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Performance Testing of Electronic Personal Dosimeters

Draft Report for Comment

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Abstract

In radiation protection, incremental control of worker radiation exposures is important to ensure that periodic dose limits are not exceeded. Electronic personal dosimeters (EPDs) are widely used for this application. As their reliability has improved users have shown an interest in their use for both incremental control and as the primary dosimeter to track the dose of record for the worker. In this application they would replace the traditional film or thermoluminescent dosimeter whose performance is thoroughly understood. The EPD brings with it some of the problems of instruments which are not seen with the traditional dosimeters. The report contains results of a survey of users and a survey of vendor literature that highlight some of the limitations and problems of EPDs.

The radiation protection community is concerned that the reliability and accuracy of the data from the EPD be comparable to traditional methods if they assume this additional role. This report lists type tests, test methods, and calibration methods intended to ensure the required reliability.

Contents

Figures

Part 1

Part 2

Tables

Part 1

Part 2

Part 3

Executive Summary

Electronic personal dosimeters (EPDs) have been used as secondary dosimetry for radiation workers for several years. With recent improvements in electronics, their size has decreased while their capability and reliability have increased. With the increase in reliability, the EPD is being considered for primary dosimetry in place of the commonly used film badges and thermoluminescent dosimeters. A review of the literature (including test data) and a survey of users and potential users of EPDs indicates some limitations exist in the use of EPDs due to their performance in the work environment. Notable limitations are their poor low-energy response and their susceptibility to electromagnetic interference. In many cases these limitations will not preclude their use since their performance appears comparable to present primary dosimetry for many work environments.

In order to facilitate the deployment of the EPD as a primary dosimeter, this report presents type-test criteria and methods in the format of a type-test standard. In addition to the type test, data-specific recommendations are provided for the calibration, functional testing, performance testing, and acceptance testing of the EPD. These are presented as a system of control with specific recommendations for relating the performance and acceptance tests to the original type tests through a source check methodology.

Specific recommendations are to continue side by side testing of the EPD with conventional primary dosimeters both on workers and in typical field test geometries. A pilot evaluation of the type-test criteria presented should be conducted by testing of selected EPDs. Concurrently, user guidelines for calibration, training periodic testing, and criteria for a performance evaluation program should be developed. The performance evaluation can be conducted either through modification of the current NVLAP accreditation program for personnel dosimetry or through one of the existing calibration accreditation programs.

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General Introduction

Electronic personal dosimeters (EPDs) have long been used as secondary dosimetry for radiation workers and, due to their ease of reading and alarm capability, have largely replaced pocket ion chambers for this application. As the size of these units has diminished and their capabilities have increased with improvements in electronics, they are being considered for primary dosimetry in place of the commonly used film badges and thermoluminescent dosimeters (TLDs). It has been predicted that such devices may replace survey instruments and personal dosimeters (Swinth 1988). However, consideration of EPDs as primary dosimeters is currently in an evolutionary phase. Although they are well established as secondary or supplemental dosimeters, their reliability and performance fall short of present primary dosimeters. As deficiencies are noted, solutions are being found.

This document examines the reliability and use of EPDs and proposed manufacturer and user standards for EPDs and their readers. Part 1 discusses the capabilities of EPDs and reports on a survey of users and vendors to determine their performance in the field. Part 1 also includes information on methods to calibrate EPDs and to ensure their continuing performance. It also includes recommendations to answer some of the recurring questions surrounding the use of EPDs as a dosimeter of record or primary dosimeter. Part 2 provides type-testing standards for EPDs and recommends techniques for their periodic testing and calibration. Part 3 provides similar standards for EPD readers. It is intended that Parts 2 and 3 can be modified by users' and test laboratories' experience with EPDs but will provide baseline standards and type-testing for their methodical use.

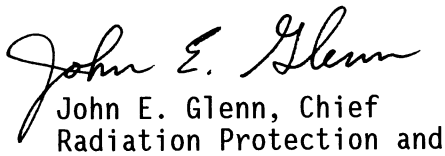
FOREWORD

This report discusses the use of Electronic Personnel Dosimeters (EPDs) as potential alternatives for the film badges and thermoluminescent dosimeters (TLDs) that are now the most widely used methods for determining the ionizing radiation dose to radiation workers. EPDs have been used as secondary dosimetry for radiation workers for several years, and as their capability and reliability have improved with time, users are now considering using them as primary dosimetry for their radiation workers. The radiation protection community is concerned that the reliability and accuracy of data from the EPD be comparable to the traditional methods currently used if they are to assume the role of primary dosimetry. To address this concern, the NRC contracted for a current evaluation of the use of EPDs for primary dosimetry for radiation workers.

The work described herein was performed under contract with Battelle's Pacific Norhwest Laboratory. It discusses EPD capabilities and reports on a survey of users and vendors regarding the performance of EPDs in the field. It also provides type-testing criteria in the format of a type-test standard and recommends techniques for performance testing and calibration. It also provides similar standards for EPD readers.

NUREG\CR-6354 is being published for comment. The NRC is requesting that interested parties review the report and its recommendations and provide additional recommendations and/or constructive comments on its contents.

NUREG/CR-6354 is not a substitute for NRC regulations and compliance is not required. The approaches and/or methods described in this NUREG are provided for information only. Publication of this report does not necessarily constitute NRC approval or agreement with the information and recommendations contained herein.



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Part 1

Issues in Performance and Use of Electronic Personal Dosimetry Systems

1 Background

The potential advantages of EPDs have long been recognized (Brown 1966; Erickson 1969, 1970). The major interest has been in their potential as secondary dosimetry for alarming and warning the radiation worker of high doses or dose rates. In radiation protection, incremental control of worker exposures is important to ensure that periodic dose limits are not exceeded. The classic method of accomplishing this goal is to establish area dose rates with portable instruments and then limit the work time in such areas to stay within established worker dose limits. The EPD can accomplish this task without the expense or personnel exposures from area surveys or separate stay-time monitoring of the worker. Other types of secondary dosimetry have been used for this application, such as the pocket ion chamber (PIC), but work must be stopped to read the device. This is difficult in the typical work environment, particularly when protective clothing is employed; thus, aural or other alarms that do not interrupt the flow of work are preferable. In addition to the alarm capability, the reliability of the EPD is better than that of the PIC. The PIC is generally sensitive to shock (dropping) and does not have as good a sensitivity as the EPD. However, recent models of PICs produced by the Federal Emergency Management Agency (FEMA) exhibit superior shock resistance.

As we consider the EPD for use as a dosimeter of record (primary dosimeter), several areas must be considered to ensure adequate reliability of the dosimetry information, including the absence of silent failures, dosimetric data quality that is comparable to conventional dosimeters, reliable data accessibility, and immunity to changes in readings caused by normal operating conditions (e.g., environmental conditions, interfering radiations).

Absence of Failures. Failures of electronic devices can be sudden and may be catastrophic. Anyone who has had the electronics on a modern automobile fail can attest to the sudden change in performance or lack of driveability. In the case of electronic radiation-measuring devices, the failure may not be noticed and could lead to a lack of recorded data, to corrupted data, or to data that cannot be retrieved.

Comparable Data Quality. The data quality (bias, precision) should also be comparable to the conventional primary dosimeter. Data quality is currently established by radiation test categories in the Personnel Dosimetry Performance Program operated by the National Voluntary Laboratory Accreditation Program (NVLAP).[a] For dosimeters of record, accreditation of the processor by NVLAP is required by the Nuclear Regulatory Commission (NRC) in their regulations, "Standards for Protection Against Radiation," 10 CFR 20.1501(c). Because electronic personal dosimeters do not require a processor, this leads to confusion on how such testing may be implemented or if it should be implemented.

Reliable Data Accessibility. Although most EPDs can be read directly, part of their advantage is the electronic transfer of data to centralized readers for recording and tracking. Damage to the EPD, errors in data transfer, or failure of the reader can corrupt the data or make the data inaccessible. Systems must be designed to avoid this loss of data.

(a) The program uses the American Standards National Institute (ANSI), *Personnel Dosimetry Performance—Criteria for Testing* (ANSI 1993b) to establish the performance criteria to evaluate processor performance.

Immunity to Environmental Conditions. Finally, the EPD will be susceptible to environmental conditions due to its electronic nature. Such factors are well recognized for radiation survey instruments (Swinth and Kenoyer 1985a and b) and performance standards have been written to control such problems. Electronic personal dosimeters should be adequately designed to avoid susceptibility to common environmental interferences and their performance understood well enough to avoid use outside the defined operating envelope.

Defining the required reliability for an EPD is a difficult task. One can define the reliability in terms of the catastrophic failure rate of current primary dosimeters, but this does not ensure measurement accuracy under field conditions. The catastrophic failure rate of primary dosimeters is on the order of 0.1%. Catastrophic failures from the processors' standpoint would include chemical contamination (Heinzelmann and Schumacher 1984), processing failure (reader), and damage. In most cases, such anomalies may be detected by review of the glow curve; however, this does not permit restoration of the readings, and estimates for the dose of record will be required. In the case of electronic dosimeters, mechanical damage (e.g., dropping) and electronic failures (including the readers) can lead to a catastrophic loss of data. Some interferences, such as radiofrequency, may cause large enough errors to be considered catastrophic failures. The design of the EPD or its software may also lead to failures that will be large enough to be considered catastrophic, such as a significant underresponse under certain conditions (Hirning et al. 1994).

These considerations make it important to compare the required performance of primary dosimeters and instruments to the performance of EPDs as shown through testing. The following sections set out the requirements for dosimeters and instruments and the tested performance of EPDs.

1.1 Dosimeter Performance

The factors affecting the performance of primary dosimeters (Swinth 1988, ANSI 1993b) include temperature, humidity, radiation energy, radiation direction, radiation geometry, fading, remanence, position on the body, contamination, shock/vibration, calibration accuracy, reader reproducibility, dosimeter linearity, exposure to visible or ultraviolet light, mixed field response (algorithm accuracy), unwanted radiation response, variation in sensor response, and reading errors. Fading can be an important factor (Doremus and Higgins 1994) and algorithms may be used for correction. Similarly, variations in sensor response can be adjusted by calibration or sensor (chip) selection. Dosimeters may require periodic recalibration of chip sensitivity factors to maintain their performance (Grogan et al. 1990). The major factors affecting dosimeters are well understood (Marshall et al. 1994) and may be adequately controlled by design or procedural controls.

The processor is a major participant in the quality or reliability of data obtained from the dosimeter. Early problems with consistency of primary dosimeter performance led to development of the dosimetry processor accreditation program (Swinth 1988), which is operated by NVLAP, using criteria established through technical committees operating under the auspices of ANSI. Its technical recommendations are documented in *Personnel Dosimetry Performance-Criteria for Testing*, ANSI N13.11 (ANSI 1993b). Most processors are successful at meeting the criteria established in ANSI N13.11. The passing percentage in the test categories varies from 93% to 100% with the average of the absolute bias plus the standard deviation running from 0.09 to 0.17 (passing = 0.50 with the exception of the accident categories) (Martin 1994). Other methods of dosimeter performance assurance or control are employed on a national scale, such as type testing supplemented by blind

tests in Germany (Bohm and Ambrosi 1990). Another method of auditing vendor quality is submission of audit dosimeters by the user (spiked and background dosimeters).

1.2 Instrument Performance

Instruments such as EPDs will be affected by most of the same parameters noted previously, but may also be affected by electronic interferences (radiofrequency susceptibility), magnetic interference, extracameral response, geotropism, electronic component degradation, or ambient pressure (Swinth 1988, ANSI 1989).

Instruments have definite limitations on their performance and many of these limitations have been documented in type-testing studies (Swinth and Kenoyer 1985a and b). The limitations tend to be design-specific, both in the vendor's design and the intended application, and vary with the model of instrument. Thus, the proper selection of an instrument for the intended application is extremely important (Swinth 1988) and is actively pursued by major users. A performance standard, *Performance Specifications for Health Physics Instrumentation—Portable Instrumentation for Use in Normal Environmental Conditions*, ANSI N42.17A (ANSI 1989), provides guidance on instrument performance.

In general, instruments are used in an active mode so that most users feel that they can identify anomalous readings, which are generally of less importance than errors in the dosimeter of record. When the user is performing surveys in high dose rate areas, however, for emergency response or release of materials, the user may not identify anomalous readings; early studies have demonstrated a positive value for establishing a baseline for instrument performance (Merwin et al. 1986). Instrument overload response, temperature response, dose rate linearity, energy response, and angular response can be important factors in the overall accuracy of instrument readings (Swinth 1988).

Whereas such factors as radiofrequency (r.f.) susceptibility or angular response may not be critical for surveys (for r.f., the surveyor can correlate changes with transmitter operation), they may be limiting when the readings from the instrument are integrated, as in an electronic dosimeter. Such parameters must be controlled in the design of the instrument, at least to levels that will ensure reliable operation under normally expected operating conditions.

Instruments do not require "processing" to obtain a reading. If a reader is employed with EPDs, it is used to record data from the unit and set parameters in the unit. Any processing of the sensor information is accomplished by electronics within the unit and, apart from changes at calibration, is an integral part of the design. The reliability or quality of the data is established by the design of the EPD or survey instrument and, individually, by variations in the production process.

Silent failures, susceptibility to the operating environment, and quality of data are concerns that have long been recognized for portable radiation survey instruments. A system of practices has evolved to ensure the quality of data from portable survey instruments. This involves selection of an appropriate instrument, routine testing, periodic calibration and testing, and proper maintenance. The selection of the instrument involves evaluating the conditions of use followed by comparison with type-testing data or manufacturer's specifications. Once the instrument is selected, the user then performs an acceptance test to ensure that the instruments meet the expected performance. As the instruments are used, they should be routinely checked for response to a source. This will detect silent failures. Routine calibrations and proper maintenance are designed to maintain the operating

envelope of the instrument. The standard, *Radiation Protection Instrumentation Test and Calibration*, ANSI N323 (ANSI 1993a), established criteria that will assist in maintaining the proper operational envelope; *Performance Specifications for Health Physics Instrumentation—Portable Instrumentation for Use in Normal Environmental Conditions*, ANSI N42.17A (ANSI 1989), establishes basic performance criteria. As described in ANSI N323, the calibration involves testing that will provide an assessment of operational conditions and is not a simple scale adjustment or determination of a calibration factor.

1.3 Performance of Electronic Personal Dosimeters

Although EPDs are not currently used as the primary dosimeter (dose of record), they are used for control of worker exposures. Because of the concern over maintaining radiation doses as low as reasonably achievable (ALARA) and concern over exceeding legal (or administrative) limits while efficiently employing staff, the industry has been concerned over the performance of electronic dosimeters for several years. The EPD readings should reliably "track" the primary dosimeter results and provide continuous, convenient indication of dose results. This has resulted in dose/dose rate alarms and readers that accumulate worker doses. The readers have often been incorporated into access control systems to control worker exposures (Advertising Section 1987).

Users and regulators have tested dosimetry systems to ensure some measure of reliability. Most of these tests have been designed around the use of EPDs as secondary dosimeters. However, recent tests have considered the use of EPDs as primary dosimeters. In addition, user/regulator testing of field data and vendor advertisements provide an indication of present performance of EPDs.

1.3.1 Test Results—Secondary Dosimetry

From 1978-1982, type tests were performed on 105 EPDs representing 21 models (Mulhern et al. 1979; Fox et al. 1980, 1982). Problems were observed in moisture resistance and shock resistance. The units generally survived "polite" abuse, and the radiation response (energy dependence, dose rate response, etc.) was satisfactory. Most of the units would have passed the requirements in the standard, *Performance Requirements for Pocket-Sized Alarm Dosimeters and Alarm Ratemeters* ANSI N13.27-1981 (ANSI 1981). However, none of the models would pass the severe industrial or environmental conditions designed into the testing. The authors did suggest that many of the problems could have been corrected with a little "creative engineering and ingenuity." Although most EPDs survived a 1.2-meter drop (the maximum in ANSI N13.27), it is important to note that as the drop-test height increased from 1.2 to 2.4 meters, there was a progressive elimination of surviving units. The testing also included "toss" and "crush" tests that do not appear in the standard. These tests are representative of construction environments and few of the electronic dosimeters survived.

Due to the lack of a comprehensive standard for EPDs, the ANSI N42.17A criteria for portable instruments (ANSI 1989) have been used as guidance for some testing. Six units of the Alnor Model RAD-80R were used in a type test against criteria in ANSI N42.17A.[a] Testing indicated that this model could meet all the requirements of ANSI N42.17A, with the exception of the angular response and accuracy requirement at exposure rates near the advertised maximum of 100 R/h. At high dose rates, the units overresponded by 17% versus the allowed 15%. Observations on newer models

(a) K. L. Swinth. 1987. "Testing of the Alnor RAD-80R Against Specifications in Draft ANSI Standard N42.17A." Report prepared for Alnor Nuclear Corporation, September 1987.

indicated that the dose rate response had been improved significantly. The angular response at 120 keV compared to normal incidence is lower (70%) than the requirement (80%) for sources that would be above the user. The response at high angles, 90°, is affected by attenuation in the battery pack and causes the response to be lower than the recommended 50% of the reference direction response. The units are also susceptible to moisture, and it was found that if moisture enters the annunciator hole, the units could fail.

Additional unpublished testing has been performed on EPDs using the ANSI N42.17A test criteria and methods often supplemented by criteria from the International Electrotechnical Commission (IEC) standards. General observations are that battery location does affect angular response, that the energy compensation of detectors can vary among EPDs, and that silicon diodes or Geiger-Mueller-based EPDs will underrespond at low energies. Electronic personal dosimeters passed the "shall" criteria for energy response (±20% from 80 to 1250 keV), but failed the "should" criteria (±20% from 20 to 3000 keV). Although EPDs passed the shock and vibration tests, significant changes were occasionally observed in the pre- and post-testing readings.

Some testing has been performed on the Science Applications International Corporation PD-4 performed using criteria from several standards (Johnson 1993). Testing was performed using the dosimetry performance energy test criteria from ANSI N13.11 (ANSI 1993b) and DOE-EH/0027 (DOE 1986). Performance was evaluated against criteria in ANSI N13.27 (ANSI 1981) of ±30% from 80 to 1250 keV, which the EPD passed. The PD-4 would also have passed the "shall" criteria from ANSI N42.17A (ANS 1989). However, the EPD would not pass the dosimetry performance criteria for any test category using a photon energy below approximately 60 keV. Angular response was good over the range tested (±80°) and dose rate response was good up to 500 R/h (±10%). No deficiencies were noted during environmental tests.

1.3.2 Test Results—Primary Dosimetry

At the present time, there is only one model of electronic dosimeter designed and intended directly for the primary dosimeter market. This dosimeter was developed by the National Radiological Protection Board (NRPD) in conjunction with Siemens-Plessey Ltd. in the United Kingdom (Marshall et al. 1990) and is marketed in the United States by Siemens.

The CANDU Owner's Group in Canada sponsored a test of the Siemens unit (Hirning et al. 1994) with test criteria based on Ontario Hydro Specifications, a draft IEC standard, and a draft IEC dosimetry standard.[a] Table 1 shows a summary of test results.

In general, the performance of the dosimeters was good. They met most of the criteria in the standards and specification used for the evaluation. However, the following deficiencies were found: slow response time; sensitivity to high-frequency electromagnetic fields (EMF); poor resistance to dropping; and an alarm that is not loud enough. In addition, the response of the EPD to low-energy beta rays may be too low, limiting some applications.

Testing was performed with preproduction models, and the testers experienced serious problems with the reliability of EPD operation. During the tests, individual units exhibited erratic behavior, such as ceasing to operate for no apparent reason or giving readings that were clearly inconsistent with readings of other units subjected to the same test conditions. Although the causes of some of the

(a) Draft IEC Standard 45B 104E (Draft Standard for Direct Reading Personal Dose Equivalent and/or Dose Equivalent Rate Monitors for X, Gamma and High Energy Beta Radiation).

Table 1. Summary of CANDU-Sponsored EPD Tests

Test Number	Test	Test Criteria Compliance: Specifications	IEC-EPD	IEC-TLD		Comments
		Penetrating	Penetrating	Penetrating	Shallow	
1	Reproducibility	+	N/A	+	+	Operational problems: units 1, 4, 19, 20.
2	Accuracy	N/A	+	N/A		7 of 8 OK for penetrating rate; total dose OK.
3	Linearity	+/-	+	+	+	3 of 4 linear for dose rate; display does not meet specification criteria. Observed "half readings."
4	Detection Threshold	N/A	N/A	+	+	Dropped and malfunctioned.
5	Self-Irradiation	N/A	N/A	+	+	
6	Gamma Energy	+	+	+	+	
7	Beta Energy	+	-		+	
8	Mixed Field	N/A	N/A	N/A		
9	Photon Angular Response	+	+	?	?	IEC-EPD criteria not met at 75° for 65-keV x-rays.
10	Overload and Recovery	+	+	N/A		
11	Neutron Response	+	+	N/A		
12	Response Time	-	-	N/A		
13	Temperature Dependence	+	+	N/A		3 of 4 showed 9999; ceased to operate after irradiation.
14	Humidity Effect	+	+	N/A		
15	EMI:[a] Pulsed Magnetic	+	N/A	N/A		
16	EMI: Electrostatic and Discharge	+	+	N/A		
17	EMI: 60 Hz E&H[b]	+	+	N/A		
18	EMI: EMF	-	-	N/A		
19	Light Exposure	N/A	N/A	N/A		

Table 1. (continued)

Test Number	Test	Test Criteria Compliance: Specifications	IEC-EPD	IEC-TLD		Comments
		Penetrating	Penetrating	Penetrating	Shallow	
20	Alarm Loudness	-	-	N/A		
21	Alarm Accuracy	comment	comment	N/A		Not satisfying requirement when rate > rate alarm, but OK for rate < rate alarm. Dose OK.
22	Drop Test	-	-	+		
23	Vibration	N/A	+	N/A		
24	Clip Force	+	N/A	N/A		
25	Splashing	+	N/A	N/A		
26	Battery Lifetime	+	+	N/A		

+ Met criteria
- Failed criteria
N/A Not applicable
+/- Both failures and successes
Penetrating = Penetrating or deep dose
(a) EMI = Electromagnetic interference
(b) E = Electric Field; H = Magnetic Field

faults have apparently been found and corrected by the manufacturer, a later set of 20 production units included two defective units for a defective rate of 10% (or higher), which is clearly unacceptable.

During linearity testing, it was found that some of the EPDs started to record only one-half the delivered dose after repeatedly running the self-test feature. This was investigated by the manufacturer and found to be a specific software design error, which was corrected. The failure occurred randomly (approximately 10% of trials) and could be corrected by removing the battery and resetting the EPD.

Testing on the Siemens EPD has also been performed at DOE's Savannah River Site (Gregory 1994). The testing was performed as a study of the EPD and performance was not consistently benchmarked against criteria in any standard. Failures were noted on water immersion testing, drop testing, and EMF sensitivity. The immersion test failure was due to beta window sealing (manufacturer quality control). The EPDs were found to be sensitive (susceptible) to the EMF from walk-through metal detectors, proximity badge readers, and, in some cases, to the field near "Handie-Talkie" transmitters. In all cases, the sensitivity was only in close proximity (inches) to the active antenna. Quantitative values of field strengths were not available. It is important to note that the lack of proper conductive sealant around the beta window can lead to EMF sensitivity.

Comparison of exposure records for a Geiger-Mueller-based EPD and a NVLAP-accredited TLD badge at Southern California Edison showed a positive ratio of EPD to TLD readings of 1.33.[a] Several items were explored to determine the source of the discrepancy, including calibration method, energy response, angular response, recording threshold, rate dependence, placement, dose conversion factors, workplace spectra, and backscatter. All of the factors affect response, but it was felt that the major improvement would be achieved by using a calibration method that reduced scatter contribution and by using a phantom during calibrations. Cumulative EPD and TLD readings were brought into closer agreement by introducing an increasing dose cutoff per entry on the EPD data ranging from 1 mR/entry to 4 mR/entry as the dose of record increased.

Cumulation of data by Merlin Gerin on their dosimeters indicates a difference between the TLD and EPD on the order of 4% to 10%, with the cumulative TLD readings typically exceeding the EPD readings. The correlation improved for higher exposures where censoring of low-dose data for the EPD was not as great a problem.

In a French study (Delacroix et al. 1995), the performance of a credit-card-sized silicon diode-based EPD that was issued as a dosimeter was compared against film badges (the legal dosimeter) in a hospital setting and in a company producing radioelements for medical and industrial uses. The unit proved very reliable, and agreement with the film record was good when the average doses were greater than the "threshold" of the film (i.e., lower limit of detection). The common problem of workers using the dosimeter as a survey meter was noted, but it was also noted that active dosimetry promotes a dialog between the workers and health physicists. Additional technical data on the dosimeter can be found in Lacoste and Lucas (1994).

1.3.3 Dose Measurement Capability

Testing of EPDs against ANSI N13.11 (ANSI 1993b) test categories and paired comparisons when worn by actual workers provides important data for judging the EPD for use as a primary dosimeter.

(a) Letter from J. Rolph to K. Swinth, August 22, 1994.

Figures 1 and 2 show energy response curves for EPDs and TLDs, respectively. This highlights one of the serious limitations of the EPD, which is brought out in evaluations of their dose measurement capability and noted in the studies cited below.

R. Fard (1994) evaluated four EPDs (two based on silicon diodes, and two based on compensated GM detectors) against selected photon energies using the tolerance criteria in ANSI N13.11 (ANSI 1993b) and against paired comparisons with primary dosimeter data provided by nuclear power plants. On paired comparisons between the EPD and a Panasonic Model UD-802AS TLD, the precision of the EPDs was typically better than the TLD. However, the poor low-energy response of the EPDs resulted in significant negative bias at low energies, thus resulting in a tolerance level ($T = |B| + S$)[a] greater than that for the TLD dosimeter. The bias at 120 keV and 166 keV was between -0.26 and -0.92, while at 112 keV it was between -0.80 and 0.01. At 662 keV, the bias was between -0.02 and 0.11, while at 1250 keV the bias was between -0.13 and 0.045 (Fard 1994). At the higher energies, the biases of the TLDs and EPDs were comparable. Three of the four EPDs consistently performed with a tolerance level less than 0.50, thus meeting the ANSI N13.11 criteria. When testing against the accident category in ANSI N13.11 (ANSI 1993b), the EPDs were well within the 0.30 tolerance criteria of the standard. At low irradiation levels (< 100 mrem), the tolerance statistic did not degrade for EPDs as noted for the TLDs. This was due to better precision and a single detector. However, the EPDs will not meet the energy response requirement in ANSI N13.27-1981 (ANSI 1981), which requires $\pm 30\%$ from 50 to 1250 keV.

(a) T = tolerance level
B = bias
S = precision.

Fard (1994) also studied monthly dosimetry data from nuclear power plants to determine the level of agreement between primary dosimeter and EPD data. Six of the plants used the same model EPD, and in approximately half of the cases, the data were not significantly different. In most plants, the EPDs are set to respond approximately 10% high. However, the collective dose data were generally low in comparison to the primary dosimeter.

The study by Fard (1994) did not include EPDs designed specifically for primary dosimetry, but comparisons have been made elsewhere with the Siemens unit. The study at DOE's Savannah River Site (Gregory 1994) showed that for an on-phantom comparison, the units exhibited a bias of $-33.4 \pm 4.9\%$ when 10 EPDs were compared with the site's primary dosimeter. The shallow dose exhibited a bias of $-75.5 \pm 5.7\%$. The shallow dose comparison is still under investigation. A "representative" waste sample was used to irradiate the dosimeters and EPDs on a phantom.

Currently, a paired comparison of TLDs and EPDs is being performed at the Savannah River Site with six staff members. Data for the first quarter were considered promising. Although the data appear to track in magnitude, it is difficult to make comparisons because the total doses are low and the backgrounds are high. Again, the "deep" dose appears to track much closer than the "shallow" dose (Gregory 1994).

Intercomparison of a variety of EPDs at Oak Ridge National Laboratory (Casson et al. 1994) indicated that most of the models do quite well for high-energy photons. Response falls off dramatically for M30 x-rays (20 keV average), but most units perform adequately for M150 x-rays (70 keV average). Tests were also conducted with $^{90}Sr/^{90}Y$ betas and moderated ^{252}Cf neutrons. Only one model had satisfactory (but low) beta response and

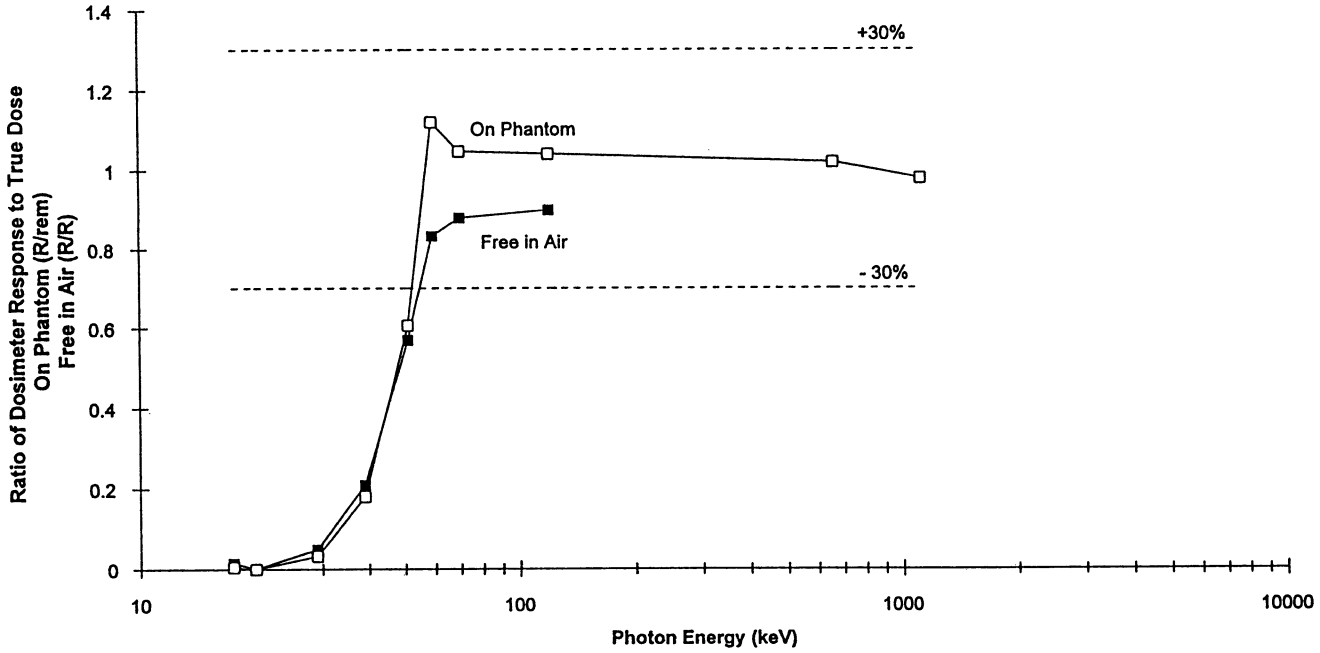

Figure 1. Energy Response of Electronic Dosimeter Using Geiger-Mueller Detector (Johnson 1993)

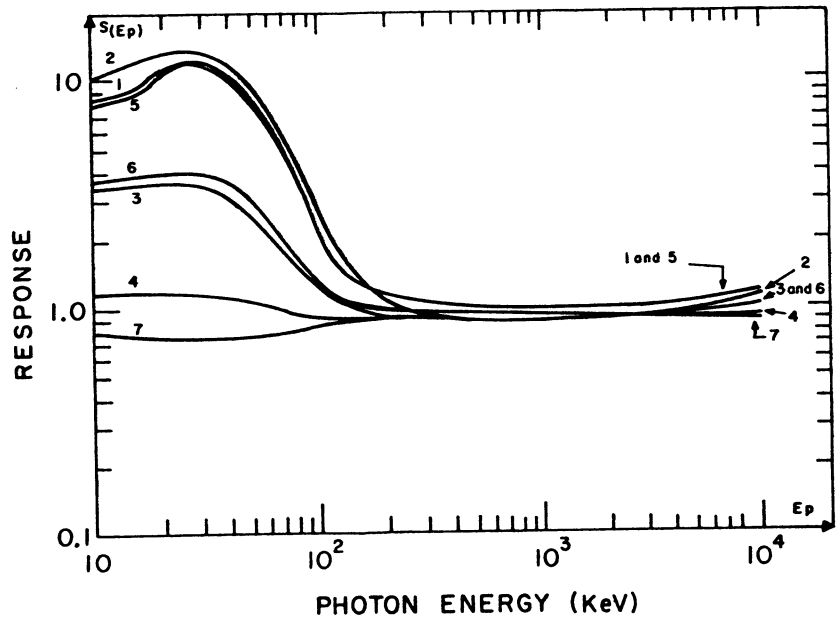

Figure 2. Theoretical Sensitivity of Thermoluminescent Phosphors as a Function of Photon Energy, Calculated as the Ratio of the Energy Deposited in the Phosphor to the Energy Deposited in Tissue: (1) $CaSO_4$; (2) CaF_2; (3) Al_2O_3; (4) LiF; (5) $CaCO_3$; (6) SiO_2; and (7) $Li_2B_4O_7$ (Cluchet and Joffre 1967)

only one model was designed for and responded to neutrons significantly. Performance tests at the Pacific Northwest Laboratory (Piper et al. 1993) on the Siemens EPD demonstrated excellent performance against ANSI N13.11-1983 and DOE/EH-0027 test categories with the exception of the low-energy x-ray categories M30 (20 keV average) and K17 (17 keV K-fluorescence technique). The unit passed the beta test categories, but failed in neutron categories as one would expect. The test data indicated that the unit would pass the testing criteria to individual as well as mixed beta-photon fields over its stated range of sensitivity. Based on these studies, it can be concluded that EPDs are available and adequate for high and moderate energy photon radiation exposure environments, but that they are not adequate for very low-photon-energy (<70 keV) environments nor for neutron exposure monitoring. Only the Siemens unit is adequate for beta particle exposure environments.

1.3.4 Discussion

Until recently, testing and evaluation of the EPD focused on its use as a secondary dosimeter for work control purposes. The only guidance on electronic dosimeter performance, ANSI N13.27 (ANSI 1981), recognizes this important function and emphasizes features important to secondary dosimetry. Electronic advances providing automatic recording of worker doses from EPDs and the good correlation of EPD and TLD readings have made many consider use of the EPD as a primary dosimeter. Manufacturers have responded by improving the convenience and quality of their systems and, in one case, designed an EPD specifically aimed at the primary dosimetry market. Users (and vendors) have also performed formal evaluations of systems aimed at their use for primary dosimetry. Based on the evaluations discussed in this section, we can reach several general conclusions:

- Most EPDs have a poor energy response below approximately 70 keV.

- Environmental conditions, such as electromagnetic radiations and moisture, can affect EPD performance.

- The EPD is still evolving. Some inherent defects have been located (e.g., software malfunction) and, in some instances, the quality of delivered units has been unacceptable (e.g., high failure rate).

- The correlation between collective worker doses on TLDs and EPDs generally agrees to better than $\pm 10\%$.

- Due to the poor low-energy response, the single detector EPD will not pass ANSI N13.11 dosimetry performance test criteria (ANSI 1993b) for categories using low-energy photons.

- The criteria used in evaluating performance vary widely. In addition, the tests are not always objective. For example, in one case, r.f. susceptibility was tested by placing the antenna of a transceiver within "one-half inch" of the EPD. Radiofrequency field intensity varies rapidly with distance (approximately as r^2), and repeatability or reproducibility of tests requires a field intensity measurement. Transceiver output can also vary with factors such as battery condition or condition of the transceiver.

- Dose conversion factors needed to convert air kerma to deep and shallow dose equivalent are not used for instrument testing or calibration. Ambient dose equivalent and directional dose equivalent should be used for instruments. Care must be taken to use the appropriate conversion factors for EPDs.

2 Survey Results

A survey questionnaire was designed to determine the present extent of use of EPDs, their conditions of use, problems encountered in the field, and recommendations for testing and accreditation of EPDs as substitutes for passive whole body personnel dosimeters. Arrangements were made for this questionnaire to be distributed by the Nuclear Energy Institute (NEI) to the NUMARC Administrative Points of Contact. Results from this questionnaire were returned to the Pacific Northwest Laboratory (PNL) without identification of the source. Therefore, this survey was conducted in a single blind format.

The questionnaire was sent by NEI to 67 sites representing commercial nuclear power plants and 14 other sites including fuel fabrication facilities. Sixty-one of the 67 (97%) sites representing power plants returned completed questionnaires, along with two fuel fabrication facilities. In a couple of cases, both individual nuclear power plants and the corporate office answered the questionnaire resulting in some duplication. Since the survey was designed to draw out trends, rather than being a statistical analysis, this was not a limiting consideration. A copy of the questionnaire and the tabulated results are included in Part 1, Appendix A.

Although not all questions yielded clear answers, the results did indicate many common findings that are summarized below:

- Thermoluminescent dosimeters and other types of passive dosimeters are used as the primary dosimeters (dosimeters of record). The EPDs are used as pocket alarming dosimeters for specific jobs. Over half the respondents issue EPDs for all entries to Radiation Control Areas, while others issue them only for High Radiation Areas or special work.

- About half of the respondents said that they would consider using EPDs as the primary dosimeter. However, since most EPDs do not respond to betas and neutrons, they would issue TLDs or other passive dosimeters to measure these radiations. In the case of betas, several respondents indicated they would use workplace surveys to show that beta doses were inconsequential and adequately controlled by control of the penetrating dose.

- Most respondents are generally pleased with the performance and reliability of EPDs, although certain failures or problems seem to be common among a number of respondents. These include data losses from battery or electronic failures, failures in high-humidity environments, susceptibility to radiofrequency and electromagnetic field interference, and design deficiencies such as displays that "blanked out" on failure rather than alarming. In addition, the majority reported problems in hearing the audible alarms.

- The responses indicate that the level of agreement between EPDs and TLDs was approximately 5%, but some reported differences of greater than 8%.

- One additional point that was mentioned by a number of respondents indicated a nonuniformity in the use of EPDs. Many respondents indicated that they were not source-checking the EPDs, or were checking them only infrequently. The reason given was the reliance on the internal electronic checks incorporated into the

instruments or on checks performed by the readers.

- Typical dose rates are 1 to 100 mR/h in work areas, but most respondents had areas from 5 to 100 R/h (typically 7 to 10 R/h).

- Temperatures were typically 60° to 90°F, but temperatures around 130°F were cited for extreme conditions. Few respondents noted temperatures below freezing.

- Approximately one-fourth of the respondents indicated that the EPDs should meet dosimetry performance (i.e., NVLAP) criteria or similar criteria. One respondent indicated there was no need for a NVLAP program.

- Some respondents indicated a need for routine source checks (daily), while others indicated this was not needed and made a plea that any guidance look ahead five years to the technical capability that will be available.

From the results of this survey, it can be concluded that users at commercial power plants believe that the present generation of EPDs is capable of reliably measuring photon exposures and alarming at preset dose equivalents or dose equivalent rates. With regard to the question of using EPDs as whole body personnel dosimeters, it is the opinion of most users that such devices could be used for this purpose. It was also clear that EPDs are not without problems and that the problems are different from those experienced using TLDs.

A survey of vendors was performed to determine the advertised specifications for EPDs. The results are summarized in Part 1, Appendix B. Information in the vendors' literature is generally incomplete and of unknown origin.

3 Type Test Criteria

Type-test criteria for the use of EPDs as primary dosimeters along with the associated reader must be realistic while assuring that the EPD can deliver primary dosimetry information with adequate reliability. The test criteria for EPDs and readers can fall into three broad categories:

- mandatory for dose of record—This includes radiation response criteria, such as dose rate independence, energy response, angular response, immunity to interfering ionizing radiations, and coefficient of variation (precision). Immunity to interfering conditions, such as temperature, humidity, shock, electromagnetic interference, etc., are also important to the reliability of the data, as are the accuracy of data retention, reliability of transfer to a central record system, and operational lifetime.

- required for dose/dose rate control—Criteria such as alarm setpoint accuracy, alarm intensity, overload response, and dose rate linearity are important for dose/dose rate control.

- supporting criteria—Criteria such as mass, size, clip strength, decontaminability, readability, marking, labeling, etc., are support criteria, but may have an impact on overall data reliability. For example, clip strength and mass will affect dropping rate and severity of shock damage. Reference point marking may influence the quality of the calibrations.

Part 1, Appendix C compares criteria from various standards, which are directed toward type testing of a device. Recommendations based on these criteria, along with findings from the survey and available testing data, are provided in the following subsections. The rationale for electromagnetic interference criteria, temperature criteria, radiation energy response criteria, and dose rate linearity criteria are provided at the end of this section.

3.1 Test Criteria

The testing criteria found in Parts 2 and 3 may be used as type-test criteria or as routine test criteria.

The type tests are performed on a random sample of dosimeters representative of the routine production of the dosimeters. Due to the large number of such dosimeters expected to be in use, the type test should be carried out on a sample of 15 or more dosimeters. Smaller samples may be used on specific tests, as noted. Routine tests are expected to be performed on each dosimeter and to relate the performance of each dosimeter to the type-test data. Routine tests may also be used as acceptance tests (see Section 3.1.2).

One assumption of type testing is that the tested product represents a sample of the manufactured product. Thus any subsequent changes in the product will render the test data invalid unless it can be demonstrated that the changes will not affect performance. This includes changes in components including their source of manufacture, and any changes in software algorithms used by the microprocessor. Temperature and overload response are examples of parameters that can be affected by changes in components or algorithms. Changes should be reviewed by the testing laboratory or by another independent party to determine if type testing needs to be repeated. The routine tests and

calibrations may not be sensitive to performance changes introduced by design changes.

For simplicity, the tests are presented in the form of a standard using the presentation format in the ANSI N42.17 standards (ANSI 1989) with the performance requirements followed by the test method. Setting forth a basic test method is essential to performing tests that are reproducible and objective. Tests should be reproducible by any manufacturer or test laboratory that has established appropriate quality control procedures and follows the general test procedures.

The laboratory performing these tests should have an established quality assurance program complying with national and international guidance. It is recommended that the testing laboratory comply with appropriate guidance in ISO/IEC Guide 25, *General Requirements for the Competence of Calibration and Testing Laboratories* (ISO 1990). The testing laboratory should have an established secondary radiation calibration capability or equivalent as recognized by accreditation through the programs operated by NVLAP or the Health Physics Society (HPS). Each test shall follow documented procedures and all test values (temperature, acceleration, distance, etc.) shall be established with measurement equipment whose calibration (including the uncertainty) is documented and relatable to national standards. Specific test and quality control procedures are beyond the scope of this report.

Several tests call for the separate testing with beta and photon sources. When a single detector serves the function of beta and photon detection, this is not required for temperature, radiofrequency, or other test of influence quantities. It is still required for the radiation response tests.

The tests for the EPD in the form of a standard are found in Part 2. Tests for the reader are found in Part 3. Adequate performance of the reader is essential to the use of the EPD as a primary dosimeter.

3.2 Rationale for Selection of Criteria

Energy Response. The performance requirements are provided in two categories defined for specific energy ranges. The first range is from 100 keV to 1250 keV with a response of $\pm 30\%$ referenced to ^{137}Cs and a response at high energies (approximately 6 MeV) within $\pm 50\%$ of the ^{137}Cs (660-keV) response. The second category is the "low-energy" category, extending from 20 keV to 1250 keV with a response of $\pm 30\%$ referenced to ^{137}Cs. The energy range from 100 keV to 1250 keV for the deep-dose response should be adequate for applications at nuclear power plants.

Spectroscopy measurements at nuclear power plants (Roberson et al. 1984) have shown that the typical "plant mix" of radioisotopes is a mixture of primarily ^{137}Cs and ^{60}Co. At reactors studied by Roberson et al., most have radiation fields of nearly all medium-energy photons, due to radioactive decay of cobalt and/or cesium isotopes, or a combination of medium-energy photons with a scatter continuum. Low-energy photons at commercial nuclear reactors occur because of scattering in shielding material. Note that "low-energy," in this context, refers to photons with energies <200 keV, "medium-energy" refers to 200-keV to 3-MeV photons, and "high-energy" to photons with energies >3 MeV. As noted in the previous section, comparison of EPDs with TLDs has shown good agreement in the nuclear power plant radiation environment. These EPDs were not designed specifically for low-energy photon detection; due to their adequate performance, it does not seem advisable to place unnecessary requirements on their energy response. Sorber et al. (1988) performed a study showing a lack of low-energy photons in selected nuclear power plants, thus supporting the study of Roberson et al. (1984).

Electromagnetic Interference. The recommendation of an r.f. test intensity of 100 V/m, as noted in ANSI N42.17A (ANSI 1989), was retained. Although some interference can be expected, this is higher than radiofrequency protection guides from approximately 3 to 300 MHz, and testing has shown that compatibility with 100-V/m test levels is feasible for radiation protection instruments (Swinth and Kenoyer 1985a and b). Since r.f. intensity decreases by approximately $1/r^2$, it may be necessary for EPD users to institute administrative controls on use of "walkie-talkies," metal detectors, heat sealers, etc., to avoid interference. Other controls, such as metallic bags, can be employed if r.f. interference proves troublesome. Near radars and other high-powered or directional transmitters, it may be necessary to routinely employ additional shielding. When EMFs exceed 100 V/m, electromagnetic interference will be common; it is unlikely below 1 V/m (White 1995).

Temperature Response. The temperature response range is changed to a 0° to 55°C for a ±15% change in response. This is in agreement with the maximum temperatures reported in the survey.

3.3 Routine Tests

Routine tests are required on *each* dosimeter and may be part of the initial calibration. The routine tests are expected to provide assurance that each dosimeter meets specifications demonstrated during the type tests. The following recommendations require development of the routine tests during the type-testing procedures. The routine test fixtures and recommendations will be specific to each model of EPD.

The parameters subject to routine testing include energy dependence, angular dependence, and overload response. In addition, temperature and electromagnetic susceptibility should be subject to periodic testing. The frequency of such testing should depend upon the manufacturing process, the consistency demonstrated in type tests, and any changes in components provided by suppliers. Routine tests should also be repeated after maintenance.

The first step is to establish a fixture with a reproducible geometry to hold the electronic dosimeter. The fixture should also have fixed positions for test sources and be provided with a low-energy (^{241}Am [60 keV] or ^{57}Co [122 keV]) and a high-energy (^{137}Cs [660-keV]) source. The ratio of the source responses at normal incidence will provide assurance that the energy response is correct, while tests at ±60° from normal incidence will test the angular response. This type of simplified routine testing is compatible with the recommendations in *The Examination and Testing of Portable Radiation Instrument for External Radiations* (HSE 1990). The fixture plus sources can be placed in an environmental chamber for temperature testing.

Routine linearity test and overload response should be checked during the initial calibration procedure (see Part 1, Section 4.3).

4 Performance Assurance

This section discusses the steps needed to provide continued assurance of EPD performance following a type test that demonstrates that a sample of dosimeters perform adequately against established criteria: manufacturer quality control, acceptance testing, calibration, functional checks, performance tests, and manufacturer's maintenance. Figure 3 illustrates the relationship of the EPD and its field use (deployment) to the various processes needed to ensure its performance as a primary dosimeter. The dotted lines illustrate points at which the type test results could be related directly to individual EPD performance using a source geometry established during the type testing.

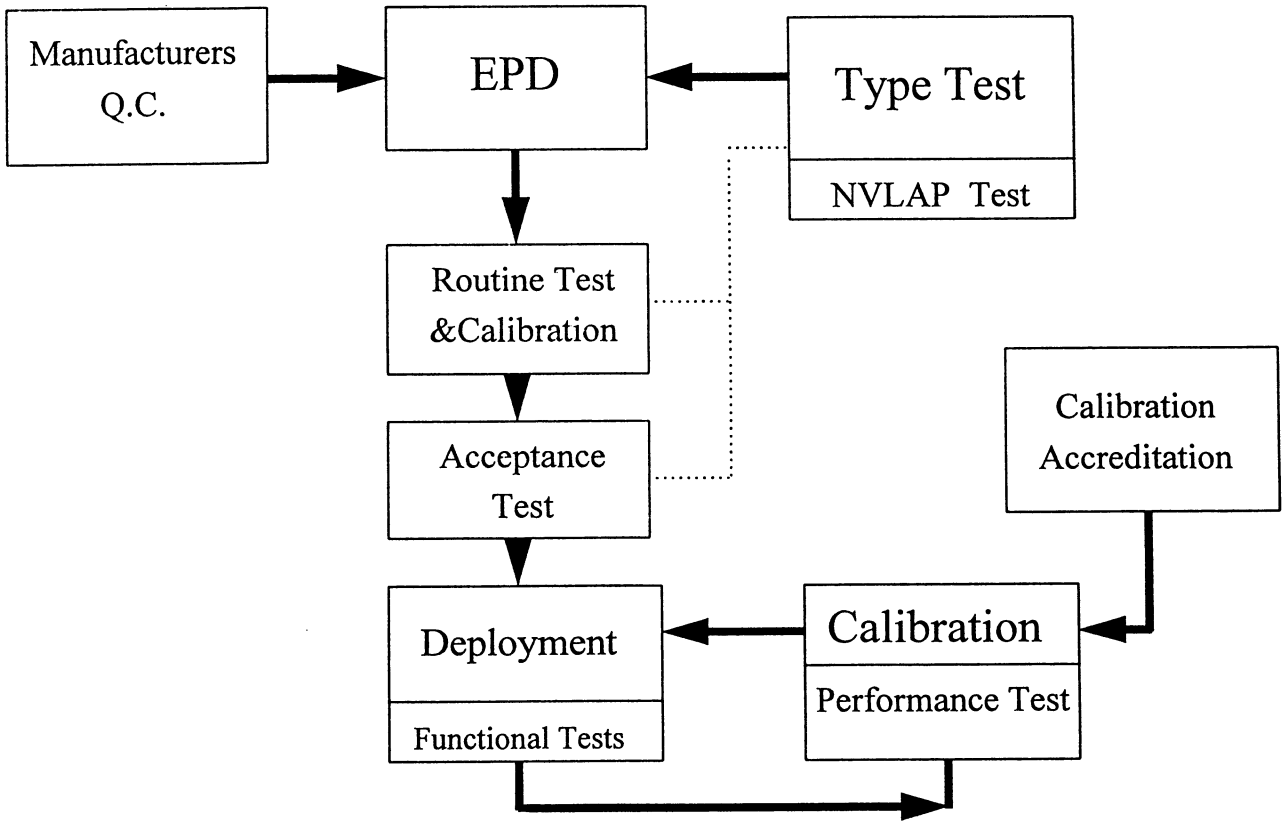

Figure 3. Required Process for Making Electronic Personal Dosimeters Primary Dosimeters

4.1 Manufacturer Quality Control

Once adequate performance is demonstrated, the manufacturer must establish quality control procedures to ensure that manufacturing processes or components do not affect EPD performance. Standard electronic manufacturing quality control procedures should ensure that the EPDs are consistent. However, the manufacturer should have a test protocol that will demonstrate that each EPD meets basic performance criteria related to the type testing. By establishing simplified tests during the type-testing, the manufacturer will be able to test the radiation performance of each EPD and could extend this to other performance elements, such as r.f. susceptibility or temperature response. The establishment of these routine tests is discussed in Section 3.3.

This testing will not ensure the long-term reliability of the manufactured unit. Methods of testing products and eliminating early failures are well known and, in some cases, required by contract. A "burn-in" period of operation at an elevated temperature will eliminate some early failures. The Navy has an established reliability screening program (DON 1979) consisting of temperature cycling and random vibration. For high-value products where field repairs will be costly or where high reliability is demanded by the application, such screening is important. Recommendations for manufacturer reliability screening are beyond the scope of this report and are the responsibility of the manufacturer. Success of the EPD as a primary dosimeter may depend on reduction of failures.

4.2 Acceptance Testing

Each EPD should be acceptance tested. This requires testing against specific purchasing specifications to ensure that such specifications are met. Generally, acceptance testing will consist of checking the calibration and sampling performance against selected criteria as deemed necessary. An acceptance test, which should precede the initial instrument calibration, should consist of (1) a physical inspection, (2) general operations tests, and (3) source tests. The physical inspections and general operations tests should be performed on each EPD. The source tests should be performed on a random selection of approximately 10% of the EPDs. If one unit in a sample from a large quantity fails the test, an additional 10% should be tested. An additional failure would require testing (or return to the vendor) of the entire batch.

Physical Inspection. This consists of general inspection for placement of labels, physical damage, testing of moving parts, and making sure batteries are fresh and properly installed.

General Operation. The EPD should be cycled through all of its modes of operation, including self-test sequences, data transfer to a reader, and operability of internal test circuits (background counting).

Source Tests. The EPD should be tested for response to a source, reproducibility of readings (exposed to the same dose/dose rate several times), stability, temperature response, humidity response, angular response, and photon energy response. As noted under manufacturer quality control, if suitable tests are established during type-testing, the user can rapidly ensure performance compliant with type-testing performance with single point tests.

Instrument Calibration. The initial EPD calibration is part of the acceptable test and should include a comparison of instrument linearity and overload response against specifications.

4.3 Calibration

Examining the calibration or adjusting the calibration of the EPD is important and should be performed periodically. The recommendations of ANSI N323 (ANSI 1993a) for annual calibration should be followed. The new draft of the ANSI N323 standard includes guidance for dose rate and integrating instruments that are applicable; relevant guidance is incorporated into the three steps listed below.[a] However, when the EPD is used for dosimetry, the appropriate dose equivalent conversion factors must be applied and the calibration must be performed on a phantom. The factor to convert air kerma to dose equivalent is 1.21 for ^{137}Cs (ANSI 1993a).

1. Since EPDs have a dose-rate function, this should be tested and adjusted first during the calibration process.

   Linear readout instruments with a single calibration control for all scales shall be adjusted either at the point recommended by the manufacturer or at a point within the normal range of use. Instruments with calibration controls for each scale shall be adjusted on each scale. The same principles should be applied to microprocessor-controlled instruments.[a]

   For instruments that also use a dead-time adjustment or setting, this adjustment should be made at the same time the calibration adjustment is performed. Dead-time adjustments should comply with the recommendations of the manufacturer.

2. Next, the adjustments should be checked.

   After adjustment, the response of the instrument shall be checked near the end points of each scale (approximately 20% and 80% of full scale). Instrument readings shall be within $\pm 10\%$ of conventionally true values (CTV) at these two points.

3. Following the dose rate adjustment, the integration or dose function should be checked.

   Instruments which integrate dose shall be checked at a minimum of two dose rates at approximately 20% and 80% of the stated dose rate range or as recommended by the manufacturer. The integrations shall continue to a value sufficient to assure a statistically valid reading which shall be within 10% of the CTV. For digital instrumentation, integration should be checked to the maximum reading, obtainable on the display. If it is not practical to accomplish the full-scale radiological integration, the electronics and display may be checked electronically at the maximum integration point and with the radiological integration being performed at a lower point that is achievable.

   Thus, one would select a high- and a low-dose rate and integrate the dose until a "reasonable" reading is obtained. Although the standard[a] calls for integration to the maximum value, this may not be achievable and electronic checking of the readout may be deemed sufficient. Integration should test to values that are expected in the workplace. The calibration should also test the data transmission accuracy of the EPD.

Calibrations should be performed on a phantom in a low-scatter geometry. Calibrations will require the use of a collimated source (^{137}Cs [660 keV] is recommended) in an open air geometry. Primary

(a) Draft ANSI N323A-199X, "Radiation Protection Instrumentation Test and Calibration—General Requirements and Portable Survey Instruments."

calibrations of EPDs should follow the recommendations of ISO-4037 (1979) for source and calibration geometry. Since most EPDs have poor low-energy response, their calibration will be sensitive to changes in scattered radiation and attention must be paid to ensuring a low and unchanging scatter geometry. Calibration of reference fields is generally performed with an ion chamber having a flat energy response; the ion chamber will be insensitive to variations in the low energy component but the EPD will not be insensitive to the same changes. Alternatively, EPDs properly calibrated in an accredited calibration laboratory can be used to transfer the calibration to a "box calibrator" or other relatively high-scatter geometry with or without a phantom. This practice is recognized and described in the Health Physics Society accreditation criteria (Section C.10.6)[a] for tertiary laboratories.

Some EPDs are adjusted during calibration by the manufacturer using a complex iterative process (Siemens 1994). It is not practical for the user to duplicate this process, but the calibration should be designed to ensure continued accuracy of EPD performance and elimination of EPDs that no longer maintain the $\pm 10\%$ accuracy noted in ANSI N323 (ANSI 1993a). Siemens also produces a source check device that will permit adequate performance testing of their EPDs.

4.4 Functional Checks

Functional checks of the EPD should be performed periodically. Functional checks are often qualitative and will include source checks, electronic tests, etc. Many EPDs have internal check functions and integrate normal background radiation to determine that the detector and electronics remain functional. These are deemed adequate in lieu of source checks, which are recommended "daily or before each use" in ANSI N323 (ANSI 1993a). If the units do not perform the internal background tests on each detector, frequent source checks should be performed. The recommended frequency is daily or before each use for primary dosimeters to ensure that loss of data is minimized.

4.5 Performance Tests

As noted, functional tests are not intended to test the accuracy of EPD performance. Periodic performance tests should be performed to ensure that the EPD is operating within a prescribed range of performance. For EPDs, this may consist of a monthly test of response to a standard source or sources at known dose or dose rate representative of conditions in the work environment.

Some vendors sell devices suitable for source checking their EPDs (Siemens 1994). In many cases, these are suitable to ensure that the EPD is performing within the accuracy specified at calibration.

4.6 Maintenance

The EPDs used as primary dosimeters should not be repaired or altered by the user. To maintain the necessary quality, damaged or malfunctioning EPDs should be returned to the manufacturer for repair. Repaired devices shall be tested and calibrated to ensure performance comparable to new EPDs.

(a) "Criteria for Accreditation of Calibration Laboratories by the Health Physics Society," available from the Health Physics Society, McLean, Virginia.

4.7 Design Changes

Changes in the design, including changes in the components, their source of manufacture or in the software algorithms shall be independently reviewed to determine any potential affects on performance and type testing shall be repeated as required. Algorithms shall not be changed by the user unless the individual algorithms have been independently reviewed or have been the subject of a type test.

5 Implementation Issues

Several issues remain on the implementation of the EPD as a primary dosimeter in addition to meeting the specific performance criteria outlined in this report. In this section, the issues are discussed and specific recommendations given.

- Several users of EPDs, both national and foreign, have noted the tendency of workers to use the EPD as a survey meter. This will invalidate the results from the EPD and lead to recording of excessively high exposures.

  Recommendation. Two steps should be taken to eliminate the tendency to use the EPD as a survey meter. First, display of dose rate should be eliminated and replaced by a single resetting alarm. If additional dose rate information is needed, survey meters or supplemental EPDs should be used. Second, administrative controls should be used, including worker training on the use of EPDs and worker reprimands for misuse of EPDs. This is in keeping with practices for present primary dosimeters.

- In some cases, the EPD is issued to an individual, while in other cases, it is used as a communal device and read upon entry and exit. Upon exiting the radiation area, the EPD is returned to the pool (usually a storage rack) for access and use by additional workers.

  Recommendation. For all routine radiation workers, the EPDs should be issued to the individual. This will maintain identity of permanently stored information in the EPD and will lead to improved care and responsibility for the EPD.

  The issue of incidental (management, visitors) and contract radiation workers remains. The EPD is very valuable in these circumstances due to use as an aid in tracking worker exposure. It is recommended that communal EPDs not be issued and read as primary dosimeters until adequate quality control is demonstrated at each site. Demonstration may consist of paired comparisons of a dosimeter from a NVLAP-approved processor and the EPD computer record of the worker's exposure. Once consistency and reliability of results are demonstrated and documented, the passive dosimeter may be phased out. This is subsequent to any comparisons provided during a planned program implementation.

- Permanence of record is an issue with the EPD since electronic failure could lead to loss of data. Many EPDs periodically write the dose data to a nonvolatile EEPROM memory. Transfer of data on the Siemens unit occurs every 15 minutes.

  Recommendation. Permanency of data is a concern and any EPD used as a primary dosimeter should have a nonvolatile memory with dose data written to memory at least every 15 minutes. Documented procedures for recovery of the information from the nonvolatile memory must exist.

- Susceptibility of the EPD to electromagnetic interference (e.g., r.f. emissions) is a common problem and virtually impossible to eliminate in intense fields such as pulsed radar or radio/TV transmitters. In some cases, manufacturing mistakes have led to increased susceptibility (Gregory 1994).

Recommendation. Elimination of all electromagnetic interference is impossible. Three steps should be implemented to control this problem. First, all EPDs should pass the test criteria noted in the standard. Second, manufacturers should have a quality control program that tests each EPD for susceptibility. Third, users should eliminate use of EPDs in high r.f. emission areas or areas with intense magnetic fields, should institute worker training programs, and should use worker reprimands where guidance is not followed.

- The simpler EPDs have poor low-energy response.

  Recommendation. As noted earlier, the poor low-energy response does not seem to be a severe problem in many environments. Compensation of the detectors can be studied analytically (Tseng and Chang 1992) and probably improved by the manufacturers. Most potential users of EPDs have several years of data accumulated with NVLAP-qualified dosimeters which can be used to substantiate or refute concerns over beta and low-energy photons. Indications from dosimeter processors are that significant beta or low energy photon exposures are rare at nuclear power plants. This supports the studies of Roberson et al. (1984) and Sorber et al. (1988).

  The lower photon energy requirement for the measurement of the deep dose ($H_p[10]$) is given as 50 keV in several standards. This is because below 50 keV, the value of $H_p(10)$ per air kerma decreases rapidly as a function of decreasing energy, down to zero at 10 keV, while that for the shallow dose ($H_p[0.07]$) decreases by only 20% down to 10 keV. Thus, below 50 keV, it is the shallow dose (personal dose equivalent $H_p[0.07]$) that is more restricting. Also, the data produced by ICRU and ICRP show that below 100 keV, the measurement of $H_p(10)$ significantly overestimates the effective dose equivalent as well as the dose to most individual organs. Hence, it can be argued that the dosimeter's $H_p(10)$ response can fall significantly at low energies to compensate for this overestimation. Alternatively, there is no need to establish a requirement for measurements below 50 keV.

- Measurement of the shallow dose is not possible with most EPDs. Also, neutron dose is not easily or accurately measured by using EPDs.

  Recommendation. Users should review worker exposure data to determine the need to measure the shallow dose. Survey respondents indicated that shallow dose is generally not a concern and that shallow dose and neutron dose could be handled by supplemental dosimetry or workplace studies.

  The conventional dosimeter is worn on the trunk placed on top of clothing. Usually, such workers wear a shirt or blouse and a coverall. With the thinnest shirt being about 30 mg/cm^2, it is obvious that the worker's body is never receiving a dose equivalent at a depth of 0.07 mm (7 mg/cm^2). It is also questionable that the shallow dose recorded should be assumed to be received by the wearer's extremities. The spatial dose-rate distribution from weakly penetrating radiations is frequently very variable, so it would seem more prudent to monitor its dose at the location where the dose is accumulated, namely by the issue of conventional extremity and skin dosimeters. Thus, requirements for neutron and shallow dose measurements with EPDs are not justifiable in most cases and are probably handled better with conventional dosimeters.

- Alarms are often difficult to hear and, in the case of multiple alarms, difficult to distinguish.

  Recommendation. Manufacturers are aware of the alarm problem and the use of earphones, vibrators, etc., should eliminate the audibility problem. Reduction of dose-rate alarms and other alarms should reduce the problems with multiple alarms. Dose, dose overload, battery failure, and dosimeter failure should trigger audible alarms; combining the three latter alarms would be practical since they indicate a need to leave the area and check the dosimeter for condition. Actual alarm condition could be displayed. Thus, one dose, one dose-rate, and one "failure" alarm would need to be available.

- Demonstration of compatibility with NVLAP criteria for personal dosimetry (ANSI 1993b) is felt to be necessary for general acceptance of the EPD by some. Others feel that such testing is unnecessary.

  Recommendation. Testing of the EPD to the type-test criteria will provide the data needed to reconstruct the expected performance for the radiations and mixture categories identified in ANSI N13.11 (ANSI 1993b). Separate testing to N13.11 criteria is not needed, but should be evaluated during initial type test evaluations.

- Several contacts have noted the lack of guidance on the proper calibration of an EPD.

  Recommendation. As noted in Section 4.3, most of the guidance needed for calibration exists, but is not identified as applicable to EPDs. Guidance should be developed under the auspices of one of the calibration accreditation programs (HPS or NVLAP) and quickly developed into a calibration standard similar to ANSI N323 (ANSI 1993a).

6 Conclusions and Recommendations

The present state of electronic dosimetry does not meet the quality of response established for current primary dosimetry systems. The EPD is still undergoing a "commissioning" phase when limitations are being identified and eliminated and performance improved.

Neither present primary dosimeters nor the EPD are without limitations and both require training and administrative controls to ensure useable measurements. Figure 4 illustrates the situation. Ideally, the EPD performance envelope and the envelope (set) conditions representing the user operational environment would coincide exactly. The set of operational environments or conditions not included in the performance envelope must be inconsequential or adequately covered by administrative controls. The process of identifying these limitations (type testing) is important in the establishment of effective controls and in eliminating these limitations. Section 5 discussed some of the recognized limitations and provides recommendations to minimize these limitations.

The intersection of the envelopes of performance and operational conditions is complete enough to meet operational deployment of the EPD as a primary dosimeter in selected instances. At least two nuclear power plants (Mercer 1995, Simpson 1995) are in the process of implementing the EPD as the primary dosimeter. The users cite cost advantages over current TLD dosimetry. Although a representative of the American Nuclear Insurers has expressed concern over changes in dosimetry practices (Forbes 1995), the concern focuses on the need for duplicate (primary and secondary) dosimetry systems to better "fend off" legal challenges. The move away from the present NVLAP accredited passive dosimetry systems was not the major concern.

To hasten the acceptance of EPDs as primary dosimeters, several steps should be taken over the next one to two years. The major steps are outlined below.

- Encourage continued side-by-side use of EPDs and current NVLAP-accredited primary dosimetry systems at several sites under controlled conditions. For sites intending to use the EPD as a primary dosimeter, this should be part of the documentation maintained to show that the EPD provides the required dosimetry under their operational environment. The evaluation period should be limited to approximately one year. Follow the steps indicated below:

  a) For 6 months, compare the EPD and TLD measurements to determine that data are comparable. Perform paired comparisons and use a statistical test to show results are equal.

  b) If data are adequate from 1a), use the EPD data as dose of record without processing/ recording of TLD data unless the EPD data are inadequate. This process should continue for one year and all replacements of EPD data should be recorded.

- Perform controlled evaluations of EPDs and NVLAP-accredited primary dosimetry systems side-by-side in typical work situations. Idealized calibrations or test geometries may not provide adequate comparison of expected dosimetry system performance. Extended sources and other geometry effects encountered in the workplace must be evaluated.

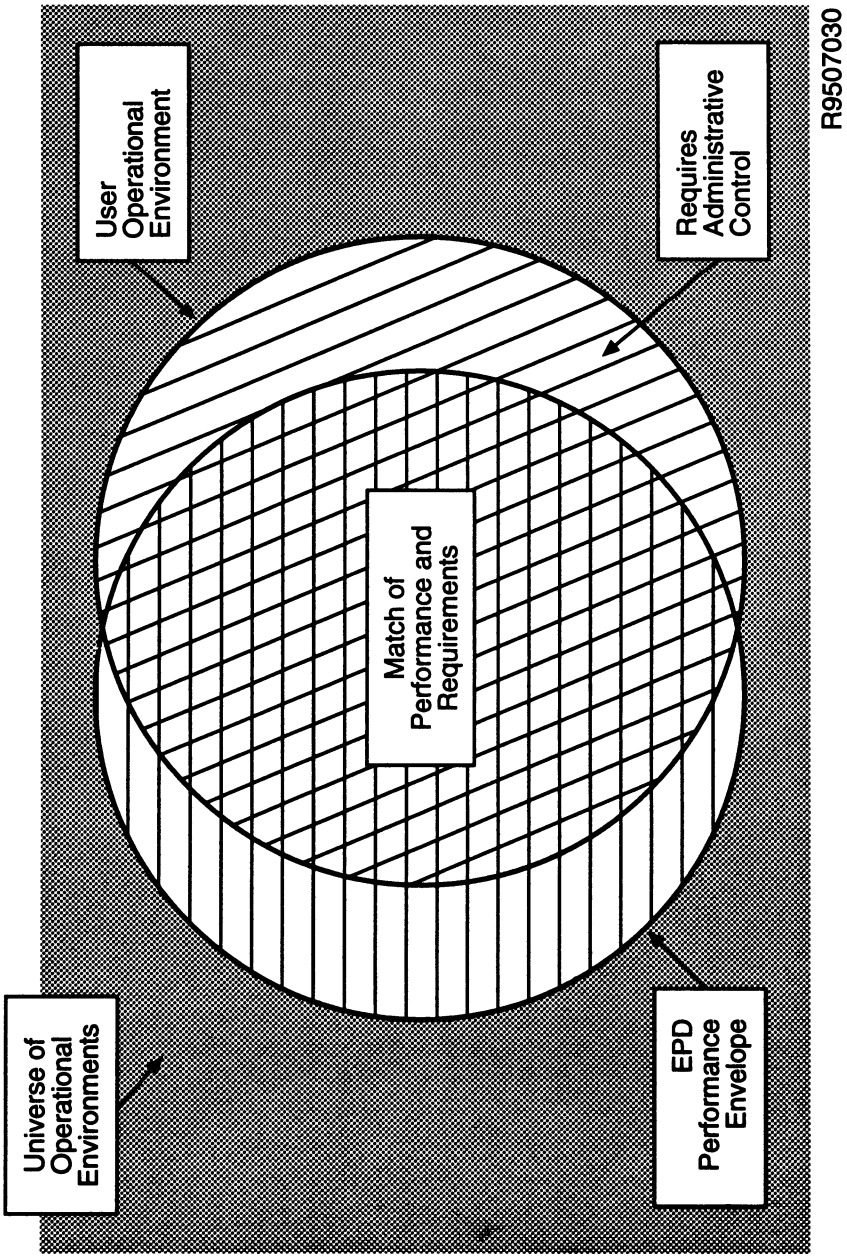

Figure 4. Performance Envelopes Showing the Intersection of EPD Performance and User Performance Requirements

- Perform pilot evaluation of a type-testing program for accreditation of EPDs for primary dosimetry. The program should have the following features:

  a) Type testing by an independent testing laboratory using critical criteria identified in this report. The type-testing program should be conducted by an independent laboratory with secondary laboratory radiation calibration accreditation through either the HPS or NVLAP.

  b) Evaluation of manufacturer's program to evaluate quality assurance and quality control practices.

  c) Evaluate the manufacturer's calibration program and recommended calibration procedures.

  d) Evaluate the use of a "standard fixture" to relate type-test data to routine-testing or acceptance-testing procedures.

- Develop user guidelines for deployment of EPDs as primary dosimeters. The guidelines would cover the following:

  - acceptance-testing programs
  - calibration techniques and programs
  - functional-testing and performance-testing
  - control of EPD use, worker training, and records.

The guidelines may be developed either as an NRC regulatory guide, as program operational criteria through an accreditation program or through a combination of these options. For example, either the HPS or NVLAP could develop calibration criteria and a program to accredit users of electronic dosimeters. This would include onsite assessment criteria and performance test criteria. The performance test could consist of either furnishing the user with a "calibrated" electronic dosimeter and request a recalibration at a specific dose rate and energy or testing the calibration of a few (one to five) of the user's electronic dosimeters. Either process of performance evaluation is compatible with the recommendations of NIST (Eisenhower 1983).

Broad stakeholder involvement should be pursued to ensure a program that meets the needs of the maximum number of users. The guidelines should also include audit criteria. The user programs should be evaluated either through an accrediting organization or through NRC inspectors. However, accreditation programs do not evaluate day-to-day user practices and inspectors will need to be aware of practices that may compromise the use of EPDs for primary dosimetry work, such as their use as a survey meter.

Present EPDs are not adequate for consideration as a primary neutron dosimeter (Alberts et al. 1994) and type-test criteria for such devices have not been included. This would require addition of information on neutron energy and angular response.

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Part 1, Appendix A

Electronic Personal Dosimeter Survey Results

The following sections present the results of the survey distributed to users of electronic personal dosimeters (EPDs) and then the survey itself.

A.1 Results of Survey for Electronic Dosimeter Users

Analysis of Results by Question (55 respondents)

1. Forty-six respondents are currently using electronic personal dosimeters (EPDs).

2. Five of 8 planned to use them in the future.

Part A. Facilities that did not currently use EPDs

1. At facilities that did not use EPDS, the number of employees issued dosimeters varied from 100 to >3000.

2. They most often monitored photons, with betas and neutrons less often.

3. Of those who answered regarding using EPDs as a dosimeter of record, 8 of 13 said they would not use them for general issue.

4. Of those who answered regarding using EPDs as a dosimeter of record for radiation workers, three said they would three said they would not.

5. Of those who answered regarding using EPDs as a dosimeter of record for special purposes or for access control, three said they would and three said they would not.

Note: Not all numbers will tally to 55, because some respondents did not answer all questions. Respondent data is indicated in parentheses.

Part B. Facilities that are using EPDs

1. Merlin-Gerin models accounted for the majority of devices in use (35,387), followed by Alnor (4,610), SAIC (3,017), Eberline (3,000), Dositec (1,850), and Xetex (650).

2. Most respondents (22) indicated that 90-100% of badged workers wore EPDs in the last year. Various other percentages were indicated by the remaining respondents.

3. Of the respondents, most (33) said that EPDs were not worn both outside and inside the Radiation Area. Some (14) said that it was worn in both places, and 29 said that it depended on the job assignment.

4. The majority (45) said that EPDs were not assigned to a single worker.

5. The majority (43) said that EPDs were assigned on an as-needed basis.

6. The majority (44) said that EPDs were assigned for a particular job.

7. Most respondents said that EPDs were used as pocket alarming dosimeters replacing self-reading dosimeters (pencils).

8. The majority (34) responded that there were times when a more conventional dosimeter would be chosen over an EPD.

9. The types of radiation measured were predominantly photons (47), followed by betas (29) and neutrons (29).

10. Most respondents said they would issue supplemental thermoluminescent dosimeters (TLDs) to measure beta or neutron if the EPDs were accepted for dose of record for photons.

11a. The comparison of EPDs to TLDs for measuring photons had no clear answer. Many respondents (14 and 11) found EPDs to be within 2-4% and 4-6% of TLDs, respectively. However, 13 respondents found them to differ by more than 8%.

11b. Both beta (23) and low-energy photon (19) were nearly equally reported to be the nonpenetrating radiations they were unable to detect with EPDS.

12a. Thirty-two respondents would consider using EPDs as dose of record for all currently monitored personnel, but 13 would not.

12b. Sixteen respondents would consider EPDs for dose of record for only radiation workers, but 17 would not.

13a. Most respondents (32) said that multiple EPDs are not used in place of multiple conventional dosimeters. Sixteen said they were.

13b. Of those who said multiple EPDs were not used, the majority (22) said that they would consider using EPDs in this way. Nine said they would not.

14. Most respondents said that both visual (35) and audible (48) alarms were present on their EPDs. Two had vibrational alarms.

15a. The majority (45) said the audible alarm models were used in high noise areas.

15b. Again, the majority (36) said there were problems hearing EPD alarms in high noise areas. Twelve reported no problems.

16. Forty-eight of 49 respondents indicated that low-energy photons and betas were not significant contributors to personnel doses.

17. Typical dose equivalent rates monitored with EPDs varied considerably, from a few mrem/hr to hundreds of mrem/hr.

18. Extreme dose equivalent rates also varied considerably, from a few tens of mrem/hr to several rem/hr.

19. Typical dose equivalents recorded during a single use were mostly (28 responses) below 10 mrem.

20. Approximately equal numbers observed (20) and did not observe (27) an energy dependence in their EPDs.

21. The majority of respondents (41) calibrate their EPDs semi-annually.

22. The most common (48 responses) calibration source is ^{137}Cs. One respondent uses ^{60}Co.

23. All 47 respondents to this question indicated that EPDs hold their calibration well.

24. The respondents were divided on how frequently the EPDs are to be source-checked. Fourteen checked at each entry, 18 did no checks, 7 checked them daily. Other frequencies were used by various respondents (quarterly, monthly, weekly, etc.)

25. Again, the majority (20) reported using ^{137}Cs for a check source, but four others used ^{60}Co, one used ^{133}Ba, and two used background.

26. Sixteen of 46 respondents indicated a problem with a loss of data due to battery failure or charge depletion.

27. Typical environmental conditions under which EPDs are used were reported as having wide ranges. Temperatures 50° to 90°F, pressures 740 to 760 mm Hg, humidity, 20 to 90%, with no reports of typical radiofrequency values.

28. Extreme conditions were reported as follows: temperature 50° to 130°F, pressures up to 2 atmospheres, humidity 10 to 100%, radiofrequency unknown but high due to welding.

29. For the various failures or erroneous responses of EPDS, 39 of 48 respondents reported electronic failures, 15 reported magnetic field interference, 23 radiofrequency interference, 4 temperature problems, and 11 humidity problems. There were no reports of high radiation failures.

30. There were no reports of problems due to neutrons or radon.

31-33. The responses to these essay questions are summarized in the discussion section of the report.

A.2 Survey Distributed to Electronic Dosimeter Users

This survey is being conducted by Pacific Northwest Laboratory and the Nuclear Regulatory Commission, assisted by the Nuclear Energy Institute, to study the use and performance of Electronic Personal Dosimeters (EPDs). To help assure respondent confidentiality, please do not write any identifiers on this form.

PART A

1. Are you using or have you used EPDs?

   [ ] Yes [ ] No (if you answered "Yes" to question #1, skip to Part B)
   (if you answered "No" to question #1, complete Part A only)

2. Are you planning to use EPDs in the future?

   [ ] Yes [ ] No (if you answered "No" to question #2, explain why).

3. At present, how many employees per year at your facility are issued personnel dosimeters?

_____ employees

4. What type of radiation must be measured by dosimeters at your facility?

[ ] Photons [ ] Beta [ ] Neutron

5. If a method existed to ensure the integrity of EPDs and their capability to store and retain accurate data, would your facility consider their use in providing "dose of record" or as the permanent record of dose for:

a) all currently monitored personnel?

[ ] Yes [ ] No

b) only personnel who are considered "Radiation Workers?"
[ ] Yes [ ] No

c) only personnel who perform work in areas for which their dose is monitored remotely, who wear an alarming dosimeter (as good practice), and/or are issued a. special dosimeter for access control (e.g., self-reading dosimeter, EPD, etc.)?

[ ] Yes [ ] No

PART B

1. What model(s) and approximately how many EPDs do you use at your facility?

Models:

Quantity:

2. What percentage of your badged workers have worn EPDs in the past year at your facility?

_____%

3. Were the EPDs worn both inside and outside the Radiation Area?

[ ] Yes [ ] No

4. Are EPDs permanently or semi-permanently assigned to a single worker?

   [ ] Yes [ ] No

5. Are EPDs assigned on an as needed basis?

   [ ] Yes [ ] No

6. How long are the EPDs assigned for?

   [ ]Job [ ] Shift [ ] Day [ ] Week [ ] Month]Year

7. Briefly explain when or why EPDs are used at your facility.

8. Are there times or applications where you would choose a more conventional dosimeter rather than an EPD?

   [ ] Yes [I No

   If you answered "Yes," please briefly explain and give the reasons why a conventional dosimeter would be chosen.

9. What type of radiation must be measured by dosimeters at your facility?

   [ ] Photons [ ] Beta [ ] Neutron

10. Since most EPDs are for photon dose/dose rates only, how would your facility handle exposures to beta and neutron if EPDs were accepted for dose of record?

11. Comparison of EPDs to conventional dosimeters.

a) How have your EPD results compared to TLD results for penetrating radiation (gamma)?

[ ] within 0-2%
[ ] within 2-4%
[ ] within 4-6%
[ ] within 6-8%
[ ] >8%

b) What non-penetrating radiations have EPDs been unable to detect at your facility?

[ ] Beta _____ keV
[ ] Low energy photon _____ keV

12. If a method existed to ensure the integrity of EPDs and their capability to store and retain accurate data, would your facility consider their use in providing "dose of record" or as the permanent record of dose for:

a) all currently monitored personnel?

[ ] Yes [ ] No

b) only personnel who are considered "Radiation Workers?"

[ ] Yes [ ] No

c) only personnel who perform work in areas for which their dose is monitored remotely, who wear an alarming dosimeter (as good practice), and/or are issued a special dosimeter for access control (e.g., self-reading dosimeter, EPD, etc.)?

[ ] Yes [ ] No

13. Are multiple EPDs used in place of multiple conventional dosimetry at your facility?

[ ] Yes [ ] No

If you answered "No," would you consider using multiple EPDs where multiple badging is employed?

[ ] Yes [ ] No

14. What type of alarms are on your EPDS?

[ ] Visual [ ] Audible [ ] Vibrational

15. Are your EPDs with audible alarms used in areas with high noise levels?

[ ] Yes [ ] No

If you answered "Yes," have there been problems with hearing an EPD audible alarm in a high noise area?

[ ] Yes [ ] No

16. Are low energy photons and beta particles responsible for a significant proportion of personnel dose at your facility?

[ ] Yes [ ] No

If you answered "Yes," what are the mean energies of each?

_____ keV beta
_____ keV low energy photon

17. What are the **typical** dose rates in areas in which EPDs are used in your facility?

18. What are the **extreme** dose rates in areas in which EPDs are used in your facility?

19. Approximately what dose is commonly recorded during a single use?

20. Have you observed that EPD response is energy dependent?

[ ] Yes [ ] No (if "Yes" please describe)

21. How often do you calibrate EPDS?

[ ] Per Job [ ] Monthly [ ] Quarterly [ ] Yearly [ ] Other _____

22. What isotopic sources do you utilize for calibration?

23. Do the EPDs hold their calibration well?

[ ] Yes [ ] No

24. How frequently are your EPDs source-checked?

25. What isotopic sources do you use for the source-check?

26. Has your facility experienced data loss as a result of battery failure or charge depletion?

[ ] Yes [ ] No

27. What are **typical** environmental conditions in which EPDs are used in your facility?

Temperature: _____
Pressure: _____
Humidity: _____
RF Field: _____

28. What are **extreme** environmental conditions in which EPDs are used in your facility?

Temperature: _____
Pressure: _____
Humidity: _____
RF Field: _____

29. Have the EPDs ever failed or responded in an erroneous manner at your facility because of:

- electronic malfunction within the dosimeter?	[ ] Yes [I No
- magnetic field interference?	[ ] Yes [I No
- radiofrequency field interference?	[ ] Yes [ ] No
- high radiation fields?	[ ] Yes [ ] No
- temperature?	[ ] Yes [ ] No
- humidity?	[ ] Yes [ ] No

If you answered "Yes" to any of the above, please describe and give details.

30. Has your facility experienced any interference with EPD operation due to neutrons or radon?

[ ] Yes [ ] No

31. Discuss any unusual problems encountered or any significant experience (positive or negative) with EPDS.

32. In developing performance criteria and standards for EPDS, what requirements would, you suggest be placed on EPDs with respect to performance or use?

33. Additional comments.

Part 1, Appendix B

Electronic Personal Dosimeter Vendor Survey Results

The following tables compare specifications for EPDs taken from vendor-provided literature. Each table covers several pages and is titled as follows:

As noted in the tables, the vendors do not provide the same data elements nor do they specify performance data in a consistent manner. The tables do provide an overview of units available and a general idea of performance.

Table B.1. Radiological Specifications I

Vendor	Model	Energy Response		Angular Response		Dose Accuracy		Dose Equivalent Rate Linearity
		Range	Performance	Range	Performance	Range	Performance	
Aloka	PDM-102	50 keV - 3 MeV	± 30%	All energies		10 - 9999 μSv	± 10%	Within ±10% at 100 mSv/h; within ±20% at 300 mSv/h
				-75° ≤ θ ≤ +75°	-10% to +0%			
				15° ≤ φ ≤ 165°	-10% to +5%			
Aloka	PDM-107	30 keV - 200 keV	± 30%	30 keV		10 - 9999 μSv	± 20%	Within ±10% at 30 mSv/h; within ±20% at 100 mSv/h
				-45° ≤ θ ≤ +45°	-60% to +0%			
				40° ≤ φ ≤ 135°	-80% to +0%			
				100 keV				
				-75° ≤ θ ≤ +75°	-25% to +0%			
				15° ≤ φ ≤ 135°	-20% to +0%			
				135° ≤ φ ≤ 150°	-60% to -20%			
				662 keV				
				-75° ≤ θ ≤ +75°	-25% to +0%			
				15° ≤ φ ≤ 135°	-10% to +0%			
				135° ≤ φ ≤ 165°	-80% to -10%			

Table B.1. Detector Performance Measures I (Continued)

Vendor	Model	Energy Response		Angular Response		Dose Accuracy		Dose Equivalent Rate Linearity
		Range	Performance	Range	Performance	Range	Performance	
Aloka	PDM-203	50 keV - 3 MeV	± 30%	All energies		10 - 9999 mrem	± 10%	Within ±10% at 10 rem/h; within ±20% at 30 rem/h
				$-75° \leq \theta \leq +75°$	-10% to +0%			
				$15° \leq \phi \leq 165°$	-10% to +5%			
Aloka	PDM-253	50 keV - 3 MeV	± 30%	All energies		10 - 9999 mrem	± 10%	Within ±10% at 10 rem/h; within ±20% at 30 rem/h
				$-75° \leq \theta \leq +75°$	-10% to +0%			
				$15° \leq \phi \leq 165°$	-10% to +5%			
Centronic	6000	35 keV to 2.0 MeV	±20%	<No Data>		<No Data>		< 5% below 20 mSv/h < 20% below 1 Sv/h
Centronic	6001	50 keV to 1.2 MeV	±15%	<No Data>		<No Data>		< 7% below 200 mSv/h < 15% below 7 Sv/h
Dosimeter Corporation of America	25	48 keV to 1.2 MeV	±30%	All θ	±20%	±10% up to 100 R/h ±30% from 100 R/h to 1000 R/h		±20% to 100 R/h ±30% from 100 R/h to 1000 R/h
				All ϕ	-0% to +20%			
Dositec	A15	60 keV to 6 MeV	±25%	<No Data>		±20% for from 1 mR/h to 100 R/h fields		±20% for from 1 mR/h to 100 R/h fields

Table B.1. Detector Performance Measures I (Continued)

Vendor	Model	Energy Response		Angular Response		Dose Accuracy		Dose Equivalent Rate Linearity
		Range	Performance	Range	Performance	Range	Performance	
Dositec	L36	60 keV to 6.2 MeV	±25%	^{137}Cs		±10% to 116 R/h		±12% to 116 R/h
				$-90° \leq \theta \leq +90°$	-29% to +0%			
				$0° \leq \phi \leq 180°$	-24% to +0%			
Health Physics Instruments	4080	70 keV to 1.2 MeV	-84% to +0%	<No Data>		<No Data>		±15% to 1 R/h
		70 keV to 250 keV	±4%					
Health Physics Instruments	4083	45 keV to 1.2 MeV	±40%	<No Data>		<No Data>		±20% from 1 mR/h to 100 R/h
Merlin Gerin	DM 61	60 keV to 3 MeV	±30% (±20% from 100 keV to 1.3 MeV)	±20% (with ^{137}Cs source) ±50% (in battery direction)		<No Data>		<No Data>
Merlin Gerin	DM 71	60 keV to 3 MeV	±30% (±20% from 100 keV to 1.3 MeV)	±20% (with ^{137}Cs source) ±50% (in battery direction)		<No Data>		<No Data>
Merlin Gerin	DMC 90	60 eV to 3 MeV	Follows the theoretical curve (ICRU 39) better than ±20%	"in compliance with IEC standards 45 B better than ±20%, ^{137}Cs better than ±50% ^{241}Am for 0°±90° except in the direction of the battery."		"Accuracy of factory calibration: better than ±5% (^{137}Cs, 0.2 mSv/h)		Better than ±10% up to 1 Sv/h, ±25% up to 3 Sv/h. No saturation up to 20 Sv/h.

Table B.1. Detector Performance Measures I (Continued)

Vendor	Model	Energy Response		Angular Response		Dose Accuracy		Dose Equivalent Rate Linearity
		Range	Performance	Range	Performance	Range	Performance	
Merlin Gerin	DMC 100	60 keV to 3 MeV	Follows the theoretical curve (ICRU 39) better than ±20%	<No Data>		Accuracy of factory calibration: better than ±5% (^{137}Cs, 0.2 mSv/h)		Better than ±10% up to 1 Sv/h, ±25% up to 3 Sv/h. No saturation up to 20 Sv/h.
Panasonic	ZP-141	100 keV to 6 MeV	±20%	<literature unreadable>		±10% of set value (10 mR or more at ^{137}Cs)		±10% (10 R/h max)
		70 keV to 6 MeV	±30%					
Panasonic	ZP-142	30 keV to 200 keV	±30%	40 keV X-ray		±10% of set value (10 mR or more at ^{137}Cs)		±10% (10 R/h max)
				-90° ≤ θ ≤ +40°	-20% to +0%			
				+40° ≤ θ ≤ +90°	-100% to -20%			
				-60° ≤ φ ≤ +60°	±50%			
				^{60}Co				
				-90° ≤ θ ≤ +90°	-10% to +0%			
				-90° ≤ φ ≤ -75°	-30% to -10%			
				-75° ≤ φ ≤ +90°	-10% to 0%			
SAIC	PD-1	50 keV to 3 MeV	±20%	<No Data>		<No Data>		<No Data>

Table B.1. Detector Performance Measures I (Continued)

Vendor	Model	Energy Response		Angular Response		Dose Accuracy		Dose Equivalent Rate Linearity
		Range	Performance	Range	Performance	Range	Performance	
SAIC	PD-2	50 keV to 3 MeV	±20%	^{60}Co		0.02 μSv to 50.0 Sv	±0.02 μSv	±15% from 0 μSv/h to 5 Sv/h
				$-90° \leq \theta \leq +90°$	-20% to +0%			
				$0° \leq \phi \leq 180°$	-20% to +0%			
				^{137}Cs				
				$-90° \leq \theta \leq +90°$	-30% to +0%			
				$0° \leq \phi \leq 180°$	-25% to +0%			
SAIC	PD-3	50 keV to 3 MeV	±20%	^{60}Co		0.02 μSv to 50.0 Sv	±0.02 μSv	±15% from 0 μSv/h to 5 Sv/h
				$-90° \leq \theta \leq +90°$	-20% to +0%			
				$0° \leq \phi \leq 180°$	-20% to +0%			
				^{137}Cs				
				$-90° \leq \theta \leq +90°$	-30% to +0%			
				$0° \leq \phi \leq 180°$	-25% to +0%			

Table B.1. Detector Performance Measures I (Continued)

Vendor	Model	Energy Response		Angular Response		Dose Accuracy		Dose Equivalent Rate Linearity
		Range	Performance	Range	Performance	Range	Performance	
Siemens	EPD	20 keV to 1.5 MeV	±30%	^{137}Cs γ-rays - EPD mounted on PMMA phantom		100 μSv at 5 mSv/h	±10%	±10% from 0 to 0.5 Sv/h ±20% from 0.5 to 1 Sv/h ±30% from 1 to 2 Sv/h ±50% from 2 to 4 Sv/h Continues to accumulate dose data at a rate greater than 4 Sv/h from 4 to 50 Sv/h
				$-105° \pm \theta \pm +105°$	-33% to +0%			
				$\theta = 180$	-25%			
				$0° \leq \phi \leq +180$	-25% to +0%			
Technical Associates	PDA-2	80 keV to 1.3 MeV	±15	<No Data>		0 - 99,999.9 mR	Better than ±15% plus 0.1 mR (measured with ^{137}Cs γ)	Linear to rates up to 20 R/h
Technical Associates	PDA-2E (Alarming Finger Dosimeter)	GM tube in finger probe is "not energy compensated." No other data provided.		<No Data>		0 - 99,999.9 mR	Better than ±15% plus 0.1 mR (measured with ^{137}Cs γ)	Linear to rates up to 20 R/h
TSA Systems, Ltd	PM-1202	0.662 to 1.5 MeV	±15%	<No Data>		±30%		<No Data>

Table B.1. Detector Performance Measures I (Continued)

Vendor	Model	Energy Response		Angular Response		Dose Accuracy		Dose Equivalent Rate Linearity
		Range	Performance	Range	Performance	Range	Performance	
Victoreen	885	40 keV to 1.2 MeV	-20% to +40%	<No Data>		At 660 keV for rates up to 0.1 R/h	≤ ±15%	Response drops off 5% at 1 R/h Response drops off 10% at 3 R/h
Victoreen	05-205 (radiation rate monitor)	35 keV to 1300 keV	From 150 beeps per mR to 800 beeps per mR	<No Data>		<Rate Meter - Dose Accuracy Not Applicable>		<No Data>
Xetex	415A	60 keV to 1.3 MeV	±15%	<No Data>		±15%		<No Data>
Xetex	415B	60 keV to 1.3 MeV	±15%	<No Data>		±15%		<No Data>
Xetex	420B	60 keV to 1.3 MeV	±15%	<No Data>		±15%		Rated accuracies apply at rates to 50 R/h.
Xetex	425A	60 keV to 1.3 MeV	±15%	<No Data>		±15%		Rated accuracies apply at rates to 50 R/h.
Xetex	444A	60 keV to 1.3 MeV	±25%	<No Data>		±10%		<No Data>

Table B.2. Radiological Specifications II

Vendor	Model	Extracameral Response	Photon Radiation Overload	Interfering Radiation
Aloka	PDM-102	<No Data>	<No Data>	<No Data>
Aloka	PDM-107	<No Data>	<No Data>	<No Data>
Aloka	PDM-203	<No Data>	<No Data>	<No Data>
Aloka	PDM-253	<No Data>	<No Data>	<No Data>
Centronic	6000	<No Data>	<No Data>	<No Data>
Centronic	6001	<No Data>	<No Data>	<No Data>
Dosimeter Corporation of America	25	<No Data>	<No Data>	<No Data>
Dositec	A15	<No Data>	<No Data>	<No Data>
Dositec	L36	<No Data>	Detector saturates at about 260 R/h in gamma field at or above that level.	Detector reads < 1% of neutron dose equivalent rate.
Health Physics Instruments	4080	<No Data>	<No Data>	<No Data>
Health Physics Instruments	4083	<No Data>	<No Data>	<No Data>
Merlin Gerin	DM 61	<No Data>	Overflow signal from 100 rem/h to 1000 rem/h.	<No Data>
Merlin Gerin	DM 71	<No Data>	Overflow signal from 100 rem/h to 1000 rem/h.	<No Data>
Merlin Gerin	DMC 90	<No Data>	Dose overflow signal at >10 Sv. - Dose rate overflow signal at >1 Sv/h.	<No Data>
Merlin Gerin	DMC 100	<No Data>	Dose overflow signal at >10 Sv. - Dose rate overflow signal at >1 Sv/h.	<No Data>

Table B.2. Detector Performance Measures II (Continued)

Vendor	Model	Extracameral Response	Photon Radiation Overload	Interfering Radiation
Panasonic	ZP-141	<No Data>	<No Data>	<No Data>
Panasonic	ZP-142	<No Data>	<No Data>	<No Data>
SAIC	PD-1	<No Data>	<No Data>	<No Data>
SAIC	PD-2	<No Data>	<No Data>	<No Data>
SAIC	PD-3	<No Data>	<No Data>	<No Data>
Siemens	EPD	<No Data>	<No Data>	Detector responds to neutron fields at <2% of true neutron dose. - No significant response to alpha emissions of radon or of its progeny. - Not suitable for environments where high-powered radar may be in use.
Technical Associates	PDA-2	<No Data>	<No Data>	<No Data>
Technical Associates	PDA-2E (Alarming Finger Dosimeter)	<No Data>	<No Data>	<No Data>
TSA Systems, Ltd	PM-1202	<No Data>	<No Data>	<No Data>
Victoreen	05-205	<No Data>	<No Data>	<No Data>
Victoreen	885	<No Data>	<No Data>	<No Data>
Xetex	415A	<No Data>	<No Data>	<No Data>
Xetex	415B	<No Data>	<No Data>	<No Data>

Table B.2. Detector Performance Measures II (Continued)

Vendor	Model	Extracameral Response	Photon Radiation Overload	Interfering Radiation
Xetex	420B	<No Data>	<No Data>	<No Data>
Xetex	425A	<No Data>	<No Data>	<No Datá>
Xetex	444A	<No Data>	<No Data>	<No Data>

Table B.3. Environmental Performance Measures I

Vendor	Model	Temperature Range	Humidity Range	Pressure Range	Mechanical Shock Resistance	Moisture Resistance	Construction
Aloka	PDM-102	0 to 45°C	<No Data>	<No Data>	<No Data>	<No Data>	<No Data>
Aloka	PDM-107	0 to 40°C	<No Data>	<No Data>	<No Data>	<No Data>	<No Data>
Aloka	PDM-203	0 to 45°C	<No Data>	<No Data>	<No Data>	<No Data>	<No Data>
Aloka	PDM-253	0 to 45°C	<No Data>	<No Data>	<No Data>	<No Data>	<No Data>
Centronic	6000	-20°C to +50°C	<No Data>	<No Data>	Passed 1.5-m drop test	<No Data>	High-impact ABS plastic
Centronic	6001	-20°C to +50°C	<No Data>	<No Data>	Passed 1.5-m drop test	<No Data>	High-impact ABS plastic
Dosimeter Corporation of America	25	Reads within ±20% of actual dose/dose rate for the temperature range from -10°C to +50°C	Reads within ±20% of actual dose/dose rate up to 95% relative humidity (RH), non-condensing.	<No Data>	Meets both ANSI N13.27 and IEC 45B Drop Test Standards.	Unit is splashproof	Stainless steel-filled, conducting plastic.
Dositec	A15	-20° to +60°C	up to 95% RH	<No Data>	Meets ANSI 13.27-1981 drop test standards	<No Data>	High-impact Plastic
Dositec	L36	-20° to +60°C	up to 95% RH	<No Data>	Meets ANSI 13.27-1981 drop test standards	Modified unit performed "acceptably" in spray test.	High-impact Plastic
Health Physics Instruments	4080	<No Data>	<No Data>	<No Data>	<No Data>	<No Data>	Black anodized aluminum

Table B.3. Environmental Performance Measures I (Continued)

Vendor	Model	Temperature Range	Humidity Range	Pressure Range	Mechanical Shock Resistance	Moisture Resistance	Construction
Health Physics Instruments	4083	Reads within ±10% of actual dose/dose rate for the temperature range from +15°C to +35°C. - Reads within ±20% of actual dose/dose rate for the temperature range from 0°C to +50°C	from 20% to 90% RH, noncondensing.	<No Data>	Mild shocks have no effect, large shocks may increment display by an mR.	<No Data>	<No Data>
Merlin Gerin	DM 61	-10°C to +60°C Maximum nondestructive operating temperature: +60°C	up to 100% RH	600 to 1200 mbar	<No Data>	Watertight at a depth of 1 meter	Cast polycarbonate
Merlin Gerin	DM 71	-10°C to +60°C Maximum nondestructive operating temperature: +60°C	up to 100% RH	600 to 1200 mbar	<No Data>	Watertight at a depth of 1 meter	Cast polycarbonate

Table B.3. Environmental Performance Measures I (Continued)

Vendor	Model	Temperature Range	Humidity Range	Pressure Range	Mechanical Shock Resistance	Moisture Resistance	Construction
Merlin Gerin	DMC 90	Variation $< \pm 10\%$ from 0° to +50°C. Variation $< \pm 20\%$ from -10° to +60°C.	Variation $< \pm 10\%$ from 40% to 90% RH at 35°.	<No Data>	Survives over 1.2-m drop onto concrete.	<No Data>	<No Data>
Merlin Gerin	DMC 100	<No Data>	<No Data>	<No Data>	<No Data>	<No Data>	<No Data>
Panasonic	ZP-141	0°C to +45°C	20% to 90% RH	<No Data>	<No Data>	<No Data>	Plastic with stainless steel clip
Panasonic	ZP-142	0°C to +40°C	20% to 90% RH	<No Data>	<No Data>	<No Data>	Plastic with stainless steel clip
SAIC	PD-1	-25°C to +60°C	Up to at least 95% RH	<No Data>	Meets drop test in Paragraph 3.1.3 of ANSI N13.27-1981.	<No Data>	<No Data>
SAIC	PD-2	-25°C to +60°C	Up to at least 95% RH, noncondensing	<No Data>	Meets drop test in Paragraph 3.1.3 of ANSI N13.27-1981.	<No Data>	<No Data>
SAIC	PD-3	-25°C to +60°C	up to at least 95% RH, non-condensing	<No Data>	"Meets drop test in Paragraph 3.1.3 of ANSI N13.27-1981."	<No Data>	<No Data>

Table B.3. Environmental Performance Measures I (Continued)

Vendor	Model	Temperature Range	Humidity Range	Pressure Range	Mechanical Shock Resistance	Moisture Resistance	Construction
Siemens	EPD	-10° to +40°C - <0.2 μSv/h increase in background dose rate - < ±20% change in response to ^{137}Cs at 7.5 μSv/h at 20°C	Up to 90% RH (noncondensing)	<No Data>	The unit will remain fully operational with no loss of data after a 1.5-m drop on each of its 6 faces onto concrete. - A special detector will trigger special processing to take place to counteract the effect of physical impact.	<No Data>	Case is magnesium alloy with polyester coating.
Technical Associates	PDA-2	<No Data>	<No Data>	<No Data>	<No Data>	<No Data>	High-impact, injection-molded ABS
Technical Associates	PDA-2E (Alarming Finger Dosimeter)	<No Data>	<No Data>	<No Data>	<No Data>	<No Data>	High-impact, injection-molded ABS
TSA Systems, Ltd	PM-1202	+10°C to +40°C	< 85% RH at 30°C	66 kPa to 106.7 kPa	<No Data>	<No Data>	<No Data>
Victoreen	05-205	<No Data>	<No Data>	<No Data>	<No Data>	<No Data>	Inpact-resistant, molded plastic case.

Table B.3. Environmental Performance Measures I (Continued)

Vendor	Model	Temperature Range	Humidity Range	Pressure Range	Mechanical Shock Resistance	Moisture Resistance	Construction
Victoreen	885	0 to 40°C - Temperature dependence within 0.2% per °C.	0 to 99% RH noncondensing	<No Data>	<No Data>	<No Data>	Molded impact-resistant plastic case
Xetex	415A	-20°C to +50°C	<No Data>	<No Data>	<No Data>	<No Data>	<No Data>
Xetex	415B	-20°C to +50°C	<No Data>	<No Data>	<No Data>	<No Data>	<No Data>
Xetex	420B	-20°C to +50°C	<No Data>	<No Data>	<No Data>	<No Data>	Anodized aluminum case
Xetex	425A	-20°C to +50°C	<No Data>	<No Data>	<No Data>	<No Data>	Anodized aluminum case
Xetex	444A	-20°C to +50°C	<No Data>	<No Data>	<No Data>	<No Data>	Extruded aluminum

Table B.4. Environmental Performance Measures II

Vendor	Model	Electromagnetic Fields	Temperature Shock	Vibration	Electrostatic Discharge
Aloka	PDM-102	<No Data>	<No Data>	<No Data>	<No Data>
Aloka	PDM-107	<No Data>	<No Data>	<No Data>	<No Data>
Aloka	PDM-203	<No Data>	<No Data>	<No Data>	<No Data>
Aloka	PDM-253	<No Data>	<No Data>	<No Data>	<No Data>
Centronic	6000	<No Data>	<No Data>	<No Data>	<No Data>
Centronic	6001	<No Data>	<No Data>	<No Data>	<No Data>
Dosimeter Corporation of America	25	Reads within ±15% for RF fields of 60 Hz, 400 Hz, 0.3 to 35 MHz, 140 MHz, 400 MHz, 915 MHz and 2450 MHz at 100 V/m. - Reads within ±15% for magnetic fields of 800 AT/m. - Reads within ±15% for static electric fields of 5000 V/m.	<No Data>	<No Data>	<No Data>
Dositec	A15	<No Data>	<No Data>	<No Data>	<No Data>
Dositec	L36	No evidence of interference when exposed to a RF generator transmitting at 451 MHz, a frequency commonly used for portable two-way communications.	Variations within ±15% of reference reading when exposed to rapid (< 15 sec) variations in temperature of -29°C and of +28°C.	<No Data>	<No Data>
Health Physics Instruments	4080	<No Data>	<No Data>	<No Data>	<No Data>
Health Physics Instruments	4083	Very strong microwave fields may cause the canary to count.	<No Data>	<No Data>	<No Data>

Table B.4. Environmental Performance Measures II (Continued)

Vendor	Model	Electromagnetic Fields	Temperature Shock	Vibration	Electrostatic Discharge
Merlin Gerin	DM 61	<No Data>	<No Data>	<No Data>	<No Data>
Merlin Gerin	DM 71	<No Data>	<No Data>	<No Data>	<No Data>
Merlin Gerin	DMC 90	<No Data>	<No Data>	<No Data>	<No Data>
Merlin Gerin	DMC 100	<No Data>	<No Data>	<No Data>	<No Data>
Panasonic	ZP-141	<No Data>	<No Data>	<No Data>	<No Data>
Panasonic	ZP-142	<No Data>	<No Data>	<No Data>	<No Data>
SAIC	PD-1	<No Data>	<No Data>	<No Data>	<No Data>
SAIC	PD-2	<No Data>	<No Data>	<No Data>	<No Data>
SAIC	PD-3	<No Data>	<No Data>	<No Data>	<No Data>
Siemens	EPD	Within 10% of normal response for: - 10 kHz to 250 kHz rms electric fields of 25 V/m strength. - 250 kHz to 1 GHz rms electric fields of 50 V/m strength. - 50 Hz to 60 Hz rms magnetic fields of H=60 A/m. - 10 kHz to 250 kHz rms magnetic fields of H=1.5 A/m. - Static magnetic fields of B=1.5 mT.	<No Data>	<No Data>	Will perform within 10% of its normal response when subjected to an electrostatic discharge of 2 mJ at 6 kV.
Technical Associates	PDA-2	<No Data>	<No Data>	<No Data>	<No Data>
Technical Associates	PDA-2E (Alarming Finger Dosimeter)	<No Data>	<No Data>	<No Data>	<No Data>
TSA Systems, Ltd	PM-1202	<No Data>	<No Data>	<No Data>	<No Data>

Table B.4. Environmental Performance Measures II (Continued)

Vendor	Model	Electromagnetic Fields	Temperature Shock	Vibration	Electrostatic Discharge
Victoreen	05-205	<No Data>	<No Data>	<No Data>	<No Data>
Victoreen	885	<No Data>	<No Data>	<No Data>	<No Data>
Xetex	415A	<No Data>	<No Data>	<No Data>	<No Data>
Xetex	415B	<No Data>	<No Data>	<No Data>	<No Data>
Xetex	420B	<No Data>	<No Data>	<No Data>	<No Data>
Xetex	425A	<No Data>	<No Data>	<No Data>	<No Data>
Xetex	444A	<No Data>	<No Data>	<No Data>	<No Data>

Table B.5. Factors Which Affect Data Integrity

Vendor	Model	Zero Reset	Battery Life	On/Off Control	Testing Functions	Low Battery Indication
Aloka	PDM-102	When switched off	1 month - continuous use	Present and accessible to the wearer	<No Data>	<No Data>
Aloka	PDM-107	When switched off	2 weeks - continuous use	Present and accessible to the wearer	<No Data>	<No Data>
Aloka	PDM-203	When switched off	1 month - continuous use	Present and accessible to the wearer	<No Data>	<No Data>
Aloka	PDM-253	When placed in case or rack	1 month - continuous use	<None>	<No Data>	<No Data>
Centronic	6000	*Centronic units store up to 896 Dose or Max Rate readings, or up to 448 Dose and Max Rate readings together. Memory is nonvolatile; data is retained if battery is removed*	800 hours in background, non-alarming condition	Present and accessible to the wearer	<No Data>	Audible and visual indication
Centronic	6001		800 hours in background, non-alarming condition	Present and accessible to the wearer	<No Data>	Audible and visual indication
Dosimeter Corporation of America	25	<No Data>	5 months under normal operating conditions	<No Data>	<No Data>	Lo Batt indication on LCD
Dositec	A15	*Capable of storing dose history data at intervals from 0.1 minutes to 32 hours. No data available on memory volatility.*	35 days (usage pattern unspecified)	Present on dosimeter	<No Data>	BAT/LOW on LCD display, 12 hours life remaining

Table B.5. Factors Which Affect Data Integrity (Continued)

Vendor	Model	Zero Reset	Battery Life	On/Off Control	Testing Functions	Low Battery Indication
Dositec	L36	Capable of storing dose history data at intervals from 0.1 minutes to 32 hours. No data available on memory volatility.	6 months (usage pattern unspecified)	Present on dosimeter	<No Data>	BAT/LOW on LCD display, 12 hours life remaining
Health Physics Instruments	4080	When switched off	1000 hours	Recessed on/off switch	<No Data>	Dosimeter beeps when switched on. Length of beep indicates battery condition.
Health Physics Instruments	4083	Turning the instrument on resets the display and the integrate alarm.	Approximately 2000 hours	Recessed switch - "P" model has "finger-operated switch."	<No Data>	"Beeps if at least 20 hours remain."
Merlin Gerin	DM 61	<No Data>	1 year (continuous operation and 5 rem/year)	<No Data>	Continuous testing of background radiation count. Continuous battery status testing. Audible alarm, indicator lamp and display tested each time the dosimeter is inserted into a reader.	"Battery Low" indicated on display

Table B.5. Factors Which Affect Data Integrity (Continued)

Vendor	Model	Zero Reset	Battery Life	On/Off Control	Testing Functions	Low Battery Indication
Merlin Gerin	DM 71	<No Data>	1 year (continuous operation and 5 rem/year)	<No Data>	Continuous testing of background radiation count. Continuous battery status testing. Audible alarm, indicator lamp and display tested each time the dosimeter passes in front of a magnet.	"Battery Low" indicated on display
Merlin Gerin	DMC 90	*Dose history record stored. No data available on memory volatility.*	> 18 months (continuous use at 0.05 Sv/year). The battery can operate for a full 10 hours after the "battery low" alarm is generated.	<No Data>	Display and Buzzer: activated at each change of status. - Detector: "continuous monitoring of background radiation" with fault message and audible alarm. - Battery: periodic test.	"Audible and visual alarms"
Merlin Gerin	DMC 100	*Dose history record stored in EEPROM.*	18 months in active mode	<No Data>	Regular testing of detector (every 10 min) - Periodic battery testing with indication of reserve time.	Reserve tie indication. Audible alarm in case of loss of power
Panasonic	ZP-141	<No Data>	Approximately 200 hours	<No Data>	<No Data>	"Battery voltage drop alarm" displayed.

Table B.5. Factors Which Affect Data Integrity (Continued)

Vendor	Model	Zero Reset	Battery Life	On/Off Control	Testing Functions	Low Battery Indication
Panasonic	ZP-142	<No Data>	Approximately 200 hours	<No Data>	<No Data>	"Battery voltage drop alarm" displayed.
SAIC	PD-1	<No Data>	500-600 hours of continuous operation.	<No Data>	Built-in LCD test, user-controlled.	BATT icon begins to flash with 48 hours of remaining life.
SAIC	PD-2	<No Data>	750 hours at 0.1 Sv using alkaline batteries - 1000 hours at 0.1 Sv using lithium batteries	<No Data>	<No Data>	Displays low life indicator when 24 hours of life remain.
SAIC	PD-3	<No Data>	750 hours at 0.1 Sv using alkaline batteries - 1000 hours at 0.1 Sv using lithium batteries	<No Data>	<No Data>	Displays low life indicator when 24 hours of life remain.
Siemens	EPD	A Dose Reset facility may be enabled on the EPD2 model.	12 months in continuous operation at an average dose rate of 5 μSv/h	<No Data>	<No Data>	Battery Low flag displayed on LCD.

Table B.5. Factors Which Affect Data Integrity (Continued)

Vendor	Model	Zero Reset	Battery Life	On/Off Control	Testing Functions	Low Battery Indication
Technical Associates	PDA-2	"Protected" reset button provided on unit	500 h at -0.1 mR/h	Switch provided on unit (cover plate available)	<No Data>	LED on front panel illuminates when less than 8 hours of battery life remain. (Memory of dose is retained for at least 20 hours with "dead" battery)
Technical Associates	PDA-2E (Alarming Finger Dosimeter)	"Protected" reset button provided on unit	500 h at -0.1 mR/h	Switch provided on unit (cover plate available)	<No Data>	LED on front panel illuminates when less than 8 hours of battery life remain. (Memory of dose is retained for at least 20 hours with "dead" battery)
TSA Systems, LTD.	PM-1202	<No Data>	<No Data>	<No Data>	<No Data>	<No Data>
Victoreen	05-205	N/A (radiation rate meter)	1000 h at 8 h per day	Present on dosimeter	<No Data>	<No Data>
Victoreen	885	Equipped with protected reset switch (pencil needed to actuate)	30 days - continuous use - 120 days at 8 h per day in low radiation field	None	<No Data>	3 decimal points appear on display when approximately 100 hours of battery life remain.

Table B.5. Factors Which Affect Data Integrity (Continued)

Vendor	Model	Zero Reset	Battery Life	On/Off Control	Testing Functions	Low Battery Indication
Xetex	415A	"Protected reset switch"	Six months under normal use.	Present and user accessible	Display/Battery Test button	When Display/Battery Test button is pressed, test lamp illuminates to indicate battery condition.
Xetex	415B	"Protected reset switch"	Six months under normal use.	Present and user accessible	Display/Battery Test button	When Display/Battery Test button is pressed, test lamp illuminates to indicate battery condition.
Xetex	420B	"Protected reset switch" (may be made an internal control as an option)	300 h at 10 mR/h	Present and user accessible (may be eliminated as an option)	Complete circuit test whenever unit is reset.	Unit will operate at 10 mR/h for 8 h after indication.
Xetex	425A	"Protected reset switch" (may be made an internal control as an option)	300 h at 10 mR/h	Present and user accessible (may be eliminated as an option)	Complete circuit test whenever unit is reset.	Unit will operate at 10 mR/h for 8 h after indication.
Xetex	444A	<No Data>	1 year, based on 8 hour day	<No Data>	"A" ful[1] test"	Includes "battery condition warning"

Table B.6. Human Factors Parameters

Vendor	Model	Visual Readout	Audible Indication	Alarms	Weight	Size
Aloka	PDM-102	4-digit liquid crystal display	<No Data>	<No Data>	~ 50 g	30 mm W x 145 mm L x 12 mm D
Aloka	PDM-107	4-digit liquid crystal display	<No Data>	<No Data>	~ 50 g	30 mm W x 145 mm L x 12 mm D
Aloka	PDM-203	4-digit liquid crystal display	<No Data>	<No Data>	~ 50 g	30 mm W x 145 mm L x 12 mm D
Aloka	PDM-253	4-digit liquid crystal display	<No Data>	<No Data>	~ 50 g	30 mm W x 145 mm L x 12 mm D
Centronic	6000	LCD: 4 6-mm-high digits for dose (or dose rate); 6 3.5-mm-high digits for dose rate (or time) - Display Ranges Dose: 0-9999 mSv 0.0001-mSv steps Dose Rate: 0-999.9 mSv/h 0.001-mSv/h steps Time: 0-9999 h 1-sec steps	4 buzz types. 80 dB at 30 cm	4 rate levels, full rate, pre-dose, full dose, full dose, timer, incremental buzz (chirper), GM tube, battery	110 g	60 mm W x 110 mm L x 18 mm D

Table B.6. Human Factors Parameters (Continued)

Vendor	Model	Visual Readout	Audible Indication	Alarms	Weight	Size
Centronic	6001	LCD: 4 6-mm-high digits for dose (or dose rate); 6 3.5-mm-high digits for dose rate (or time) - Display Ranges Dose: 0-9999 mSv 0.0001-mSv steps Dose Rate: 0-9999 mSv/h 0.001-mSv/h steps Time: 0-9999 h 1-sec steps	4 buzz types. 80 dB at 30 cm	4 rate levels, full rate, pre-dose, full dose, full dose, timer, incremental buzz (chirper), GM tube, battery.	110 g	60 mm W x 110 mm L x 18 mm D
Dosimeter Corporation of America	25	"Auto ranging" - Display ranges: Dose: 1 mR to 999 R Dose Rate: 1 mR/h to 999 R/h Time: 00:01 h to 99:59 h	5 distinct audio patterns, one for each alarm. - > 85 dBA at 30 cm	Dose: 2 alarm levels, dose and high dose. Dose Rate: 2 alarm levels, rate and high rate. Time: Alarm available in manual mode. - Alarm setpoint ranges Dose: 1 mR to 999 R Dose Rate: 1 mR/h to 999 R/h Time: 00:01 h to 99:59 h	90 g	48 mm W x 90 mm L x 35 mm D

Table B.6. Human Factors Parameters (Continued)

Vendor	Model	Visual Readout	Audible Indication	Alarms	Weight	Size
Dositec	A15	3-digit LCD display - Dose range: 0 to 999 R with increments of 1 mR - Dose Rate range: 0 to 100 R/hr with increments of 1 mR/hr - Red LED illuminates during all alarms	Chirp mode available - 0,1,2,4, ... to 256 mR per chirp. - 90 dBA at 30 cm	Dose: may be set from 1 mR to 65 R in increments of 1 mR - 4-Level Dose: identifies 1/4, 1/2, 3/4 and full scale setting - Dose Rate: 1 mR (sic) to 65 mR (sic) with increments of 1 mR/hr - Reminder Time: may be set from 0.1 minute to 30 hours - Stay Time: may be set from 1 minute to 30 hours	77 g	48 mm x 70 mm x 17 mm
Dositec	L36	3-digit LCD display - Dose range: 0 to 999 R with increments of 1 mR - Dose Rate range: 0 to 100 R/h with increments of 1 mR/h - Red LED illuminates during all alarms	Chirp mode available - 0,1,2,4, ... to 256 mR per chirp. - 90 dBA at 30 cm	Dose: may be set from 1 mR to 65 R in increments of 1 mR - 4-Level Dose: identifies 1/4, 1/2, 3/4 and full scale setting - Dose Rate: 1 mR (sic) to 65 mR (sic) with increments of 1 mR/h - Reminder Time: may be set from 0.1 min to 30 h - Stay Time: may be set from 1 min to 30 h	77 g	48 mm W x 70 mm L x 17 mm D

Table B.6. Human Factors Parameters (Continued)

Vendor	Model	Visual Readout	Audible Indication	Alarms	Weight	Size
Health Physics Instruments	4080	6 digit LCD - 3/16-in.-high digits - Display Range: 0.1 to 999.99 mR	Piezoelectric Beeper Beeps every 0.01 mR and at turn on. Length of beep indicates battery condition.	<None>	72 g	32 mm W x 109 mm L x 24 mm D
Health Physics Instruments	4083	6 digit LCD - 0.2-in.-high digits - Display Range: 1 to 999.999 mR	Chirp mode available may be set to 0.1, 1, 2, 4, ... to 2048 mR per chirp, or may be switched off.	"Integrate alarm" May be set to 0.1, 1, 2, 4, ... to 1024 mR. - Both integrate alarm and chirper cannot be set to the same number. - The 0.1-mR level is approximate.	78 g	31 mm W x 114 mm L x 19 mm D
Merlin Gerin	DM 61	4-digit liquid crystal display - Dose measured in rem. Dose rate measured in rem/h - Indicator lamp flashes for each 0.1 mrem	Audible pulse. May be programmed to sound for every 0.1, 1, or 10 mrem, if required.	Can be set over the entire measurement range. Continuous sound for dose rate alarm. Intermittent alarm for dose alarm and defect.	180 g	116.7 mm H x 76 mm W x 34 mm D
Merlin Gerin	DM 71	4-digit liquid crystal display - Dose measured in rem. Dose rate measured in rem/h - Indicator lamp flashes for each 0.1 mrem	Audible pulse. May be programmed to sound for every 0.1, 1, or 10 mrem, if required.	Can be set over the entire measurement range. Continuous sound for dose rate alarm. Intermittent alarm for dose alarm and defect.	180 g	116.7 mm H x 76 mm W x 34 mm D

Table B.6. Human Factors Parameters (Continued)

Vendor	Model	Visual Readout	Audible Indication	Alarms	Weight	Size
Merlin Gerin	DMC 90	Six digits and six symbols - Dose Display: from 1 μSv to 10 Sv. Overflow indicated above 10 Sv. - Dose Rate Display: from 0.01 mSv/h to 999.9 mSv/h. Overflow indicated above 1 Sv/h. - High-efficiency red LED - One LED flash per μSv integrated (up to 10 Hz)	May select 1 beep per 1 μSv, 10 μSv or 100 μSv.	$\leq$ 80 dBA at 30 cm - Dose Alarm: 1 or 2 thresholds, adjustable over the entire display range. Flashing dose alarm symbols. Intermittent sound (2 sec on, 2 sec off). - Dose Rate Alarm: 1 or 2 thresholds, adjustable over the entire display range. Flashing dose rate alarm symbols. Continuous sound. - Concurrent Dose and Dose Rate Alarms: "dose alarm" and "dose rate alarm" symbols alternate and an intermittent sound is generated (4 sec on, 1 sec off).	120 g	96 mm H x 60 mm W x 28.5 mm D

Table B.6. Human Factors Parameters (Continued)

Vendor	Model	Visual Readout	Audible Indication	Alarms	Weight	Size
Merlin Gerin	DMC 100	39 mm x 12 mm liquid crystal display. 6 digits and 8 symbols. - Flashing LED for two exclusive modes: - 1 flash per mrem - 3 close flashes while any alarm is active.	May select 1 beep per 0.1 mrem, 1 mrem, or 10 mrem, or per 1, 4, or 8 pulses from the detector. - ≤ 85 dB at 30 cm.	1 prealarm threshold and 1 alarm threshold for the dose, adjustable over the entire display range. - 1 prealarm threshold and 1 alarm threshold for the dose rate, adjustable over the entire display range. - 1 alarm threshold for the time, adjustable from 00 h 01 min to 99 h 59 min. - Alarm acknowledgement by push button actuation.	110 g	106 mm H x 58 mm W x 22 mm D
Panasonic	ZP-141	4-digit LCD - Dose display range: 0 R to 999.9 R Dose rate display range: 0 R/h to 999.9 R/h	Click generated every 0.1 mR	Dose alarm settable from 0.001 R to 999.9 R. Dose rate alarm settable from 0.001 R/h to 999.9 R/h. Time alarm settable from 1 min to 23 h 59 min. "The buzzer sound level is over 60 phones at position of 20 cm from front of buzzer surface."	≤100 g	113 mm H x 53 mm W x 17 mm D

Table B.6. Human Factors Parameters (Continued)

Vendor	Model	Visual Readout	Audible Indication	Alarms	Weight	Size
Panasonic	ZP-142	4-digit LCD - Dose display range: 0.0 mR to 9999 mR Dose rate display range: 0.0 mR/h to 9999 mR/h	Click generated every 0.1 mR	Dose alarm settable from 0.1 mR to 9999 mR. Dose rate alarm settable from 0.1 mR/h to 9999 mR/h. Time alarm settable from 1 min to 23 hrs 59 min. "The buzzer sound level is over 60 phones at position of 20 cm from front of buzzer surface."	≤100 g	113 mm H x 53 mm W x 17 mm D
SAIC	PD-1	LCD: 5-mm-high digits. Display is a 37 mm long, transreflective LCD with pushbutton-controlled backlight. - Dose: 3-digit floating point with automatic ranging through units of μR, mR or R. - Dose Rate: 3-digit floating point with automatic ranging through units of μR/h, mR/h, or R/h - Event: Gamma icon flashes once per Geiger pulse at low dose rates - displays continuously at high dose rates.	Sound Level ≥ 80 dBA at 30 cm - One chirp per preset dose increment.	Dose alarm: Continuous beeping until muted by Mode-Switch closure. - Rete alarm: Continuous beeping while ambient radiation level exceeds preset rate alarm level.	< 90 g with battery	48 mm H x 72 mm L x 17 mm D

Table B.6. Human Factors Parameters (Continued)

Vendor	Model	Visual Readout	Audible Indication	Alarms	Weight	Size
SAIC	PD-2	LCD with push-button controlled backlight. - 3-digit floating point readout - units of μSv, mSv or Sv (autoranging). - Gamma icon flashes once per Geiger pulse ($\sim$ 0.015 μSv).	Speaker sound level 75 dBA at 30 cm (continuous tone). - Chirp: One beep per preset dose increment, if enabled.	Continuous beeping for Dose alarm. - Continuous beeping while above rate alarm level. - Alarms are set through PDR reader. Dose: Settings from 0.1 μSv to 50 Sv. Pre-dose: Settings from 0.1 μSv to 50 Sv. Dose Rate: Settings from 0.40 μSv/h to 9.99 Sv/h. Stay Time: Settings from 6 sec to 109 h. Pre-Stay Time: Settings from 6 sec to 109 h. Visual: Dose alarm flashes "DOSE"; dose rate alarm flashes "RATE"; stay time shows "m"	< 90 g with battery	48 mm W x 72 mm L x 17 mm D

Table B.6. Human Factors Parameters (Continued)

Vendor	Model	Visual Readout	Audible Indication	Alarms	Weight	Size
SAIC	PD-3	LCD with push-button controlled backlight. - 3-digit floating point readout - units of μR, mR or R (autoranging) - Gamma icon flashes once per Geiger pulse ($\sim$ 0.015 μR)	Speaker sound level 75 dBA at 30 cm (continuous tone). - Chirp: One beep per preset dose increment, if enabled.	Continuous beeping for Dose alarm. - Continuous beeping while above rate alarm level. - Alarms are set through PDR reader. Dose: Settings from 10 μR to 999 R. Pre-dose: Settings from 10 μR to 999 R. Dose Rate: Settings from 40 μR/h to 999 Sv/h. Stay Time: Settings from 6 sec to 109 h. Pre-stay yime: Settings from 6 sec to 109 h. Visual: Dose alarm flashes "DOSE"; dose rate alarm flashes "RATE"; stay time shows "m".	< 90 g with battery	48 mm W x 72 mm L x 17 mm D

Table B.6. Human Factors Parameters (Continued)

Vendor	Model	Visual Readout	Audible Indication	Alarms	Weight	Size
Siemens	EPD	7-segment 4-digit liquid crystal display. - Displays deep dose from 0 μSv to 9999 μSv, or from 10.0 mSv to 999.9 mSv (autoranging). - Displays deep dose rate from 0 μSv/h to 9900 μSv/h. Resolution: 2 significant figures.	Alarm sounder: 2 kHx, typically 80 dBA at 30cm. - Three sounding modes: continuous, slow intermittent, and fast intermittent	Deep dose rate alarm threshold: 7.0 μSv/h upwards.	Approx. 170 g	62.5 mm W x 86 mm L x 30.2 mm D
Technical Associates	PDA-2	6-digit LCD - Range: 0 to 99,999.9 mR (may be factory set for μSv)	Emits a beep at each mR or at every 10 mR of exposure (beep rate is set with a "protected" switch).	Continuous beep when alarm setpoint is reached - User may preset 99 alarm levels ranging from 10 - 990 mR - Alarm set and reset control located on front panel	5 oz.	2.5 in. W x 3.8 in. L x 1 in. D
Technical Associates	PDA-2E (Alarming Finger Dosimeter)	6-digit LCD - Range: 0 to 99,999.9 mR (may be factory set for μSv)	Emits a beep at each mR or at every 10 mR of exposure (beep rate is set with a "protected" switch)	Continuous beep when alarm setpoint is reached - User may preset 99 alarm levels ranging from 10 - 990 mR - Alarm set and reset control located on front panel	5 oz.	2.5 in. W x 3.8 in. L x 1 in. D

Table B.6. Human Factors Parameters (Continued)

Vendor	Model	Visual Readout	Audible Indication	Alarms	Weight	Size
TSA Systems, Ltd	PM-1202	Accumulated dose range: 1 μSv to 2295 μSv - Dose rate range: 0.10 μSv/h to 22.96 μSv/h	Audio alarm present - May be set to "emit a clicking sound in the presence of gamma radiation."	Accumulated dose alarm threshold: 10 μSv to 990 μSv (increments of 10). When the set threshold is exceeded, an audio alarm will be sounded every second until the threshold is reset. - Dose rate alarm threshold: 0.1 μSv/h to 9.9 μSv/h (increments of 0.1). When the set threshold is exceeded, an audio alarm will be sounded every second until the threshold is reset.	100 g	46 mm W x 134 mm L x 21 mm D
Victoreen	885	3-digit LED - range 0 to 999 mR - Activated by spring-loaded pushbutton	1 chirp per 0.025 mR - 2400 Hz, 75 dB at 30 cm	<None>	6 oz.	2.5 in. x 4.5 in. x 1 in.
Victoreen	05-205	<None>	At low sensitivity setting: 2 chirps per minute in 1 mR/h field - At high sensitivity setting: 60 chirps per minute in 1 mR/h field - (Sensitivity controlled by switch on monitor)	<None>	4 oz.	3.6 in. L x 2.5 in. W x .84 in. D

Table B.6. Human Factors Parameters (Continued)

Vendor	Model	Visual Readout	Audible Indication	Alarms	Weight	Size
Xetex	415A	4-digit LED - Dosimeters may be ordered with display ranges of 1-9999 mR, 0.1-999.9 mR, 0.01-99.99 mR, or 0.001-9.999 mR. - Activation of push-button required to display dose rate.	Dosimeter with 1-9999 mR display range chirps once per mR or 20 times per mR (switch selectable). - Dosimeter with 0.1-999.9 mR display range chirps 10 times per mR or 100 times per mR (switch selectable). - Dosimeter with 0.01-99.99 mR display range chirps 100 times per mR. - Dosimeter with 0.01-99.99 mR display range chirps 1000 times per mR.	<None>	170 g	58 mm W x 110 mm L x 28 mm D

Table B.6. Human Factors Parameters (Continued)

Vendor	Model	Visual Readout	Audible Indication	Alarms	Weight	Size
Xetex	415B	4-digit LED - Dosimeters may be ordered with display ranges of 1-9999 mR, 0.1-999.9 mR, 0.01-99.99 mR, or 0.001-9.999 mR. - Activation of push-button required to display dose rate.	Dosimeter with 1-9999 mR display range chirps once per mR or 20 times per mR (switch selectable). - Dosimeter with 0.1-999.9 mR display range chirps 10 times per mR or 100 times per mR (switch selectable). - Dosimeter with 0.01-99.99 mR display range chirps 100 times per mR. - Dosimeter with 0.01-99.99 mR display range chirps 1000 times per mR.	Alarm point may be set by a switch on the back of the instrument. - Dosimeter with 1-9999 mR display range has an alarm range of 4-2048 mR. - Dosimeter with 0.1-999.9 mR display range has an alarm range of 0.4-204.8 mR. - Dosimeter with 0.01-99.99 mR display range has an alarm range of 0.04-20.48 mR. - Dosimeter with 0.01-99.99 mR display range has no alarm.	198 g	58 mm W x 125 mm L x 28 mm D
Xetex	420B	Display range: 0 to 999,999 mR in 1 mR steps (LCD).	75 dB at 30cm, 1 chirp per mR accumulated. - Different tones for exposure and rate alarms. - Subminiature jack for earphone (included).	Dose Alarm Range: 10 mR to 9990 mR in 10 mR steps. - Dose Rate Alarm Range: 100 to 9900 mR/h in 100 mR/h steps.	250 g	66 mm W x 147 mm L x 28 mm D

Table B.6. Human Factors Parameters (Continued)

Vendor	Model	Visual Readout	Audible Indication	Alarms	Weight	Size
Xetex	425A	Display range: 0 to 9999 mR in 1 mR steps (LED).	75 dB at 30cm, 1 chirp per mR accumulated. - Different tones for exposure and rate alarms. - Subminiature jack for earphone (included).	Dose Alarm Range: 1 mR to 999 mR in 1 mR steps. - Dose Rate Alarm Range: 100 to 9900 mR/h in 100 mR/h steps.	250 g	66 mm W x 147 mm L x 28 mm D
Xetex	444A	4-digit LCD (4.5-mm-high digits) - Dose display range: 1 to 9999 mR. - Dose Rate display range: 1 to 100 mR/h.	1 chirp per mR	Dose Alarm Range: 0 mR to 9999 mR in 1 mR steps. - Dose Rate Alarm Range: 1mR/h to 100 R/h in 1 mR/h steps.	199 g	54 mm W x 110 mm L x 26 mm D

Part 1, Appendix C

Comparative Performance Specifications for Electronic Personnel Dosimeters

Table C.1 lists performance specifications for electronic personnel dosimeters (EPDs) obtained from the draft standard ANSI N13./27-1975, *Performance Requirements for Pocket-Sized Alarm Dosimeters and Alarm Ratemeters*; draft standard ANSI N42.20-1994, *Performance Criteria for Active Personnel Radiation Monitors*; the established standard ANSI N42.17A, *Performance Specifications for Health Physics Instrumentation—Portable Instrumentation for Use in Normal Environmental Conditions*; and Draft International Electrotechnical Commission (IEC) Standard 45B-104E, *Draft Standard for Direct Reading Personal Dose Equivalent and/or Dose Equivalent Rate Monitors for X, Gamma, and High Energy Beta Radiation*. The first column of the table lists the specific requirement. The entries from each document were summarized adjacent to the related listed requirement. In some cases, entries from a particular document were distributed among several listed requirements. Requirements addressed by a standard but not appearing in the list of requirements were added to the list of requirements. Blank entries under particular documents indicate that the document did not specifically address the requirement. In contrast to the other documents, the established standard ANSI N42.17A does not specifically address EPDs. However, the requirements in the standard were interpreted as they might apply to EPDs.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Size (maximum)		15 cm (length) x 3 cm (deep) x 8 cm (wide) without clip.	Type 1: 15 cm x 8 cm x 3 cm Types 2 & 3: 20 x 10 x 5 cm	15 cm (length) x 3 cm (deep) x 10 cm (wide) without clip.
Mass		≤ 200 gm	Type 1: ≤200 g Type 2: ≤300 g Type 3: ≤400 g	≤200 gm
Case		Smooth, rigid shock resist. Clip or lanyard. Should enable proper orientation.	Smooth, rigid, resistant to shock, dust, moisture. Clip or lanyard. Should enable proper orientation.	Smooth, rigid, resistant to shock, dust, moisture. Clip or lanyard. Should enable proper orientation.
Clip		500 gm clip load. Distance from EPD to surface clipped ≤1 cm.		Hold three times weight of EPD when clipped to one layer of cloth (190 g/m^2).
Controls	Switches protected from accidental or unauthorized operation. Manufacturer shall state action taken to meet requirement.	Controls for turning on or off or dose clearing, shall be restricted to authorized users. Reset or deactivate only through external control unit with above restrictions.	Switches protected from accidental or unauthorized operation. Switch operation shall not interfere with dose integration. Switches operable through plastic bag/gloved hands. Battery change must require special tool.	Switches protected from accidental or unauthorized operation. Switch operation shall not interfere with dose integration. Switches operable through plastic bag/gloved hands. Battery change must require special tool.
Alarms General		Alarm for all modes (dose and dose rate). Unique alarm for all modes.	Located so alarm can be seen or heard by user.	Located so alarm can be seen or heard by user. Minimum number of. Multiple alarms must be distinct.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Alarms Visual		Visual alarm shall be a powered light.		
Alarms Audible		Audible alarm shall provide level of 80 db at 30 cm.	Frequency 1 to 5 kHz. Pulsed alarm interval ≤2 seconds. Level ≤85 dBA at ears if worn at recommended position. 100 dBA at 30 cm. Earphones or visual for noisy environments.	Frequency 1 to 3 kHz. Pulsed alarm interval ≤2 seconds. Level ≤85 dBA at ears if worn at recommended position. 100 dBA at 30 cm. Earphones or visual for noisy environments.
Alarms Vibratory		Vibratory alarm shall be felt through cotton shirt.		
Alarms Disable		Alarms shall be protected from unauthorized disabling.	No setting of alarms by external switches. By readout device only or limited access system.	No setting of alarms by external switches. By readout device only or limited access system.
Alarms Presets		Capability for preset levels. At least one level in each decade if fixed levels. Disabling of controls for modifying presets by user shall be possible.	Setpoints at any level in effective range or one value in each decade.	Setpoints at any level (for dose alarm, both deep and shallow dose) in effective range or one value in each decade.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Exterior Markings	Function of external controls, displays, adjustments identified. Internal controls shall be identified through markings on circuit boards and in manual. Include maker, model, serial number, effective center location. Markings legible/fixed.	Shall include manufacturer, model, serial number, calibration reference points. Reference orientation, if critical, shall be marked. Controls on exterior shall be identified and detailed in manual.	Case shall have markings to indicate effective center of detector on front (or back) and side. Reference with respect to user shall be indicated.	Reference point for calibration and test, and reference orientation with respect to user shall be indicated on outside of dosimeter.
Units of Readout	Shall indicate units of readout.	Dose-equivalent meters in rem or sievert. Dose-equivalent rate meters in rem/h or Sv/h.	Shall be in units of dose equivalent and/or dose equivalent rate.	Shall be in units of dose equivalent and/or dose equivalent rate.
Ease of Decontamination	Should be made to simplify decontamination. Openings in case should be made to minimize absorption of contamination.	Surfaces smooth, nonporous with minimum structure. Penetrations sealed. Replaceable parts.	Case shall be constructed of materials easy to decontamination.	Case constructed for minimum retention and ease of decontamination. Meters with covers shall conform to standard.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Measurement Ranges	Readings of beta-photon dose and dose rate devices should be in units of dose or dose rate. Dose equivalent or dose equivalent rate for neutron instruments.	Minimum range of 1 mrem to 10 rem and/or 1 mrem/h to 10 rem/h.	Types 1,2: 0.1 mrem to 100 rem, 1 to 100 mrem/h. Type 3: 1 mrem to 100 rem, 1 mrem/h to 10 rem/h. Detection limit is dose when variance in 10 readings at low end of lowest scale is >20%.	Recommended range: 0.1 mrem/h to 1 rem/h and 0.1 mrem to 100 rem for X, gamma, and beta.
Display	Analog with scale markings. Linear scales: major divisions at 0 and 100% of full scale and at 3 to 12 points equally spaced in between. Logarithmic scales: each decade marked with >4 but ≤12 approximately equally spaced major divisions between limits. Minor divisions should be provided to increase resolution. Scale readable from normal operating position.	If provided, display shall give three digits or greater auto-ranging. Display shall indicate alarm condition. Display shall indicate units of measurement were appropriate.	Shall be digital and shall be clearly visible by wearer during normal use.	Shall be digital and shall be clearly visible by wearer during normal use. Indicate measured quantity. Distinguish deep and shallow dose.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Background Response		In background ($\sim$10 μrem/h), $<$1 mrem in 8 hours after zero. For sensitivity of 0.1 mrem, $\leq$0.2 mrem in 8 hours (i.e., reading change $\leq +100\%$ background after zero; no change in LSD if LSD in decade above accumulated background not including rounding).		
Effective Range of Indication/ Measurement		Shall cover effective range of measurement.	Effective range shall not be less than first non-zero indication in second least significant digit up to maximum value on each range. Auto-switching between detectors if applicable. Tests in standard shall be performed on each detector. Range changing shall be automatic.	Effective range shall not be less than first non-zero indication in second least significant digit up to maximum value on each range. Auto-switching between detectors if applicable. Tests in standard shall be preformed on each detector. Range changing shall be automatic.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Battery Status Indication	Shall be equipped with test circuit or other indicator of battery condition for each battery circuit.	Indication when ≥8 hours of operation remain.	Indication when ≥8 hours of operation remain at 10 mrem/h including 1 min of alarm. Change of ≤15% in reading after next 8 hours.	Indication when ≥8 hours of operation remain at 10 mrem/h including 1 min of alarm. Indication by external readout permissible.
Saturation		Dosimeters for dose of record: dose shall be marked to show dose range exceeded. Manufacturer shall state range within accuracy requirements.		
Memory Protection (Retention)		Alarm levels, critical information maintained in nonvolatile state (dose also if used for record). Clearing or resetting only by authorized operator.	(Applies to dosimeter and associated readout system.) Dose reading should not change more than 2%, or a single change in least significant digit for 8 hours from end of exposure. Twenty-four hours after power loss, reading shall not change greater than the greater of 5% or 1 mrem upon replacement of power.	(For beta and gamma, deep and shallow dose only. Applies to dosimeter and associated readout system.) Reading should not change more than 2%, or a single change in least significant digit for 8 hours from end of exposure. Twenty-four hours after power loss, reading should be ≤±2%, or no change in least significant digit on power return.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Alarms Latching and Non-latching Reset	Alarms remain active ≥5 minutes until reset manually (latching) or clear when dose rate reduced below alarm level (nonlatching). Alarms shall continue to operate at levels above alarm levels. Dose from trip delay ≤10 mrem. Delay for trip ≤1 minute.	Alarms remain active ≥5 minutes until reset manually (latching) or clear when dose rate reduced below alarm level (nonlatching). Alarms shall continue to operate at levels above alarm levels. Dose from trip delay ≤10 mrem. Delay for trip ≤1 minute.		
Battery Power (Primary)	Nonrecharge life: ≥100 hours using batteries readily available. Shall state lifetimes and temperature ranges for operation and storage. Low battery indication shall be no lower than the minute voltage for satisfactory operation (see Battery Power [General]).	Nonrecharge life: ≥100 hours using batteries readily available. Shall state lifetimes and temperature ranges for operation and storage. Batteries for alarms shall power active alarms for ≥10 minutes. Indication of battery condition shall be evident.	After 100 hours of continuous operation in 1 to 10 mrem/h, instrument shall meet radiation performance requirements in standard. New batteries shall operate 15 minutes with audio and visual alarms activated.	(For beta and gamma, deep and shallow dose.) After 2000 hours of continuous operation in 1 to 10 mrem/h, response shall change ≤15% and instrument shall meet performance requirements in standard. New batteries shall operate 15 minutes with audio and visual alarms activated.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Battery Power (Secondary)			After 10 hours of continuous use in 1 to 10 mrem/h, reading change shall be ≤15% with other functions remaining within specifications. Recharged batteries shall operate with audio and video alarms activated for 15 minutes. Batteries shall recharge in ≤12 hours.	(For beta and gamma, deep and shallow dose.) After 10 hours of continuous use in 1 to 10 mrem/h, reading change shall be ≤15% with other functions remaining within specifications. Recharged batteries shall operate with audio and video alarms activated for 15 minutes. Batteries shall recharge in ≤12 hours.
Battery Power (General)	Manufacturer shall state minimum voltage for satisfactory operation (change in response ≤10% compared to response with fresh batteries).		Facilities for testing battery under maximum use shall be provided. Proper polarity for battery connection clearly indicated.	Facilities for testing battery under maximum use shall be provided. Proper polarity for battery connection clearly indicated.
Check Circuits	Audit and test circuits and audio indicators, automatic or manual, are recommended.	Means to test or indicate correct operation of internal circuits, audio, and display without reader.		
Battery Power Indicator	Mean reading at failure notice ≤±10% from mean reading with new batteries.	Mean reading at failure notice ≤±10% from mean reading with new batteries.		

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Mechanical Shock	Change in response $\leq 15\%$ after 10 shocks of 50 g peak acceleration applied for a nominal 18 msec in each of three mutually orthogonal axes. The physical condition shall not be affected by the shocks.	Change $\leq 10\%$ after drop onto a concrete surface. Stored information not affected. (Note: no distance specified.)	Change in displayed and stored values $\leq 10\%$ after drop from 1.5 meters onto hard wood surface on each of six surfaces. No visible damage and controls will operate correctly. After drops, accuracy and linearity must be $< \pm 10\%$ (dose readings of 20%, 50%, 80% of full range).	Affect in performance $< \pm 10\%$ after drop from 1.5 meters onto a concrete surface. Tests conducted on each of 6 faces and type test shall be performed on 3 dosimeters. Stored deep and shallow dose data shall not be lost by drops. Physical damage shall be noted.
Vibration	Change in response $\leq 15\%$ after vibrations of 2 g for 15 minutes in the range 10 to 33 Hz. The physical condition shall not be affected by the vibration.	Change $\leq 15\%$ after 2 g for 25 minutes in the range 10 to 33 Hz. Physical condition unaffected.	Change $\leq 10\%$ in indicated or stored reading after 2 g_n for 15 minutes in range 10 to 33 Hz in each of 3 orthogonal axes. Same accuracy and linearity required as mechanical shock.	Change $\leq 10\%$ in mean response after 2 g_n for 15 minutes in range 10 to 33 Hz. Physical condition shall not be affected.
Drift		Background due to electronic noise or interfering responses < 0.2 mrem in 8 hours.		

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Accuracy	Mean response within 15% of true value.	Mean response within 15% of true value.	Relative error $\leq \pm 15\%$ over effective dose rate range and $\leq \pm 20\%$ over effective dose rate range. Relative error $\leq \pm 30\%$ in lowest decade.	Relative intrinsic error (deep and shallow dose) $\leq \pm 10\%$ over effective range of dose, $\leq \pm 15\%$ over effective range of dose rate. In lowest scale of dose rate, $\leq \pm 30\%$.
Repeatability and Reproducibility (Precision, Coefficient of Variation)	Coefficient of variation of 20 readings from a single EPD $\leq 10\%$ for dose rate and dose equivalent rate EPDs exposed to ≥ 1 mrad/h and ≥ 10 mrem/h, respectively.	Coefficient of variation $\leq 3\%$ for each EPD separately (repeatability) or for n EPDs collectively (reproducibility) exposed to 100 mrem.	Variance in 10 sets of exposures shall be $\leq 5\%$. A set consists of exposures of 10%, 50%, and 80% of full scale, and to a maximum of 100 rem.	

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Response Time	Beta/Photon Maximum Times Rate range: $>10^{-4}$ to $\leq 10^{-3}$ rem/h,rad/h Time: 30 sec Rate range: $>10^{-3}$ to $\leq 10^{-2}$ rem/h, rad/h Time: 10 sec Rate range: $>10^{-2}$ to $\leq 10^{-1}$ rem/h, rad/h Time: 5 sec Rate range: $>10^{-1}$ to ≤ 1 rem/h, rad/h Time: 3 sec Rate range: >1 rem/h, rad/h Time: 2 sec Neutron Maximum Times Rate range: $< 5x10^{-2}$ rem/h Time: 30 sec Rate range: $5x10^{-2}$ to ≤ 1 rem/h Time: 10 sec Rate range: >1 rem/h Time: 5 sec Neutron/photon or neutron, beta, photon EPDs shall meet least restrictive requirements.	Beta/Photon Maximum Times Rate range: $>10^{-4}$ to $\leq 10^{-3}$ rem/h,rad/h Time: 30 sec Rate range: $>10^{-3}$ to $\leq 10^{-2}$ rem/h,rad/h Time: 10 sec Rate range: $>10^{-2}$ to $\leq 10^{-1}$ rem/h,rad/h Time: 5 sec Rate range: $>10^{-1}$ to ≤ 1 rem/h,rad/h Time: 3 sec Rate range: >1 rem/h,rad/h Time: 2 sec Neutron Maximum Times Rate range: $< 5x10^{-2}$ rem/h Time: 30 sec Rate range: $5x10^{-2}$ to ≤ 1 rem/h Time: 10 sec Rate range: >1 rem/h Time: 5 sec Neutron/photon or neutron, beta, photon EPDs shall meet least restrictive requirements.	Dosimeter must respond to step change in dose rate (>1 mrem/h) within 5 seconds with a relative error $<10\%$.	(For beta, gamma and deep, shallow dose.) Dosimeter must respond to step change in dose rate (for rates >1 mrem/h) within 5 seconds with a relative error $<10\%$.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Photon Energy Dependency	Useful range stated and graphically depicted. Useful range shall be the range over which the ratio of the mean response normalized by true value at corresponding energy to reference response normalized by true value at reference energy shall fall within 0.8 to 1.2. Useful range should be at least 20 keV to 3 MeV and shall be at least 80 keV to 1.25 MeV. Energy used as reference must be stated. For energies outside specified range, maker shall state useful energy range and EPD shall be marked clearly for restricted applications. Range of energies where EPD response is 0.5 to 1.5 times true value stated or graphically indicated.	No response variation >30% from 80 keV to 1.25 MeV. Response shall be stated and graphically indicated from 20 keV to 3 MeV. For energies up to 6 MeV, H_d shall not differ by more than -50% to +100% from true value.	No response variation >30% from 80 keV to 1.25 MeV referenced to ^{137}Cs.	No response variation >30% from 70 keV (Category I: 80 keV; Category II: 20 keV) to 1.2 MeV referenced to ^{137}Cs. Response shall be stated and graphically indicated over same interval. For energies up to 10 MeV, $H_p(10)$ shall not differ by more than -50% to +100% from response to ^{137}Cs.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Beta Energy Dependence	Range shall be stated and should be at least 0.2 MeV to 3.5 MeV (E_{max}). In this range, the ratio of the mean response normalized by true value (7 mg/cm^2) at corresponding energy to reference response normalized by true value (7 mg/cm^2) at reference energy shall fall within 0.5 to 1.5 between 0.5 MeV and 3.5 MeV (E_{max}) and should fall within 0.5 to 1.5 between 0.2 MeV and 3.5 MeV (E_{max}). Reference energy source shall be specified. Beta cutoff energy shall be stated along with density thickness of detector cover.	No response variation in shallow dose $>50\%$ from 0.5 MeV to 3.5 MeV. Response should not vary $>50\%$ from 0.2 to 3.5 MeV. The reference energy shall be specified. Beta cutoff energy and density thickness shall be stated.	For average energy greater than 2.0 MeV, reading should not differ $>50\%$ from true value of shallow dose equivalent.	For maximum energy of 0.78 MeV and 2.2 MeV, response shall be within $\pm 30\%$. The response at maximum energy of 0.25 MeV and 3.5 MeV shall be stated.
Neutron Energy Dependence	Range shall be stated. In this range, the ratio of the mean response normalized by true value at corresponding energy to reference response normalized by true value at reference energy shall fall within 0.5 to 2.0.	Energy response shall be provided by the manufacturer.		

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Angular Dependence (Gamma and Neutron Radiation)	Mean response $\leq \pm 45°$ from direction of maximum response shall be $\geq 80\%$ of maximum response. At 90° from direction of maximum response, mean response shall be $\geq 50\%$ of maximum response. Applies to at least two representative energies. Angular response to neutron radiation shall be stated by manufacturer. Angular response shall be provided as polar plot.	Ratio of reading at 0°to readings at 0° to $\pm 75°$ (for two planes, one horizontal and one vertical through the front face of the dosimeter) shall be within $\pm 50\%$ of the ratios (^{241}Am or 60-keV filtered x-ray): 0.99 (15°), 0.97 (30°), 0.90 (45°), 0.77 (60°), 0.51 (75°); and within $\pm 20\%$ of the ratios (^{137}Cs): 1.0 (15°), 1.0 (30°), 0.98 (45°), 0.95 (60°), 0.80 (75°). The manufacturer shall state the response at 90°.	Ratio of reading at 0° to readings at 0° to $\pm 75°$ (for two planes, one horizontal and one vertical through the front face of the dosimeter) shall be within $\pm 50\%$ of the ratios (^{241}Am or 60-keV filtered x-ray): 0.99 (15°), 0.97 (30°), 0.90 (45°), 0.77 (60°), 0.51 (75°); and within $\pm 20\%$ of the ratios (^{137}Cs): 1.0 (15°), 1.0 (30°), 0.98 (45°), 0.95 (60°), 0.80 (75°). The manufacturer shall state the response at 90°	For deep and shallow dose, ratio of reading at 0° to readings at 0° to $\pm 60°$ (for two planes, one horizontal and one vertical through the front face of the dosimeter) shall be within $\pm 50\%$ of the ratios (^{241}Am or 60-keV filtered x-ray): 0.99 (15°), 0.97 (30°), 0.90 (45°), 0.77 (60°), 0.51 (75°); and within $\pm 20\%$ of the ratios (^{137}Cs): 1.0 (15°), 1.0 (30°), 0.98 (45°), 0.95 (60°), 0.80 (75°). The manufacturer shall state the response at 90°

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Angular Dependence (Beta Radiation)	Mean response $\leq \pm 45°$ from direction of maximum response shall be $\geq 50\%$ of maximum response. Angular response shall be provided as polar plot.			For deep and shallow dose, ratio of reading at 0° to readings at 0° to ±60° (for two planes, one horizontal and one vertical through the front face of the dosimeter) shall be within ±30% of the ratios: 1.03 (20°), 1.10 (40°), 1.14 (60°) [NRPB ^{90}Sr (20 cm)]; 1.02 (20°), 1.08 (40°), 1.09 (60°) [NRPB ^{90}Sr (30 cm)]; 1.02 (20°), 1.10 (40°), 1.15 (60°) [PTB ^{90}Sr Type 1 (30 cm)]; 1.02 (20°), 1.10 (40°), 1.19 (60°) [PTB ^{90}Sr Type 2 (30 cm)].
Dose-Equivalent Rate Dependence		Response change $<20\%$ from true value for rates ≤ 100 rem/h and 5-second exposure to ~100 mrem/h.	Relative error $< \pm 20\%$ for dose equivalents up to 100 rem/h and 5-second exposure to ~100 mrem/h.	(For beta and gamma, shallow and deep dose.) Dose equivalent relative intrinsic error $< \pm 10\%$ for rates ≤ 1000 rem/h.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Overload Characteristics	For radiation levels greater than highest scale or decade, EPD shall continue to operate and analog readout shall be off-scale at higher end of scale and shall remain so until field level is reduced below full scale. Digital read-outs should convey that level exceeds upper detection limit as described by manufacturer. When radiation field is removed, EPD reading shall return to expected value within 2 minutes.	Readout shall indicate that upper limit has been exceeded. Manufacturer shall state time for ratemeters to return to on-scale reading after removal from field. Dosimeters shall remain off-scale after removal from field. For ratemeters where dose rate exceeds measurable rate during integration, overload condition shall be indicated and remain until reset. The manufacturer shall state the upper limit of measurable rate.	For rates greater than the maximum value of last decade to two times maximum value, instrument shall indicate off-scale during exposure. Manufacturer shall state time for ratemeters to return to on-scale reading after removal from radiation field. For ratemeters where dose rate exceeds measurable rate during integration, overload condition shall be indicated and remain until reset. The manufacturer shall state the upper limit of measurable rate.	(For beta and gamma, shallow and deep dose.) For rates greater than the maximum value of last decade to 10 times maximum value, instrument shall be off-scale during exposure. Manufacturer shall state time for ratemeters to return to on-scale reading after removal from radiation field. For dose equivalent irradiation, indication shall remain off-scale after removal from field. For rate-meters where dose rate exceeds measurable rate during integration, overload condition shall be indicated and remain until reset. The manufacturer shall state the upper limit of measurable rate.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Alarm Accuracy Dose Rate Monitors		For rates 80% of set point, alarm shall not activate for more than 10% of a 10-min period. For rates 120% of setpoint, alarm should activate in 5 sec or n seconds such that n times setpoint is <1 mrem. Alarm shall remain active for 90% of observation time.	For rates 80% of set point, alarm shall not activate for more than 10% of a 10-min period. For rates 120% of set-point, alarm shall be activated for 90% of the test period. For rates 120% of set-point, alarm should activate in 5 sec or n seconds such than n times setpoint is <1 mrem.	For rates 80% of set point, alarm shall not activate for more than 10% of a 10-min period. For rates 120% of setpoint, alarm shall be activated for 90% of the test period. For rates 120% of setpoint, alarm should activate in 5 sec or n seconds such than n times setpoint is <1 mrem.
Alarm Accuracy Dose Monitors		No alarm when dose is 0.85 of setpoint. Alarm shall activate when dose is 1.15 of setpoint.	No alarm when dose is 0.85 of setpoint. Alarm shall activate when dose is 1.15 of setpoint.	No alarm when dose is 0.85 of setpoint. Alarm shall activate when dose is 1.15 of setpoint.
Extracameral Response	For external detectors separate from remainder of unit, extracameral response shall be $\leq \pm 5\%$ of intensity of exposing field up to a maximum intensity equal to scale in use.	Response from non-detector part (for separated instru-ments) should be $\leq \pm 5\%$ of lowest decade.		

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Radio Frequency Fields	Change in response ≤15% for intensities of ≤100 V/m in the range 0.3 MHz to 35 MHz or at 140 MHz or both. Alternatively, manufacturer shall specify in the documentation that EPD may be sensitive to and not operate properly in RF.	Warning shall be given if indication of monitor affected by RF. Range of frequencies, types of EMF, and maximum intensities shall be stated if insensitivity is claimed. Change in response shall not be greater than the greater of +10% or 10 mrem/hr for 100 kHz to 500 MHz at 100 V/m and 500 MHz to 1.0 GHz at 10 V/m.	Warning shall be given if indication of monitor affected by RF. Range of frequencies, types of EMF, and maximum intensities shall be stated if insensitivity is claimed. Change in response shall not be greater than 10% for 100 kHz to 500 MHz at 100 V/m and 500 MHz to 1.0 GHz at 1 V/m.	(For deep and shallow dose) Warning shall be given if indication of monitor affected by RF. Range of frequencies, types of EMF, and maximum intensities shall be stated if insensitivity is claimed. Change in response shall not be greater than 10% for 100 kHz to 500 MHz at 100 V/m and 500 MHz to 1.0 GHz at 1 V/m.
Microwave Fields	Change in response ≤15% for intensities ≤100 W/m^2 at 915 MHz or 2450 MHz. Alternatively, manufacturer shall specify in the documentation that EPD may be sensitive to and not operate properly in such fields.	Dosimeter shall be labelled sensitive if change in response is greater than the lesser of 15% or 15 mrem/h for 915 MHz and 2.4 GHz at ≤100 W/m^2.		If a concern, testing shall be conducted using section 7.3 of ANSI N42.17 (ANSI 1989).

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
External Electrical Fields	Change in response ≤15% for ≤5000 V/m electrostatic or to 60 Hz and 400 Hz fields at ≤100 V/m. Alternatively, manufacturer shall specify in the documentation that EPD may be sensitive to and not operate properly in such fields.	Change in response shall not be greater than the lesser of +15% or 15 mrem/h for ≤5000 V/m electrostatic or to 60 Hz and 400 Hz fields at ≤100 V/m.	Change in response ≤20% for electrostatic field of 5000 V/m.	
External Magnetic Field	Change in response ≤15% for ≤800 A/m magnetic field. Alternatively, manufacturer shall specify in the documentation that EPD may be sensitive to and not operate properly in such fields.	If indication of dose is affected by magnetic fields, a warning shall be given and documented. Change in response shall not be greater than the lesser of +10% or 10 mrem/hr for 50 Hz or 60 Hz fields at ≥100 A/m.	Change in response ≤20% after 10-min of pulsed 800 A/m field (on for 15 sec, off for 2 min).	If indication of dose is affected by magnetic fields, a warning shall be given and documented. Change in response shall ≤10% for 60 Hz fields at ≤60 A/m.
Interfering Ionizing Radiations	No response greater than that stated by manufacturer for nondesigned radiations at or below 10^4 dpm/cm^2 (alpha), 10 rad/h (beta or photon), and/or 1 rem/h (neutron).	No response greater than that stated by manufacturer for nondesigned radiations.	No responses greater than 2.5% of full scale after 1-rem exposure.	Response to neutrons <1%. Neutron response shall change photon response ≤1%.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Electrostatic Discharge		Change in response shall not be greater than the lesser of +10% or 10 mrem/h for 6 kV, 2 mJ (earthed chassis) with ≥10 seconds between discharges. Test method agreed between maker and user.	Change in response shall not be greater than 10% for 6-kV, 2-mJ discharge across case on grounded chassis with ≥10 seconds between discharges. Test method agreed between maker and user.	Change in dose shall not be greater than 10% for 6-kV, 2-mJ discharge across case on grounded chassis with ≥10 seconds between discharges.
Ambient Temperature	Range where reading changes ≤15% from response at 22°C to be stated. Change ≤15% (0°C to 40°C), ≤20% (-10°C to 50°C) referenced to 22°C. Corrections for air density made where needed.	Change in response ≤20% at midscale of second most significant range for -10°C to 40°C and ≤50% for -18°C to 50°C.		(For beta and gamma, deep and shallow dose.) Response change ≤15% (0°C to +55°C), ≤10% (-10°C to +40°C), ≤20% (-25°C to 50°C.)
Temperature Shock	Change in response ≤15% for change (<5 min) from/to 20°C to/from 50°C or -10°C.	Change in response ≤15% at midscale of second most significant range for ±30°C change (<5 min) from 20°C.	Change in response ≤15% for change (<5 min) from/to 20°C to/from 50°C or -10°C.	Change in response ≤15% for change (<5 min) from/to 20°C to/from 50°C or -10°C.
Relative Humidity	Change in response <15% for 40%RH to 95%RH (22°C) referenced to 40%RH (22°C).	Change in response <10% at midscale of second most sensitive range for 40%RH to 95%RH.	Change in response <10% for 40%RH to 95%RH.	(For beta and gamma, deep and shallow dose.) Change in response ≤10% for 40%RH to 90%RH.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Ambient Pressure	Change in response ≤15%, referenced to 101 kPa, over range of 70 kPa to 106 kPa. Corrections for air density made where needed.	Unsealed detectors using air for detection only. Pressure at which tests performed and effects shall be stated.	Unsealed detectors using air for detection only. Pressure at which tests performed and effects shall be stated.	Unsealed detectors using air for detection only. Pressure at which tests performed and effects shall be stated.
Sealing/ Splashproof	Manufacturer shall state efforts to protect against moisture. Change in response ≤15% after fine water spray of approximately 4 L/min for approximately 2 min at a distance of 2 m. Not applicable to detectors open to air or with thin windows.	Manufacturer shall state precautions to prevent ingress, and tests and results shall be described to show effectiveness of sealing.	Change in response ≤15% after fine water spray of approximately 4 L/min for approximately 2 min at a distance of 2 m.	Manufacturer shall state precautions to prevent ingress, and tests and results shall be described to show effectiveness of sealing. Change in response ≤1% during and after lightly falling rain (0.6 cm/h) for 2 h at 20°C.
Storage		Shall satisfy specifications of standard after storage for ≥3 months (may be without batteries) between -25°C to +50°C.		Shall satisfy specifications of standard after storage for ≥3 months (may be without batteries) between -25°C to +50°C.
Reader			Data transfer to reader shall be verified for accuracy. Transfer will occur with a change of no more than ± one digit in the least significant position.	

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Operational Status Indication				Indication shall be given of operation in conditions where accumulation of dose equivalent is not accurate (e.g., detector failure) or when battery condition is such that dosimeter can no longer meet requirements in standard.
Scaling Factors	Linear scales: factor between adjacent scales ≤ 10. Logarithmic scales (switched): overlap required - should be one decade. Device shall indicate scale and units for each scale. Floating decimal points shall be displayed if used. Multiple scales, if used, of nonlinear analog displays should overlap.			
Alarm Threshold	For devices that alarm, threshold shall be in percent of scale or display units. Protected from unplanned adjustment.			

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Response to Mixed Radiation Fields				Response to deep and shallow dose should be independent. Response to weakly and strongly penetrating radiation should be additive.
Light Exposure				Dosimeter response and communication facility should not be influenced by light.
Light Flash				Dosimeter response should not be influenced by light flash when exposed to 100 W/s flash for 10 times.
Zero Set (Indication)	If available, it shall function correctly in radiation fields with intensities up to limit of each scale or decade.			
Data Permanency				Damage to dosimeter's readout system should not prevent readout of dose. Manufacturer shall state method used to retrieve dose record.

Table C.1. Performance Specifications for Electronic Personnel Dosimeters (Continued)

Requirements	ANSI N42.17A (1989)	ANSI N13.27 (1975)	ANSI N42.20 (1994)	IEC Standard
Alarm Threshold Drift	Exposure trip level shall drift $\leq \pm 10\%$ from set point over 500 h.			
Stability	Change in response $\leq 6\%$ over 3 h.			
Geotropism	Change in response $\leq 6\%$ from change in spatial orientation.			

Part 2

Standard for the Performance Testing of Electronic Personal Dosimetry Systems

1. Introduction—Type Tests

1.1 Purpose

This standard defines the performance tests to be used to demonstrate that an electronic personal dosimetry system has an acceptable performance for use as a primary dosimeter. It specifies the design requirements and the performance characteristics of the dosimeter. Its purpose is to help establish a uniform approach to personal dosimetry using electronic dosimetry and to establish criteria that will permit the use of electronic dosimeters as primary dosimetry (dose of record).

1.2 Scope

The standard applies to electronic dosimeters which are worn on the trunk of the body and are used for the measurement of personal dose equivalents $H_p(10)$ and $H_p(0.07)$ to its wearer from external x, gamma, and beta radiation. The standard is applicable for dosimetry performed for health protection under controlled and uncontrolled conditions (accident dosimetry). It applies to electronic dosimeters used for measuring the personal dose equivalents $H_p(10)$ and $H_p(0.07)$ from x and gamma radiation of energies 15 keV to 2 MeV and for beta radiation of mean energy >0.25 MeV. At the present time, instruments to measure the neutron dose equivalent are excluded from the standard. The standard specifies general requirements for the electronic dosimeter and for those aspects of its associated readout system which affect the accuracy of readout of dose equivalent or the setting of the dosimeter's alarms.

1.3 Review

The standard shall be reviewed and updated by the Nuclear Regulatory Commission (NRC) until such time that the NRC adopts an available consensus standard.

2. Definitions

For the purpose of this standard, the following definitions apply.

2.1 Conventional True Value of a Quantity

The best estimate of the value, determined by a primary or secondary standard or by a reference instrument that has been calibrated against a primary or secondary standard.

2.2 Error of Indication

The difference between the indicated value of a quantity, H_i, and the conventional true value of that quantity, H_t, at the point of measurement. It is expressed as $H_i - H_t$.

2.3 Response

The response, R, of a dosimeter is the ratio of the dosimeter's indicated value (H_i) to the conventional true value (H_t):

$$R = \frac{H_i}{H_t}$$

2.4 Relative Error Indication

The quotient of the error of indication of a measured quantity (H_i) by the conventional true value (H_t) of that measured quantity. It may be expressed as a percentage:

$$I = [(H_i - H_t) \times 100]/H_t \ \%$$

2.5 Relative Intrinsic Error

The relative error of indication of a dosimeter with respect to a quantity when subjected to a specified reference radiation under specified conditions.

2.6 Point of Test

The point of test is the point at which the reference point of the dosimeter is placed for purposes of calibration or type test and at which the conventionally true value of the calibration quantity is known. The dosimeter and the recommended standard test phantom should be regarded as a unit for measuring the calibration quantity. The reference point of this unit by convention is the reference point of the dosimeter and should be positioned at the point of test.

2.7 Reference Point of a Dosimeter

The reference point of a dosimeter is the point to be used in order to position the dosimeter at the point of test. The reference point should be marked on the dosimeter by the manufacturer. If this proves impossible, the reference point should be indicated in the accompanying documentation supplied with the dosimeter. The reference point shall be taken as the geometrical center of the dosimeter if additional information is not provided.

2.8 Reference Orientation and Calibration Direction

The reference orientation of the dosimeter with respect to the direction of radiation indicated by the manufacturer.

2.9 Tissue

When the word "tissue" is used in this standard, the specification given in ICRU 33 (1980) is implied.

2.10 Dose Equivalent

The dose equivalent, H, is the product of D and Q, at the point of interest in tissue, where D is the absorbed dose and Q is the quality factor (ICRU 40 [1986]):

$$H = DQ$$

Note: For x, gamma, and beta radiation, Q may be taken as equal to unity for external radiation (ICRP Publications 26 [1977] and 60 [1990]). The SI unit of dose equivalent has been given the name sievert (Sv):

$$1 \text{ Sv} = 100 \text{ rem}$$

2.11 Absorbed Dose

The absorbed dose, D, is the quotient of $d\epsilon$ by dm, where $d\epsilon$ is the mean energy imparted by ionizing radiation to matter of mass dm:

$$D = d\epsilon/dm$$

The special name for the SI unit of absorbed dose is gray (Gy):

1 Gy = 100 rad

2.12 Kerma

The kerma, K, is the quotient of dE_{tr} by dm, where dE_{tr} is the sum of the initial kinetic energies of all the charged ionizing particles liberated by uncharged ionizing particles in a material of mass dm: thus, $K = dE_{tr}/dm$.

The special name for the SI unit of kerma is gray (Gy):

1 Gy = 100 rad.

2.13 Personal Dose Equivalent, $H_p(d)$

The personal dose equivalent, $H_p(d)$, is the dose equivalent in ICRU tissue, at an appropriate depth, d, below a specified point on the body.

Any statement of personal dose equivalent should include a specification of the reference depth, d. In order to simplify notation, it should be expressed in millimeters (mm).

For weakly penetrating radiation, a depth of 0.07 mm for the skin is employed and is denoted by $H_p(0.07)$. For strongly penetrating radiation, a depth of 10 mm is employed and is denoted by $H_p(10)$.

Note: For the calibration of personal dosimeters, the definition of $H_p(d)$ is considered to include the ICRU tissue slab phantom of 300 mm x 300 mm x 150 mm depth to represent the human torso (for calibration of whole body dosimeters).

Note: For the purposes of this standard, $H_p(10)$ is taken as equivalent to the deep dose equivalent (H_d), which is the dose equivalent at a tissue depth of 1 cm (1000 mg/cm^2). $H_p(0.07)$ is taken as equivalent to the shallow dose equivalent (H_s), which applies to the external exposure of the skin or an extremity. It is taken as the dose equivalent at a tissue depth of 0.007 cm (7 mg/cm^2) averaged over an area of 1 cm^2.

2.14 Primary Standard

A standard which has the highest metrologic qualities. Primary standards are maintained at national laboratories that participate in recognized international intercomparisons of primary standards laboratories coordinated by the BIPM.

2.15 Secondary Standard

A standard whose value is fixed by direct comparison with a primary standard and is accompanied by a certificate which documents that traceability. Secondary standards are maintained by laboratories which have national standing.

2.16 Tertiary Standard

A standard whose value is fixed by comparison with a secondary standard.

2.17 Response Time

The time interval between the instant that a dosimeter is exposed to a radiation source and the instant the dosimeter reads 90% of its steady state value.

2.18 Geotropism

A change in dosimeter reading with a change in the dosimeter orientation as a result of gravitational effects.

2.19 Temperature Shock

A rapid and large temperature change.

2.20 Coefficient of Variation, V

The ratio V of the estimate of the standard deviation, s, to the arithmetic mean, $\bar{x}$, of a set of n measurements x_i, given by the formula

$$V = s / \bar{x} = (1 / \bar{x}) \sqrt{\frac{(x_i - \bar{x})^2}{n-1}}$$

2.21 Effective Range of Measurement

The range of values of the quantity to be measured over which the performance of a dosimeter meets the requirements of this standard.

2.22 Extracameral

Pertaining to that portion of the instrument exclusive of the detector.

2.23 Dosimeter Overload

Exposure of a dosimeter to a radiation field delivering a dose equivalent or having a dose equivalent rate in excess of the dosimeter's intended upper limit of use.

3. Test Nomenclature

3.1 Qualification Tests

Qualification tests are performed in order to verify that the requirements of a specification are fulfilled. Qualification tests are subdivided into type tests and routine tests, as defined below.

3.1.1 Type Tests

A test of one or more dosimeters made to a certain design to show that the design meets the specifications of this standard.

3.1.2 Routine Tests

A test to which each individual dosimeter is subjected during or after manufacture to ascertain whether the dosimeter complies with certain criteria.

3.2 Acceptance Tests

Contractual tests carried out on a dosimeter of a particular type before the dosimeters are put into service for the first time. The tests are intended to demonstrate that every dosimeter in a consignment conforms with its specification.

3.3 Supplementary Tests

Tests intended to provide supplementary information on certain characteristics of the dosimeters. Usually, such tests are required when the dosimeter is to be used under abnormal conditions which are outside those specified in this standard. Such tests should be agreed upon by the manufacturer and user.

4. Mechanical Characteristics of the Monitor

4.1 Size

The dimensions should not exceed 15-cm length, 3-cm depth, and 10-cm width, excluding any clip or retaining device.

4.2 Mass

The mass should not exceed 200 g.

4.3 Case

The case should be smooth, rigid, shock resistant, and dust- and moisture-proof. Means shall be provided for fixing the dosimeter to clothing, e.g., a strong clip, a ring, or a lanyard. Due regard should be given to the necessary orientation of the detector and alarm indicators.

4.4 Switches

If external switches are provided, these shall be adequately protected from accidental or unauthorized operation. Operation of any switches provided shall not interfere with the integrating function of the dosimeter. Switches should be operable through a plastic bag, if used for contamination or moisture control, and with gloved hands.

5. General Characteristics

5.1 Scale Markings

The indication for direct-reading dosimeters shall be digital (non-analogue) and shall be shown in units of dose equivalent or dose equivalent rate, for example, millisieverts (mrem) or millisieverts/hour (mrem/hour), respectively. The display shall be clearly visible and be easy to read by the wearer. The display shall also indicate the quantity being measured, clearly differentiating indicated values that apply to deep or shallow dose equivalent ($H_p[10]$ and $H_p[0.07]$).

5.2 Dosimeter Markings

The reference point for calibration and test purposes shall be indicated on the outside of the dosimeter (see subclause 2.7). The reference orientation with respect to the wearer shall also be marked on the dosimeter.

5.3 Protection Against Radioactive Contamination and Other Hostile Environments

In designing the dosimeter, consideration shall be given to minimizing the retention of contamination and to the ease of removing any contamination. A dosimeter may be provided with an additional cover to protect it from becoming contaminated and to protect it from other hostile environments. If fitted with a protective cover, the dosimeter shall still conform to the requirements of this standard.

5.4 Dose Equivalent Rate and Dose Equivalent Ranges

For most applications, the dose equivalent rates to be measured by the dosimeters are within the range from 0.1 mrem/h to 1000 rem/h (1 μSv/h to 10 Sv/h) for x, gamma, and beta radiations.

Likewise, the dose equivalents to be measured are within the range 0.1 mrem to 100 rem (1 μSv to 1 Sv) for x, gamma, and beta radiations.

5.5 Effective Range of Measurement or Indication

The effective range of measurement shall not be less than from the first non-zero indication in the second least significant digit up to the maximum indication on each range. (For example, for a display with a maximum indication of 199.9, the effective range must extend from 1.0 to 199.9).

Where more than one detector is used for measurement over the complete range (for either the photon or beta particles), automatic switching shall be provided between the detectors. The tests of this standard shall be performed for all detectors. Where the dosimeter has range-change facilities, these shall also be automatic.

5.6 Presetable Alarm Levels

It shall not be possible to set alarm levels (dose, dose rate) by external switches on the dosimeter. The alarm levels should either be set by the associated readout system, or it should be possible to inhibit unauthorized change of alarm levels by an electronic or mechanical system preventing unauthorized access to the alarm levels.

5.6.1 Dose Equivalent Alarms

Either it shall be possible to set this alarm for both $H_p(10)$ and $H_p(0.07)$ to any value over the complete effective range of measurement of the dosimeter, or it shall be possible to set the alarm to at least one value in each decade of this range (for example, 0.3, 3, 30, 300 mrem and 3 and 30 rem [3 μSv, 30 μSv, 0.3 mSv, 3 mSv, and 30 mSv and 300 mSv]).

5.6.2 Dose Equivalent Rate Alarms

Either it shall be possible to set this alarm to any value over the complete effective range of measurement of the dosimeter, or it shall be possible to set the alarm to at least one value in each decade of this range (for example, 0.3, 3, 30 mrem/h, and 3 and 30 rem/h [3 μSv/h and 3 v/h, 0.3 mSv/h, 3 mSv/h, 30 mSv/h, and 300 m ı]).

5.6.3 Alarm Output

(a) Location
The audible and/or visual alarm shall be located so that when the dosimeter is worn on the body, the alarm can still be heard or seen by the wearer.

(b) Audible Alarm
The frequency should be within the range 1000 to 3000 Hz. Where an intermittent alarm is provided, the signal interval shall not exceed 2 seconds. When the dosimeter is worn in the recommended position on the body, the volume at the user's ears shall exceed 85 dBA. The A-weighted sound level shall not exceed 100 dBA at 30 cm from the alarm source. Where ambient noise levels would make this alarm inaudible, a visual signal or ear phones shall be provided.

(c) The number of audible types of alarms should be minimized, but when multiple alarms exist, they shall be easily differentiated by the user. It shall not be possible to reset the deep dose equivalent ($H_p[10]$) alarm.

5.6.4 Additional Indication

Indication shall be given of operation in conditions in which the accumulation of dose equivalent is not accurate (within the specifications of this standard), e.g., low battery supply, detector failure, and use in fields of high dose equivalent rate.

6. General Test Procedures

6.1 Nature of Tests

Unless otherwise specified in the individual clauses, all the tests enumerated in this standard are to be considered as type tests (see subclause 3.1.1 above). Certain tests may be considered as acceptance tests by agreement between the manufacturer and the user (see subclause 3.2 above). Certain tests may also be used as routine tests (see subclause 3.1.2.)

6.2 Reference Conditions and Standard Test Conditions

Reference conditions are given in the second column of Table 1. Except where otherwise specified, the tests in this standard shall be carried out under standard test conditions given in the third column of Table 1. For those tests not carried out under standard test conditions, the values of temperature, pressure, and relative humidity at the time of test shall be stated and the appropriate corrections made to give the response under reference conditions. The values of any corrections shall also be stated.

For those tests intended to determine the effects of variations in the influence quantities given in Table 1, all other influence quantities should be maintained within the limits for standard test conditions given in Table 1, unless otherwise specified in the test procedure concerned.

Under reference conditions, all influence quantities and dosimeter parameters have values (so-called "reference values") at which the correction factor for the dependence on that influence quantity has a value of 1.0. The phantom for the reference conditions is the reference phantom, i.e. the definition phantom of the calibration quantity. The backscatter of the phantom used for the irradiations may affect the performance of the dosimeter and is hereafter also regarded as an influence quantity.

6.3 Position of Dosimeter for Purpose of Tests

For all tests involving the use of radiation, the reference point of the dosimeter (see subclause 2.7 above) shall be placed at the point where the conventional true value of the quantity to be measured is known and in the orientation with respect to the direction of the radiation field, as indicated by the manufacturer. This shall not be required for test of variation of response with angle of incidence.

6.4 Low Dose Equivalent Rates

For the measurement of low dose equivalent rates, it is necessary to take account of the contribution of background radiation to the dose equivalent rate at the point of test as well as any inherent effects (electronic noise or inherent radioactivity). It is advisable to only use components with a total inherent contribution corresponding to less than 10 μrem/h (0.1 μSv/h).

Table 1. Reference Conditions and Standard Test Conditions

Influence	Reference Conditions	Standard Test Conditions (unless otherwise indicated)
Reference photon radiation	^{137}Cs	^{137}Cs
Reference beta radiation	$^{90}Sr/^{90}Y$	$^{90}Sr/^{90}Y$
Reference neutron radiation	^{252}Cf	^{252}Cf
Reference phantom	30 x 30 x 15 cm slab of ICRU tissue	30 x 30 x 15 cm slab of ICRU tissue
Calibration phantom	PMMA phantom	PMMA phantom
Stabilization time	15 minutes	>15 minutes
Ambient temperature	20°C	18° to 22°C[a]
Relative humidity	65%	50% to 75%[a]
Atmospheric pressure	101.3 kPa	86 to 106 kPa[a]
Power supply voltage[b]	Nominal power supply voltage	Nominal power supply voltage ±1%
Power supply frequency[b]	Nominal frequency	Nominal frequency ±1%
Power supply waveform[b]	Sinusoidal	Sinusoidal with total harmonic distortion lower than 5%
Gamma radiation background	Absorbed dose rate in air of 0.1 μGy/h or less if practical	Ambient absorbed dose rate in air or ≤0.25 μGy/h
Angle of incidence or radiation	Calibration direction given by manufacturer	Direction given ±5°
Electromagnetic field of external origin	Negligible	Less than the lowest value that causes interference
Magnetic induction of external origin	Negligible	Less than twice the value of the induction due to the earth's magnetic field
Neutron radiation background	Negligible	Negligible
Orientation of monitor (geotropism)	To be stated by the manufacturer	Stated orientation ±5°
Assembly controls	Set up for normal operation	Set up for normal operation
Contamination by radioactive elements	Less than Reg. Guide 1.86 (NRC 1974) values	Less than Reg. Guide 1.86 (NRC 1974) values

(a) The actual values of these quantities at the time of test shall be stated. These values are applicable for temperate climates. In hotter or colder climates, the actual value of the quantities at the time of test shall be stated. Similarly, a lower limit of pressure of 70 kPa may be permitted at high altitudes.
(b) Only for readout systems which are operated from the mains.

6.5 Statistical Fluctuations

For any test involving the use of radiation, if the magnitude of the statistical fluctuations of the indication is a significant fraction of the variation of the indication permitted in the test, then sufficient readings shall be taken to ensure that the mean value of such readings may be estimated with sufficient accuracy to determine whether the requirements for the characteristic under test are met. Specific guidance on the required number of readings is given in Part 2, Appendix B.

6.6 Reference Radiations and Calibration Phantom

Unless otherwise specified in the individual methods of test, all tests involving the use of radiation shall be carried out with the specified type of radiation (see Table 2). The production and conditions of use of the radiation sources shall be in accordance with the following recommendations: ISO 4037 - Part 1, ISO 4037 - Part 2 (ISO 1994b) and ISO 6980. (ISO (1994a)

6.6.1 Reference Gamma, Beta, and Neutron Radiation

(a) The reference gamma radiation shall be that provided by the nuclide ^{137}Cs.

(b) The reference beta radiation shall be that provided by a $^{90}Sr/^{90}Y$ source.

(c) The reference neutron radiation shall be that provided by a ^{252}Cf source or ^{241}Am-Be.

6.6.2 Calibration Phantom

For all the tests involving the use of radiation, unless stated otherwise in the specific test clause, the dosimeters shall be irradiated on a standard polymethylmethacrylate (PMMA) slab calibration phantom, as defined in ANSI N13.11 (ANSI 1993). This calibration phantom closely represents the human torso with regard to backscatter of the incident radiation. It is a PMMA slab phantom of 30 cm x 30 cm x 15 cm depth, with a density of 1.19 g/cm^3 and a mass composition of 8.05% H, 59.99% C, and 31.96% O. The conversion coefficients given in this standard from air kerma or absorbed dose to personal dose equivalent relate to the ICRU reference phantom.

When the PMMA slab phantom is used in the tests specified in this standard, no correction factors shall be applied to correct for any differences in backscatter relative to ICRU tissue.

Note: Recently, the ISO has selected a water slab phantom as the standard for irradiations. There are differences in backscatter at low energies between the two phantoms, and although the water phantom is a better representation of ICRU tissue, to promote consistency with ANSI N13.11, the PMMA phantom was selected.

7. Radiation Performance Requirements and Tests

7.1 Relative Intrinsic Error

7.1.1 Requirements

Under standard test conditions, with the calibration controls adjusted according to the manufacturer's instructions, the relative intrinsic error of the dosimeter shall not exceed $\pm 10\%$ over the whole effective range of dose equivalent measurement and shall not exceed $\pm 15\%$ over the whole effective range of dose equivalent rate measurement. For the lowest decade of dose equivalent rate, a relative intrinsic error $\pm 30\%$ shall not be exceeded. These requirements are applicable for both photon and beta radiations and for both deep and shallow dose.

Table 2. Tests Performed with Variations of Influence Quantities, Applicable for Both the Measurement of $H_p(10)$ and $H_p(0.07)$

Characteristic Under Test or Influence Quantity	Range of Values of Influence Quantity	Limits of Variation of Indication	Method of Test (Subclause from this Standard)
Relative intrinsic error	Effective range of measurement	Dose equivalent ±15%(1,4) Dose equivalent rate ±20%(1,3,4)	7.1.2
Response time	5 s	< ±10%	7.2.1.2
Accuracy of alarm levels	All settings	Dose equivalent ±15%(1,4) Dose equivalent rate ±20%(1,4)	7.3.2.2 7.3.1.2
Radiation energy			
Beta	$>E_{max}$ = 0.25 MeV	±30%(4)	7.4.2
Photon	20 keV to 1.25 MeV	±30%(4)	7.4.4
	100 keV to 1.25 MeV	±30%(4)	7.4.4
	100 keV to 1.25 MeV	±30%(4)	7.4.4
	6 MeV	-50% to +100%(2,4)	7.4.4
Angle of incidence			
Beta	0° to ±60°	$H_p(0.07)$ ±30% for $^{90}Sr/^{90}Y$	7.5.2
Photon	0° to ±60°	$H_p(10)$ ±20% for ^{137}Cs	7.5.4
		$H_p(10)$ ±50% for ^{241}Am	7.5.4
Retention of reading	8 hours	± 2%	7.6.2 (1)
	24 hours after loss of principal power supply	± 2%	7.6.2 (1)
Dose equivalent rate dependence	Up to 1 Sv/h	< ±10%	7.7.2
Response to neutrons	^{252}Cf or ^{241}Am-Be	< 1%	7.10.2
Overload	10 times range maxima	Indication > full scale	7.8.2
Response to mixed fields	^{137}Cs and ^{204}Tl	< 1%	7.9.2
Power supply voltage			
Primary batteries	After 2000 h continuous use	±15%(5)	8.1.4
Secondary batteries	After 10h continuous use	±15%(5)	8.1.4
Drop tests	1.5 m	±10%	9.1
Vibration test	3 g_n over frequencies of 10 to 33 Hz	±15%	9.2.2
Ambient	0°C to +55°C	±15%(4)	10.1.2
Temperature 3)	-10°C to +40°C	±10%(4)	10.1.2
Temperature shock	-25°C to +55°C	±20%(4)	
	-10°C to +50°C	±15% relative to + 20°C	10.1.2

Table 2. Tests Performed with Variations of Influence Quantities, Applicable for Both the Measurement of $H_p(10)$ and $H_p(0.07)$ (Continued)

Characteristic Under Test or Influence Quantity	Range of Values of Influence Quantity	Limits of Variation of Indication	Method of Test (Subclause from this Standard)
Relative humidity	40% to 95% at +35°C	±10%(4)	10.2.2
Atmospheric pressure	(7)	(7)	10.3
Electromagnetic field of external origin	100 V/m at 100 kHz to 500 MHz	±10%	10.5.2
	1 V/m at 500 MHz to 1 GHz	±10%	10.5.2
Magnetic field of external origin	60 A/m at 50 to 60 Hz	±10%	10.6.2
Electrostatic	6 kV, 2 mJ	±10%	10.7.2
Light expousre	Halogen lamp 10,000 ft-candles	No change permitted	10.8.2
Splash/rain resistance	0.6 cm rain/h	No change permitted	10.10.2
Clip force		Support dosimeter's own weight	10.11.2
Light flash	1000 W/s ten times	No change permitted	10.9.2

(1) This error is additional to the uncertainty associated with the determination of the conventional true dose equivalent rate (see subclause 8.1.3).

(2) This additional requirement is applicable only to monitors used for measuring doses in the vicinity of power reactors producing 6-MeV gamma radiation from ^{16}N.

(3) For the lowest decade or scale of the dose equivalent rate, ±30% is applicable.

(4) Of the indication under standard test conditions.

(5) Of the initial indication.

(6) Monitors intended for use in temperate climates. In hotter or colder climates, other limits may be specified. For monitors intended for operation at very low temperatures, means of heating the batteries may be provided.

(7) No general specification. Range of values of influence quantities and limits of variation of indication to be specified if required.

7.1.2 Determination of Relative Intrinsic Error

(a) Source to be Used
For purposes of this test, the conventional true value of the personal dose equivalent, or rate, at the point of test shall be known with an uncertainty of less than $\pm 5\%$ for photon radiation and less than $\pm 10\%$ for beta radiation. The test shall be performed with sources of ^{137}Cs and $^{90}Sr/^{90}Y$ irradiating the dosimeter on the calibration phantom (see subclause 6.6.2) in the calibration direction. More than one ^{137}Cs source or $^{90}Sr/^{90}Y$ source may be required in order to cover the complete range of values indicated by the dosimeter. In this case, the relative activities of the sources used shall be such that the useful range of dose equivalent (rates) obtainable from each source at the point of test (by alteration of the distance between the source and the detector of the dosimeter) overlaps the useful range of dose equivalent (rates) obtainable from at least one other of the sources used. In this way, the dose equivalent (rates) obtainable from all sources used may be calibrated in terms of that from one particular source, which may be considered as the reference source.

Where possible, dose equivalent rates of < 100 mrem/h (< 1 mSv/h) should be used for determining the relative intrinsic error for dose-equivalent-measuring dosimeters. Where for practical reasons this is not possible, e.g., exposure times would be too long, corrections for nonlinearity at these higher dose equivalent (rates) shall be applied, if required. Subclause 7.7 describes the tests for determining dose equivalent rate dependence of dose-equivalent-measuring dosimeters.

(b) Tests to be Performed
A type test shall be carried out on at least 15 dosimeters of the series to determine the calibration error and on five dosimeters to determine the dose and dose rate linearity error. The calibration error test shall be performed on all dosimeters used in the type testing. Routine calibration tests shall be performed on each dosimeter. The tests shall be performed with beta reference sources and with photon reference sources as appropriate.

(c) Calibration Error
Fifteen dosimeters shall be irradiated on the phantom for one value of dose equivalent and one value of dose equivalent rate. The test for dose equivalent rate shall be made at 50-150 mrem/h (0.5-1.5 mSv/h) and the dose equivalent test shall be made at 20-50 mrem (0.2-0.5 mSv).

(d) Linearity Error
Five or more dosimeters shall be irradiated on the phantom for at least three values in each decade of dose equivalent or dose equivalent rate. These shall be at approximately 20%, 50%, and 80% of each full decade reading.

7.1.3 Interpretation of the Results

If the values of relative intrinsic error fall within the following limits, the requirements of subclause 7.1.1 can be considered to be met.

(a) Calibration Error
The relative error of indication for calibration, I_{cal}, for each measurement must fall within $\pm 10\%$. The error of indication shall be recorded for each dosimeter and used, as appropriate, in subsequent type tests. The mean error of indication, I_{cal}, and its coefficient of variation, V, shall be

calculated. The coefficient of variation, V_{cal}, shall meet the following criterion:

$$\frac{2V_{cal}}{H_t} \leq 0.1$$

(b) Linearity Error
No single value of the error of indication, $I_{lin} - I_{cal}$, shall exceed $\pm 10\%$ for dose equivalent.

For dose equivalent rate, no single value of the error of indicator, $I_{lin} - I_{cal}$, shall exceed $\pm 15\%$ or for the lowest decade $\pm 30\%$.

Note: I_{cal} must be less than 10%. It is assumed that there is no uncertainty associated with the conversion coefficients used to convert photon air kerma or beta absorbed dose to personal dose equivalent. The above requirements are applicable to any associated readout system supplied.

7.2 Response Time

These tests shall be performed separately for photon radiation and beta radiation and for both the measurement of $H_p(10)$ and $H_p(0.07)$.

7.2.1 Dose Equivalent Rate Dosimeters

7.2.1.1 Requirements

When the dosimeter is subjected to a step increase or decrease in dose equivalent rate within the effective range of the dosimeter, the readout shall indicate the new dose equivalent rate with an error of less than 10% within five seconds. This shall apply for dose equivalent rates greater than 1 mrem/h (10 μSv/h).

7.2.1.2 Method of Test

For this test, place the dosimeter in a photon field with a dose equivalent rate > 10 μSv/h and allowed to stabilize. Take the reading, $\dot{H}_{low}$. Then, increase the dose equivalent rate nearly instantaneously by approximately a factor of 10, with readings recorded continuously until the dosimeter stabilizes at the new higher dose equivalent rate. The change to 90% of the high reading, $\dot{H}_{high}$, shall take less than five seconds. Next, reduce the dose equivalent rate nearly instantaneously to the initial value $\dot{H}_{low}$. The dosimeter reading shall be within 10% of the new reading $\dot{H}_{low}$ within five seconds.

7.3 Accuracy of Alarm to Set Value

These tests shall be performed separately for photon radiation and for beta radiation and for the measurement of both $H_p(10)$ and $H_p(0.07)$.

7.3.1 Dose Equivalent Rate Dosimeters

7.3.1.1 Requirements

When the dosimeter is subjected to dose equivalent rates of 0.80 of the dose equivalent rate alarm set point for 10 minutes, the alarm shall not be activated for more than 10% of the period of the test. Similarly at a dose equivalent rate of 1.2 of the set alarm level, this alarm shall be activated for 90% of the observation time. When the unit is subjected to dose equivalent rates of 1.20 of the dose equivalent rate alarm set point the alarm should activate within five seconds or within a time such that the product of this time and the dose equivalent rate of the alarm point is less than 1 mrem (10 μSv).

At least two tests shall be carried out, one with the alarm set to near the maximum range of indication and one with the alarm set to near the maximum value of the second least significant decade. Allowance shall be made for the difference in calibration versus the conventional true dose equivalent rate to which the dosimeter is subjected. Where this is I_{cal}%, the dose equivalent rates used

shall be: 0.80 (1 - I_{cal}/100) and 1.20 (1+I_{cal}/100) of the dose equivalent alarm set point.

7.3.1.2 Method of Test

For this test, place the dosimeter on the calibration phantom. For 10 minutes, expose the dosimeter to the lower dose equivalent rate: [0.80 (1-I_{cal}/100) (the set alarm level)]. During this time, the alarm shall not be activated for more than 10% of the time. Tests shall be performed on 15 dosimeters.

Expose the dosimeter to the upper dose equivalent rate: [1.2(1+I_{cal}/100) (the set alarm level)]. Measure the time it takes for the alarm to activate. This time shall be less than 5 seconds, or this time multiplied by the dose equivalent rate shall be less than 1 mrem (10 μSv). Over the whole period of the test, the alarm shall be activated for at least 90% of the time.

7.3.2 Dose Equivalent Dosimeters

7.3.2.1 Requirements

When the dosimeter is subjected to a dose of 0.85 of the dose equivalent alarm set point, no alarm shall be given. When the dosimeter is subjected to a dose equivalent of 1.15 of the dose equivalent alarm set point, the alarm shall sound.

At least two tests shall be carried out, one for an alarm set point near the maximum range of the dosimeter and one near the maximum value of the second least significant decade.

7.3.2.2 Method of Test

For this test, place the dosimeter on the calibration phantom. The dosimeter shall be reset and then subjected to a conventional true dose equivalent rate such that the alarm will not occur for at least 100 seconds. Increase the time of exposure of the dosimeter until the alarm occurs. The following criterion shall be met: The quotient [(the alarm set point in mrem (Sv)) (3600)] ÷ [(the dose equivalent rate used in mrem/h (Sv/h)) (time in seconds)] shall lie within the range [0.85 (1 - I_{cal}/100)] to 1.15 (1+I_{cal}/100)], where I_{cal} is the percentage error in the calibration to the conventional true dose equivalent rate used.

7.4 Variation of Response with Radiation Energy

Testing should be performed on five dosimeters.

7.4.1 Requirements - Beta Radiation

The response in the calibration direction to incident beta radiation of energies E_{max} = 0.78 MeV and E_{max} = 2.2 MeV shall be within ±30% for all dosimeters. The response at E_{max} = 0.25 MeV and E_{max} = 3.5 MeV shall be stated.

7.4.2 Method of Test

For this test, place the dosimeter on the calibration phantom. The following energies selected from the list of beta reference radiations specified in ISO 6980 (ISO 1994a) shall be used:

- ^{204}Tl (E_{max} = 0.78 MeV)
- ^{90}Sr/^{90}Y (E_{max} = 2.2 MeV)
- ^{106}Ru/^{106}Rh (E_{max} = 3.5 MeV).

The results shall be expressed as the ratio of the indicated value $H_p(10)$ to the conventional true value of the personal dose equivalent (rate) of the deep dose and the ratio of the indicated value of the shallow dose to the conventionally true value of the shallow dose equivalent (rate) $H_p(0.07)$ of each radiation energy. In principle, it is desirable that this test be performed at the same dose equivalent (rate) for each radiation energy. In practice, this

may not be possible; in which case, the indicated dose equivalent (rate) at each radiation energy shall be corrected for the relative intrinsic error (interpolated if necessary) at that indicated dose equivalent (rate) for the reference beta radiation source (see subclause 7.1.2).

7.4.3 Requirements - Photon Radiation

The useful energy range for photons shall be stated and graphically indicated and shall be the continuous interval of photon energies over which the following condition is met for all dosimeters tested:

$$0.7 \leq \frac{(\bar{r}_{en_i}/CTV_{en_i})}{(\bar{r}_{ref}/CTV_{ref})} \leq 1.3$$

where $\bar{r}_{en_i}$ = the mean indicated reading to photon radiation of energy i

$\bar{r}_{ref}$ = the mean indicated reading to the reference photon radiation (^{137}Cs)

CTV_{en_i} = the conventially true value of the photon radiation of energy i

CTV_{ref} = the conventially true value of the reference photon radiation (^{137}Cs).

Two conditions are recognized and denoted by the following categories:

- Category I (high-energy spectra): Requirements noted above shall be met for 100 keV to 1.25 MeV.

- Category II (low-energy spectra): Requirements noted above shall be met for 20 keV to 1.25 MeV.

Note: If the dosimeter is to be used for measuring doses in the vicinity of nuclear reactor installations producing gamma radiation with energies up to 10 MeV, its response in terms of $H_p(10)$ at the appropriate high energy shall not differ by more than -50% to +100% from its response to the ^{137}Cs reference source.)

7.4.4 Method of Test

For this test, place the dosimeter on the calibration phantom. Each test shall be performed with a minimum of five dosimeters. At least the following energies selected from the list of photon reference radiations specified in ANSI N13.11 (ANSI 1993) should be used: filtered x-rays M30, M60, M100, M150, H150; and gamma radiation from ^{241}Am (60 keV), ^{137}Cs (662 keV), and ^{60}Co (1.17 and 1.33 MeV).

As required above, additional tests shall also be performed with 6-MeV gamma radiation. The results shall be expressed as the ratio of the indicated values of $H_p(10)$ and $H_p(0.07)$ to their corresponding conventionally true value of the personal dose equivalent (rate) $H_p(10)$ and $H_p(0.07)$ for each radiation energy. At 6 MeV, the conventionally true values should also be at depths of 10 and 0.07 mm. Whenever necessary, the dosimeter should be exposed with the series of additional build-up "caps" of tissue equivalent material so that the response of the dosimeter can be determined under conditions of transient electronic equilibrium.

In principle, it is desirable that these tests be performed at the same dose equivalent (rate) for each radiation energy. In practice, this may not be possible, in which case the indicated dose equivalent (rate) at each radiation energy shall be corrected for the relative intrinsic error (interpolated if necessary) at that indicated dose equivalent (rate) for the reference gamma radiation source (see subclause 7.1.2).

7.5 Variation of Response with Angle of Incidence of Radiation

7.5.1 Requirements - Beta Radiation

For two planes, one horizontal and one vertical through the front face of the dosimeter (see Figure 1), the ratio of the dosimeter reading at $\alpha = \pm 20°$, $\pm 40°$, and $\pm 60°$ (relative to the $\alpha = 0°$ reading) shall be within $\pm 30\%$ of the ratios given in Table A.1 (Part 2, Appendix A) for the $^{90}Sr/^{90}Y$ source for both the measurement of $H_p(10)$ and $H_p(0.07)$. The test shall be performed on five dosimeters and all shall comply with the requirements.

7.5.2 Method of Test

Place the dosimeter on the calibration phantom in its normal position of use, with the $^{90}Sr/^{90}Y$ source of radiation in the reference direction for calibration purposes as specified by the manufacturer. Note the reading in this position. For the two planes, horizontal and vertical, rotate the dosimeter and its phantom in both directions to angles of $\pm 20°$, $\pm 40°$, and $\pm 60°$ from normal incidence. Take the readings shall be taken at all these orientations and calculate the ratios at these angles relative to 0°. These ratios shall be within $\pm 30\%$ of the appropriate values in Table 1 (above).

7.5.3 Requirements - Photon Radiation

For two planes, one horizontal and one vertical through the front face of the dosimeter (see Figure 1), the ratio of the dosimeter reading at $\alpha°$ relative to the reading at $\alpha = 0°$ for angles from 0° to +60° and -60° shall be within $\pm 20\%$ of the ratios given in Table A.2 (Part 2, Appendix A) for ^{137}Cs and within $\pm 50\%$ of the ratios for H150 (Category I) or M100 (Category II) for both $H_p(10)$ and $H_p(0.07)$. The test shall be performed on five dosimeters and all shall comply with the requirements.

7.5.4 Method of Test

The test shall be performed for both the photon radiation from H150 (Category I) or M100 (Category II) and from ^{137}Cs (662 keV). The production and conditions of use of the radiation sources should be in accordance with the recommendations of ANSI N13.11 (ANSI 1993).

Place the dosimeter on the calibration phantom with the source of radiation in the reference direction for calibration purposes, as specified by the manufacturer. Note the reading in this position. For two planes, horizontal and vertical, rotate the dosimeter and the phantom to angles of $\pm 20°$, $\pm 40°$, and $\pm 60°$. Take the readings at all these orientations and calculate the ratios at these angles relative to the reading at 0°. These ratios shall be within $\pm 20\%$ of the ratios in Table A.2 (Part 2, Appendix A) for ^{137}Cs and within $\pm 50\%$ of the ratios in Table A.2 for the x-ray radiations.

7.6 Retention of Dose Equivalent Reading

This applies to dosimeters that measure dose equivalent, i.e., not to dose equivalent rate measurements. These requirements shall be tested separately for photon radiation and for beta radiation and for both the measurement of $H_p(10)$ and $H_p(0.07)$.

7.6.1 Requirements

(a) At the end of any exposure period, the reading of the dosimeter and that indicated by any associated readout system if supplied should not change by more than $\pm 2\%$ or a single change in the least significant digit, whichever is the greatest, over the next 8 hours.

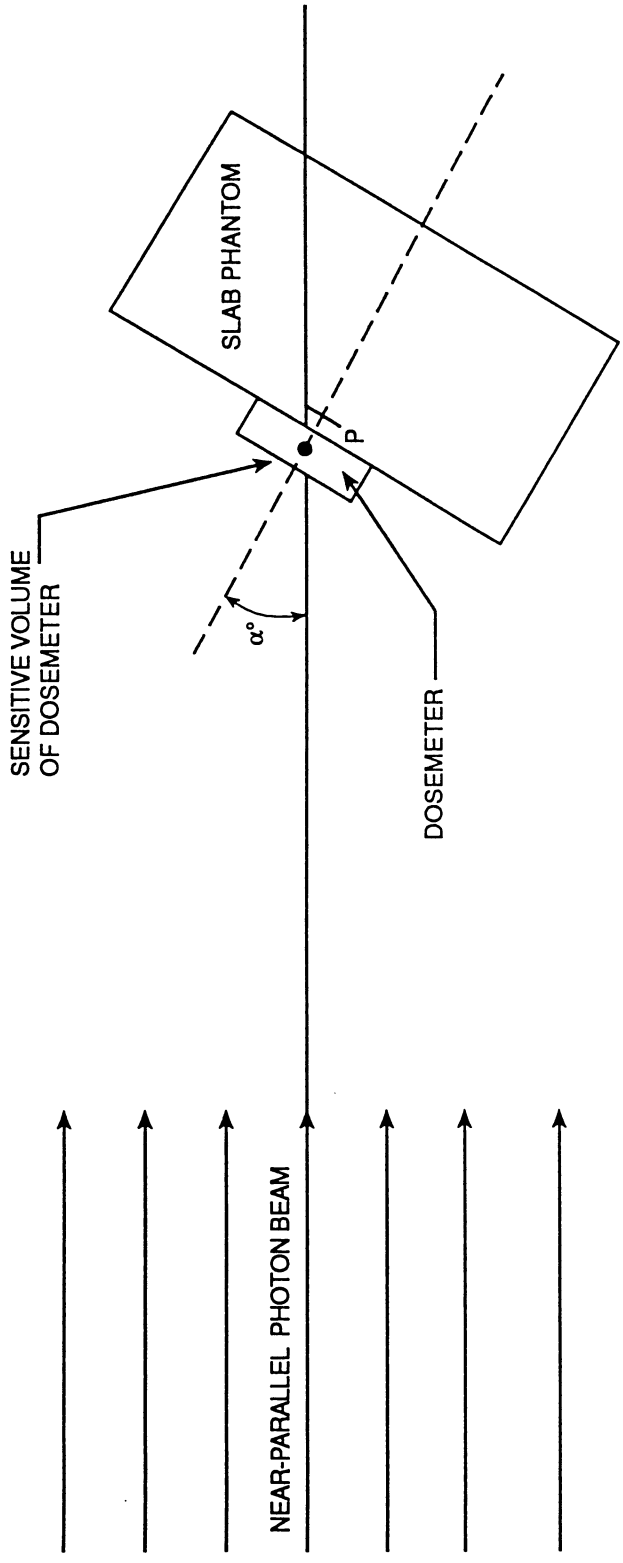

Figure 1. Arrangement for the Calibration of Personal Dosemeters at Angle α°

(b) After 24 hours from the loss or interruption of the principal voltage supply the integrated dose equivalent measured by the dosimeter, and from any associated readout system, prior to this loss or interruption shall not change by more than $\pm 2\%$, or a change in the least significant digit, upon replacement of the principal voltage supply.

7.6.2 Method of Test

(a) This test need not be made with the dosimeter on a phantom. Expose the dosimeter to a source of radiation that gives a dose equivalent sufficiently high that any subsequent accumulation due to background radiation can be neglected. Cease the irradiation immediately when the integration period is completed and note the displayed reading. Every hour up to 8 hours from the end of the integration period, read the display. None of these eight readings should differ by more than a single digit or by more than $\pm 2\%$ compared with the initial reading, whichever is the greatest.

(b) Expose the dosimeter to a source of radiation giving a dose equivalent sufficiently high that any subsequent accumulation due to background radiation can be neglected. Note the display reading. Remove the principal batteries from the dosimeter. (When the principal battery fails or is removed, the reading may disappear or be replaced by some instruction). After 24 hours, replace or recharge the principal batteries of the dosimeter. The reading of dose equivalent obtained shall not differ by more than $\pm 2\%$ from the last value obtained before the principal batteries were removed, or there should be no change in the least significant digit.

7.7 Dose Equivalent Rate Dependence of Dose Equivalent Dosimeters

7.7.1 Requirements

The response of the dosimeter shall be such that its dose equivalent relative intrinsic error remains within $\pm 10\%$ for all dose equivalent rates up to 1000 rem/h (10 Sv/h).

This requirement shall be tested separately for both photon radiation and beta radiation and for the measurement of both $H_p(10)$ and $H_p(0.07)$. Five randomly selected dosimeters should be tested.

7.7.2 Method of Test (Type Test Only)

This test need not be made with the dosimeter on a phantom. Determine the relative intrinsic error of the dosimeter at 80% of each decade when the dosimeter is exposed to a reference source at approximately the following dose equivalent rates: 0.1 rem/h (1 mSv/h), 1.0 rem/h (10 mSv/h), 10 rem/h (100 mSv/h), 100 rem/h (1 Sv/h), and 1000 rem/h (10 Sv/h).

Since at the lower dose equivalents the exposure times will be too short for the higher rates, while at high dose equivalents the exposure times will be too long for the lower rates, these tests should exclude any exposures involving times of less than 10 seconds or exceeding 10 hours.

However, since the dosimeter may be worn operationally in areas of transient high dose equivalent rates, the dosimeter shall be tested for short exposure under these conditions. The dosimeter shall be exposed for 5 seconds at approximately 100 mrem/h (1 Sv/h) and it shall then read within $\pm 10\%$ of the calculated dose equivalent for 5-seconds irradiation.

7.8 Overload Characteristics

7.8.1 Requirements

These requirements shall be separately tested for both photon radiation and for beta radiation and for both the measurements $H_p(10)$ and $H_p(0.07)$. Tests shall be performed on five dosimeters.

For dose equivalent (rates) greater than that corresponding to the maximum value of the upper decade and up to 10 times the maximum indication, the dosimeter shall be "off-scale" at the higher end of the scale and shall remain so while in that radiation field. The manufacturer shall state the time taken for dosimeters that indicate dose equivalent rate to return to the appropriate "on-scale" dose equivalent rate reading, following their irradiation to this over exposure. For the dose equivalent irradiation, the indication shall remain "off-scale" upon removal from the radiation field. For dose equivalent dosimeters where the dose equivalent rate during integration exceeds the effective range of measurement (see subclause 5.5), an overload condition shall be indicated and remain until reset.

7.8.2 Method of Test

7.8.2.1 Dose Equivalent Dosimeters

The dosimeter shall be irradiated to a dose equivalent of 10 times the maximum range value. The indication of the dosimeter shall remain at the maximum of the range and an overload indication shall be displayed.

7.8.2.2 Dose Equivalent Rate Dosimeter

The dosimeter shall be irradiated, for example, for 10 minutes, to a dose equivalent rate of 10 times the maximum range value. The indication of the dosimeter shall remain at the maximum of the range and an overload indication shall be displayed.

Upon removal of this "off-scale" dose equivalent rate, the time shall be measured for the indication of the dosimeter to return to an appropriate "on-scale" dose equivalent rate.

7.9 Response to Mixed Radiation Fields

7.9.1 Requirements

The dosimeter's response for the measurement of $H_p(10)$ and $H_p(0.07)$ should be independent of each of these separate measurements and the measurement of weakly and strongly penetrating radiation should be additive.

7.9.2 Method of Test

For this test, place the dosimeter on the ISO calibration phantom.

(a) Expose the dosimeter to a ^{137}Cs source at 15° to the reference direction at >100 mrem/h (>1 mSv/h). Note the dose equivalent readings $H_p(10)_{Cs}$ and $H_p(0.07)_{Cs}$ over a fixed period. Reset the dose display to zero.

(b) Remove the ^{137}Cs source, and expose the dosimeter to the beta radiation from a ^{204}Tl source positioned at -15° to the reference direction at >100 mrem/h (>1 mSv/h). Note the dose equivalent readings $H_p(10)$ and $H_p(0.07)$ over the same fixed period as used in (a) above. Reset the dose display to zero.

(c) Expose the dosimeter to both the ^{137}Cs and ^{204}Tl sources using the same geometries and exposure times as in (a) and (b) above. Note the dose equivalent readings $H_p(10)_{Cs+Tl}$ and $H_p(0.07)_{Cs+Tl}$. These combined readings should equal the addition of corresponding readings taken in (a) and (b), i.e., $H_p(10)_{Cs+Tl} = H_p(10)_{Cs} + H_p(10)_{Tl}$ and $H_p(0.07)_{Cs+Tl} = H_p(0.07)_{Cs} + H_p(0.07)_{Tl}$.

7.10 Response to Neutron Radiation

Dosimeters shall be designed so as to limit, as far as practicable, the influence of neutron radiation.

7.10.1 Requirements

(a) The response to neutrons shall be less than 1%.

(b) The response to neutrons shall not change the dosimeter's response to photon radiation by more than 1%.

7.10.2 Method of Test

For these tests, it is not necessary to expose the dosimeter on a phantom.

(a) Expose the dosimeter to either a ^{241}Am/Be source or to a ^{252}Cf source (ISO 8529 [ISO 1989]). Corrections shall be made for the gamma emission from the source being used. For example, the gamma personal dose equivalent $H_p(10)$ from the neutron source can be determined using a Geiger-Mueller counter or TLD-700. The neutron source shall be positioned at $+45°$ to the reference direction. The exposure time used should be sufficient to give a neutron dose equivalent, $H_p(10)$, of about 100 mrem (1 mSv). At the end of this exposure time, note the two readings $H_p(10)_n$ and $H_p(0.07)_n$. Neither of the two readings should exceed 1 mrem (10 μSv). Reset both readings.

(b) Expose the dosimeters to a ^{137}Cs source at $-45°$ to the reference direction. The source or the source/detector distance shall be closer such that after the same exposure time as used for the neutron exposure in (a), the delivered dose is 100 mrem (1 mSv). Note the two readings $H_p(10)_{Cs}$ and $H_p(0.07)_{Cs}$. Reset both readings.

(c) Expose the dosimeter to both the ^{137}Cs and neutron sources using the same geometries and exposure time as in (a) and (b) above. At the end of this exposure time, note the two readings $H_p(10)_{Cs+n}$ and $H_p(0.07)_{Cs+n}$. These two readings should not differ by more than 1% from the $H_p(10)_{Cs}$ and $H_p(0.07)_{Cs}$ readings.

8. Electrical Performance Requirements and Tests

8.1 Power Supplies - General Battery Operation

Facilities shall be provided for testing the battery under maximum load during use. In addition, indication shall be provided that at least 8-hours operational life is available at about 10 mrem/h (0.1 mSv/h) under normal conditions, including 1 minute of alarm operation. This indication may be achieved by means of the external readout system. Also, provision shall be made for indicating when the battery condition is no longer adequate for the performance of the dosimeter to meet the requirements of this standard. Primary batteries may be connected in any desired manner. The correct polarity shall be clearly indicated on the dosimeter by the manufacturer.

8.2 Requirements for Primary Batteries

These requirements shall be separately tested for photon radiation, for beta radiation, and for both measurements $H_p(10)$ and $H_p(0.07)$.

(a) When power is supplied by primary batteries, the capacity of these shall be such that, after 2000 hours of continuous operation under standard test conditions, the response of the dosimeter shall not change by more than $\pm 15\%$, other functions also remaining within specifications. The dosimeter shall

meet this specification in fields of 1 to 10 mrem/h (0.012 to 0.2 mSv/h).

(b) Immediately after new batteries are fitted, the dosimeter shall be capable of operating for at least 15 minutes with the alarm sounding and with the visual alarm displayed.

(c) The primary batteries shall not be able to be removed without the use of a special tool.

8.3 Requirements for Secondary Batteries

These requirements shall be separately tested for photon radiation and for beta radiation and for both measurements $H_p(10)$ and $H_p(0.07)$.

(a) When power is supplied by secondary batteries, the capacity of these shall be such that after at least 10 hours of continuous use, the response of the dosimeter shall not change by more than $\pm 15\%$, other functions also remaining within specifications. The dosimeter shall meet this specification in fields of 1 mrem/h to 10 mrem/h (0.01 to 0.1 mSv/h).

(b) Immediately upon recharge, the dosimeter shall be capable of operating for at least 15 minutes with the alarm sounding and with the visual alarm displayed. It shall be possible to fully re-charge the batteries from the main supply within 12 hours.

8.4 Method of Test (Primary and Secondary Batteries)

New primary batteries or fully charged secondary batteries of the type indicated by the manufacturer shall be used for each of these tests.

(a) Expose the dosimeters to a radiation field sufficient to provide a suitable indication on the dosimeter. Leave the dosimeter working in this field for a period or periods given in subclauses 8.2(a) and 8.3(a) as appropriate, and note the readings $H_p(10)$ and $H_p(0.07)$ at the end of each period. Each reading must conform with the requirements of subclause 8.2(a) or 8.3(a) as appropriate.

(b) Set the dosimeter to alarm on its lowest dose equivalent and/or dose equivalent rate setting. Expose the dosimeter to a dose equivalent rate of between 1 to 10 mrem/h (0.01 to 0.1 mSv/h) until the alarm sounds and the visual alarm is displayed. Then, after 15 minutes further exposure, observe if the alarm still sounds and if the visual alarm is still displayed.

8.5 Test for General Requirement of 8-Hours Operation (See Subclause 8.1)

Expose the dosimeter to a source of radiation until the additional indication that 8-hours operational life is available. The instrument should then be zeroed using the appropriate device (e.g., readout system). After 7 hours, 59 minutes of continuous operation under standard test conditions, but exposed to a dose equivalent rate of about 10 mrem/h (0.1 mSv/h) and with a dose equivalent (or rate) alarm set to operate, the dosimeter response shall not change by more than $\pm 1\%$, and the alarm shall continue to sound after a further minute.

9. Mechanical Performance Requirements and Tests

9.1 Drop

9.1.1 Requirements

The dosimeter shall be able to withstand drops from heights of 1.5 meters onto a concrete surface without affecting its performance, within $\pm 10\%$ (e.g., its reading). Drop tests shall be conducted on each face (six drops) of the monitor, and a type test shall be performed on three dosimeters. The stored dose information for both $H_p(10)$ and $H_p(0.07)$ shall not be lost by these drops. Any physical damage shall be noted.

9.1.2 Method of Test

Expose the dosimeter in a reproducible geometry separately to both an acceptable source of photon radiation and to an acceptable source of beta radiation, these sources having sufficient intensity to minimize the effect of the statistical fluctuations of the dosimeter readings. Then, determine the mean dosimeter readings.

Drop the dosimeter onto each of its six sides from a height of 1.5 meters. Following each drop, observe the dosimeter to determine that the reading did not change, and then return each to the test geometry to test the source response. The dose/dose rate response shall not change more than $\pm 10\%$.

9.2 Vibration Test

9.2.1 Requirements

The mean dosimeter response shall vary not more than 10% (see Table 2) from a set of reference readings following harmonic loadings of 3 g_n applied for 15 minutes in the frequency range of 10 to 33 Hz. The physical condition of dosimeters shall not be affected by this vibration (e.g., solder joints shall hold, nuts and bolts shall not come loose).

9.2.2 Method of Test

Expose the dosimeter in a reproducible geometry separately to both an acceptable source of photon radiation and to an acceptable source of beta radiation, these sources having sufficient intensity to minimize the effect of the statistical fluctuations of the dosimeter readings. Determine the mean dosimeter readings. Then, subject the dosimeter to harmonic loadings of 3 g_n for 15 minutes in each of three orthogonal directions at one or more frequencies in the range from 10 to 33 Hz. After each 15-minute vibration interval, determine the mean dosimeter readings in the same exposure geometry as used initially and compare them to the previbration set of readings.

The dosimeter shall be inspected and the physical condition documented.

10. Environmental Characteristics, Performance Requirements, and Tests

10.1 Ambient Temperature

10.1.1 Requirements

These requirements shall be separately tested for photon radiation, beta radiation, and the measurements of both $H_p(10)$ and $H_p(0.07)$.

(a) Over the ranges of temperature specified in Table 2, the indication shall remain within the limits specified in that table. A graph shall be provided showing the response as a function of temperature over the stated operational range.

(b) Temperature shock
The mean dosimeter response shall not vary by more than ±15% from a set of reference readings taken at a temperature of +20°C when the dosimeter is moved to an environment of +50°C and when the dosimeter is moved to an environment of -10°C, each in less than 5 minutes. The mean dosimeter response shall not vary more than ±15% from a set of reference readings taken at a temperature of +50°C or -10°C when the dosimeter is taken from either one of those temperatures to one of +20°C (nominal room temperature).

10.1.2 Method of Test

For this test, the dosimeter shall be exposed in a reproducible geometry to a reference source (tests shall be performed separately with a photon source and then a beta source), providing sufficient indication under standard test conditions for the test to be carried out.

(a) Place the dosimeter with the reference source in an environmental chamber and determine the mean reference reading at +22°±2°C. Then, raise or lower the temperature inside the chamber at a rate of approximately 10°C until the temperature extremes have been reached. Take sufficient data at approximately 10°C increments to fully characterize the temperature response of the dosimeter. Permit the dosimeter to come to thermal equilibrium at each temperature prior to taking data. Then, plot the results or state them as a temperature coefficient and maximum variation over a temperature range. The limits of variation of indication shall be within the value given in Table 2.

(b) Place the dosimeter in a temperature of +20°±2°C and allow it to stabilize for a minimum of 60 minutes. Expose the dosimeter in a reproducible geometry to the reference source of sufficient intensity to minimize the effect of statistical fluctuations of the dosimeter readings and to produce a response of approximately the middle of the second least significant decade. The mean dosimeter reading shall be determined after a sufficient number of readings are taken in accordance with the guidance given in subclause 6.5.

Remove the dosimeter and the source from this environment and place them directly into an environmental chamber such that the same exposure geometry is established and the temperature near the monitor is +50 (0,-5)°C. Perform this procedure in less than 5 minutes. Determine the mean dosimeter reading then and every 15 minutes for 2 hours. If the dosimeter does not fail the test within the first hour, data does not need to be taken during the second hour; however, the dosimeter should remain in this environment during the period to reach temperature stabilization. The dosimeter and source shall be removed from the environmental chamber and returned to the first environment such that the same exposure geometry is established and the temperature near the dosimeter is +20°±2°C. This procedure shall be performed in less than 5 minutes. The mean dosimeter reading shall be determined then and every 15 minutes for 2 hours. If the dosimeter does not fail within the first hour, data does not need to be taken during the second hour; however, the dosimeter should remain in this environment during the period to reach temperature stabilization.

The above test shall be repeated with the temperature inside the environmental chamber near the dosimeter at -10 (+5,0)°C.

10.2 Relative Humidity

10.2.1 Requirements

This test shall be performed separately for both photon radiation, beta radiation, and the measurements of both $H_p(10)$ and $H_p(0.07)$. The variation in the indication due to the effect of relative humidity from 40% to 95% shall be within $\pm 10\%$.

10.2.2 Method of Test

The test shall be carried out at a single temperature of $+35°C$ using an environmental chamber. For this test, expose the dosimeter to the reference source in contact with the monitor (the test is performed first for photon radiation and then for beta radiation), providing a sufficient indication under standard test conditions for the test to be carried out.

Then, maintain the humidity at each of its extreme values for at least 4 hours, and note the indication of the dosimeter during the last 30 minutes of this period. The permitted variation of $\pm 10\%$ in the indication, as specified in Table 2, is additional to the permitted variations due to temperature alone.

10.3 Atmospheric Pressure

The influence of atmospheric pressure is, in general, only significant for an unsealed detector using air or counting gas as the detecting medium. In this case, the atmospheric pressure at which all tests are performed shall be stated, and the effects of variation in atmospheric pressure shall be stated by the manufacturer.

Representative tests at other atmospheric pressures shall be performed if atmospheric pressure is expected to affect performance. The guidance provided in Section 8.6 of ANSI N42.17A (ANSI 1989) shall be used for such tests.

10.4 Sealing

The manufacturer shall state the precautions that have been taken to prevent the ingress of moisture and describe the tests and results used to demonstrate the effectiveness of the sealing. This is a very important factor for outdoor use of the dosimeter.

10.5 External Electromagnetic Fields

Unless special precautions are taken in the design of a dosimeter, it may be rendered inoperative or give incorrect indications of dose equivalent (rate) in the presence of external electromagnetic fields (EMFs), particularly radiofrequency fields.

10.5.1 Requirements

General

If the indication of a dosimeter in terms of both $H_p(10)$ and $H_p(0.07)$ may be influenced by the presence of external EMFs, a warning to this effect shall be given by the manufacturer and this shall also be stated in the operation manual. If a manufacturer claims that a dosimeter is insensitive to EMFs, the range of frequencies and types of electromagnetic radiation in which the dosimeter has been tested shall be stated by the manufacturer, together with the maximum intensity used (see Table 2).

The dosimeter shall be placed within 15-30 cm of various EMF-emitting appliances (i.e., cellular phones, electric drills, portable communicators, welders, etc.) which are activated randomly while the dosimeter is accumulating dose from a standard source. If the dosimeter operation is affected ($\pm 10\%$), the approximate field strengths shall be documented and the specific conditions under which the dosimeter field shall be noted. Tests shall be performed on a sample of 5 dosimeters.

Specific

The variation of response in terms of $H_p(10)$ and $H_p(0.07)$ shall not be greater than $\pm 10\%$ in electromagnetic radiation field strength of 100 V/m at frequencies above 100 kHz to 500 MHz and 1 V/m at frequencies above 500 MHz to 1 GHz.

10.5.2 Method of Test

Radiofrequency Field of 0.3 MHz to 100 MHz. Position the dosimeter in a radiofrequency field generation system with the field at zero intensity. Expose the dosimeter in a reproducible geometry to an acceptable source of ionizing radiation of sufficient intensity to minimize the effect of the statistical fluctuations. Then, determine the mean dosimeter reading after taking a sufficient number of dosimeter readings.

Then, expose the dosimeter to a modulated (approximately 1-kHz frequency) radiofrequency field that is 100 V/m in intensity and 0.3 MHz in frequency, in a position to produce a maximum change in instrument response. The dosimeter reading shall be observed while the frequency is increased to 100 MHz at a rate not to exceed 0.01 MHz/s from 0.3 MHz to 2 MHz, and 0.1 MHz/s from 2 MHz to 100 MHz. The field intensity is to be maintained at 100 V/m during this frequency scan.

If the radiofrequency exposure system is such that a zero-field intensity cannot be produced, the radiation-exposure geometry shall be documented and reproduced later in another location, and the mean dosimeter reading without the field determined after the exposure to the radiofrequency field.

Nominal 140 MHz Radiofrequency Field. Position the dosimeter in a radiofrequency field generation system or near a portable communication transmission and receiving unit with the field at zero intensity. Expose the dosimeter in a reproducible geometry to an acceptable source of ionizing radiation of sufficient intensity to minimize the effect of the statistical fluctuations of the dosimeter readings. Determine the mean dosimeter reading after taking a sufficient number of dosimeter readings. Then, expose the dosimeter to a radio-frequency field that is 100 V/m in intensity and a nominal 140 MHz in frequency (i.e., one of the frequencies most commonly used for portable public and government communication transmission and receiving units). Again, determine the mean dosimeter reading.

Microwave Fields. If microwave fields are felt to be a concern, testing shall be arranged using the methods and requirements of Section 7.3 of ANSI N42.17A (ANSI 1989).

10.6 External Magnetic Fields

10.6.1 Requirements

General

If the indication of a dosimeter in terms of both $H_p(10)$ and $H_p(0.07)$ may be influenced by the presence of external magnetic fields, a warning to this effect shall be given by the manufacturer and this shall also be stated in the operation manual.

Specific

The variation of response in terms of $H_p(10)$ and $H_p(0.07)$ shall not be greater than $\pm 10\%$ when the dosimeter is exposed to magnetic fields with strengths ≤ 60 A/m at 60 Hz.

10.6.2 Method of Test

Position the dosimeter in a magnetic field generation system with the field at zero intensity. Expose the dosimeter in a reproducible geometry to an acceptable source of ionizing radiation of sufficient intensity to minimize the effect of the

statistical fluctuations of the dosimeter readings. Then, determine the mean reading after taking a sufficient number of readings.

Then, expose the dosimeter to a magnetic field that is 800 A/m (approximately 10 Oe) in intensity (D.C. or 60 Hz), and determine the mean reading again.

If the magnetic field exposure system is such that a zero-field intensity cannot be produced, the radiation-exposure geometry shall be documented and reproduced later in another location, and the mean dosimeter reading without the field determined after the exposure to the magnetic field.

10.7 Electrostatic Discharge

10.7.1 Requirements

The variation of response for both $H_p(10)$ and $H_p(0.07)$ shall not be greater $\pm 10\%$ when the dosimeter is exposed to an electrostatic discharge across the case of 6 kV with energy of 2 mJ on earthed chassis and with a minimum of 10 seconds between individual discharge.

10.7.2 Method of Test

The requirements of subclause 10.7.1 shall be tested at all parts of the dosimeter that can come in contact with the body/clothes of a user under normal operations.

10.8 Light Exposure

10.8.1 Requirements

The dosimeter's response should not be influenced by light. In particular, the dosimeter's communication facility, which is used to pass information between the dosimeter and its readout system, should not be influenced by environmental light.

10.8.2 Method of Test

For these tests, the dosimeter need not be placed on a phantom. Expose the dosimeter (surface with communicator) to 10,000 ft-candles light intensity from a halogen lamp. Irradiate the dosimeter by a ^{137}Cs source for a known exposure time and geometry, and note the readings of $H_p(10)$ and $H_p(0.07)$. Then, zero the dosimeter. Repeat the same exposure but with the dosimeter now being illuminated by the halogen lamp. After the same exposure time, note the readings of $H_p(10)$ and $H_p(0.07)$. These two readings should be identical to those observed when no illumination was being applied from the halogen lamp(s).

Note: The same test may be performed with an infrared light source by agreement between the manufacturer and user.

10.9 Light Flash

10.9.1 Requirements

The dosimeter's response should not be influenced by light flash when exposed 10 times to a 100-W/s flash.

10.9.2 Method Test

For these tests, the dosimeter need not be placed on a phantom. The test method used will depend upon the method used for the communication.

10.10 Rain Resistance

10.10.1 Requirements

The dosimeter's response shall not be changed by more than 1% during and following exposure to lightly falling rain (0.6 cm/h) for a period of 2 hours at 20°C.

Note: If required by the user, salts can be added to the liquid to simulate salt spray exposure.

10.10.2a Method of Test, Nominal Rain

Place the dosimeter in a rain chamber with the dosimeter exposed to a ^{137}Cs source under a fixed irradiation geometry. For this test, all precautions (e.g., waterproof bag) provided by the manufacturer shall be used. After an exposure time of 2 hours, note the readings of $H_p(10)$ and $H_p(0.07)$. Re-zero the dosimeter, and repeat the exposure (exposing the dosimeter to the rain for the 2-hour period again), noting the readings of $H_p(10)$ and $H_p(0.07)$. To pass the test, these readings obtained during rainfall should not differ by more than 1% from the nonrainfall readings. Following this test, the interior of the instrument shall be inspected for signs of ingress of moisture.

10.10.2b Method of Test, Incidental Rain

Follow the procedures as noted in 10.01.2a but do not use any protective covers. Exposure to rain shall be limited to 10 minutes.

10.11 Clip Force

10.11.1 Requirements

The clip shall support three times the weight of the dosimeter when it is clipped to a single thickness of fabric of mass per unit of 190 g/m.

10.11.2 Method of Test

Fix three dosimeters together by tape and clip them to a single layer of fabric of mass per unit of 190 g/m. The dosimeters shall be suspended from the fabric with the clip opening pointed upward. The units shall not fall from the fabric.

10.12 Storage

All dosimeters designed for use in temperate regions shall be designed to operate within the specification of this document following storage (or transport), which may be without batteries, for a period of at least three months in the manufacturer's packaging at any temperature between -25° and +50°C. In certain circumstances, more severe specifications may be required, such as the capability of withstanding air transport at low ambient pressure.

11. Test of Data Permanency

Damage to the dosimeter's readout system should not prevent the readout of the dosimeter's stored dose records. This damage could be mechanical or the readout device could, for example, become coated in oil or become heavily contaminated with radioactivity.

The test shall be made on two dosimeters, one irradiated to give a reading of approximately 50 mrem (500 μSv) and the other to give a reading of approximately 50 rem (500 mSv). Record the exact reading of each dosimeter. Then, remove the communication device of each dosimeter.

The manufacturer shall then demonstrate that these two dosimeter readings can be read out from the dosimeter's permanent memory. The manufacturer shall also state the method used to retrieve the dose record, e.g., fitting a new communicating device or removal and remote readout of EEPROM.

12. Documentation

12.1 Type-Test Report

The manufacturer shall make available at the request of the purchaser the report on the type tests performed to the requirements of this standard.

12.2 Certificate

A certificate shall be provided with each dosimeter with at least the following information in accordance with IEC 278, *Documentation Supplied with Electronic Measuring Apparatus*:

- manufacturer's name or registered trade mark
- type of dosimeter and serial number
- detector types
- types of radiation the dosimeter is intended to measure
- reference point of the dosimeter and the calibration direction for calibration purposes and reference orientation relative to radiation sources
- location and dimensions of the sensitive volumes of the detectors
- surface masses of walls surrounding the sensitive volumes (in mg/cm)
- effective range of measurement and intrinsic error results
- response as a function of radiation energy (for both photon and beta radiation and both $H_p[10]$ and $H_p[0.07]$)
- response as a function of angle of incidence (for both photon and beta radiation and both $H_p[10]$ and $H_p[0.07]$)
- mass and dimensions of instrument
- power supply requirements
- results of temperature test (type test results).

13. Operation and Maintenance Manual

An operation and maintenance manual containing at least the following information shall be supplied:

- schematic electrical diagram including spare parts list
- operational details, maintenance and calibration procedures
- method of retention of stored dose information.

Part 2

Standard for the Performance Testing of Electronic Personal Dosimetry Systems

Part 2, Appendix A

The Calibration and Type Testing of Personal Dosimeters

ICRU Report 47 (1991) specified the personal dose equivalent, $H_p(d)$ for individual monitoring, which is the dose equivalent in soft tissue below a specified point on the body at an appropriate depth, d. For weakly penetrating and strongly penetrating radiations, the recommended depths are 0.07 and 10 mm, respectively. This leads to two variants of this quantity, written as $H_p(0.07)$ and $H_p(10)$.

The definition of personal dose equivalent for practical calibrations is also considered to apply to the dose equivalent at appropriate depths in a suitable phantom of ICRU tissue. The recommended shape of the phantom is now a slab of dimensions 30 cm x 30 cm x 15 cm deep. Conversion coefficients for photons have been calculated relating to the air kerma in a uniform parallel beam to the personal dose equivalents at depths of 0.07 mm, 3 mm, and 10 mm in the slab phantom constructed in ICRU tissue (Grosswendt 1990).[a] Values are not only given for normal incidence but also for a number of angles of incidence between 0° and 75° (see Tables A.1 and A.2).

Calibrations and type-testing are normally carried out with reference radiations that have finite spectral widths. Conversion coefficients for the reference radiations have been derived by folding the data given for monoenergetic photons into a spectra of the NIST radiations.[b] The resultant data are presented in Table A.3.

One more difficulty exists: it is impossible to make a phantom with exactly the composition of ICRU tissue so that a substitute must be chosen. The conversion coefficients for ICRU tissue given in Table A.3 must be used to calculate the dose in the phantom against which the response of the dosimeter is compared during calibration or type-testing. The water slab phantom has backscatter characteristics that are acceptably close to those of the ICRU tissue phantom for both photon and neutron radiations.

The experimental arrangement for the calibration and type-testing of dosimeters is shown in Figure 1. In practice, a strictly parallel beam is not achievable but if a source-to-dosimeter distance of at least 2 meters is chosen, the resultant error will be acceptably small. This distance should be measured to the reference point of the monitor (dosimeter). The air kerma for photon radiation should also be determined at this position (in the absence of both the monitor and the phantom) and be multiplied by the appropriate conversion coefficient to obtain the conventionally true values of $H_p(10)$ and $H_p(0.07)$.

Unless the dosimeter is highly symmetrical, angular response characteristics should be determined by rotating the dosimeter about two axes at right angles in the front face of the phantom (see subclauses 7.5.2 and 7.5.3 in this standard), with the reference point of the dosimeter on the axis of rotation.

(a) See also B. Grosswendt, "The Angular Dependence and Irradiation Geometry Factor for the Dose Equivalent for Photons in PMMA Slab Phantoms and Tissue Equivalent Material." Submitted to *Radiation Protection Dosimetry*.

(b) Private communication from W. J. Iles.

Table A.1. Required Variation of the Ratio of Reading at $\alpha°$, to $\alpha = 0°$ for a Tissue Equivalent Slab Phantom for $H_p(0.07)$ for Beta Rays (Emitted by Standard Sources and Extended Area Sources) at Angles of 20°, 40°, 60°

Nuclide[a]	Distance (cm)	Data Normalized to Zero Degrees		
		20°	40°	60°
$^{90}Sr/^{90}Y$				
Type 1[b]	30.0	1.02	1.10	1.15
Type 2[b]	30.0	1.02	1.10	1.19
^{204}Tl	30.0	0.97	0.93	0.73
^{147}Pm	20.0	0.95	0.71	—

(a) PTB-data (PTB standards) in compliance with ISO Series 1 reference radiations.
(b) Type 1: With beam-flattening filter.
Type 2: Without beam-flattening filter.

Table A.2. Required Variation of the Ratio of Reading at 0° for Photon Radiation Relative to the Reading at $\alpha = 0°$ for Monitors Used to Measure Personal Dose Equivalent (rate), $H_p(10)$ (derived from ANSI [1993])

Radiation Source	Average Photon Energy (keV)	Ratio = Reading $\alpha°$/Reading at 0°		
		$\alpha = 20°$	$\alpha = 40°$	$\alpha = 60°$
M100	51	0.	0.93	0.78
M150	70	0.	0.94	0.81
H150	117	0.	0.94	0.82
^{137}Cs	662	1.0	0.99	0.95

Table A.3. Recommended Conversion Factors from Air Kerma, Ka, to Personal Dose Equivalents, H_p**(10) and** H_p**(0.07) (ANSI 1993)**

	Conversion Coefficient	
	$H_p(0.07)/Ka$ (Sv/Gy)	$H_p(10)/Ka$ (Sv/Gy)
Mean Energy, $\bar{E}$ (keV)		
20 (M30)	1.04	0.47
34 (M60)	1.30	1.07
51 (M100)	1.62	1.65
70 (M150)	1.78	1.92
117 (H150)	1.73	1.80
Radionuclide		
^{241}Am	1.70	1.88
^{137}Cm	1.21	1.21
^{60}Co	1.17	1.18
5 MeV	(reserved)	(reserved)

Part 2, Appendix B

Statistical Fluctuations

For any test involving the use of radiation, the magnitude of the statistical fluctuations of the reading arising from the random nature of radiation alone may be a significant fraction of the variation of the mean reading permitted in the test. A sufficient number of readings shall be taken to ensure that the mean value of such readings may be estimated with sufficient precision to demonstrate compliance or noncompliance with the test requirement. Table B.1 provides guidance on the number of dosimeter readings required to determine true differences between two sets of instrument readings at the 95% confidence level (ANSI 1989). This table is based on the assumption that the probability of saying there is a difference when there is not a true difference and the probability of saying that there is no difference when there is a true difference are both equal to 0.05. Listed are the percentage difference between the means, the coefficient of variation of the sets of readings (assumed to be equal to each set), and the number of instrument readings required.

Whenever possible during testing, dose rates should be used such that the effect of the statistical fluctuations of the instrument readings is minimized. It may be necessary to take dosimeter readings mid-decade on the second or third most sensitive decade in order to accomplish this.

The interval between dosimeter readings shall be at least three times the response time in order to ensure that the readings are statistically independent.

Table B.1. Number of Instrument Readings Required to Detect True Differences (95% Confidence Level) Between Two Sets of Instruments Readings on the Same Instrument

Percent Difference	Coefficient of Variation (%)	Number of Readings
5	0.5	2
5	1.0	2
5	2.0	4
5	3.0	9
5	4.0	16
5	5.0	25
5	7.5	56
5	10.0	99
5	12.5	154
5	15.0	223
5	20.0	396
10	0.5	1
10	1.0	1
10	2.0	1
10	3.0	3
10	4.0	4
10	5.0	6
10	7.5	14
10	10.0	24
10	12.5	37
10	15.0	53
10	20.0	94
15	0.5	1
15	1.0	1
15	2.0	1
15	3.0	12
15	4.0	3
15	5.0	6
15	7.5	10
15	10.0	10
15	12.5	23
15	15.0	40
15	20.0	
20	0.5	1
20	1.0	1
20	2.0	1
20	3.0	1
20	4.0	1
20	5.0	2
20	7.5	3
20	10.0	6
20	12.5	9
20	15.0	12
20	20.0	21

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Part 3

Standard for Electronic Dosimeter Readout Systems

Part 3

Standard for Electronic Dosimeter Readout Systems

1. General Requirements

For all the tests specified for the readout system, eight irradiated electronic dosimeters shall be used. These dosimeters shall be irradiated at nominal dose equivalents, $H_p(10)$, at 0.5 (2 each), at 5, 50, 500 mrem and 5, 50, and 500 rem (5 μSv [2 each], 50 μSv, 500 mSv, 5 mSv, 50 mSv, 500 mSv, and 5 Sv). The irradiation source used shall be ^{137}Cs. It is not necessary to irradiate the dosimeters on a phantom or in a well-characterized radiation field since the performance of the dosimeters is not being determined. After irradiation, the digital readings of the eight dosimeters shall be recorded manually from the display. To perform the readout system tests, the dosimeters will have to be placed in the system so they will also be subjected to the variations in influence quantities. Their displayed readings may change. For this reason, it may be necessary to relate the performance of the readout system to the initial pretest and final post-test readings on each dosimeter. Where this is the case, the method of test indicates when dosimeter post-test readings have to be taken into account.

If the use of the readout system allows the dosimeter dose not to be reset (zeroed), it will not be necessary to reirradiate the eight dosimeters between each of the type tests.

For readout systems that do reset the dosimeters upon readout, it will be necessary to reirradiate the eight dosimeters to the nominal dose equivalents following each test of influence quantity.

Dosimeter readings may change due to background radiation, and all dosimeter readings should be recorded immediately prior to and immediately following each of the tests.

Tables 1 and 2 summarize reference and standard test conditions and test variations of influence quantities, respectively.

2. Primary Power Supply Voltage and Frequency

2.1 Requirements

The dosimeter readout shall be capable of operating with a supply voltage tolerance of +10% and -12% and supply frequencies of nominal frequency (+1 Hz, -3 Hz) with no change in the readout compared with the dosimeter display.

2.2 Method of Test

Before each and after each of the following readout conditions, record the digital display of each of the eight dosimeters.

Note: For these tests, the dosimeter display readings will not be altered by changes in readout voltage or frequency.

Table 1. Reference and Standard Test Conditions

Influence Quantities	Reference Conditions (unless otherwise indicated by the manufacturer)	Standard Test Conditions (unless otherwise indicated by the manufacturer)
Reference photon radiation	^{137}Cs	^{137}Cs
Reference neutron radiation	^{241}Am-Be or ^{252}Cf	^{241}Am-Be or ^{252}Cf
Time to establish thermal equilibrium (with power off)	60 min	≥65 min
Electronic warm-up time	15 min	≥15 min
Ambient temperature	20°C	18° to 22°C
Relative humidity	65%	60% to 75%
Atmospheric pressure	101.3 kPa	86 kPa to 106 kPa
Power supply voltage	Nominal power supply voltage, U_N	$U_N \pm 1\%$
Power supply frequency	Nominal frequency	Nominal frequency ± 2%
AC power supply waveform	Sinusoidal	Sinusoidal with total distortion lower than 5%
Electromagnetic field of external origin	Negligible	Less than the lowest value that causes interference
Magnetic induction of external origin	Negligible	Less than twice the induction due to the earth's magnetic field
Assembly controls	Set-up for normal operation	Set-up for normal operation
Contamination of radioactive elements	Negligible	Negligible

Table 2. Tests Performed with Variations of Influence Quantities

Note: This table does not give values for the limits of variation of induction since no variations are permitted in the "Requirements" for the testing.

Characteristic Under Test or Influence Quantity	Range of Values of Influence Quantity	Method of Test (subclause in Part 3 of this report)
Power supply voltage	U_N -12% to U_N +12% (when U_N = Nominal voltage)	2.2
Power supply frequency	57 Hz to 61 Hz	2.2
Power supply transients	In accordance with subclauses 3.1 and 3.2 in Part 3 of this report	3.2
Ambient temperature	Indoor use +10°C to 50°C	4.1.2
Relative humidity	40% to 90% at 35°C	5.2
Vibration tests	2 g_n over frequencies 10 Hz to 33 Hz	6.2
Drop test	1 cm	6.2
Light exposure	Halogen lamp 10,000 ft-candles	7.2
Light flash	100 W/s	8.2
Stability	14 days	9.2
External electromagnetic fields	100 V/m at 100 KHz to 500 MHz 1 V/m at 500 MHz to 1 GHz	10.2
External magnetic fields	60 A/m at 60 Hz	11.2
Electrostatic discharge	6 kV, 2 mJ	12.2

Read out the eight dosimeters under the following conditions:

- reader operated at reference voltage and frequency
- voltage 12% low and frequency -3 Hz, i.e., at 57 Hz
- voltage 12% low and frequency +1 Hz, i.e., at 61 Hz
- voltage 10% high and frequency -3 Hz, i.e., at 57 Hz
- voltage 10% high and frequency +1 Hz, i.e., at 61 Hz.

None of the readout system readings shall differ from the corresponding pre-readout dosimeter display readings.

3. Power Supply Transient Effects

3.1 Requirements

The readout system shall withstand a short interruption in power supply of duration not less than 10 ms without interruption of normal operation.

Unless otherwise agreed between the manufacturer and the purchaser, the equipment shall be capable of withstanding voltage spikes on the power supply (as specified in the method of test) without damage and without altering the performance of the readout system.

The manufacturer shall state the length of time of the readout process.

3.2 Method of Test

For each readout of the eight dosimeters, interrupt the supply for a period of 10 ms during the readout time. The readout values shall not differ from the dosimeter display readings. Voltage spikes shall be superimposed on the power supply. The spike energy shall be 0.1 J and the spike amplitudes shall be 100%, 200%, and 500% (percentage of nominal r.m.s. voltage). The spike may be generated by capacitor discharge or by any means giving an equivalent waveform. Protect the power supply lines with a suitable suppression filter, consisting at least of a choke of 500 pH capable of carrying the line current. Apply two pulses of each amplitude phased to the powerline peak voltage during the readout of each of the eight dosimeters.

None of the readout system readings shall differ from the corresponding pre-readout dosimeter display readings.

4. Environmental Test Requirements

The extent of environmental testing to be carried out shall be agreed upon between the manufacturer and purchaser. However, as a minimum requirement, the following testing applicable to indoor use shall be carried out.

4.1 Ambient Air Temperature

4.1.1 Requirements

Over the temperature range +10°C to +50°C, the readout system shall give no change in the readout compared with the dosimeter display.

4.1.2 Method of Test

If the dosimeters have passed their temperature shock tests (see subclause 10.1.1(b) of the dosimeter standard in Part 2 of this report), then the eight dosimeters do not need to be kept within the environmental chamber until they are to be read out.

Place the readout system in a chamber and maintain the temperature at +10°C for at least 4 hours. Place the eight dosimeters in turn in the system and read them out.

Then, maintain the temperature in the climatic box at +50°C for at least 4 hours. Again, place the eight dosimeters in the system and read them out.

At both +10°C and +50°C, none of the readout system readings shall differ from the corresponding pre-readout dosimeter display readings.

4.2 Relative Humidity

4.2.1 Requirements

Over the humidity range 40% to 95%, the readout system shall give no change in the readout compared with the dosimeter display.

4.2.2 Method of Test

If the dosimeter's response was found to be influenced over the range of humidity 40% to 95%, then corrections will have to be applied to allow for changes due to the dosimeter only. The tests shall be carried out at a single temperature of +35°C with the readout system placed in an environmental chamber.

Note: If the dosimeter display readings after placing them in the chamber differ from their pre-readout readings, then the readout system readings for each dosimeter should lie between the pre- and post-display readings for the corresponding dosimeters.

Maintain the humidity at 40% for at least 4 hours. Place the eight dosimeters in turn in the system and read them out. Then, remove the dosimeters from the chamber and after 1/2 hour read out their digital displays. All the eight system readouts should agree with the corresponding pre-readout dosimeter display reading.

Repeat the above test but with the relative humidity kept at 95% for at least 4 hours. All eight system readouts should agree with the corresponding pre-readout dosimeter display reading.

5. Vibration Tests

5.1 Requirements

The performance of the readout system shall not be influenced following harmonic loadings of 2 g_n applied for 15 min in the frequency range 10 to 33 Hz. The physical condition of the instrument shall not be affected by this vibration (e.g., solder joints shall hold nuts and bolts or circuit boards shall not come loose).

5.2 Method of Test

Subject the readout system to harmonic loadings of 2 g_n for 15 min at one or more frequencies in each of the following ranges: 10 to 21 Hz and 22 to 33 Hz. After each vibration interval, read out the eight dosimeters. All of the system readouts should agree with the corresponding pre-readout dosimeter display readings.

Inspect the readout system and document the physical condition.

6. Dropping Effect on Readout System

6.1 Requirements

The performance of the readout system shall not be influenced following the dropping of the system 1 cm onto a wood surface. This does not apply to readouts fastened to a wall or bench during use.

6.2 Method of Test

Drop the readout system 1 cm onto a wood surface, simulating possible drop during operation. Each corner of the system should be raised 1 cm and allowed to drop onto the resting surface. The system should be in its normal operating orientation. This applies to the entire operating unit for readers mounted in other hardware, e.g., a personal computer. Then, read out the eight dosimeters. All of the system readouts should agree with the corresponding pre-readout dosimeter display readings.

7. Light Exposure

7.1 Requirements

The readout system should not be influenced by light. In particular, the reader's communication facility, which is used to pass information between the dosimeter and the reader, should not be influenced by environmental light.

7.2 Method of Test

For these tests, place the dosimeter in the readout system. The light exposures must occur during the readout process for all eight dosimeters. Expose the readout system to a halogen lamp(s) positioned to provide 10,000 ft-candles intensity to the communication aperture. For the test, all eight system readouts should agree with the corresponding pre-readout dosimeter display readings.

8. Light Flash

8.1 Requirements

The performance of the readout system shall not be influenced by light flash.

8.2 Method of Test

For these tests, place the dosimeters in the readout system. The light exposures must occur during the readout process for all eight dosimeters. During each readout process, expose the readout system to repeated 100-W/s flashes. All eight system readouts should agree with the corresponding pre-readout dosimeter display readings.

9. Readout System Stability

9.1 Requirements

Over a period of 14 days, the performance of the readout system shall not change.

9.2 Method of Test

For the test, the readout system shall be left operating for 14 days. Every day for 14 days, read out the eight dosimeters. For each of the 14 days, the eight system readouts should agree with the corresponding pre-readout dosimeter display readings.

10. External Electromagnetic Fields

Unless special precautions are taken in the design of the readout system, it may be rendered inoperative or give incorrect indications in the presence of external electromagnetic fields, particularly radiofrequency fields.

10.1 Requirements

General

If the readout of the system may be influenced by the presence of external electromagnetic fields, a warning to this effect shall be given by the manufacturer, and this warning shall also be stated in the operational manual. If the manufacturer claims that the readout system is insensitive to electromagnetic fields, the range of frequencies and types of electromagnetic radiation in which the reader has been tested shall be stated by the manufacturer, together with the maximum intensity used.

Specific

The performance of the readout system shall not be influenced in electromagnetic radiation field strength of 100 V/m at frequencies above 100 kHz to 500 MHz, and 1 V/m at frequencies of 500 MHz to 1 GHz.

10.2 Method of Test

The methods of test shall be subject to agreement between the manufacturer and the user. Particular care must be taken to detect any enhanced response at a particular frequency.

Test the specific requirements of subclause 10.1 (above) by reading out the eight dosimeters with the readout system subjected to the field strengths and range of frequencies stated in subclause 10.1. All the system readouts should agree with the corresponding pre-readout dosimeter display readings. When the dosimeter design responds to external electromagnetic fields, record each post-readout reading of the dosimeter display. The readouts will then have to lie between the corresponding pre-readout and post-readout display of the dosimeter.

11. External Magnetic Fields

11.1 Requirements

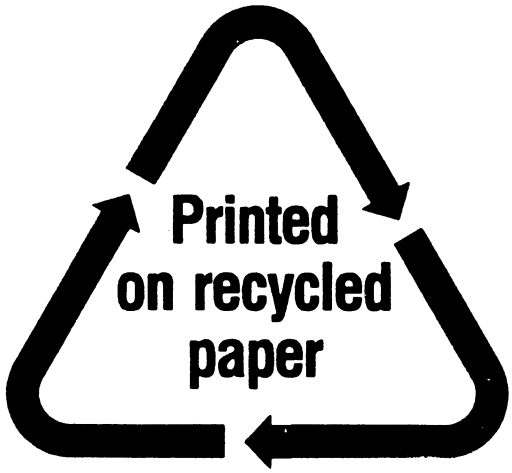
General

If the readout of the system may be influenced by the presence of external magnetic fields, a warning to this effect shall be given by the manufacturer, and this warning shall also be stated in the operational manual.

Specific

The performance of the readout system shall not be influenced in magnetic fields with strengths $\leq$60 A/m at 60 Hz.

All the system readouts should agree with the corresponding pre-readout dosimeter display



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