Turn on the instrument and pulser.
3. Adjust the pulse generator repetition rate for midscale needle deflection on the most sensitive range. Set the pen sensitivity on the recorder for midscale deflection and turn on the chart drive motor at the rate of about 100 cm/hr.
4. Starting with a light tapping rhythm subject the instrument to increasingly severe jolts by fingers and hands.
5. Increase the chart speed to about 1000 cm/hr.
6. Drop the instrument onto the concrete surface from heights of 1, 3, and 6 inches and 1, 2, 4, and 8 feet.
7. Turn off power to the instrument, pulser and strip chart recorder. Remove all connections.

8. Measure the various percentage deflections from midscale, recorded on the strip chart and note the test conditions which existed at the time of each deviation. Compare test results and the performance criteria for compliance.

V.2.5.2 Mechanical Shock⁽²⁵⁾

Equipment

1. Shock machine. The shock machine utilized shall be capable of producing the specified input shock pulse as shown on figures 1 or 2, as applicable. The shock machine may be of the free fall, resilient rebound, non-resilient, hydraulic, compressed gas, or other activating types.
- 1.1. Shock machine calibration. The actual test item, or a dummy load, which may be either a rejected item or a rigid dummy mass, may be used to calibrate the shock machine. (When a rigid dummy mass is used, it shall have the same center of gravity and the same mass as that of the test item and shall be installed in a manner similar to that intended for the test item.) The shock machine shall then be calibrated for conformance with the specified waveform. Two consecutive shock applications to the calibration load shall produce waveforms which fall within the tolerance envelope given on figures 1 or 2. The calibration load shall then be removed and the shock test performed on the actual test item. If all conditions remain the same, other than the substitution of the test item for the calibration load, the calibration shall then be considered to have met the requirements of the waveform.
2. Instrumentation. In order to meet the tolerance requirements of the test procedure, the instrumentation used to measure the input shock shall have the characteristics specified in the following paragraphs.

NOTE: It is not implied that the waveform generated by the shock machine will be the same when the actual test item is used instead of the calibration load. However, the resulting waveform is considered satisfactory if the waveform with the calibration load was satisfactory.

Shock measuring instrumentation shall be utilized to determine that the correct input shock pulse is applied to the test specimen. Generally, the shock pulse should be monitored whenever there is a change in the test setup, such as a different test fixture, different component (change in physical characteristics), different weight, different shock pulse (change in pulse shape, intensity, or duration) or different shock machine characteristics. It is not mandatory that each individual shock be monitored, provided that the repeatability of the shock application as specified in 1.1 has been established.

2.1 Frequency response. The frequency response of the complete measuring system, including the transducer through the readout instrument, shall be as specified by figure 3.

2.2 Frequency response measurement of the complete instrumentation. The transducer-amplifier-recording system can be calibrated by subjecting the transducer to sinusoidal vibrations of known frequencies and amplitudes for the required ranges so that the overall sensitivity curve can be obtained. The sensitivity curve, normalized to be equal to unity at 100 Hz, should then fall within the limits given on figure 3.

2.3 Frequency response measurement of auxiliary equipment. If calibration factors given for the accelerometer are such that when used with the associated equipment it will not affect the overall frequency response, then the frequency response of only the amplifier-recording system may be determined. This shall be determined in the following manner: Disconnect the accelerometer from the input terminals of its amplifier. Connect a signal voltage source to these terminals. The impedance of the signal voltage source as seen by the amplifier shall be made as the impedance of the accelerometer and associated circuitry as seen by the amplifier. With the frequency of the signal voltage set

- 100 Hz, adjust the magnitude of the voltage to be equal to the product of the accelerometer sensitivity and the acceleration magnitude expected during test conditions. Adjust the system gain to a convenient value. Maintain a constant input voltage and sweep the input frequency over the range from 1.0 to 9,000 Hz or 4 to 25,000 Hz, as applicable, depending on duration of pulse. The frequency response in terms of dB shall be within the limits given on figure 3.
- 2.4 Transducer. The fundamental resonant frequency of the accelerometer shall be greater than 30,000 Hz, when the accelerator is employed as the shock sensor.
- 2.5 Transducer calibration. Transducers shall be calibrated in accordance with ASA STD S2.2-1959. The accuracy of the calibration method shall be at least ± 5 percent over the frequency range of 2 to 5,000 Hz. The amplitude of the transducer being calibrated shall also be ± 5 percent over the frequency range of 4 to 5,000 Hz.
- 2.6 Linearity. The signal level of the system shall be chosen so that the acceleration pulse operates over the linear portion of the system.
- 2.7 Transducer mounting. The monitoring transducer shall be rigidly secured and located as near as possible to an attachment point of the specimen but not on the specimen itself.
3. Shock Pulses. Two types of shock pulses, a half-sine shock pulse and a sawtooth shock pulse, are specified. The pulse shape and tolerances are shown on figures 1 and 2, respectively. For single degree of freedom systems, a sawtooth shock pulse can be assumed to have a damage potential at least as great as that of a half-sine pulse if the shock spectrum of the sawtooth pulse is everywhere at least as great as that of the half-sine pulse. This condition will exist for two such pulses of the same duration if over most of the spectrum the acceleration peak value of the sawtooth pulse is 1.4 times the acceleration peak value of the half-sine pulse.

- 3.1 Half sine shock pulse. The half-sine shock pulse shall be as indicated on figure 1. The velocity change of the pulse shall be within ± 10 percent of the velocity change of the desired shock pulse. The velocity change may be determined either by direct measurement, indirectly, or by integrating (graphically or electrically) the area (faired acceleration pulse may be used for the graphical representation) under the measured acceleration pulse. For half-sine acceleration pulses of less than 3 milliseconds duration the following tolerances should apply: The faired maximum value of the measured pulse shall be within ± 20 percent of the specified ideal pulse amplitude, its duration shall be within ± 15 percent of the specified ideal pulse duration, and the velocity-change associated with the measured pulse shall be within ± 10 percent of $V_i = 2 A D/\pi$. See figure 1. The measured pulse will then be considered a nominal half-sine pulse with a nominal amplitude and duration equal to respective values of the corresponding ideal half-sine pulse. The duration of the measured pulse shall be taken as $D_m = D(.1A)/.94$; where $D(.1A)$ is the time between points at .1A for the faired measured acceleration pulse.
- 3.2 The ideal half-sine pulse. An ideal half-sine acceleration pulse is given by the solid curve. See figure 1. The measured acceleration pulse must lie within the boundaries given by the broken lines. In addition, the actual velocity-change of the shock must be within 10 percent of the ideal velocity-change. The actual velocity-change can be determined by direct measurements, or from the area under the measured acceleration curve. The ideal velocity-change is equal to $V_i = 2AD/\pi$; where A is the acceleration amplitude and D is the pulse duration of the ideal pulse.
- 3.3 Sawtooth shock pulse. The sawtooth pulse shall be as indicated on figure 2. The velocity change of the faired measured pulse shall be within ± 10 percent of the velocity change of the ideal pulse.

- 3.4 The ideal terminal-peak sawtooth. An ideal terminal-peak sawtooth acceleration pulse is given by the solid line. See figure 2. The measured acceleration pulse must be within the boundaries given by the broken lines. In addition, the actual velocity-change of the shock pulse must be within 10 percent of the ideal value. The actual velocity-change can be determined from direct measurements, or from the area under the measured acceleration curve. The ideal velocity-change is equal to $V_i = PD/2$ where P is the peak value of acceleration, and D is the pulse duration.

Procedure

The test specimen shall be mounted as specified in the component specification. Whenever possible, the test load shall be distributed uniformly on the test platform in order to minimize the effects of unbalanced loads.

1. Three shocks in each direction shall be applied along the three mutually perpendicular axes of the test specimen (18 shocks). If the test specimen is normally mounted on vibration isolators, the isolators shall be functional during the test. The specified test pulse (half-sine or sawtooth pulse) shall be in accordance with figures 1 and 2, respectively, and shall have a duration and peak value in accordance with one of the test conditions of table 1.
2. Measurements shall be made before and after the required number of shocks unless otherwise specified, and during the test if specified.

TABLE 1. 213.1. Test Condition Values

Test condition	Peak value (g's)	Normal duration (D) (MS)	Waveform	Velocity change (V _i) ft/sec
A	50	11	Half-sine	11.3
B	75	6	Half-sine	9.2
C	100	6	Half-sine	12.3
D	500	1	Half-sine 1/2/	10.2
E	1,000	0.5	Half-sine 1/2/	10.2
F	1,500	0.5	Half-sine 1/2/	15.4
G	50	11	Sawtooth 2/	8.8
H	75	6	Sawtooth 2/	7.2
I	100	6	Sawtooth 2/	9.7
J	30	11	Half-sine	6.8
K	30	11	Sawtooth	5.3

- 1/ For half-sine shock pulses of less than 3 milliseconds duration, it is not required that the envelope fall within the tolerances specified on figure 213-1. The faired amplitude of the measured pulse shall be within ± 20 percent of the ideal amplitude. The measured duration shall be within ± 15 percent of the specified amplitude duration. The velocity change of the faired measured pulse shall be within ± 10 percent of the ideal pulse. The duration of the pulse shall be measured at the 0.1A point on the pulse. The duration of the pulse shall be the duration measured at the 0.1A point divided by .94. Test conditions D, E, and F are principally applicable to semiconductors.
- 2/ Test conditions G, H, and I (sawtooth) waveforms are preferred, except for semiconductors, for which test conditions D, E, and F (half-sine) are preferred.

NOTE:

The oscillogram should include a time about $3D$ long with the pulse located approximately in the center. The integration to determine velocity change should extend from $.4D$ before the pulse to $.1D$ beyond the pulse. The acceleration amplitude of the ideal half sine pulse is A and its duration is D . Any measured acceleration pulse which can be contained between the broken line boundaries is a nominal half sine pulse of nominal amplitude A and nominal duration D . The velocity-change associated with the measured acceleration pulse is V .

FIGURE 1. 213.1. Tolerances for Half Sine Shock Pulse

NOTE:

The oscillogram should include a time about $3D$ long with the pulse approximately in the center. The integration to determine the velocity change should extend about $.4D$ before the pulse to $.1D$ beyond the pulse. The peak acceleration magnitude of the sawtooth pulse is P and its duration is D . Any measured acceleration pulse which can be contained between the broken line boundaries is a nominal terminal-peak sawtooth pulse of nominal peak value, P , and nominal duration, D . The velocity-change associated with the measured acceleration pulse is V .

FIGURE 2. 213.2. Tolerances for Terminal-peak Sawtooth Shock Pulse

FIGURE 3. 213.3. Tolerance Limits for Measuring System Frequency Response

V.2.5.3 Mechanical Shock (25)

Equipment

The shock testing apparatus specified herein and shown on figure 205-1 shall be used, as applicable. Detail drawings for the apparatus shall be as shown on figure 205-1 (see 5). The apparatus tests a minimum load of 20 pounds and a maximum load of 50 pounds. Further reference in this test method to the apparatus will be "20-50 pound." The test apparatus consists of an elevator with impact blocks attached. The elevator is raised to a specified height and dropped on an arresting material. The shock pulse is produced by allowing the loaded elevator table to fall freely into a sandbox which forms the base of this apparatus.

1. Elevator assembly. The assembly shall have a flat surface or table to allow placement of the parts and necessary weights. Mounting holes, used for clamping of parts, shall be placed in the table where needed.
2. Impact blocks. The impact blocks shall be constructed of hard maple or kiln-dried oak, and shall be of the dimensions specified on figure 205-1. The blocks shall be faced with metal to prevent wear.
3. Arresting material. The arresting material shall be sand contained in a boxlike enclosure. The sand shall be Ottawa River kiln-dried sand, screened to 30-40 grit size, and filled to depth of approximately 14 inches in the sandbox.
4. Rakes. The rake used with the 20-50 pound apparatus shall be as shown on figure 205-1.
5. Detail drawings. Copies of detail drawings may be obtained from the Defense Electronics Supply Center, Directorate of Engineering Standardization, 1507 Wilmington Pike, Dayton, Ohio 45401. When requesting copies of these drawings, both the identifying symbol number and title should be stipulated, as follows:

Drawing 205-1 - Medium Impact Shock Apparatus (20-50 Pound).

Drawing 205-2 - Medium Impact Shock Apparatus (150-400 Pound).

Procedure

The specimen shall be rigidly mounted on the elevator table by its normal mounting means. Special mounting means, when required, shall be as specified. When necessary, small bags of either lead shot or sand shall be added so that the total load on the elevator table of the 20-50 pound apparatus is at least 20 pounds. The elevator shall then be raised to the height required by the specified condition.

1. Sand raking procedure.

1.1 Compacting of sand. If the sand has just been placed in the sandbox or if it has been raked deeply, the elevator shall be dropped 10 times to insure that the sand is properly compacted.

1.2 Displaced sand. The sand which has been displaced to the sides of the sandbox by a previous drop shall be raked back toward the center of the sandbox by stroking the rake approximately one-third stroke from opposite sides toward the center. At all times the rake shall be stroked in a direction perpendicular to the impact blocks.

1.3 Leveling and conditioning of sand. The sand shall be leveled and conditioned by stroking the rake several times from the center pedestal. At the conclusion of each stroke, the rake shall be lifted from the sand and then replaced immediately behind the accumulated sand. A stroke shall then be made in the opposite direction. This procedure eliminates buildup of sand at the edges of the sandbox, and shall be continued until an even furrowed surface results.

1.4 Rake alinement and sand quantity. Care shall be taken to keep the teeth of the rake substantially vertical. Sufficient downward force shall be applied to the rake to keep the guide angles in flat contact with the flanges of the sandbox on which they ride. The proper volume of sand must be present in the sandbox to achieve satisfactory raking. (If there is too little sand, sand voids will appear on the top of the furrows; the presence of too much sand will cause the excess sand to build up at the edges of the sandbox).

- 1.5 Subsequent sand treatment. Subsequent sand treatment shall involve only shallow raking and surface preparations.
2. Level check. Prior to each drop the loaded elevator shall be suspended freely from the hoist cable and the elevator cable shall be leveled to insure that it is balanced and that it will fall squarely on the arresting material.
3. Height indication. The zero level of the height indicator shall be determined by bringing the loaded elevator down until the impact blocks just rest on the sand. Care shall be taken that the elevator be lowered gently on the sand.
4. Number and direction of applied shocks. Three shocks, with the specimen oriented in each of the six directions stated below, shall be applied (a total of 18 shocks). The specimen shall be rotated in the following directions:
 1. Bottom down.
 2. Front down.
 3. Right side down.
 4. Back down.
 5. Left side down.
 6. Top down.

If the starting point is important, it shall be specified; if not, the testing laboratory will arbitrarily assign a bottom and a front.

V.2.5.4 Mechanical Shock (27)

Equipment

Dosimeter Charger
Hardwood Surface

Procedure

1. The dosimeter shall be set to midscale reading. At any time throughout this test, the reading of the instrument shall not change by more than 10% of full scale.

2. The instrument shall be dropped once on each end and twice on its side in random orientation. Drop shall be from a height of one meter onto a hardwood surface.

At the completion of the test, no foreign materials or particles should appear on the fiber or scale images as a result of this test.

The dosimeter shall be capable of meeting all the performance specifications at the completion of this test.

V.2.5.5 Additional Applicable Test Procedures

MIL-STD-202D, method 202C

MIL-STD-810B, method 516

IEC Publication, 68-2-27

V.2.6 TEMPERATURE SHOCK

The temperature shock test is conducted to determine the effects on equipment of sudden changes in temperature of the surrounding atmosphere. Cracking or rupture of materials due to sudden dimensional changes by expansion or contraction are the principal difficulties to be anticipated.

V.2.6.1 Temperature Shock ⁽²⁴⁾

Equipment

A high temperature chamber and a low temperature chamber.

Procedure

1. The test item shall be placed in the high temperature chamber, and the internal chamber temperature raised to 71°C (160°F), and maintained for a period of not less than 4 hours.
2. At the conclusion of this time period, the test item shall be transferred, within 5 minutes, to a cold chamber with an internal chamber temperature of -54°C (-65°F).
3. The test item shall be exposed to this temperature for a period of not less than 4 hours.

4. At the conclusion of this time period, the test item shall, within 5 minutes, be returned to the high temperature chamber maintained at 71°C (160°F).
5. The test item shall be exposed to this temperature for a period of not less than 4 hours. (The test may, for convenience purposes, be interrupted during this step if desired. This is accomplished by returning the test item to ambient conditions after an exposure at high temperature of 1 hour minimum. To continue the following steps, it is required that step 1 first be repeated.)
6. Repeat steps 2 through 5.
7. Repeat steps 2 and 3.
8. Return the test item to standard ambient conditions and stabilize.
9. Operate the test item and compare the results with the data obtained under normal operating conditions.
10. Inspect the test item for physical damage.

V.2.6.2 Temperature Shock

Equipment

Nuclear precision pulse generator
Environmental chamber
Strip chart recorder

Procedure

1. Place the instrument into the chamber and connect test leads to the test pulse input and the test voltage output jacks. Turn the instrument power on and close the door of the chamber.
2. Adjust the moisture content of the chamber air until the dew point is 5°C below the lower temperature extreme. Maintain a constant dew point throughout the test.
3. Connect the pulse generator and strip chart recorder to the proper cables.
4. Turn on power to the recorder and adjust the pen to zero.

5. Turn on power to the pulse generator and adjust the pulse repetition frequency for midscale needle deflection on the most sensitive range. Adjust the pen sensitivity on the recorder for a mid-chart indication.
6. Turn on the chart advance at a speed of about 100 cm/hr.
7. Drop the chamber temperature to the lower extreme at the rate of 5°C/min. Remain at this temperature for five minutes.
8. Raise the chamber temperature to the upper extreme at the rate of 5°C/min. Remain at this temperature for 10 minutes.
9. Repeat 7 and 8 for two complete cycles.
10. Return the chamber temperature to ambient conditions at the rate of 5°C/min.
11. Turn off power to the pulser, instrument and recorder, and remove all connections.
12. Measure the various deflections from midscale pen deflection and relate them to the test conditions which existed at the time of the deflection.

V.2.6.3 Additional Applicable Test Procedures

IEC Publication 68-2-2, Sections 1 and 3.

IEC Publication 68-2-14, Chapter 1 and 3.

IEC Publication 68-2-1, Section 1

V.2.7 TEMPERATURE RANGE

The effects of temperature on the instrument as a whole is of prime importance, since instruments may be used in thermal environments ranging from sub-freezing to more than 50°C. The variation should be known so that appropriate correction factors can be applied where the instrument is used at extreme temperatures. Generally, the detector is the major contributor to temperature dependence, but other components may also contribute significantly. Occasionally a single component such as a resistor may require replacement in order to minimize temperature effects.

V.2.7.1 Temperature Range (low temperature) (24)

Equipment

Temperature chamber

Procedure

1. Place the test item in the test chamber.
2. Lower the internal chamber temperature to the storage temperature specified in the equipment specification and maintain for time specified.
3. Adjust the internal chamber temperature to the lowest temperature under which the test item is designed to operate and maintain until temperature stabilization of the test item is reached.
4. Operate the test item and compare the results with the pretest data.
5. Return the test item, nonoperating, to standard ambient conditions and stabilize.
6. Operate the test item and compare the results with the pretest data.
7. Inspect the test item for evidence of damage.

NOTE: The rate of temperature change (steps 2, 4, and 6) may be the maximum attainable by the chamber but shall not exceed 10°C (18°F) per minute.

V.2.7.2 Temperature Range (high temperature) (24)

Equipment

Temperature chamber.

Procedure

1. Place the test item in the test chamber.
2. Raise the internal chamber temperature to 71°C (160°F) or as specified in the equipment specification.
3. Maintain the internal chamber temperature for a period of not less than 48 hours while insuring the relative humidity is not in excess of 15 percent.
4. Adjust the internal chamber temperature to the highest operating temperature under which the test item is designed to operate and maintain until temperature stabilization of the test item is reached.
5. Operate the test item until the item is stabilized or as specified in the equipment specification, and compare the results with the pretest data.
6. Return the test item, non-operating to standard ambient condition and stabilize.
7. Operate the test item and compare the results with the pretest data.
8. Inspect the test item for physical damage.

NOTE: The rate of temperature change (steps 2, 4, and 6) may be the maximum attainable by the chamber, but shall not exceed 10°C (18°F) per minute.

V.2.7.3 Temperature Range (high temperature) ⁽²⁴⁾

Equipment.

Temperature chamber.

Procedure

(See note at end of procedure)

1. Place the test item in the test chamber.
2. Raise the internal chamber temperature to 49°C (120°F).

3. Maintain internal chamber temperature for 6 hours at 49°C (120°F).
4. Raise the internal chamber temperature to 68°C (154°F) within a time period of 1 hour and then maintain at that temperature for 4 additional hours.
5. Lower the internal chamber temperature to 49°C (120°F) within a time period of 1 hour.
6. Repeat steps 3, 4, and 5 two additional times (making a total of three 12-hour cycles).
7. Adjust the internal chamber temperature to the highest operating temperature under which the test item is designed to operate and maintain until temperature stabilization of the test item is reached.
8. Operate the test item until the item is stabilized or as specified in the equipment specification and compare the results with the pretest data operating conditions.
9. Return the test item, non-operating, to standard ambient conditions and stabilize.
10. Operate the test item and compare the results with the pretest data.
11. Inspect the test item for physical damage.

NOTE: The rate of temperature change (steps 2, 4, 5, 7, and 9) shall be $20^{\circ} \pm 4^{\circ}\text{C}$ (36°F) per hour.

V.2.7.4 Temperature Range⁽¹⁸⁾

Equipment

Environmental or temperature chamber.

Appropriate radiation source.

Procedure

The instrument is placed in the test chamber and a source is positioned outside the chamber to give a constant meter reading at room temperature. The temperature is raised at a rate of about $10^{\circ}\text{C}/\text{h}$ until the maximum temperature is reached. Meter readings are taken about every 5°C ,

and a plot made of scale readings versus temperature made. The temperature is then lowered at the rate of $10^{\circ}\text{C}/\text{h}$ until the lower temperature limit is reached. Meter readings are taken every 5°C . When the lowest temperature has been reached, the temperature is again raised at the rate of about $10^{\circ}\text{C}/\text{h}$ until room temperature is reached. As previously, readings are taken about every 5°C .

The test at lower temperatures is also a test for high humidity operation. At the start of the test, the air is at room temperature in the test chamber, and normally has a relative humidity of 30 to 50%. As the temperature is lowered the air in the chamber will become saturated and moisture may form inside the instrument case. In most instances trouble is not encountered with moisture until the temperature is increased from the lowest point back towards room temperature.

As these tests may last over a period longer than the life of the instrument's battery it may prove necessary to carry out these tests using an external constant voltage source.

V.2.7.5 Temperature Range

Equipment

Temperature chamber

Current source

Procedure

With a constant input current giving a reading at or near that used for the radiation calibration of the instrument, the variation in response shall be measured at the lowest and highest temperatures in the rated range, and at least at one other temperature at or near the reference temperature. The humidity shall be at or near the reference value. It shall be verified that the instrument complies with the requirement on each range provided.

V.2.7.6 Temperature (27)

Equipment

Dosimeter Charger

Temperature Chamber

Procedure

Charge the dosimeter to approximately midscale and read. Reduce the temperature of the dosimeter to -10 degrees C (14 degrees F) and read. Raise the temperature of the dosimeter to 50 degrees C (122 degrees F) and read. Return the dosimeter to +22 degrees C (71.6 degrees F) and read. Compare the test results with the performance criteria for conformance.

V.2.7.7 Radiation Monitor Temperature Coefficient

Equipment

Environmental or temperature chamber

Appropriate radiation source

Procedure

1. Turn on test item and allow appropriate warmup time.
2. Place test item in the test chamber.
3. Position the radiation source within the chamber or outside the chamber as appropriate to give a test item response (R_0) greater than 20% of full scale at ambient temperature.
4. Raise the temperature at a rate of 10°C/h until the maximum test temperature is reached. Record test item readings at 5°C intervals, i.e., at T_1 , T_2 , T_3

NOTE: For steps 5 and 6 maintain humidity at a sufficiently low level to preclude formation of condensation on the test item.

5. Lower the temperature at the rate of 10°C/h until the lower test temperature is reached. Record test item reading at 5°C intervals.

6. Raise the temperature at the rate of 10°C/h until ambient temperature is reached. Record test item readings at 5°C intervals.
7. Calculate the temperature coefficient for each pair of readings:

$$\text{Temp. Coeff. 1} = \frac{R_2 - R_1}{R_0} \times 100 = \frac{\%}{^\circ\text{C}} \times \frac{1}{T_2 - T_1}$$

where R_0 = reference reading set in step 3

R_1 = reading at temperature T_1

R_2 = reading at temperature T_2

8. Calculate the total temperature influence:

$$\text{Temp. Coeff. 2} = \frac{R_H - R_L}{R_0} \times 100 = \%$$

where R_H = highest reading observed in steps 4, 5, or 6

R_L = lowest reading observed in steps 4, 5, or 6

9. Compare temperature coefficients with the performance criteria.

V.2.7.8 Air Monitor Temperature Coefficient

Test procedure V.2.7.7 is applicable with the following modification:

1. In step 3 the radiation source geometry must be such as can be placed in the test item filter holder.

V.2.7.9 Personnel Dosimeter Temperature Coefficient

Equipment

Environmental or temperature chamber

Appropriate radiation source

Procedure

1. Zero the dosimeter.
2. Place dosimeter in chamber at ambient temperature (T_0).
3. Introduce a radiation field which produces an integrated exposure of midscale. Record the exposure (R_0) required.
4. Zero the dosimeter.
5. Raise the chamber temperature in 5°C increments and repeat steps 3 and 4 at each interval until the maximum required temperature (T_H) is reached. Record the exposures and temperatures.
6. Beginning at ambient, lower the chamber temperature 5°C increments and repeat steps 3 and 4 at each interval until the minimum temperature (T_L) is reached. Record the exposures and temperatures.
7. Calculate the temperature coefficient for each pair of readings.

$$\text{Temp. Coeff. 1} = \frac{R_2 - R_1}{R_0} \times 100 = \frac{\%}{T_2 - T_1}$$

where R_0 = reference exposure from step 3

R_1 = radiation exposure to produce midscale reading at T_1

R_2 = radiation exposure to produce midscale reading at T_2

T_1, T_2 = reference temperature in degrees centigrade

8. Calculate total temperature influence:

$$\text{Temp. Coeff. 2} = \frac{R_H - R_L}{R_0} \times 100 = \%$$

where R_H = highest exposure value from steps 5 and 6.

R_L = lowest exposure value from steps 5 and 6.

V.2.7.10 Additional Test Procedures

IEC Publication 68-2-1, Sections 2 and 3.

IEC Publication 68-2-2, Section 2 and 4.

V.2.8 HUMIDITY

The humidity test is applicable to all equipment and is conducted to determine the resistance of equipment to the effects of exposure to a warm, highly humid atmosphere. Corrosion is one of the principal effects of humidity. Hygroscopic materials are sensitive to moisture and may deteriorate rapidly under humid conditions. Absorption of moisture by many materials results in swelling, which destroys their functional utility and causes loss of physical strength and changes in other important mechanical properties. Insulating materials which absorb moisture may suffer degradation of their electrical and thermal properties.

V.2.8.1 Humidity⁽²⁴⁾

Equipment

Humidity-temperature chamber and associated equipment.

The chamber and accessories shall be constructed and arranged in such a manner as to avoid condensate dripping on the test item. The chamber shall be trap-vented to the atmosphere to prevent the buildup of total pressure. Relative humidity shall be determined from the dry bulb-wet bulb thermometer comparison method or an equivalent method approved by the procuring activity. When readout charts are used, they shall be capable of being read with a resolution within 0.6°C (1°F). When the wet bulb control method is used, the wet bulb and tank shall be cleaned and a new wick installed at least every 30 days. The air velocity flowing across the wet bulb shall be not less than 900 feet per minute. Provisions shall be made for controlling the flow of air throughout the internal test chamber area where the velocity of air shall not exceed 150 feet per minute. Steam, or distilled, demineralized, or deionized water having a pH value between 6.0 and 7.2 at 23°C (73°F) shall be used to obtain the specified humidity. No rust or corrosive contaminants shall be imposed on the test item by the test facility.

Procedure

1. Place the test item in the test chamber.
2. Dry the test item at a temperature of not less than 40°C (104°F) nor more than 50°C (122°F) for not less than 2 hours.
3. Condition the test item at 25° ± 5°C (77°F) and 50 percent relative humidity for 24 hours.
4. Take initial measurements as specified in the equipment specification.

NOTE: The test item may be readjusted or realigned as necessary to conform to the equipment specification requirements. No further realignment or readjustment shall be permitted throughout the test period other than with accessible controls, external to the test item, employed for operation of the test item. If repairs, replacement of parts, or adjustments other than by the accessible external controls are made at any time prior to completion of the measurements required at the end of the fifth cycle, all 5 of the 24 hour cycles shall be repeated. Repairs include any change to the test item that is not made by use of the accessible controls external to the test item. The test item shall only be operated when specified test measurements are being performed.

5. Subject the test item to five 24-hour cycles. A 24-hour cycle consists of 16 hours at 60° ± 5°C (140°F) and approximately 8 hours at 30° ± 5°C (86°F) (includes transition times). A relative humidity shall be maintained at 95 percent, or greater, at both temperatures. Each transition time between 30° ± 5°C (86°F) and 60° ± 5°C (140°F) shall be not greater than 1-1/2 hours. The relative humidity during each transition need not be controlled. Approximately 2 hours after stabilization during the high temperature and low temperature portions of the first or second cycle, a sampling of the atmosphere in the chamber shall be made to determine that the conditions of temperature and relative humidity are uniform throughout the chamber.

Measurements as specified in the equipment specification shall be made during the second cycle at 60° ± 5°C (140°F) immediately prior to decreasing to 30° ± 5°C (86°F).

The test item shall only be energized a sufficient time to allow the required warm-up and measurements specified in the equipment specification.

6. After completion of the fifth cycle with the test item in the chamber and the chamber at $30^{\circ} \pm 5^{\circ}\text{C}$ (86°F) and a relative humidity of not less than 95 percent, take measurements specified in the equipment specification (no repair, realignment, readjustment or replacement of parts shall be made, except as specified herein).
7. Condition the test item at $25^{\circ} \pm 5^{\circ}\text{C}$ (77°F) and 50 ± 5 percent relative humidity for not less than 12 hours nor more than 24 hours.
8. While at $25^{\circ} \pm 5^{\circ}\text{C}$ (77°F) and 50 percent relative humidity, take measurements as specified in the equipment specification.
9. Inspect test item as detect evidence of physical degradation (such as corrosion of metal parts, distortion of plastic parts, and insufficient lubrication of moving parts).

V.2.8.2 Humidity⁽²⁴⁾

Equipment

(Section 2.8.1)

Procedure

1. Place the test item in the test chamber.
2. Gradually raise the internal chamber temperature to 40.5°C (105°F) and 95 percent relative humidity in 2 hours.
3. Take initial measurements.

NOTE: The test item may be readjusted or realigned as necessary to meet specification requirements. No further readjustment or realignment shall be permitted throughout the test period other than with accessible controls employed for operation of the test item. No repair or replacement of parts shall be permitted. Equipment shall only be operated when specified test measurements are being performed.

4. Maintain the internal chamber temperature at 40.5°C (105°F) and the relative humidity at 90 percent for 16 hours.
5. Gradually decrease the internal chamber temperature to 21°C (70°F) and increase the relative humidity to 95 percent in 2 hours.

6. Maintain the internal chamber temperature at 21°C (70°F) and the relative humidity at 95 percent for 4 hours.
7. Repeat steps 4 through 6 for 20 cycles (480 hours). Take measurements as specified in the equipment specification. Prior to measurements, accumulated moisture may be removed by turning the test item upside down or shaking. Wiping is not permitted.
8. After completion of step 7 cycling, operate the test item adjusting for optimum performance only as permitted in step 3 note, and compare results with data obtained in step 3.
9. Inspect the test item for evidence of damage.

V.2.8.3 Humidity⁽²⁸⁾

Equipment

Humidity temperature chamber

Procedure

The equipment shall be placed in the test chamber in a manner similar to that in which it will be used in service. If operation of the equipment during the exposure is required such connections and instrumentation as necessary shall be made. The relative humidity shall be maintained in excess of 95 percent unless stated otherwise in the following steps. Moisture shall be provided by steam or by evaporation of tapwater having a pH value between 6.5 and 7.5 measured at 25°C. The velocity of air throughout the exposure area shall not exceed 150 feet per minute. The test chamber shall be vented to the atmosphere to prevent the buildup of pressure. Provisions shall be made to prevent the dripping of water onto the equipment from above. The procedure shall be in accordance with the following.

1. The chamber temperature shall be raised to 50°C during a 2-hour period, with the relative humidity kept in excess of 95 percent.
2. The chamber temperature shall be maintained at 50°C with the relative humidity in excess of 95 percent for 6 hours.
3. During the next 16-hour period the temperature shall drop gradually to a temperature of 38°C or lower. During this period the relative humidity shall be kept as high as possible and shall not be allowed to drop below 85 percent.

4. Steps 1, 2, and 3 constitute a complete cycle. These steps shall be continued until a total of 10 cycles (240 hours exposure) have been completed. At the completion of 10 cycles, the equipment shall be operated as soon as possible, but not later than 1 hour after completion of the 10 cycles, and checked for satisfactory operation. Satisfactory operation shall be determined by no part failures and within a specified warm-up time, readings shall indicate equipment operation within the specified limits of satisfactory operation. The warm-up time shall not exceed the time specified in the applicable detail specification.

V.2.8.4 Humidity⁽²⁹⁾

Equipment

Testing Chamber

The chamber shall be so constructed that:

1. The temperature and humidity of the chamber are monitored by sensing devices located in the working space.
2. The temperature and relative humidity in the working space can be maintained at $40 \pm 2^{\circ}\text{C}$ and $93 \begin{smallmatrix} +2\% \\ -3\% \end{smallmatrix}$ respectively.

NOTE: The temperature tolerance of $\pm 2^{\circ}\text{C}$ is intended to take account of absolute errors in the measurement, slow changes of temperature, and temperature variations of the working space. It is necessary to keep the short term temperature fluctuation within $\pm 0.5^{\circ}\text{C}$ to maintain the required humidity.

3. Condensed water is continuously drained from the chamber and not used again until it has been repurified.
4. When the humidity conditions are obtained by using an injection-type chamber, the water shall have a resistivity not less than 500 Ωm .

Precautions shall be taken to ensure that:

1. The conditions prevailing throughout the working space are uniform and as similar as possible to those prevailing in the immediate vicinity of the monitoring devices.

2. The properties or loading of the specimen under test do not appreciably influence conditions within the chamber.
3. No condensed water from the walls and roof of the test chamber can fall on the specimens.

Procedure

1. Initial measurements

The specimen shall be visually inspected and electrically and mechanically checked, as required by the relevant specification.

2. Conditioning

2.1 The specimen shall be introduced into the chamber in the state specified in the relevant specification. At the time of introducing the specimen into the chamber, care shall be taken to avoid the formation of water droplets on the specimen. This can be done by preheating the specimen to the chamber temperature.

2.2 The specimen shall be introduced into the chamber and subjected to one of the following severities, as required by the relevant specification:

4 days

10 days

21 days

56 days

NOTE: The severity VII (four days plus assisted drying) as laid down in the second edition (1960) of IEC Publication 68-2-3 has been deleted. Assisted drying can be obtained by prescribing an appropriate recovery condition (see Subclause 3.4).

2.3 The relevant specification may call for loading and/or measurements during, or at the end of, conditioning while the specimen is still in the chamber.

If such measurements are required, the relevant specification shall define the measurements and the period or periods after which they shall be carried out. For these measurements, the specimen shall not be removed from the chamber.

NOTE: Measurements preceded by recovery, which would require removal of the specimens from the chamber, are not permissible during the conditioning.

If it is desired to know the performance of the type of specimen before the end of the prescribed duration, one additional lot will be required for each specified duration.

Recovery and final measurements shall be performed separately for each lot.

3. Recovery

3.1 At the end of the conditioning, the specimen shall be subjected to standard atmospheric conditions for recovery for not less than 1 hour and not more than 2 hours.

3.2 The specimen may be transferred to another chamber for recovery or may remain in the damp heat chamber depending upon the nature of the specimen and/or the capability of the testing laboratory.

In the former case, the change-over time shall be as short as possible and shall not exceed 5 minutes. In the latter case, the relative humidity shall be reduced to between 73 percent and 77 percent r.h. in not more than 1/2 hour, after which the temperature shall be adjusted to within $\pm 1^{\circ}\text{C}$ of the laboratory temperature in not more than 1/2 hour.

3.3 The relevant specification shall state whether any special precautions shall be taken regarding removal of surface moisture.

3.4 If the standard conditions given above are not appropriate for the specimen to be tested, the relevant specification may call for other recovery conditions.

4. Final measurements

The specimen shall be visually inspected and electrically and mechanically checked, as required by the relevant specification.

The measurements shall be commenced immediately after the recovery period and the parameters most sensitive to changes of relative humidity shall be measured first. Unless otherwise specified, the measurement of these parameters shall be completed within 30 minutes.

V.2.8.5 Humidity (30)

Equipment

Temperature Humidity Chamber

Procedure

1. Initial measurements

The components shall be measured and mechanically tested as required by the relevant specification.

2. Conditioning

2.1 The chamber used for this test shall be capable of performing the following cycle of 24 hours:

The temperature shall be raised from laboratory temperature ($25^{\circ}\text{C} \pm 10^{\circ}\text{C}$) to $55^{\circ}\text{C} \pm 2^{\circ}\text{C}$ in a period of 1-1/2 to 2-1/2 hours during which the relative humidity shall be between 80 percent and 100 percent. During this period condensation on the components must occur.

The temperature shall then remain, in any region where the components are placed, at $55^{\circ}\text{C} \pm 2^{\circ}\text{C}$ for a period of 16 hours. A periodical variation of 2°C to 3°C total excursion, within the range of 53°C to 57°C , shall occur at least four times per hour. During this period the relative humidity shall be between 95 percent to 100 percent and condensation will occur on the components.

The atmosphere within the chamber shall then cool to laboratory temperature, the humidity remaining at 80 percent to 100 percent to complete the 24 hour cycle. During this period droplets of water must not be allowed to appear on the components.

2.2 The components shall be introduced into the chamber and subjected to one of the following severities as required by the relevant specification:

Severity

Cycles

IV

6

V

2

VI

1

+ assisted drying

- 2.3 If required the components shall be under load during this conditioning.
- 2.4 The components shall be removed from the chamber at the conclusion of the test cycles. They may be removed at intervals during these cycles in which event they shall be subjected to the recovery conditions specified in Clause 3.

NOTE: It is, however, undesirable to remove components from the chamber during the conditioning period.

- 2.5 The components shall only be removed from the chamber between 4 and 5 hours after switching off the source of heat and humidity and the door shall be opened for the shortest time possible.

3. Recovery

- 3.1 After each removal from the chamber the components shall be shaken by hand to remove droplets of water.
- 3.2 Components subjected to Severity VI of this test shall have assisted drying in accordance with Clause 4.5 of Part 1 (IEC Publication 68-1).
- 3.3 The components shall then remain under standard atmospheric conditions for recovery for not less than 1 hour nor more than 2 hours.

4. Final measurements

The components shall then be measured and mechanically checked as required by the relevant specification.

V.2.8.6 Humidity

Equipment

Nuclear precision pulse generator
Strip chart recorder
Environment simulation chamber
External source of power

Procedure

1. Connect the pulse generator to the test pulse input.
2. Adjust the output of the dc power supply to that of the battery power supply and connect it to the battery pack in parallel.

3. Connect the test output voltage of the instrument to the strip chart recorder, turn on the recorder and set the pen to zero.
4. Apply electrical power to the instrument, dc power supply and pulser.
5. Adjust the pulse generator repetition rate for midscale needle deflection on the most sensitive range.
6. Adjust the strip chart recorder for midscale pen deflection.
7. Place the instrument under test into the environmental chamber, close the door and turn on the chart advance motor. Set the chart speed for about 1 cm/hr and carefully note the starting point of the test.
8. Increase the relative humidity in the chamber isothermally at the rate of 20%/hr until the upper humidity limit is reached. Allow the instrument to operate under these conditions for one-half hour.
9. Raise the temperature of the chamber to the upper operating limit at constant humidity at the rate of 25°C/hr and allow the instrument to operate at these conditions for one hour.
10. Lower the relative humidity isothermally to the lower humidity limit at the rate of 20%/hr and allow the instrument to operate at these conditions for one-half hour.
11. At constant relative humidity decrease the temperature to the lower operating limit at the rate of 25°C/hr, and allow the instrument to operate at these conditions for one hour.
12. Repeat steps 8, 9, 10 and 11.
13. Raise the relative humidity and temperature to ambient conditions at the rates of 20%/hr and 25°C/hr respectively.
14. Remove the instrument from the chamber and inspect it for any visible defects.
15. Turn off electrical power from all instruments and remove all test connectors.
16. Calculate the maximum percentage deviation from midscale pen deflection on the strip chart.

V.2.8.7 Temperature-Humidity

Equipment

Environmental Chamber

Appropriate Radiation Source

Procedure

The effect of the extreme condition is to be determined by comparison of dosimeter response for a radiation exposure which produces an 80% of full scale reading while at the extreme environment, to the dosimeter response for the same exposure at normal room conditions. Initial and final readings for each test shall be taken at the same environmental conditions. The following tests are required with the dosimeter at equilibrium with the specified environment prior to exposing the dosimeter to radiation.

- With 40% humidity and temperature at 60 degrees F.
- With 40% humidity and temperature at 120 degrees F.
- With 95% humidity and temperature at 60 degrees F.
- With 95% humidity and temperature at 120 degrees F.

V.2.9 MOISTURE

Moisture tests, rain and immersion are intended to determine the efficiency of protective covers or cases designed to shield equipment from the elements.

V.2.9.1 Rain⁽²⁴⁾

Equipment

Rain chamber with wind source.

The rain chamber shall have the capability of producing falling rain and a facility for producing wind blowing at the rates specified herein. The chamber temperature shall be uncontrolled, except as regulated by water introduced as rain, throughout the test period. The rain shall be produced by a water distribution device of such design that the water is emitted in the form of droplets having a diameter range between 1 and 4 millimeters. The temperature of the water shall be between 11° and 35°C (52° and 95°F). The water distribution shall be

such that, with the wind source turned off, the rain is dispersed over the test area within the limits specified below. The wind source shall be so positioned with respect to the equipment that it will cause the rain to beat directly and uniformly against one side of the equipment. The wind source shall be capable of producing horizontal wind velocities up to 40 miles per hour. The wind velocity shall be measured at the position of the test item, prior to placement of the item in the chamber. No rust or corrosive contaminants shall be imposed on the test item by the test facility.

(The recommended method of measuring raindrop size is the flour pellet method as referenced in "The Relation of Raindrop Size to Intensity" by Laws and Parsons, Transactions of the American Geophysics Union, Part II, pps 452 to 459, 1943.)

Procedure

The test item shall be placed in the chamber in its normal operating position. The test item shall be exposed to a simulated rain at a rate of 5 ± 1 inches per hour for 10 minutes. The rate of rainfall shall then be raised to 12 ± 1 inches per hour and held at this rate for 5 minutes. The rate shall then be reduced to 5 ± 1 inches per hour for the next 15 minutes. Starting 5 minutes after the initiation of the rain, the wind source shall be turned on and adjusted to produce a horizontal wind velocity of 40 miles per hour (3,500 feet per minute). The wind source shall be turned off. Note: If specified in the equipment specification, the equipment shall be operated during the last 10 minutes of the 30-minute rain. Each of the sides of the test item that could be exposed to blown rain shall be subjected to the rain for a period of not less than 30 minutes, for a total test duration of not less than 2 hours. At the conclusion of the test period, the test item shall be removed from the test chamber, operated, and the results compared with pretest operations. The protective cover or case shall, where possible, then be removed and the test item inspected with particular attention to evidence of water penetration, such as free water, swelling of material, or other deterioration.

V.2.9.2 Rain

Equipment

Instrument under test

Rain simulator

Procedure

1. Place the instrument into the test area in its normal operating orientation.
2. Turn on the rain simulator and adjust the rainfall rate for 4 ± 1 inches per hour dispersed uniformly over the test area.
3. Commence the test with the rain originating from a point directly above the instrument and rotate the rain simulator through 45° in one direction at the rate of $1^\circ/\text{min}$.
4. Rotate the instrument 90° in the horizontal plane.
5. Repeat 2, 3, and 4 until all four sides of the instrument have been exposed to the 45° rain.
6. Remove the instrument and dry the exterior surfaces.
7. Close the instrument and perform a normal operational check, noting any abnormalities. Turn off instrument power.
8. Open the instrument and inspect all parts for any signs of moisture.

V.2.9.3 Rain(31)

Equipment

A rain chamber equal to MIL-C-8811 shall be used.

Procedure

The equipment shall be mounted in the rain chamber so as to simulate conditions of service installation. The rain test chamber temperature shall be uncontrolled, except as regulated by water introduced as rain, throughout the test period. A simulated rainfall of 4 ± 1 inch per hour as measured at the surface of the equipment by a U.S. Weather Bureau type gauge shall be produced by means of a water spray nozzle of such design

that the water is emitted in the form of droplets having a minimum diameter of 1.5 millimeters. The temperature of the water shall be uncontrolled if the water supply temperature is between 11° and 20°C, (51.8° and 68°F). The direction of rainfall shall be capable of variation up to 45° from the vertical. The rainfall shall be dispersed uniformly over the test area within the limits as specified above. Each of the 4 sides of the equipment shall be exposed to the simulated rainfall for a period of 30 minutes, for a total test duration of 2 hours. At the completion of the test, the equipment shall be examined for evidence of water penetration, such as free water, swelling, or other deterioration. The equipment shall then be operated as directed in 3.9.

V.2.9.4 Immersion⁽²⁴⁾

Equipment

Water container and accessories.

Procedure

1. Preparation. Where applicable, open and close (or remove and replace) doors and covers three times immediately before tests.
2. Test conditions. The temperature of the water shall be $18^{\circ} \pm 5^{\circ}\text{C}$ (64°F) and the temperature of the test item shall be $27^{\circ} \pm 3^{\circ}\text{C}$ (49°F) above the temperature of the water used for the test. The water container shall be of sufficient capacity so that the immersion of the test item will not raise the temperature of the water more than 3°C (5°F).
3. Performance of test. Immerse the test item (covers closed on field transported items) in the water so that the uppermost point of the test item is 36^{+5}_{-0} inches below the surface of the water. The test item shall remain immersed for 120 ± 5 minutes. Upon completion of the test period, remove the test item from the water and wipe the exterior surfaces of the test item dry. Open the test item and examine the interior and contents for evidence of leakage.

V.2.9.5 Immersion

Equipment

Water-filled tank

Procedure

1. With all instrument power off and submerge the device under test to a depth of 30 inches at the center of gravity for five minutes. Observe and note any steady emission of air bubbles during the test.
2. Remove the instrument and dry the exterior surface.
3. Open the instrument and inspect all parts for any signs of moisture. Close the instrument.
4. Turn on the instrument and perform a normal operational check, noting any abnormalities. Turn off instrument power.

V.2.9.6 Immersion⁽³¹⁾

Equipment

Immersion tank.

Procedure

The equipment shall be immersed in a suitable liquid, such as glycerine, diethylene glycol, or a saturated solution of sodium chloride. The liquid temperature shall be uncontrolled if the supply temperature is between 11° and 20°C (51.8° to 68°F). The absolute pressure of the air above the liquid shall then be reduced to approximately 1 inch of mercury and maintained for 1 minute, or until air bubbles substantially cease to be given off by the liquid, whichever is the longer. The absolute pressure shall then be increased to 2 ½ inches of mercury. Any bubbles coming from within the equipment case shall be considered as leakage. Bubbles that are the result of entrapped air on the various exterior parts of the case shall not be considered as leaks. A helium leak detector or other means of test, equal or superior in sensitivity to the immersion test method described above, may be used upon large items.

V.2.10 SOUND

V.2.10.1 Sound Level

Equipment

Sound level meter

Ear protection

Procedure

1. Put on ear protection.
2. Test operate the alarm howler and measure the sound level of the operating alarm. If alarm sound level is adjustable, measure the range of sound level adjustment available.
3. Measure background sound levels in all locations in the facility which may be occupied.
4. Determine the capability of the alarm howler to provide the required sound levels above the background levels.
5. For alarm signals which do not have a sound level adjustment, measure the sound level at a distance of 10 feet and compare with the maximum sound level specified in the performance criteria.

V.2.10.2 Sound Response Time

Equipment

Sound level meter

Ear protection

Stop watch with sweep second

Procedure

1. Put on ear protection
2. Place sound level meter microphone at a distance of 25 feet from the alarm signal device.
3. Measure the ambient background sound level.
4. Simultaneously start the stop watch and test operate the alarm signal.

5. Stop the stop watch when the sound level meter measures 10 decibels above ambient background. Note the response time on the stop watch.
6. Repeat Steps 3 through 5 and average the response times recorded.
7. Compare the average response time with the performance criteria.

V.2.10.3 Alarm Lock-on

Equipment

Appropriate radiation source

Procedure

1. Turn on test item and allow appropriate warm up time.
2. Adjust alarm set point to a convenient radiation level.
3. Increase radiation level until alarm is triggered.
4. Decrease radiation level well below alarm set point, i.e., at least 1/10 the alarm set point value.
5. Note whether the alarm continues to sound.
6. Reset the alarm.

V.2.11 HIGH PRESSURE

V.2.11.1 High Pressure

Equipment

High Pressure Chamber

Procedure

1. Place the test item in the pressure chamber.
2. Increase the chamber pressure to the specified pressure and maintain for at least one hour.
3. Return the pressure to normal and remove the test item.
4. Inspect the test item for evidence of physical damage.

V.2.12 MISCELLANEOUS

V.2.12.1 Malfunction Audit Circuit

Equipment

Appropriate Radiation Source

Procedure

1. Turn on instrument under test and allow appropriate warm up time.
2. Adjust radiation level to give a convenient indication on the test instrument.
3. Randomly disconnect and reconnect various parts of the operating instrument, i.e., signal lines, tubes, transistors, integrated circuit chips, resistor capacitors, etc., to simulate failures. Observe whether the simulated failures affect the radiation level indication and whether the malfunction/failure signal is produced.

V.2.12.2 Air Filter Efficiency⁽³²⁾

Equipment

Photometric, Light-Scattering Instrument

DOP Aerosol Generator for ≥ 0.3 μm Diameter Particles

Vacuum Pump and 9/32 I.D. or Larger Tubing (maximum 50' sample line length)

Flowmeters

Procedure

The In-Place Test. The following is a summary of most of the operations involved in conducting an in-place test using Figure 4 as an example.

FIGURE 4. Typical Arrangement for In-place DOP Test

1. A visual inspection should precede the test if it is the first test of a new system or the first test following a filter change or replacement of other devices. Visible defects and continuous leakage paths should be eliminated.
2. Adjust air flow to the expected maximum operating value.
3. Install suitable aerosol generators in the cell or work area.
4. Remove a sample from port "C" and measure its concentration with the linear, photometric, light-scattering instrument. Adjust aerosol generators or instrument sensitivity to give a suitably high reading of the aerosol concentration in the unfiltered air.
5. Verify that a representative sample exists in the duct at sample port "C".
6. Measure the concentration of the aerosol in the unfiltered air at "C".
7. Measure the concentration of the aerosol in the filtered air sample port "K". Immediately repeat Step 6 to verify that a condition of equilibrium exists.
8. Calculate the efficiency of the system as follows:

Basically, the filtration efficiency of the system is given by

$$E = 100 - 100 \frac{DS}{US}$$

where:

E = efficiency of the system in percent

US = concentration of the aerosol in the unfiltered air; that is, the sample removed from the duct upstream of the device.

DS = concentration of the aerosol in the filtered air; that is, the sample removed from the duct downstream of the device.

9. Adjust air flow to the expected minimum operating value and repeat Steps 4, 5, 6, 7, and 8.

V.2.12.3 Sampling Velocity Calibration

Equipment

Standard or Type S Pitot Tube
Differential Pressure Gauge

Procedure

1. Connect the pitot tube to the differential pressure gauge.
2. Insert pitot tube into dual sampling port and measure the velocity at the desired sampling location within the duct.
3. Calculate the sampler flow rate which will give the desired linear velocity at the sampler inlet.
4. Insert the sampler probe and adjust the sampler flow rate to the calculated value.

V.2.12.4 Illumination

Equipment

Dark enclosure (darkroom or windowless closet)

Procedure

1. Place test item in dark enclosure.
2. Turn test item on and allow appropriate warm up time.
3. With enclosure darkened, observe whether readout is sufficiently illuminated as required.

V.2.12.5 Air Flow Rate Accuracy

Equipment

Calibration rotameter (2% accuracy) of appropriate flow rate range

Procedure

1. Insert calibration rotameter in series with the flowmeter to be calibrated. (This may necessitate temporary rerouting of the sample line through the rotameter or attachment of the rotameter at the sample intake or filter holder using an appropriate air tight adapter).
2. Turn on the test item air mover.
3. If the flowrate is not adjustable, note the flowrate indicated on the test item flowmeter (f_1) and on the rotameter (f_2). Go to step 5.
4. If the flow rate is adjustable, adjust to the typical operational flowrate using the calibration rotameter to indicate flow rate. Note the flow rate indication f_1 and f_2 .
5. Calculate:
$$\text{Accuracy} = \frac{f_1 - f_2}{f_2} \times 100$$
6. If the test item is used at other flow rates than was selected in step 4, repeat steps 4 and 5 for these flow rates.
7. If the flow rate is adjustable but flow rate at which the test item will be operated is not known, perform steps 4 and 5 at 10, 40, 60 and 90% of 1) full scale on the test item flow meter or 2) air mover range.

V.2.12.6 Flow Rate Control

Equipment

Appropriate limiting orifice or "loaded" filter.

Procedure

1. Turn on test item. Observe sampling rate and adjust to the desired sampling rate if necessary. Normal clean filter media should be used during this step.

2. Introduce a filter media restriction equivalent to the maximum filter ΔP which is expected during a normal operating (filter change) period. The restriction may be a limiting orifice or an appropriately "loaded" filter. Observe any change in the sampling rate of step 1.
3. Compare any change in the sampling rate with the performance criteria requirement.

V.3 ELECTRONIC EVALUATION

V.3.1 WARMUP TIME

Warmup time is the interval after application of power during which the instrument will not meet accuracy specifications.

V.3.1.1 Warmup Time

Equipment

Radiation source(s)

Timer

Graph materials

Procedure

With the assembly off, expose the detector to an appropriate source of radiation that will provide an indication of at least half of scale maximum. Switch on the assembly and note the readings of the assembly every 20 seconds from 40 seconds to 300 seconds after switching on.

Ten minutes after switching on, take at least 10 readings and take the mean value of these as the "final value" of the indication. On a graph of indications as a function of time, draw a smooth curve that is best fit to the observed indications.

The differences between the final value and the values read from the curve at 1 min and 3 min shall lie within the limits specified.

V.3.2 ZERO DRIFT

Zero drift normally refers to instruments which have a meter movement data display. Under "no-load" conditions the meter may slowly deflect up or down scale from the "zero" position. Inadequate circuit design or faulty component parts give rise to zero drift.

V.3.2.1 Zero Drift⁽³³⁾

Equipment

Timer

Procedure

Switch on the assembly and leave for a period of 30 minutes. If a set zero control is available to the operator, this shall then be adjusted to bring the indication to zero. For some assemblies with a non-linear scale, such a control is used to bring the indication to some reference point rather than to zero. If this is the case, the control shall be set to bring the indication to the appropriate reference point.

The assembly shall be left in this condition and the reading again noted after a further four hours.

For assemblies on which background radiation corresponds to more than 1% of scale maximum angular deflection on the most sensitive range, an equivalent electrical test shall be carried out. For this electrical test, the detector may be rendered inoperative provided this is done in such a manner that the characteristics of the assembly with respect to drift are not altered.

V.3.3 STABILITY

As with zero drift, stability is a test of the adequacy of circuit design and component parts. In addition to the ability to maintain zero, the long term accuracy and precision are tested.

V.3.3.1 Stability

Equipment

Standard nuclear source set

Calibration jig

Procedure

1. Turn on instrument and allow appropriate warm-up time.
2. Adjust the instrument to read zero when not in radiation field if necessary.
3. If instrument falls within specification for the zero, place the instrument in a radiation field and check accuracy and precision at the midpoint of each range (see note at end of test).
4. Remove instrument from radiation field and leave on.
5. After at least two hours, recheck zero reading for drift.
6. Repeat steps 2 through 5 at intervals until the required total time has elapsed.

Note: If at any time during the test, the test instrument fails to meet the zero drift, accuracy or precision specifications, the stability test may be terminated.

V.3.3.2 Stability⁽²³⁾

Equipment

Voltage and current measuring instruments

Procedure

Some power supplies have variable output, especially for the high voltage. With constant input voltage the output range is checked at the end points and the stability noted. The measurements should include both voltage and current outputs. Generally, the circuitry of the instrument is used as the load, but fixed resistors can be used to provide loads of any desired value. The stability of the voltage and current output is observed as a function of load, output voltage, and input voltage. Modern power supplies should generally be capable of providing stable high voltages to within a few percent.

V.3.4 LINEARITY

The linearity should not be confused with the linearity of the instrument as a whole. The instrument linearity can only be checked by tests in radiation fields whose levels can be varied over the

working range of the instrument. The rate-meter linearity is easily and quickly checked by putting a signal similar to that provided by the detector into the detector input of the circuit.

V.3.4.1 Linearity

Equipment

Nuclear precision pulse generator

Procedure

1. Disconnect any detector inputs.
2. Connect the pulse generator to the test pulse input. Turn on the instrument and pulser.
3. Set the pulse repetition frequency to zero and check the zero point of the meter.
4. Adjust the pulse repetition rate for full scale needle deflection on the most sensitive range.
5. Decrease the frequency of pulses to 80, 60, 40, and 20% of the full scale frequency and note the meter reading.
6. Decrease the sensitivity by changing scales and set the pulser's frequency for a full scale indication.
7. Repeat steps 5 and 6 until all scales have been tested. The instrument should now be on the least sensitive scale.
8. Without changing the scale, adjust the pulse frequency to give a deflection which is equivalent to a full scale reading on the next most sensitive scale.
9. Switch to the next most sensitive scale and record the percent error from 100% of full scale.
10. Repeat the procedure of 8 and 9 until full scale deflection is tested on the most sensitive scale.
11. Turn off power to pulser and instrument. Remove pulser connection from the test pulse input.

V.3.4.2 Linearity⁽³⁴⁾

Equipment

Electric current or electric charge source

Instrument under test

Procedure

For the purpose of defining non-linearity the following may be adopted. One reading M is taken as a reference point which should be the calibration point at which the radiation calibration factor for the instrument is determined; the input signal Q required to produce this reading is measured. At another reading m produced by an input signal q the non-linearity is given by

$$\left(\frac{m}{M} \cdot \frac{Q}{q} - 1 \right).$$

For an exposure meter the input signal is electric charge while for an exposure-rate meter the input signal is electric current.

The non-linearity shall be determined by measurements made at not fewer than five evenly spaced points on the display device. When possible, an ionization chamber should be disconnected from the measuring assembly and the input signal provided by an electrical charge or current source of known accuracy. The non-linearity shall be measured for the whole measuring assembly and not for the display device alone. For a multi-range instrument it shall be verified that the non-linearity does not depend on the range used.

V.3.5 SWITCHING TRANSIENTS

Switching transients refer to quick, violent, large excursions of the meter when the range switch is changed from one range to the next.

V.3.5.1 Switching Transient

Equipment

Nuclear precision pulse generator

Stopwatch

Procedure

1. Connect the pulse generator to the test pulse input. Turn on the instrument and pulser.
2. Adjust the pulse repetition frequency for midscale needle deflection on the most sensitive range.
3. Quickly switch upscale and back, measuring with the stopwatch the time required for the needle to become stable at midscale.
4. Move the range switch upscale, set the pulser for midscale needle deflection and repeat the test for both the up and downscale switching operations.
5. After all the scales have been tested turn off the power to the instrument and pulser, and remove the connection from the test pulse input.

V.3.5.2 Switching Transient⁽³⁵⁾

Equipment

Stopwatch

Procedure

The range switch shall be changed stepwise in both directions, and the magnitude and the recovery time of switching transients noted; the meter reset shall not be used for this test.

V.3.6 VOLTAGE/FREQUENCY

Line powered equipment may be subjected to transient or steady state voltage and frequency deviations which could affect reference voltage values and timing circuits or other aspects of electronic circuits resulting in marginal performance.

V.3.6.1 Voltage/Frequency

Equipment

Source of variable voltage and frequency

Nuclear precision pulse generator

Strip chart recorder

Procedure

1. Connect the test output voltage of the instrument to the strip chart recorder, turn on the recorder and set the pen to zero.
2. Connect the pulse generator to the test pulse input. Connect the instrument to the voltage output of the variable AC power supply.
3. Adjust the variable power supply for normal line voltage and frequency. Turn on the instrument and pulser.
4. Adjust the pulse generator repetition rate for midscale needle deflection on the most sensitive range.
5. Adjust the strip chart recorder pen sensitivity for midscale pen deflection. Set the chart speed for about 10 cm/hr, carefully note the initial pen position and turn on the chart drive motor.
6. Raise the voltage to the upper limit plus 10% of the difference and operate the instrument for 1/2 hour.
7. Raise the frequency to the upper limit plus 5% of the difference and operate the instrument for 1/2 hour.
8. Lower the voltage to the lower limit less 10% of the difference and operate the instrument for 1/2 hour.
9. Lower the frequency to the lower limit less 5% of the difference and operate the instrument for 1/2 hour.
10. Increase the chart speed to about 1000 cm/hr and in 5 second cycles vary the voltage and frequency between the states existing in 7 and 9 for 20 seconds.

11. Turn off power to the pulser, instrument under test, strip chart recorder, and variable AC power supply. Remove all connections.
12. Measure the amounts of deflection recorded on the strip chart.

V.3.6.2 Voltage/Frequency⁽²²⁾

Equipment

Source of variable voltage and frequency.

Source of appropriate nuclear radiation.

Procedure

Reference measurements shall be made at nominal voltage and frequency. The equipment shall then be operated at the extreme limits of the steady state band in combinations of voltage and frequency. The equipment shall be operated at least 15 minutes in each combination during which time measurements shall be taken to insure performance within limits established in the individual equipment specification.

V.3.6.3 Voltage/Frequency⁽²⁶⁾

Equipment

Spike Generator with characteristics as follows:

(1) Pulse Width	- 10 microseconds
(2) Pulse Repetition Rate	- 3 to 10 p.p.s
(3) Voltage Output	- Not less than 200 V. peak
(4) Output control	- Adjustable from 0 to 200 V. peak
(5) Output Spectrum	- 160 dB μ v/MHz at 25 kHz
decreasing to 115 dB v/MHz
at 30 MHz
(6) Phase Positioning	- 0 to 360 degrees
(7) Source Impedance (with
injection transformer)	- 0.06 ohms
(8) Transformer (current capacity)	- 30 amperes
(9) External Synch	- 50 to 800 Hz
(10) External Trigger	- 0 to 20 p.p.s.

Capacitor - The 10 microfarad feedthrough capacitor as specified for Method CE01.

Oscilloscope - Any oscilloscope with 10-MHz bandwidth and adequate sweep rates is acceptable.

Procedure

1. Connect test sample and test instrumentation as shown in Figure 5 for equipments powered from a.c. lines and Figure 6 for equipments powered from d.c. lines.
2. Series, shunt, or both test methods may be used provided that approval has been granted by the procuring activity.
3. When a generator with a high source impedance is used, its output shall be loaded and calibrated as indicated in Figure 7.
4. The applied spike amplitude, rise time, and duration, as measured by the oscilloscope across the input terminals of the test sample, shall follow the typical wave shape specified in the applicable limits.
5. Synchronization and triggering shall be used to position the spike to specific test sample signal conditions which will produce maximum susceptibility.
6. Positive and negative, single and repetitive (6 to 10 p.p.s) spikes shall be applied to the test sample's ungrounded input lines for a period not to exceed 30 minutes in duration. Spikes shall be synchronized to the power line frequency and positioned on each 90 degree phase position for a period not less than 5 minutes. Positioning of the spike from 0 to 360 degrees of the power line frequency is also required. Spike synchronization frequency shall be varied from 50 to 800 Hz and its effect on equipment susceptibility noted. On equipment employing digital circuitry, the spike shall be triggered to occur within the time frame of any gate or pulse generated by the logic circuitry.
7. If susceptibility occurs, determine and record its threshold level, repetition rate, phase position on the a.c. waveform, and time occurrence on digital gates.

FIGURE 5. CS06-1. Conducted Susceptibility, Spike, Power Leads: Series Injection

FIGURE 6. CS06-2. Conducted Susceptibility, Spike, Power Leads: Parallel Injection

CONNECT A CALIBRATED 5 OHM NON-INDUCTIVE LOAD RESISTOR TO GENERATOR TO VERIFY SPIKE CHARACTERISTICS

FIGURE 7. CS06-3. Calibration of Spike Characteristics

V.3.6.4 Voltage Frequency⁽³⁶⁾

Equipment

The measuring apparatus is shown in Figure 8.

Figure CS01-2 (not shown) shows the construction data for an acceptable isolation transformer. The transformer shall carry all currents without saturation, shall have low leakage reactance, less than one microhenry, and shall have a secondary current capability of 35 amperes (power line current) a.c. or d.c. with 10-percent drop.

A 100-microfarad capacitor across d.c. power sources might be required if difficulty is encountered in obtaining the required test voltage.

Procedure

The test setup is shown in Figure 8.

1. If the output impedance of the signal source looking into the secondary terminals of the isolation transformer is unknown, measurement shall be as follows:

- (a) Apply a signal to the primary of the transformer and measure the open circuit secondary voltage (V_{oc}).
- (b) Connect a known load, R_L , across the secondary and measure the closed circuit secondary voltage (V_{cc}).
- (c) The impedance shall be calculated as follows:

$$Z = \frac{R_L (V_{oc} - V_{cc})}{V_{cc}}$$

- (d) Repeat the above at one frequency per decade from 30 Hz to 50 kHz (including 30 Hz and 50 kHz).
 - (e) The measured impedance shall be less than or equal to 0.5 ohms. If it is not, adjust the turns ratio until the desired impedance is attained.
2. The test sample shall be connected as shown in Figure 8.
 3. The oscillator shall be tuned through the required frequency range, the output to the specified level adjusted and verification made that: (a) malfunction is present (b) there is degradation of

FIGURE 8. CS01-1. Conducted Susceptibility, 30 Hz to 50 kHz Typical Test Setup

performance, or (c) deviation from indication occur beyond tolerance indicated in the equipment specification or approved test plan. The frequency range within 10 percent of the rated power frequency can be omitted, unless otherwise specified by the procuring activity.

4. If the test sample is susceptible to the specified limit level, the output shall be decreased to determine the susceptibility threshold level. This value shall be recorded.
5. The power voltage applied to the test sample shall be measured over the frequency range of the test and recorded. In some cases, the supply voltage will have to be raised to compensate for losses in the isolation transformer.

Note: On a.c. lines, a network to eliminate the power frequency at the oscilloscope, VTVM, or EMI meter will simplify measurement.

V.3.7 ELECTROMAGNETIC INTERFERENCE

Electromagnetic radiation of many kinds can cause unusual effects and spurious response. The circuitry, rather than the detectors, is more commonly affected. In most cases, well designed circuits with good electrical shielding will not be affected by electromagnetic fields.

V.3.7.1 Electric Field⁽³⁶⁾

Equipment

- (a) Signal source.
- (b) EMI meter.
- (c) Antennas (for receiving and transmitting specified Electric Field).
- (d) Output Monitor - to monitor performance of test sample.

Procedures

1. The test setup shall be as required by the general testing requirements of this standard for placement of antennas.
2. Test signals shall be selected in accordance with MIL-STD-461

3. Field shall be generated, as required, with the antenna specified in MIL-STD-461. Care shall be taken so that the test equipment is not affected by the test signals.
4. The output of the signal generator shall be adjusted so that the generated fields at the test sample correspond to the applicable limit. The specified field strengths shall be established by placing a field measuring antenna at the same distance, or relative location where the test sample will be placed. The power at the input terminals of the transmitting antenna required to establish the specified field shall be monitored and recorded. When a test is performed, this same power shall be applied to the transmitting antenna terminal. When baluns or other matching networks are used, any losses shall be properly compensated.
5. Determine those frequencies at which the test sample is susceptible. At these frequencies, determine the threshold of susceptibility. Record all pertinent data.

V.3.7.2 Electric Field⁽³⁶⁾

Equipment

Parallel Plate Line (see Figures 9 and 10).

Signal Source capable of delivering the required signals.

EMI meter.

Matching networks (see Figure 11).

30 KHz Low Pass Filter.

Procedure

1. Set up the equipment as shown in Figure 11 with special emphasis on placing the test sample as much to the center of the line as possible. Interconnecting and power leads shall be kept 4 to 6 centimeters above the ground plane and laid out parallel to the line for a length not less than 2 meters. Select test signals in accordance with applicable requirements of MIL-STD-461 or as specified in the test plan.

FIGURE 9. RSOL-1. Parallel Strip Line for Radiated Susceptibility Tests

2. By means of the calibration chart of electric field intensity as a function of the EMI meter reading, corrected by the matching pad insertion loss, adjust the output of the signal generator so that the fields between the plates correspond to the applicable limits.
3. The equipment shall be tested at two orientations in its upright position, one where the front face of the equipment is directed out toward the side of the line and another where the face is directed along the length of the line.
4. Other orientations shall be tested. Sides which have openings for power leads, shafts, ventilation, etc., shall be faced upward toward the top line plate. Care must be taken to preserve the test sample's natural grounding arrangement; for example, if the equipment as it is used in the field does not have direct chassis, grounding such an arrangement shall be retained at all orientations. In no case shall the test sample be closer than 10 cm. to the upper plate.

FIGURE 10. RS04. Parallel Strip Line for Radiated Susceptibility Tests (top and side view)

FIGURE 11. RS04-3. Setup for Susceptibility Tests Using Parallel Plate Line

5. Determine the frequencies and the minimum field strength at which the test sample is susceptible. Record all pertinent data.

Notes

1. Especially important to obtaining a uniform field that is accurately represented by the calibration chart, is the loading of the line with a noninductive 83-ohm resistor. This applies equally to the matching network used with the EMI meter. All resistors should be chosen with ± 1 percent of tolerance.
2. Care should be taken to assure that the resistive load used will be able to handle the power which is to be applied.
3. The EMI meter should be placed outside of the screen room if high intensity fields are being generated. Cables leading to the EMI meter should be kept as short as possible.

FIGURE 12. RS04. Line Calibration Chart

V.3.7.3 Magnetic Induction Field⁽³⁶⁾

Equipment

1. Spike Generator. - Spike generators shall be as specified in Method CS06 of this standard.
2. Step-down Transformer and Variac. - The step-down transformer and variac shall be capable of carrying the currents required by this test.
3. Oscilloscope.

Procedure

1. Cable Susceptibility Test (Test 1). - The cable susceptibility test shall be performed as specified hereinafter.
 - 1.1 Power Frequency Test. - Tape two current-carrying insulated wires to each wire bundle in the test setup with the current carrying wire around the wire bundle, spiralling at two turns per meter (equally spaced) and running the entire length of the bundle to within 15 cm of each end connector. (See Figure 13(A). Apply the required current at the test sample power frequency(ies) to one test wire at a time. Monitor for susceptibility.
 - 1.2 Spike Test. - Make the test setup as shown in Figure 13(B). Repeat 1.1 applying the required spike, and monitor for susceptibility.
2. Case Susceptibility Tests (Test 2). - The case susceptibility test shall be performed as specified hereinafter.
 - 2.1 Case Test. - Wrap several turns of insulated wire around each case in the test sample. These turns should be located as shown in Figure RS02-2(a) and held in place by tape. Apply the current specified in the applicable limits at the test sample's power frequency(ies) through the wire and monitor the test sample for malfunction, degradation of performance, and changes in indication.

NOTE:

- (1) L SHALL BE THE LENGTH OF THE CABLE IN THE ACTUAL INSTALLATION OR 1.5 METERS, WHICHEVER IS LESS

FIGURE 13. RS02-1. Radiated Susceptibility, Magnetic Induction Field, Cable Test

2.2 Spike Test. - Make the test setup as shown in Figure RS02-2(b).

Repeat 2.1 applying the required spike and monitor for susceptibility.

Notes.

1. A.c. power input and output leads are exempt from the cable test.
2. It is not the intention of the cable test to test individual wires but to test groups or bundles or wires. The bundles should be made up as specified in the contract or order or installation instructions.
3. Keep current carrying wires 15 cm away from cable connectors.
4. All cables should be at least 5 cm above the ground.
5. In order to minimize test time, test as many boxes and wire bundles at the same time as practicable.
6. The power frequency used for test purposes is that frequency used in the operational system.

V.3.7.4 Magnetic Field⁽³⁶⁾

Equipment

1. Radiating Loop. - The radiating loop shall be as shown in MIL-STD-461. The loop is capable of producing a magnetic flux density of 5×10^{-5} Tesla/Ampere at a point approximately 5 cm from the face of the loop. It shall be supported on a wooden form or similar non-conducting material.
2. Signal Source. - The signal source shall be as specified in MIL-STD-461. The loop shall be supplied with sufficient current capable of producing magnetic flux densities 20 to 30 dB greater than the applicable limit at the test frequency.
3. EMI Meter or Narrow band VTVM. - The EMI Meter or Narrow band VTVM shall be capable of reading levels as low as 30 μ v in the 30-Hz to 30-kHz frequency range. The equipment shall have a 10-Hz or narrower bandwidth at the 3-dB points.

Procedure

1. Position the field radiating loop 5 cm from the surface of the test sample. The plane of the loop shall be parallel to the plane of the test sample's surface. (See Figure 14.)
2. Supply the loop with sufficient current to produce magnetic flux densities approximately 20 to 30 dB greater than the applicable limit at the test frequencies.
3. Move the loop over the entire surface and signal input and output cables and connectors to determine the point at which the applied field produces the maximum effect on the test sample.
4. With the loop at the point of maximum susceptibility, adjust the loop current until the performance of the test sample is not affected by the applied field.
- 4.1 For test samples with an aural output, adjust the loop current until the test sample gives a reading 20 dB greater than its internal noise. If a 20-dB value cannot be obtained, a 6-dB interference signal-to-noise ratio will be used.

- 4.2 For test samples with outputs other than aural, the degree of degradation shall be defined in the test plan.
- 4.3 For test samples with aural and nonaural outputs, the test shall be performed to meet both steps 4.1 and 4.2.
5. Record the magnitude of the magnetic field density produced by the source and the maximum value of magnetic flux density required by step (4) above.
6. Repeat steps 1 through 5 at the test frequencies approved in the test plan.

Notes.

1. The magnitude of the magnetic flux density produced by the magnetic field source will be converted to a value representing the equivalent interfering magnetic flux density for a 6-dB signal-to-noise ratio in a system bandwidth of 1 Hz. To make this conversion, the calculations specified hereinafter are necessary:
 - 1.1 If a 20-dB interfering signal-to-noise ratio was used the magnetic flux density recorded in step 5 shall be reduced by 14 dB.
 - (a) If the bandwidth of the tunable voltmeter or EMI meter is greater than that of the test sample or if the overall bandwidth of the test sample plus measuring instrument is greater than 1 Hz, the value will be further reduced by a factor of $10 \log \Delta f_v$ where Δf_v is the 3-dB bandwidth of the EMI meter or tunable voltmeter. This final value shall be recorded at that frequency.
 - (b) If the overall bandwidth of the test sample, plus measuring instruments is less than 1 Hz, or if the bandwidth of the tunable voltmeter or EMI meter is less than that of the test sample, the magnetic flux density recorded shall be increased by a factor $10 \log \frac{1}{\Delta f_s}$, where Δf_s of the overall 3 dB bandwidth of the test sample. This final value shall be recorded and compared with the limit.

1.2 If a 6-dB signal-to-noise ratio was used, the magnetic flux density recorded in step 5 shall be approximately adjusted as specified in 1.1(a) and 1.1(b).

R = RESISTOR OF 1 OHM (A 1-VOLT OUTPUT TO THE VOLTMETER YIELDS A 1 AMP INPUT TO THE LOOP)

FIGURE 14. RS01-1. Radiated Susceptibility, 30 kHz to 30 kHz, Magnetic Field

V.3.7.5 Electromagnetic Interference

Equipment

Instrument under test

Nuclear precision pulse generator

Source(s) of E-M radiation similar to that encountered under normal instrument use

Procedure

1. Connect the pulse generator to the test pulse input, turn on pulser and instrument power.
2. Adjust the pulse repetition rate for midscale needle deflection on the most sensitive range.
3. Adjust the source of E-M radiation to the prescribed power level and observe instrument for any response in excess of the permissible limits.
4. Repeat for all sensitivity ranges and all individual sources of E-M radiation.
5. Repeat test on most sensitive range with all sources of E-M radiation present.
6. Turn off power to instrument, pulser, and E-M radiation sources. Remove pulser connection from test pulse input.

V.3.7.6 Electromagnetic Interference

Equipment

Potential AC Transient and Induced Field Generators

Examples: Electric Motors

Typewriter

Calculator

Induction Heater

RF Welder

Motor Ignition

Procedure

1. For line operated instrument, plug the instrument and the selected potential EM source into a common power outlet. Power cables should be long enough to be laid parallel to each other for at least several feet.
2. For battery instruments or non-line operated EM sources, simply operate the instrument and EM source in close proximity.
3. With the instrument warmed up and operating, start and stop the selected EM source several times. Observe any instrument response.
4. Operate the EM source for five minutes as it might normally be used. Observe any instrument response.
5. Repeat 1, 2, and 3 for as many EM sources as are appropriate.

V.3.7.7 Electrostatic Charge⁽²³⁾

Equipment

Electrostatic Charge Source

Procedure

The effect of electrostatic charge is easily checked qualitatively by moving a charge comb or piece of plastic around the instrument and detector, and noting any deviation in meter reading.

V.3.7.8 Radiofrequency Susceptability

Equipment

Radio Frequency Studies Facility (Sandia Laboratories)

Appropriate Nuclear Radiation Source

Provision for Remote Viewing of Test Instrument Response

Procedure

1. Turn on test instrument and allow an appropriate warmup time.
2. Adjust the nuclear radiation level to give a response of about midscale on the test instrument.

3. Subject the test instrument, electronics, cables, radiation² detector, etc., to at least 10 seconds of pulsed radio frequency radiation with a peak field intensity of 1000 V/m.
4. During Step 3 observe the test instrument for any induced change in the indicated nuclear radiation level of Step 2.

V.3.7.9 Microwave Susceptibility

Equipment

Microwave Oven

Microwave Power Meter

Appropriate Radiation Source

Procedure

1. Place the test system in the microwave oven. Turn system on and allow appropriate warmup time.
2. Place the radiation source in the oven in proximity to the test system so that a radiation level of about midscale on the low range is indicated.
3. Turn on the oven power and adjust the microwave power level to the desired value, i.e., 10 mW/cm².
4. Observe the test instrument for any induced change in the indicated nuclear radiation level.

V.3.8 BATTERY LIFE

Most portable instruments use batteries as the prime energy source. The batteries may supply the power directly to the circuit, or in instruments of recent design, the batteries furnish energy to solid state supplies which convert the low voltage of several low cost, dry batteries to the high and intermittent voltages needed by the circuit. Batteries may be employed as emergency power in instruments designed for line operation.

V.3.8.1 Battery Life

Note: This is a destructive test which is intended to be performed on random samples which are discarded after testing.

Equipment

Strip chart recorder
Resistive load equivalent to instrument
Environmental simulation chamber
Battery power supply pack (3)

Procedure

1. Place a battery pack into the chamber which is stable at the (high) (low) temperature limit. Connect one end of a pair of test leads to the battery pack and let the other ends hang free outside of the chamber.
2. Close the chamber door and allow one-half hour for temperature equilibrium to be reached.
3. Connect the two terminals of the resistive load to the strip chart recorder and zero the pen.
4. Attach the two free test leads to the two terminals of the resistive load and adjust pen sensitivity for a full scale pen deflection.
5. Note carefully the starting position of the chart and turn on the chart advance motor, at a speed of about 10 cm/hr.
6. Measure the distance of chart travel to the point where the voltage falls below minimum acceptable limits and convert to time.
7. Disconnect all leads, remove and discard the battery pack.
8. Turn off all instrument power.

V.3.8.2 Battery Life⁽³⁵⁾

Equipment

Appropriate radiation source.

Procedure

Battery lifetime shall be determined with fresh batteries installed in the instrument. The instrument shall be turned on in a field <0.1 mR/hr.

and left on continuously. At intervals, the response of the instrument should be tested with a flux providing approximately a half-scale reading; the point in time at which the instrument response no longer meets all performance specifications should be used to determine battery lifetime and corresponding end-point voltage.

V.3.8.3 Battery Life

Equipment

Appropriate radiation source
Clock timer
Environmental chamber

Procedure

1. Place a set of fresh batteries in the test item.
2. Turn on the test item and allow appropriate warmup time.
3. At ambient temperature, introduce a radiation exposure rate sufficient to produce a test item response of 10 percent of maximum full. Record the response.
4. Start clock timer. At 24-hour intervals, record test item response. (Shorter intervals may be employed.)

NOTE: Suspend the test at any time the response consistently indicates less than 90 percent of the response of Step 3 and record the elapsed time at which this occurs.

5. Continue the test (except in the case of the note above) until the required time has elapsed.
6. Repeat Steps 1 through 5 for other temperature conditions using the environmental chamber as appropriate.

V.3.8.4 Battery Exchange

Equipment

Appropriate radiation source
Replacement battery(s)

Procedure

1. Turn on test item and allow appropriate warmup time.
2. Expose the test item to the radiation source in reproducible geometry so that an instrument response of about midscale on the lowest range (identified by the range criteria).
3. Remove the radiation field, turn off the instrument and replace all batteries.
4. Turn on the test item and allow appropriate warmup time.
5. Return the test item to the reproducible radiation geometry of Step 2 and observe any change in the instrument response from the response of Step 2.
6. If the change exceeds the performance criteria requirement, repeat Steps 3 through 5 to confirm the result.

V.3.8.5 Low/Dead Battery Indication

Equipment

1000 ohm potentiometer
Multimeter (voltmeter)

Procedure

1. Disconnect the test item battery at the positive polarity battery terminal.
2. Connect one resistance leg of the potentiometer to the positive polarity battery terminal and connect the slide tap leg of the potentiometer to the test item power lead removed in Step 1.
3. Connect the multimeter (voltmeter) to the potentiometer tap leg and the negative battery terminal.
4. Adjust the potentiometer to the minimum resistance (short) position and note the multimeter voltage reading.
5. Turn on test item and allow appropriate warm-up time.
6. Zero the test item and switch to the most sensitive scale. Note the test item reading.
7. Adjust the potentiometer so that the multimeter voltage reading is 70 percent of Step 4. Note the test item reading. Check the

- zero adjustment. If rezeroing is required, attempt to do so.
Compare the results of this step with the performance criteria.
8. Repeat Step 7 at decreased voltage intervals of 10 percent (60, 50, 40 percent, etc.) down to the minimum voltage attainable with the test system.
 9. Compare the results of the test with the performance criteria.

V.3.9 ELECTRICAL LEAKAGE

V.3.9.1 Electrical Leakage

Equipment

Environmental Chamber

Dosimeter Charger

Procedure

The discharge of the dosimeter in the absence of a radiation environment above normal background (usually 0.02 mR/hr) shall be measured at +50 degrees C (122 degrees F) and 90 percent relative humidity. A fully charged dosimeter shall discharge no more than 2 percent per 24 hours. The test period shall equal or exceed 25 hours. Initial and final readings of the dosimeter shall be made at the same temperature. This test shall be repeated at -10 degrees C (14 degrees F) with any relative humidity.

V.4. RADIOLOGICAL EVALUATION

V.4.1 RANGE

The term range covers a multitude of features. The range is, of course, the whole of the instrument response. For instruments with linear readout, the range is ordinarily expressed in terms of zero to maximum full scale reading obtainable. For instruments with logarithmic readout, the range must necessarily be expressed in terms of the minimum and maximum scale reading obtainable.

In the typical evaluation, the range of the instrument is usually not specifically checked, for other aspects of the evaluation will adequately cover this area. However, a rapid check of the range can be easily made by simply varying the source to detector distance.

V.4.1.1 Range

Equipment

Standard nuclear source set

Calibration jig

Procedure

1. Turn on instrument and allow appropriate warmup time.
2. Mount instrument on calibration jig.
3. Turn instrument to most sensitive scale and move source towards instrument until instrument responds. Note distance.
4. Move source towards instrument until full scale reading is obtained on least sensitive scale. Note distance.
5. Compare true dose rate at distances obtained in 4 and 5 with instrument readings at those distances and with the range specified in the performance criteria.

V.4.1.2 Alarm Set Point Range

Equipment

Appropriate Radiation Source

Calibration Jig

Procedure

1. Turn on test item and allow appropriate warmup time.
2. Mount test item on calibration jig.
3. Turn instrument to most sensitive scale and set alarm point at 20% of full scale.
4. Slowly increase the radiation exposure rate until the alarm is triggered.
5. Compare the actual exposure rate at the initiation of the alarm with the value of the indicated set point.
6. Repeat 3 through 5 using 80% of full scale.
7. Repeat 3 through 6 for all other test item ranges.

V.4.1.3 Range

Equipment

Appropriate Photon Radiation Source (>2 MeV energy)

Procedure

1. Turn on test item and allow appropriate warmup time.
2. Expose the detector to a photon flux of about 350 photons/sec ($E > 2$ MeV).
3. Observe whether the test item responds to the stated photon flux with an indication of about 10^{-2} Ci/m.
4. Increase the photon flux by five orders of magnitude.
5. Observe whether the test item response is within the upper range limit with an indication of about 10^3 Ci/m.
6. This procedure assumes the worst case from a sensitivity standpoint, i.e., the plume is rising at an angle of 90° to the horizontal. If the plume rises at a shallower angle, upward corrections for sensitivity can be made using Figure 15.

FIGURE 15. Normalized High Energy Photon Flux as a Function of θ and ϕ

V.4.1.4 Range

Equipment

Appropriate Photon Radiation Source ($E > 2 \text{ MeV}$)

Calibration Jig

Procedure

- A. For a detector at the approximate center of the containment volume (21):

$$GS = \frac{Ci/cm^3 (1 - e^{-4.5 \times 10^{-5} r})}{3.4 \times 10^{-15}}$$

Where

- G = geometry factor for test item = photon/count
S = count rate in counts per second
 Ci/cm^3 = specified noble gas concentration in containment
r = radius of containment vessel in cm
GS = photons/count x counts/sec = photon/sec passing through the detector

1. Calculate GS for the known r and for the specified lower range limit concentration.
2. Expose the test item detector to a photon rate calculated in-step 1.
3. Observe that the test item remains on scale and responds with an indication in units equivalent to specified concentration. Units of indication may be concentration or count rate. (Solving the equation for S for a known geometry factor will give the equivalent count rate indication.)
4. Repeat Steps 1, 2, and 3 using the upper range limit concentration.

B. For a detector on the containment vessel wall⁽²¹⁾:

$$GS = \text{Ci/cm}^3 \left(\frac{1 - \frac{1}{9 \times 10^{-5} r} + \frac{e^{-9 \times 10^{-5} r}}{9 \times 10^{-5} r}}{6.8 \times 10^{-15}} \right)$$

See Part A for explanation of symbols.

1. Perform Steps 1 through 4 of Part A.

V.4.1.5 Range

Equipment

⁹⁰Sr-Y Source(s) of such geometry (diameter, thickness, material, etc.), that they may be put in place of the filter media in the test item (activity determined in Step 2)

Procedure

1. Make an assumption as to the maximum sampling time (t min) in which the specified lower limit concentration (C) should be detected at the known sampling rate (f liters per min.)
2. Calculate the filter radioactivity (A) assuming 100% collection efficiency.

$$A = ftc$$

$$\text{Example: } f = 30 \text{ l/m} = 3 \times 10^4 \text{ cc/min}$$

$$t = 20 \text{ sec} = 1/3 \text{ min}$$

$$c = 10^{-10} \text{ Ci/cm}^3$$

$$A = 3 \times 10^4 (1/3)(10^{-10}) = 1 \text{ } \mu\text{Ci}$$

3. Place a ⁹⁰Sr-Y source of about the activity calculated in Step 2 in the filter holder of the test item. Do not operate the vacuum system while the source is in place.

4. Turn on the test item and allow an appropriate warmup time.
5. Observe that the test item remains on scale and responds with an indication in units equivalent to the specified concentration.
6. Repeat Steps 2 through 5 using the specified upper limits concentration.

V.4.1.6 Iodine Range

The range test of V.4.1.5 is applicable with the following modifications:

1. Substitute ^{131}I , mock iodine or other radionuclide source of appropriate energy (0.364 MeV) for the $^{90}\text{Sr-Y}$ source.

V.4.1.7 Liquid Effluent Range

Equipment

^{137}Cs source or other appropriate source of photons
 $E \geq 600 \text{ keV}$.

Procedure

For a detector at the center of the sampled medium:

$$S_A = 6 \times 10^{10} C (1 - e^{-\mu_s r})$$

C = specified radionuclide concentration = Ci/cm^3

$$\mu_s = 0.3 \text{ cm}^{-1}$$

r = radius of source media

S_A = photon flux at the detector in units of $\text{photons/cm}^2 \text{ sec}$

1. Calculate S_A for the lower limit concentration specified.
2. Turn on the test item and allow an appropriate warmup time.
3. Expose the detector to a photon flux ($E \leq 600 \text{ keV}$) of $S_A \times$ surface area (A) of the detector

Example:

$$C = 10^{-9} \text{ Ci/cm}^3$$

$$r = 30 \text{ cm}$$

Detector = 0.5 inch x 0.5 inch cylindrical crystal.
The crystal surface area $A = 6.2 \text{ cm}^2$

$$S_A = 6 \times 10^{10} (10^{-9}) (1 - e^{-0.3(30)})$$
$$= 60 \text{ photons/cm}^2 \text{ sec}$$

$$S_A = 60 \times 6.2 = 370 \text{ photons/sec}$$

4. Observe that the test item remains on scale and responds with an indication in units equivalent to the specified concentration.
5. Repeat the procedure for the upper range limit of radionuclide concentration.

V.4.1.8 Range (Auto Ranging)

Equipment

Appropriate radiation source
Calibration jig

Procedure

1. Turn on test item and allow appropriate warmup time.
2. Place test item (detector) on calibration jig.
3. Adjust radiation exposure rate to a level which should register about 10% of full range on the lowest range of the test item.
4. Note whether the test item selects an appropriate scale.
5. Slowly increase the radiation exposure rate to the level of 50% of the next higher range.
6. Note whether the instrument properly selects the next higher range.
7. Repeat Steps 6 and 7 for all remaining scale ranges.

V.4.1.9 Pu Particulates (Alpha) Range

Equipment

^{239}Pu source on simulated filter media (see Step 2)

Procedure

1. Calculate the test source sizes (A_0) required. The ^{239}Pu source needed for this test is calculated as follows:

$$A_0 = f C_0 t$$

where: f = sampler flow rate in cm^3/min

C_0 = range criteria concentration in $\mu\text{Ci}/\text{cm}^3$

t = 30 min or other appropriate sampling time

for example, if:

$$f = 20 \text{ lpm} = 2 \times 10^4 \text{ cm}^3/\text{min}$$

$$C_1 = 10^{-1} \mu\text{Ci}/\text{cm}^3 \text{ (upper range)}$$

$$C_2 = 10^{-5} \mu\text{Ci}/\text{cm}^3 \text{ (lower range)}$$

therefore:

$$\begin{aligned} A_1 &= 2 \times 10^4 \text{ cm}^3/\text{min} (10^{-1} \mu\text{Ci}/\text{cm}^3)(30 \text{ min}) \\ &= \underline{6 \times 10^4 \mu\text{Ci}} \end{aligned}$$

$$\begin{aligned} A_2 &= 2 \times 10^4 \text{ cm}^3/\text{min} (10^{-5} \mu\text{Ci}/\text{cm}^3)(30 \text{ min}) \\ &= \underline{6 \mu\text{Ci}} \end{aligned}$$

2. Obtain sources of activity A_1 and A_2 evenly distributed and well fixed over a media which approximates the geometry of the filter of the system being tested.
3. Disable test item vacuum system.
4. Turn on test item and allow appropriate warmup time.
5. Place source A_1 in filter holder (source side facing detector).
Do not operate vacuum system while source is in place.
6. Observe and record the response of the test item for source A_1 .
7. Repeat Steps 5 and 6 for Source A_2 .
8. Compare range response with performance criteria requirement.

V.4.1.10 Beta-Gamma Particulate Range

The range test of V.4.1.9 is applicable with the following modifications:

1. Substitute ^{137}Cs for the ^{239}Pu sources.

V.4.1.11 Pu (Particulate) Range

The range test of V.4.1.9 is applicable with the following modifications:

1. Calculate the value of C_o as follows:

$$C_o = \frac{7.4 \times 10^{-4} (S_p A)}{\text{CFM}} \mu\text{Ci/cm}^3$$

where CFM = flow rate of the sampled media (cfm)

$S_p A$ = Pu specific activity (alpha curies/gm)

2. Procedure is performed for only one source activity level.
3. $t = 30$ minutes

V.4.1.12 Pu (Particulate) Range

The range test of V.4.1.9 is applicable with the following modifications:

1. Calculate the value of C_o as follows:

$$C_o = \frac{35 (S_p A)}{\text{CFM}} \mu\text{Ci/cm}^3$$

where CFM = flow rate of the sampled media (cfm)

$S_p A$ = Pu specific activity (alpha curies/gm)

2. Procedure is performed for only one source activity level.
3. $t = 1$ minute

V.4.1.13 Pu (Particulate) Range

The range test of V.4.1.9 is applicable with the following modifications:

1. Calculate the value of C_o as follows:

$$C_o = \frac{3.5 \times 10^{-5} (S_p A)(W)}{(t)(CFM)} \text{ } \mu\text{Ci/cm}^3$$

where: $S_p A$ = Pu specific activity (alpha curies/gm)

W = postulated Pu release (grams)

t = sampling duration (min)

CFM = flow rate of sampled media (cfm)

V.4.1.14 Criticality Detector Range

Equipment

Pulsed critical assembly. For example, the Oak Ridge HPRR Facility

Procedure

1. Make arrangements for use of a pulsed critical reactor assembly.
A minimum of four reactor pulses will be required.
2. Set up criticality detector at a distance of about 20 meters from the critical assembly.
3. Turn on test item and allow appropriate warm up time. Adjust the alarm point to the most sensitive setting.
4. Pulse the critical assembly to produce the pulse length and yield of condition (a) Table 4. Note the response of the test item.
5. Reset test item if necessary.
6. Repeat steps 4 and 5 using condition (b).
7. Repeat using condition (c).

8. Repeat using condition (c).
9. If proposed application requires, the test item should also be tested for conditions (e), (f), (g), and (h).

TABLE 4.

Criticality Detector Testing Conditions

<u>Condition</u>	<u>Pulse Length</u>	<u>Yield *</u>
a	1 msec	10^{15} fissions
b	3 sec	10^{15} fissions
c	1 msec	10^{19} fissions
d	3 sec	10^{19} fissions
e	1 msec	10^{15} fissions
f	3 sec	10^{15} fissions
g	1 msec	4×10^{19} fissions
h	3 sec	4×10^{19} fissions

* These conditions are difficult to produce exactly. Acceptable test conditions are as stated +25%.

V.4.1.15 Integrated Dose Range

Equipment

Appropriate radiation source(s)

Calibration jig

Procedure

1. Turn on test item and allow appropriate warm-up time.
2. Place test item and radiation source in calibration jig.
3. Adjust the exposure [dose] rate to an appropriate low rate considering the lower integrator range value.
4. Reset the integrator.
5. Accumulate an exposure [dose] which gives an integrator reading of 0.1 R [rad]. Record the "true" exposure [dose] required.
6. Adjust the exposure [dose] rate to a level at which the required upper limit of integrator range will be reached in a reasonable time period.
7. Reset the integrator.
8. Accumulate an exposure [dose] which gives an integrator reading of the required upper range limit. Record the "true" exposure [dose] required.
9. Compare the "true" exposure [dose] of steps 5 and 8 with the integrating range requirements.

V.4.1.16 Integrated Dose Range

Equipment

Appropriate Radiation Source

Procedure

1. Zero dosimeter.
2. Place dosimeter and radiation source in calibration jig.
3. Accumulate dose to the dosimeter in increments of 20% of full scale. At each increment, remove the dosimeter and read the indicated dose.
4. Compare the indicated doses with the true doses and with the accuracy requirement for personnel dosimeter.

V.4.1.17 Flow Through Ion Chamber Range

Equipment

$^{90}\text{Sr-Y}$ source(s) of point or other geometry which may be introduced into the ion chamber to give about 50% of first scale reading.

Current Source

Voltmeter

Procedure

1. Disconnect and do not operate vacuum pumps during the test.
2. Turn on monitor and allow appropriate warmup time.
3. Check and adjust detector and other critical voltage to specifications
4. Check and adjust zero.
5. Calculate simulated volume source strength of source to be employed.

$$S(\text{Ci}/\text{cm}^3) = \frac{A(\mu\text{Ci})}{V \cdot \text{cm}^3}$$

Where

S = simulated volumetric activity

A = source activity

V = ion chamber volume

Example: $A = 1 \times 10^{-6} \text{ Ci}$

$V = 10^3 \text{ cm}^3$

$$S = \frac{1 \times 10^{-6}}{10^3} = 1 \times 10^{-9} \text{ Ci}/\text{cm}^3$$

6. Insert the source (A) into the ion chamber near the geometric center.
7. Observe the monitor indication and compare with the calculated, S, value.
8. If a $^{90}\text{Sr-Y}$ source is available which will provide an appropriate test of the upper range limit, repeat Steps 5 through 7 for that source.
9. If sources are not available or impractical, disconnect the signal lead from the ion chamber. Connect the output from the high impedance current source to the signal lead.

10. Adjust the current flow to match the monitor indication of Step 7.

11. Use multiples of the Step 10 current value to provide the appropriate test value for the upper range limit.

V.4.2 LINEARITY

Linearity of an instrument is a function of both electronic linearity and radiation linearity. The tests of section 3.4 are sufficient for checking electronic linearity. Tests of linearity of a radiation detection instrument as a whole must be done with radiation so as to include the potential nonlinearity of the radiation detector.

V.4.2.1 Linearity (18)

Equipment

Calibration jig

Radiation source(s)

Procedure

Similarity method for sub-range linearity checks.

High activity radiation sources are not always available for instruments that operate over a wide range of exposure or dose-rates. A technique has been developed to calibrate these multi-ranged instruments using low activity radiation sources [75, 76]. The method is based upon the fact that the particle flux density or exposure rate at a fixed point at a certain distance from physically identical sources (located at the same position), i.e. same isotope and geometrical dimensions, but of different activities is directly proportional to the source activity regardless of the location and composition of the surrounding medium. For example, if the instrument has a series of sub-ranges 1, 10, 100....., two sources whose activities differ by about a factor of 10 should be chosen. The following procedure is then followed:

1. The instrument's bottom range is initially calibrated using properly certificated sources and jigs;
2. The source with the smallest activity is placed at a distance from the instrument so that the dial reading is 1/2 of the first sub-range;
3. The small source is then replaced by the larger source and the instrument is calibrated at 1/3 full scale of second sub-range;

4. Steps 1 and 2 are repeated for $1/2$ and $2/3$ of the first and second scales;
5. Next the source with the smallest activity is placed at a distance from the instrument so that the dial reading is $1/3$ of the second sub-range.
6. The small source is then replaced by the larger source and the instrument calibrated for $1/3$ full scale of the third range.
7. Steps 1 and 2 are repeated for $1/2$ and $2/3$ of the second and third scales.

This procedure can be repeated for the fourth, fifth, etc. sub-ranges

This method allows the instrument to be placed very near the source, thus obtaining large readings with radiation sources of low activity. When using sources at a short distance, however, it is necessary to be sure that there is no recombination of ions in the detector caused by a non-uniform distribution of ion production in the working volume. Moreover, for detectors consisting of few GM or proportional counters, it is important to be sure that there are no losses of pulses owing to dead time and paralysis in the counter closest to the source.

Ratio of activities or emission rates of the sources can be measured with an accuracy of $\pm 1\%$ at the secondary standard laboratory with any instrument sensitive to the radiation emitted, and it is not necessary to know the exact activities or emission rates.

This method is known as the similarity method and can be applied to gamma and neutron measuring instruments as well as to beta-measuring instruments [76]. In the latter case, gamma sources are also used for checking sub-ranges with the similarity method. Beta-measuring instruments are sensitive to the gamma-radiation and the secondary electrons act in the same way as beta-particles in the detector. The similarity method is especially useful for beta-measuring instruments because for

"normal" calibration it is necessary to have three sources for each sub-range, i.e. about 15 standard beta-sources in all for the whole measurement range. Using the similarity method may, in principle, decrease this number to one and one set of gamma-sources can be used for all types of beta-measuring instruments as well as for gamma-measuring instruments.

If a beta-measuring instrument has a device for compensating the background, it should be switched off during such linearity checking. The background compensation may be separately checked by means of any beta-source.

Exact positioning of the sources during the linearity checks depends on the quality of the device used. Machining the source holder and appropriate socket permits sources to be located with an accuracy of 0.1 - 0.2 mm which leads to an additional error of not more than 4% at a distance of 1 cm from the detector. However, distances of 3 - 5 cm are used normally. Therefore, the additional error due to inexact positioning is not more than $\pm 1\%$.

The analysis of the errors arising during the linearity checks shows that the similarity method leads to an additional error of about 1 - 2% in comparison with the calibration of all sub-ranges by means of secondary standard sources calibrated at a national laboratory.

V.4.3 SENSITIVITY

The sensitivity of an instrument describes its capability in discriminating between two approximately equal quantities. Sensitivity should be constant over the entire instrument range, and is best expressed in terms of percent of full scale for instruments with linear readout. For instruments with logarithmic readout, sensitivity should be expressed as percent of the actual scale reading with the scale reading stated.

V.4.3.1 Sensitivity

Equipment

- Trolley or carriage calibration jig.
- Appropriate radiation source.

Procedure

1. Turn on instrument and allow appropriate warmup time.
2. Mount instrument on calibration jig.
3. With instrument set on most sensitive scale adjust detector to source distance to obtain a 20% of full scale reading. Note the distance.
4. Move instrument toward source in small and reproducible increments and note distance traveled before meter responds.
5. Return instrument to original position and repeat 4 several times and average the distances obtained.
6. Repeat 4 and 5 moving instrument away from source.
7. Calculate the actual exposure at the points where the meter responded to the change in distance. The difference divided by the actual reading is the sensitivity.
8. Repeat 3 through 7 using 80% full scale.
9. Repeat experiment on all scales.

V.4.3.2 Sensitivity

Equipment

Several alpha sources, each having slightly different strength or a single source covered with mesh to absorb various fractions of the alpha.

Procedure

1. Turn the instrument on and allow appropriate warmup time.
2. With the instrument set on the most sensitive scale, select an alpha source which will give a response of about 20% of full scale in a reproduceable geometry. Note the instrument reading.
3. Replace the alpha source with one of slightly larger or smaller value and note the instrument reading if detectably different from 2 above.
4. Repeat with other sources or appropriate source shields until the smallest detectable instrument reading difference is found.

5. For a linear scale - divide the smallest detectable difference of Step 4 by the full scale range and multiply by 100. This is the sensitivity in percent.
For a log scale - divide the smallest detectable difference of step 4 by the decade value upon which the readings were obtained. This is the sensitivity in percent.
6. Repeat steps 2 through 5 using sources which give an instrument response of about 80% of full scale reading.
7. Compare determined sensitivities with performance criteria for conformance.

V.4.4 DETECTION LIMIT

The detection limit is the minimum (or, less commonly, the maximum) radiation reading which can be obtained, with the instrument. This value can be obtained from the sensitivity.

V.4.4.1 Detection Limit

Equipment

Appropriate radiation sources(s)
Calibration jig(s)

Procedure

1. Turn instrument on and allow appropriate warmup time.
2. Switch the instrument to the appropriate scale and place the instrument or detector as appropriate in the calibration jig.
3. Adjust the radiation level at the instrument detector to the lowest detection level required by the performance criteria.
4. Note the instrument response and compare with the performance criteria for conformance.
5. Switch the instrument to the appropriate range and adjust the radiation level to the highest detection level required by the performance criteria.
6. Note the instrument response and compare with the performance criteria for conformance.

7. Repeat 2 through 6 for each type and energy of radiation specified in the detection range performance criteria.

V.4.5 ACCURACY

Accuracy is the relationship of the instrument reading to the true value, and is expressed as a limit or range in terms of percent of the true value. Accuracy is the sum total of all factors which may adversely affect the reading of the instrument, including reproducibility. The term accuracy generally refers to the total uncertainty (± 3 standard deviations) in the instrument reading, with the measurement made under nearly ideal conditions, and with appropriate corrections made for such factors as temperature, pressure, energy, and geometry.

V.4.5.1 Accuracy ⁽³³⁾

Equipment

Appropriate radiation source

Calibration jig

Procedure

For assemblies provided with substantially linear scales, the type test shall be carried out on all the ranges, and on at least 3 points on each of them, at about 75%, 50% and 30% of the scale range with a measurement mandatory in the overlapping range (except for the first range).*

For assemblies with a single range, substantially logarithmic graduation, the test shall be performed for at least two values in each decade of exposure rate measured.

* At the higher exposure rates, this direct form of test may require the use of a source of the reference gamma radiation of inconveniently high activity. In this case, some other sources of radiation (e.g., a suitable X-ray generator) may be used, provided suitable corrections are made for any difference in the sensitivity of the instrument to such radiation and to the reference gamma radiation, caused by the difference in the energy of the radiation used.

The results of the tests will be plotted on a graph in semi-logarithmic co-ordinates, having as abscissa the exposure rate (in logarithmic scale) and as ordinate (in linear scale) the intrinsic errors E, expressed in % by the relationship:

$$E = 100 \frac{R_i - R_t}{R_t} \%$$

where: R_i = indicated exposure rate

R_t = conventionally true exposure rate.

On this graph, draw the horizontal lines Δ_1 and Δ_2 corresponding to the maximum error allowed for the determination of the conventionally true exposure rate.

Measure the width H of the band including the experimental points. Draw the straight line D falling in the middle of this band. D must fall between Δ_1 and Δ_2 and H shall be less than 20%.

Exceptionally, if H is lower than the above limits, then it is admissible that the straight line D falls externally to the band limited by Δ_1 and Δ_2 provided that the addition of $\frac{H}{2}$ and the distance from D to the nearer of the lines Δ_1 and Δ_2 is less than 10%.

This allowance is to give a certain tolerance to the assemblies having a limited dispersion.

V.4.5.2 Accuracy⁽²³⁾

Equipment

Appropriate radiation source(s)

Calibration jig

Procedure

Accuracy is best determined with a calibrated source. Instrument readings over the entire range are compared with the "true" value as determined from the source strength. Presented on the following page are some actual data obtained with an ion chamber survey meter:

<u>True mR/hr</u>	<u>Instrument mR/hr</u>	<u>Instrument Range</u>
15	14	X 1
30	30	X 1
45	47	X 1
50	45	X 10
100	95	X 10
300	310	X 10
450	460	X 10
1500	1600	X 100
3000	3000	X 100
4500	4800	X 100

This instrument was rated as having an accuracy of $\pm 10\%$.

V.4.5.3 Accuracy⁽³⁵⁾

Equipment

Appropriate radiation sources

Calibration jig

Procedure

An instrument shall be exposed to photon fluxes with known spectral distribution and exposure rates of approximately one-fifty, one-half, and four-fifths the indicated full-scale or decade range. This shall be done for all ranges or decades and the error determined by the following equations:

For logarithmic readouts

Percent error =

$$\left(\frac{\text{Meter Reading} - \text{True Exposure Rate}}{\text{True Exposure Rate}} \right) \times 100 \quad (\text{equation 1})$$

The maximum error for each decade or range shall be stated.

For linear readouts

Percent error =

$$\left(\frac{\text{Meter Reading} - \text{True Exposure Rate}}{\text{Full-scale Reading}} \right) \times 100 \quad (\text{equation 2})$$

V.4.5.4 Accuracy

Equipment

Calibration jig

Standard nuclear source set

Procedure

1. Turn on instrument and allow appropriate warmup time.
2. Mount instrument in calibration jig.
3. Turn instrument to most sensitive scale and adjust source to detector distance so that instrument reads 30% of full scale. Note the distance between source and detector.
4. Compare instrument reading to the true value, and calculate accuracy.
5. Repeat for 50% and 80% of full scale reading.
6. Repeat procedure for all scales.

V.4.6 PRECISION

V.4.6.1 Precision

Equipment

Instrument under test

Standard nuclear source set

Calibration jig

Procedure

1. Turn on instrument and allow appropriate warmup time.
2. On most sensitive scale set source such that meter read 20% of full scale. Note reading.
3. Move instrument back from source and return instrument to exact same position and note reading.
4. Repeat 3 two to three more times.
5. Calculate standard deviation by

$$\sigma = \sqrt{\frac{\sum (X - \bar{X})^2}{n}}$$

6. Repeat 3, 4 and 5 at 80% of full scale reading on most sensitive scale.
7. Repeat experiment for all scales.

V.4.6.2 Precision ⁽³⁷⁾

Equipment

Appropriate radiation source(s)
Calibration jig

Procedure

1. Reproduceability is determined by placing the instrument in a constant radiation field for one minute, taking a reading and then removing the source for one minute before replacing the source in exactly the same position. This process is done for a minimum of ten times.
2. Calculate the standard deviation of the ten results.
3. Repeat 1 and 2 on each range.

V.4.7 ENERGY DEPENDENCE

Energy dependence--also known as spectral sensitivity--refers primarily to the response of an instrument to x or gamma radiation of different energies. Energy dependence is caused by many factors, the two most important ones being photoelectrons (and, to a lesser degree, Compton electrons) from the detector wall, and self-absorption within the detector wall. These effects are, of course, competitive.

V.4.7.1 Photon Energy Dependence ⁽³⁵⁾

Equipment

Appropriate radiation source(s)

Calibration jig

Procedure

For energies below about 1.5 MeV, the ratio of indicated to true exposure or exposure-rate as a function of energy shall be obtained at several effective energies over the operating energy range specified for the instrument. For the energy region below 200 keV, the ratio of indicated to true exposure or exposure-rate should be measured at appropriate increments. Increments of ≤ 25 keV should be used. For the energy region above 200 keV but less than about 1.5 MeV, photon energies of 662 keV (^{137}Cs) or 1.25* MeV (^{60}Co) should be used. For energies above about 1.5 MeV, the source and energy of the photons shall be given (for example, Van de Graaff, $^{19}\text{F}(\rho, \alpha)^{16}\text{N}$, $E_\gamma = 6.3, 7.1$ MeV). At least one energy in the range 1.5 - 10 MeV shall be used. Extrapolations shall not be made above the highest energy nor below the lowest energy for which tests are performed.

* Effect energy for the 1.17 MeV and 1.33 MeV photon emission from ^{60}Co .

V.4.7.2 Photon Energy Dependence (23)

Equipment

Appropriate radiation source(s)

Calibration jig

Procedure

To evaluate energy dependence, the detector is placed in a field of known strength and energy and the response compared with the true exposure rate. Ordinarily, the instrument is calibrated with a source having an energy of approximately 1 MeV, and the instrument response normalized to this energy.

Several effective energies in the range of 10 keV to greater than 1 MeV are necessary to achieve an accurate indication of energy dependence. An X-ray machine--preferably with 300 kVp capability--can be used to obtain effective energies in the 50-250 keV_{Eff} region by means of heavily filtered spectra; a wide beam K fluorescent source can be used to conveniently obtain essentially monoenergetic photons in the region 8-100 keV_{Eff}. The higher energies are provided with nuclides, commonly ¹³⁷Cs (662 keV_{Eff}), ²²²Ra + daughters (~800 keV_{Eff}), and ⁶⁰Co (1.25 MeV_{Eff}). A typical series of energies for a cutie pie type instrument might be 8, 17, 23, 40, 60, 80, 100, 125, 175, 200, 662, 1250 keV_{Eff}.

Energy dependence should be determined with both open and closed window, and often for other conditions, such as with the beam end--on or through a thicker side wall. Energy dependence should be reported as a +, - percentage over a specific energy range or a +, - percentage normalized to a specific energy. Graphical presentation, in the form of a plot of response per unit exposure as a function of energy is a superior method of showing energy dependence.

V.4.7.3 Photon Energy Dependence

Equipment

Appropriate radiation source(s)
Calibration jig

Procedure

The dosimeters shall be fully charged and then discharged by radiations of several energies to produce readings of approximately 80% of full scale. Tests shall be made at extremes of the stated energy range and at several additional points between the lower extreme and 200 keV. If the lower extreme is 30 keV, tests shall be made at approximately 30, 50, 80, 120, 160 and 200 keV. In lieu of testing at the upper extreme of the energy range above 1300 keV (Cobalt-60), the manufacturer may provide analytical evidence of expected dosimeter performance based on charged particle equilibrium, attenuation theory at energies of 2 and 3 MeV, materials of construction, and other major influencing factors. Exposures shall be made at a rate at least a factor of 1000 below the maximal permissible exposure rate certified for the instrument.

Exposures shall be made with the dosimeter perpendicular to the beam.

V.4.8 ANGULAR DEPENDENCE

Because most detectors are not spherical, angular dependence may cause serious discrepancies in readings. In particular, angular dependence becomes significant when a fixed geometry or windowed detector is used in an ambient field or in such a manner that the window cannot be pointed towards the direction of the field.

V.4.8.1 Angular Dependence ⁽³³⁾

Equipment

Appropriate radiation source
Exposure jig

Procedure

1. Place the assembly in its normal position of use, with the source of radiation in such a position that a line from the source of radiation to the centre of the detector coincides with the calibration direction specified by the manufacturer.
2. The reading in this position shall be noted.
3. The assembly or the source of radiation shall then be turned in a horizontal plane through appropriate angles from this position and the reading noted.
4. Similar observations shall then be taken as either the assembly or the source of radiation is rotated in a vertical plane.

V.4.8.2 Angular Dependence⁽²³⁾

Equipment

Appropriate radiation source

Exposure jig

Procedure

Angular dependence is best checked through a full 360° in perpendicular planes, one parallel to the horizontal and the other to the vertical axis of the detector. Measurements should be made at 15° increments. If the detector is symmetrical about an axis, the determination can be made over 180° or 90° , as indicated by the geometry.

The statement of angular dependence should be expressed as $\pm$ percentage from a fixed point, usually the so-called "normal" of the detector. However, a graphical representation is superior, as is true for energy dependence.

V.4.8.3 Angular Dependence (35)

Equipment

Appropriate radiation source

Exposure jig

Procedure

To determine angular dependence the instrument or detector or source, as applicable, shall be rotated through at least two perpendicular planes using the center of the sensitive volume of the detector as axis of rotation, and the ratio of indicated to true exposure rate obtained for at least thirty degree increments and three energies, one in each third of the specified operating energy range of the instrument. For symmetrical instruments or detectors, this rotation need not be accomplished over the entire 360 degree ranges, but should be representative of the response as a whole.

V.4.9 RESPONSE TIME

A finite period of time is required for an instrument to respond to transient input conditions. This response time is related to circuit design and may, in many cases be easily varied according to the requirements of the user.

V.4.9.1 Response Time

Equipment

Nuclear precision pulse generator

Stopwatch

Instrument under test

Procedure

1. Disconnect any detector inputs.
2. Connect the pulse generator to the test pulse input. Turn on the instrument and pulser.

3. Set the pulse repetition frequency to zero and check the zero point of the meter.
4. Adjust the pulse repetition rate for full scale needle deflection on the most sensitive scale.
5. Open the connection between the pulse generator and instrument and simultaneously start the stopwatch.
6. Observe the movement of the needle and stop the watch as the needle passes the 10% of full scale point. Allow the needle to go all the way to zero. Record the elapsed time indicated on the watch and reset it.
7. Close the connection between the pulse generator and instrument and simultaneously start the stopwatch.
8. Observe the movement of the needle and stop the watch as the needle passes the 90% of full scale point. Record the elapsed time indicated on the watch and reset it.
9. Switch to the next scale and adjust the pulse repetition rate for full scale needle deflection.
10. Repeat steps 5 through 9 on all scales.
11. Turn off power to the pulser and instrument. Remove pulser connection from the test pulser input.

V.4.9.2 Response Time⁽³⁵⁾

Equipment

Appropriate radiation source

Calibration jig

Procedure

Response time specified shall be determined by measuring the time for the entire system to reach 90 percent of the midscale reading when the instrument is exposed to a step change in flux sufficient to provide a midscale or mid-decade reading. This test shall be performed on all ranges or decades, as applicable.

The instrument shall be removed from a radiation field providing a full-scale or decade reading, and the time required for the scale or decade reading to return to 10 percent of full-scale or decade shall be noted.

V.4.9.3 Response Time⁽³³⁾

Equipment

Appropriate radiation source and exposure or
Nuclear pulse generator

Procedure

Note: Response time is defined by the time required to reach the value:

$$N + \frac{63}{100} (N' - N)$$

where N is the initial indication and N' is the final indication.

1. The test may be carried out either with a suitable source of radiation or by the injection of a suitable electrical signal into the input of the measuring assembly.
2. The initial and final exposure rates shall differ by a factor of 10 or more and measurements shall be carried out for both an increase and a decrease in the exposure rate by this factor.
3. If the lowest significant (non-zero) marking on the meter scale corresponds to an exposure rate of $\bar{R}$, then for increasing exposure rate the initial indication N shall not exceed $10 \bar{R}$; for decreasing exposure rate the final indication N' shall not exceed $10 \bar{R}$.
4. If the electrical method of test is employed, the injected signals shall correspond to the above requirements.
5. For the increasing exposure rate test, the assembly shall be subjected first to the higher exposure rate and the indication N' noted.

6. The assembly shall then be subjected to the lower exposure rate for a time sufficient for the indication N to reach a steady value and this indication noted.
7. The exposure rate shall then be changed as quickly as possible to that corresponding to the indication N', and the time taken to read the value given by the formula in the note above measured.
8. The decreasing exposure rate test shall be performed in the same way with the values of exposure rates corresponding to N and N' interchanged.

V.4.10 OVERLOAD RESPONSE

V.4.10.1 Overload Response (35)

Equipment

Appropriate radiation source

Calibration jig

Procedure

Saturation is easily checked by placing the instrument in an appropriate radiation flux, and increasing the intensity until the effect is noted or a predetermined level--usually 100 times the maximum range of the instrument--is reached. This should be checked on all ranges.

V.4.10.2 Overload Response (33)

Equipment

Appropriate radiation source

Calibration jig

Procedure

1. The assembly shall be submitted to the following exposure rates for a period of 5 minutes:
 - 100 times the scale maximum for scale maximum up to and including 10 R/h;
 - 10 times the scale maximum with a lower limit of 1000 R/h for scale maximum more than 10 R/h.

2. The indication of the assembly shall remain out of scale at the higher end of the scale range throughout this period.

V.4.10.3 Overload Response⁽³⁸⁾

Equipment

Appropriate radiation sources

Exposure jig

Procedure

For instruments with switchable scale ranges,¹ the requirement shall apply on each range. Compliance is checked:

1. For exposure meters whose nominal full scale value is less than 800 R, by irradiation for 10 minutes by gamma or X radiation having an exposure rate such that the exposure in this period is not less than 100 times the nominal full scale value, or an exposure rate of 10^4 R/h, whichever is the lesser.

For exposure meters whose nominal full scale value is not less than 800 R, by irradiation to twice the nominal full scale value at a rate not less than 10^4 R/h.²

There shall be an evident indication of overload within a period of twice the time for the full scale exposure to be received and this indication must persist for at least one hour after cessation of the irradiation.

¹ Alternatively, these instruments may be provided with automatic upwards range switching operable by overload, with an evident indication.

² The exposure rate and duration to be agreed upon by manufacturer and user.

2. For exposure rate meters, by irradiation for a period of 2 minutes at an exposure rate of not less than 100 times the nominal full scale value or 10^4 R/h, whichever is the lesser. There shall be an evident indication within 5 seconds that the instrument is reading out of scale at the higher end and this indication must persist until the irradiation ceases.

Note: Instrument circuitry may, due to a scale-of-two dividing effect, sometimes cause a spurious fall-back indication not detected by the foregoing tests. Compliance should therefore be checked by presenting the instrument to a steadily increasing field rising to at least 10 times the nominal full scale value at a rate not exceeding the factor e (2.718, the base of natural logarithms) in a period equal to the time constant of the instrument.

3. For neutron fluence measuring instruments, by irradiation for a period of 10 minutes by a fluence of neutron energy within the stated response range of the instrument and of such rate that the fluence in this period is not less than 100 times the nominal full scale value.

There shall be an evident indication of overload within a period of twice the time for the full scale fluence to be received and this indication must persist for at least one hour after cessation of the irradiation.

4. For neutron fluence rate measuring instruments, by irradiation for a period of 2 minutes to a fluence of neutron energy within the stated response range of the instrument and of a fluence rate between two and three times the nominal full scale value.

There shall be an evident indication within one minute that the meter is reading out of scale at the higher end and this indication must persist until the irradiation ceases.

Note: For instruments indicating in rems, the equivalent fluence should be in accordance with the current recommendations of the International Commission on Radiological Protection.

V.4.10.4 Overload Response

Equipment

Standard nuclear source set.

Calibration jig.

Procedure

1. Turn on instrument and allow appropriate warmup time.
2. Mount instrument in calibration jig.
3. Set instrument on most sensitive range.
4. Introduce instrument to appropriate radiation flux and increase intensity up to and beyond full scale until (a) the instrument fails to give full scale response or (b) a level of at least 100 times the full scale is reached.
5. Repeat 4 for all ranges.

V.4.11 EXTRACAMERAL EFFECT

Extracameral effects are meter deflections caused by interaction of the ionizing radiation with part of the instrument other than the true detector or ionization chamber component. The effect is most prevalent in ionization chamber type instruments.

V.4.11.1 Extracameral Effect

Equipment

Standard nuclear source set

Procedure

1. Place detector and instrument at the baseline extremes of an imaginary isosceles triangle and turn on instrument to the most sensitive scale.

2. Move the source along the perpendicular baseline bisector until a full scale reading is obtained.
3. Note the source position and withdraw it while the connector nearest the detector is removed.
4. Reposition the source and measure the nondetector induced radiation. Compare the percentage obtained with that stated in the performance criterion.
5. Replace the source and turn off instrument power. Reconnect the detector assembly.

V.4.11.2 Extracameral Effect⁽²³⁾

Equipment

Appropriate radiation source
Radiation source collimator
Radiation shielding material

Procedure

It is necessary to check extracameral effects by shielding the detector or limiting the size of the radiation beam. By using a well collimated beam, 2mm wide, a scan can be made across the instrument. The meter reading can then be plotted as a function of location.

V.4.12 RADIATION RATE

V.4.12.1 Radiation Rate Effect

Equipment

Dosimeter Charger
Appropriate Radiation Source

Procedure

The dosimeter shall be fully charged and exposed to a source of the appropriate energy at the specified maximum exposure rate. For test purposes the total exposure shall exceed 80% of full scale. The sensitivity of the dosimeter at the maximal rate shall differ

by no more than 10% from the sensitivity at the radiation rate employed in the accuracy test. For this test, sensitivity is defined as instrument reading divided by true exposure.

V.4.13 DETECTOR RESOLUTION

V.4.13.1 Detector Resolution

Equipment

Crystal Detector Subassembly
Multichannel Analyzer
High Voltage Supply
Signal and High Voltage Cables and Connectors
Appropriate Radiation Source, e.g., 1 lb of KCl.

Procedure

1. Connect high voltage supply to high voltage input of the crystal-photomultiplier-preamplifier subassembly.
2. Connect multichannel analyzer input to the subassembly preamplifier signal output.
3. Turn on high voltage and adjust to appropriate operating voltage for the photomultiplier being tested.
4. Place a one pound container of KCl crystals or other source of approximately 2.5 MeV photons against the crystal end of the subassembly.
5. Adjust the gain of the multichannel analyzer until the photopeak resides about midscale.
6. Accumulate a photopeak whose peak channel contains about 1000 counts.
7. Determine the width (number of channels) of the photopeak at a level of one-half of the peak height.

8. Calculate the percent full width half maximum (FWHM) by the formula:

$$\% \text{ FWHM} = \frac{W}{C} \times 100$$

where: W = Peak width at one-half maximum
C = Channel number of peak channel

Example: Refer to Figure 16, the accumulated count for a typical test system.

W = 17 3/4 channels at 1/2 maximum

C = Channel 246

$$\text{Therefore: } \% \text{ FWHM} = \frac{17 \frac{3}{4}}{246} \times 100 = 7.2\%$$

FIGURE 16. Photomultiplier Resolution

V.4.14 EXCESSIVE RADIATION

V.4.14.1 Excessive Radiation (27)

Equipment

Dosimeter Charger

Appropriate Radiation Source(s)

Procedure

Electrical Leakage After Excessive Radiation - Dosimeters Having Ranges 5 R Full Scale or Greater

gamma radiation totalling 2000 Roentgens delivered at a rate between 1000 and 10,000 R/hr. Immediately after exposure, the dosimeter shall be fully charged and adjusted to zero scale reading. Readings shall be taken at the end of four hours and again at 48 hours, and leakage shall not exceed 5% of full scale during the first four hours and 10% during the 48 hour period after zeroing the dosimeter.

V.4.14.2 Excessive Radiation (27)

Equipment

Dosimeter Charger

Appropriate Radiation Source(s)

Procedure

Electrical Leakage After Excessive Radiation - Dosimeters Having Ranges Less Than 5 R Full Scale

The dosimeter at normal conditions shall be exposed to X or gamma radiation totalling 200 Roentgens delivered at a rate between 100 and 1000 R/hr. Immediately after exposure the dosimeter shall be fully charged and adjusted to zero scale reading. Readings shall be taken at the end of four hours and again at 48 hours, and shall not exceed 5% of full scale during the first four hours and 10% during the 48 hour period after zeroing the dosimeter.

V.4.14.3 Excessive Radiation

Equipment

Radiation Source, such as ^{60}Co , Radium, Machine, etc.

Procedure

1. Turn on the instrument under test and allow an appropriate warmup time.
2. Place the instrument system (electronics, cables and detector) in a relatively uniform radiation field which will give the desired total exposure in a convenient time period (see note).
3. Inspect the system for evidence of physical damage resulting from the radiation.
4. Check the instrument for conformance with the sensitivity and accuracy criteria.

Note: Exposure rate should be less than the upper limit of the instrument rate to preclude damage due to rate overload during this test.

V.4.15. RESPONSE TO UNWANTED RADIATIONS

Checking the rejection of unwanted radiations is often more art than science. For example, energy dependence must be considered, particularly when evaluating the rejection of photons by neutron or alpha scintillation instruments. Neutrons may show a similar energy dependence, with a response being elicited, say, only by thermal neutrons. And, the undesired response may not appear except in a mixed field.

V.4.15.1 Unwanted Radiation Response (Criticality Detector and Alarm System)

Equipment

Calibration Jig

Appropriate Radiation Source(s)

Procedure

1. Turn test item on and allow appropriate warm-up time.
2. Place test item in calibration jig.
3. Switch instrument to the most sensitive range if there is more than one range.
4. Adjust the alarm set point to the lowest practical setting.
5. Introduce photon dose rate of 50 R/hr. Note the response of the test item.

V.4.15.2 Unwanted Radiation Response

Equipment

Appropriate beta radiation source(s)

Procedure

1. Zero dosimeter.
2. Place dosimeter and beta source ($E \leq 2$ MeV) in calibration jig and accumulate a beta dose to the dosimeter of 100 rad.
3. Read the dose indicated on the dosimeter and compare with the require response.

V.4.15.3 Unwanted Radiation Response

Equipment

Appropriate radiation source

Procedure

1. Turn on test item and allow appropriate warm-up time.
2. Subject test items to a photon dose rate of 10^3 R/hr ($E > 0.5$ MeV).
3. Note response of test item.

V.4.15.4 Unwanted Radiation Response

Equipment

Appropriate radiation source(s)

Procedure

1. Turn on test item and allow appropriate warm-up time.
2. Introduce a photon dose rate of 10 R/hr ($E > 0.5$ MeV).
3. Note the response of the test item in both channels, i.e., high energy photon and low energy photon + beta.
4. Repeat steps 2 and 3 for low energy photons ($E < 50$ keV).
5. Repeat steps 2 and 3 using a beta dose rate of 10 rad/hr ($E > 0.5$ MeV).
6. Compare test results with criteria requirement.

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For ease of citation and reference, American National Standards, published by or under the aegis of the American National Standards have been collected into a single subgrouping listing the ANSI identification number followed by the year of publication and, if applicable, revision, the title, and a precis and/or statement re applicability.

- 1) C39.1-1964. "Requirements for Electrical Indicating Instruments". Of possible limited or minimal applicability; refers primarily to characteristics and specifications for ammeters, power meters and related meters; does not specify test or evaluation procedures.
- 2) C39.3-1948 (Revised 1968). "Specifications for Shock-Testing Mechanism for Electrical Indicating Instruments". Describes the design, construction, theory, use and calibration of a mechanical shock-testing device; of possible limited applicability.
- 3) C39.6-1963. "Requirements for Automatic Digital Voltmeters and Ratio Meters:.. Provides classifications, definitions, reference standards, calibration and test procedures for primarily dc meters; of limited or minimal applicability.
- 4) C42.30-1957. "Instruments, Meters, and Meter Testing". Basically a listing of definitions of terms which may be of limited utility in describing test results.
- 5) C42.100-1972. "Dictionary of Electrical and Electronics Terms". A potentially useful reference; incorporates definitions of and pertaining to various gas-filled radiation detectors, test procedures and calibration terminology.
- 6) N1.1-1967. "Glossary of Terms in Nuclear Science and Technology". Useful for ensuring consistency and accuracy of terminology.

- 7) N4.1-1967. "Guide for Classifying Electrical Insulating Materials Exposed to Neutron and Gamma Radiation". Although designed primarily for insulators in the power reactor environment, this standard could have some applicability, especially with regard to specifying exposure limits. A revised version is in press.
- 8) N13.1-1969. "Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities". Of applicability primarily to instrumentation which makes use of air moving or filtration equipment; provides both design data and bases for developing evaluation procedures.
- 9) N13.4-1971. "Specification of Portable X- or Gamma Radiation Survey Meters". Useful primarily for specifying instrument performance and for certain specific tests and techniques related to instrument performance.
- * 10) N13.5-1972. "Performance Specifications for Direct Reading and Indirect Reading Pocket Dosimeters for X- and Gamma Radiation". Although dosimeters are outside the scope of the study, some of the concepts, techniques and tests are applicable.
- 11) N16.2-1969. "Criticality Alarm System". Of limited applicability; however, some of the methodology and specifications may be of general interest.
- * 12) N42.1-1969. "Test Procedures for Semiconductor Radiation Detectors". Although specific to a portion rather than the complete instrument package, the procedures and concepts described are generally applicable and of interest, especially when taken with Reference 13, infra.
- * 13) N42.2-1969. "Test Procedures for Amplifiers and Pre-amplifiers for Semiconductor Radiation Detectors". Highly useful and applicable to emergency instrumentation when used in conjunction with Reference 12, supra; not strictly performance-oriented and basically electronic tests.

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- 18) N45.2.4-1972. "Installation, Inspection, and Testing Requirements for Instrumentation and Electric Equipment During the Construction of Nuclear Power Generating Stations". Of interest primarily to assure that the installation of fixed emergency radiological monitoring instrumentation will meet established criteria appropriate to quality assurance and operation.
- 19) N101.1-1972. "Efficiency Testing of Air-Clearing Systems Containing Devices for Removal of Particulates". Designed primarily for large operational (i.e., 'process') systems; however, some of the methodology and concepts are applicable.
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OTHER OFFICIAL STANDARDS

The same format has been followed as with the ANSI standards listing, except that each standard cited is preceded by a letter code designating the organization publishing the standard. The key to the code is given below:

EIA	Electronic Industries Association
ICRU	International Commission on Radiological Units and Measurements
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISA	Instrument Society of America
NBS	National Bureau of Standards
NCRP	National Council on Radiation Protection and Measurement

- 21) EIA-RS-186-B (1960). "Test Measurements for Electronic Parts". Basically, electromechanical tests, of limited applicability for systems.
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2. MIL-B-17530 Performance Standards for Electronic Equipment.
- *3. MIL-E-5272A Environmental Testing.
4. MIL-T-17113 General Specification for Shock, Vibration and Inclination Tests for Electronic Equipment.
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