EVALUATION OF THE SCIENCE APPLICATIONS
INTERNATIONAL CORPORATION PD-4
ELECTRONIC DOSIMETER

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MASTER

EXECUTIVE SUMMARY

The SAIC PD-4 electronic dosimeter was tested against the criteria given in ANSI N13.27 and for stability and angular response. Based on the results of the testing, the SAIC PD-4 electronic dosimeter is considered acceptable as a supplemental dosimeter for use at the Hanford Site with the following limitations. Though the dosimeter has a rate mode, it may not be used to establish worker dose rates. The dosimeter underresponds at high dose rates and may not be used in dose rate fields that exceed 600 R/h. The dosimeter also underresponds to photon energies less than 70 keV and should not be used in areas where the external photon dose would be primarily from plutonium and its decay products. Because of the transmitter, the dosimeter has a relatively short battery life. The batteries should be replaced with fresh batteries by trained personnel each time the dosimeter is used (or once each day if used continuously). The requirement that an instrument be returned to the calibration facility for battery changes is waived for this instrument.

CONTENTS

EXECUTIVE SUMMARY	iii
1.0 INTRODUCTION	1.1
2.0 TESTING FOR MANDATORY REQUIREMENTS	2.1
2.1 ENERGY DEPENDENCE	2.1
2.2 ANGULAR RESPONSE	2.3
2.3 STABILITY	2.3
2.4 LINEARITY	2.3
3.0 TESTING FOR NONMANDATORY REQUIREMENTS	3.1
3.1 PHYSICAL CHARACTERISTICS	3.1
3.2 DISPLAY	3.1
3.3 CLIP	3.2
3.4 EXTERNAL CONTROLS	3.2
3.5 RANGE	3.2
3.6 ALARMS	3.3
3.7 POWER	3.4
3.8 BATTERY LIFE	3.4
3.9 ENVIRONMENTAL CONDITIONS	3.6
4.0 CALIBRATION	4.1
5.0 REFERENCES	5.1

FIGURES

2.1	Energy Response of SAIC PD-4 Electronic Dosimeter	2.2
2.2	Stability of SAIC PD-4 Electronic Dosimeters	2.5
2.3	Linearity of SAIC PD-4 Electronic Dosimeter	2.7

TABLES

2.1	Angular Response of PD-4 Dosimeters Exposed to 1.5 rem on Phantom	2.4
2.2	Linearity of SAIC PD-4 Electronic Dosimeters	2.8
3.1	PD-4 Electronic Dosimeter Physical Dimensions and ANSI N13.27 Limits	3.1
3.2	Current Drain of SAIC PD-4 Electronic Dosimeters	3.4
3.3	Range of Observed Battery Lives for PD-4 Transmitter at Various Transmission Intervals	3.5

1.0 INTRODUCTION

This report was prepared by staff of the Pacific Northwest Laboratory (PNL)^(a) to evaluate the SAIC PD-4[™] electronic dosimeter and the RadStar[™] radio telemetry system.^(b) The PD-4 dosimeter is essentially an SAIC PD-1 dosimeter coupled with a radio transceiver. The dosimeter is monitored using the RadStar software on a portable computer which is connected to a transceiver. Since the dosimeter may be used independent of the RadStar telemetry system, the dosimeter and the telemetry system were evaluated separately. The dosimeter was evaluated for use as a supplemental dosimeter, and may not be used to establish worker dose.

The only mandatory requirements for electronic dosimeters are in the Hanford Site Radiological Control Manual (HSRCM), Article 513, which requires testing supplemental dosimeters for energy dependence, stability, and linearity.^(c) The HSRCM also requires that the Hanford External Dosimetry Program staff approve the use of supplemental dosimeters. Additional recommendations are found in ANSI N13.27, a nonmandatory standard. There are no requirements for the performance of a dosimeter telemetry system. The system uses a 50-mW spread spectrum transmitter and a frequency band, which is available for general use without permit or license.

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- (a) Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.
 - (b) PD-4 and RadStar are trademarks of Science Applications International Corporation.
 - (c) Hanford Site Radiological Control Manual, HSRCM-1, HSRCM Project Group, Hanford Site.

2.0 TESTING FOR MANDATORY REQUIREMENTS

2.1 ENERGY DEPENDENCE

The energy dependence of the PD-4 dosimeter was measured over the range 17.5 keV to 1.25 MeV using NIST traceable photon sources and the criteria stated in ANSI N13.11 and DOE/EH-0027.^(a) The M30, M50, S75, M100, and M150 x-ray exposures follow the ANSI standard, and the H150, K17, and K59 x-ray exposures comply with the DOE standard. The x-ray exposures were corrected to 22°C, 760 mm Hg. The dosimeter was placed on a whole body phantom with the front of the dosimeter perpendicular to the beam. The front surface of the phantom was exposed to 1.5 rem for each beam energy, and the ratio of the exposure recorded by the dosimeter to the dose delivered to the phantom was plotted in Figure 2.1. The response of one dosimeter was measured at all the energies.

To verify that the dosimeter used was indicative of the performance of the group, the responses of four dosimeters were measured for ¹³⁷Cs (662 keV) photons and for M150 (70 keV) and M30 (20 keV) x-rays.^(b) The four dosimeters overresponded an average of 8% at 662 keV, and underresponded an average of 17% at 70 keV. The coefficient of variation for the response of the three dosimeters was 2.8% for 662 keV, 17% at 70 keV, and 25% at 20 keV.

The requirement from ANSI N13.27 is that the dosimeter response shall be within $\pm 30\%$ over the range from 80 keV to 1.25 MeV for exposure rates less than 1 R/h. As shown in Figure 2.1, the PD-4 dosimeter meets this requirement.

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- (a) Larbe, K. K. April 8, 1993, memo to M. L. Johnson, "SAIC Low-Energy Photon Response Study." Pacific Northwest Laboratory, Richland, Washington.
- (b) Large, K. K. May 10, 1993, memo to M. L. Johnson, "SAIC PD-4 Consistency Study." Pacific Northwest Laboratory, Richland, Washington.

FIGURE 2.1. Energy Response of SAIC PD-4 Electronic Dosimeter

2.2 ANGULAR RESPONSE

The angular response of the PD-4 dosimeter was measured by exposing the dosimeter to ^{137}Cs (662 keV) photons and M150 (70-keV) x-rays.^(a) The dosimeter was first placed vertically on a whole body phantom with the center line of the phantom maintained at 1 meter from the source. The phantom was exposed to 1.5 rem (1.46 R at 662 keV and 1.09 R at 70 keV) at the angles 0° , $\pm 30^\circ$, $\pm 60^\circ$, and $\pm 85^\circ$. The test was repeated with the dosimeter in the horizontal position. In both orientations, the front of the dosimeter was facing the beam.

The results of the angular response testing are shown in Table 2.1. There are no requirements for angular response other than that the angular response of the dosimeter should be known.

2.3 STABILITY

The dosimeter stability was tested by exposing three dosimeters with fresh batteries to a 1-R/h field for 5 minutes and recording the total dose. The exposure was repeated periodically over the life of the battery and the results are shown in Figure 2.2. The dosimeters were zeroed and left on between exposures. The transmission time on all three dosimeters was 10 seconds.

Since there is no requirement for electronic dosimeter stability, the requirement for portable instrument stability from ANSI N42.17A was used. This requires that the instrument response vary not more than 6% over a 24-hour period. The response of the PD-4 dosimeter varied less than 6% over the battery life of the dosimeter (about 21 hours) and, thus, is considered stable.

2.4 LINEARITY

The instrument response to exposure rates ranging from 10 mR/h to 3000 R/h was measured. One dosimeter, SN RT1007, was tested to the full range

(a) Large, K. K. May 11, 1993, memo to M. L. Johnson, "SAIC PD-4 Angular Response Testing." Pacific Northwest Laboratory, Richland, Washington.

TABLE 2.1. Angular Response of PD-4 Dosimeters Exposed to 1.5 rem (1.46 R at 662 keV, 1.09 R at 70 keV) on Phantom

Angle	¹³⁷ Cs, 662 keV, 1.5 rem (1.46 R)			M150, 70 keV, 1.5 rem (1.09 R)		
	PD-4 Response (R)	PD-4 Response/ Actual Exposure (R/R)	PD-4 Response/ Actual Dose (R/rem)	PD-4 Response (R)	PD-4 Response/ Actual Exposure (R/R)	PD-4 Response/ Actual Dose (R/rem)
Vertical						
0°	1.65	1.13	1.10	1.23	1.13	0.82
+30°	1.62	1.11	1.08	1.17	1.07	0.78
+60°	1.62	1.11	1.08	1.09	1.01	0.73
+85°	1.40	0.96	0.93	0.627	0.58	0.42
-30°	1.63	1.12	1.09	1.23	1.13	0.82
-60°	1.59	1.09	1.06	1.14	1.05	0.76
-85°	1.56	1.07	1.04	0.982	0.90	0.65
Horizontal						
+30°	1.60	1.10	1.07	1.44	1.32	0.96
+60°	1.31	0.90	0.87	0.226	0.21	0.15
+85°	1.35	0.92	0.90	0.973	0.89	0.65
-30°	1.62	1.11	1.08	1.36	1.25	0.91
-60°	1.53	1.05	1.02	0.453	0.42	0.30
-85°	1.31	0.90	0.87	0.561	0.51	0.37

of exposure rates. Others were tested at a few points to verify that the performance of dosimeter RT1007 was indicative of the performance of the group.

The linearity of dosimeter RT1007 was measured by exposing the dosimeter for at least 5 minutes at each exposure rate. The accumulated dose at the end of each minute was recorded along with the actual dose delivered to the dosimeter. The testing was performed using the 318 Building High Exposure Facility and the 318 Building Well Room. Both facilities use ¹³⁷Cs and ⁶⁰Co sources to cover a broad range of exposure rates. Linearity curves for both ⁶⁰Co and ¹³⁷Cs were generated.

FIGURE 2.2. Stability of SAIC PD-4 Electronic Dosimeters

The ratio of the dosimeter response to the actual exposure is shown in Figure 2.3. The response is within 10% for exposure rates up to 500 R/h. Between 500 R/h and 750 R/h the dosimeter begins to overrespond up to a maximum overresponse of about 400% at 1000 R/h at which time the response begins to drop down. The overresponse was due to the algorithm used to compensate for the deadtime. The overresponse was considered acceptable since the dosimeter responded correctly at the exposure rates at which it would actually be used.

To verify that the response described above was indicative of all the dosimeters, the response of two additional dosimeters, RT1005 and RT1006, was measured at 0.1 R/h, 1 R/h, and 10 R/h. The linearity was measured by exposing the dosimeters for 3 to 10 minutes at each exposure rate. Then the ratio of the exposure recorded by the dosimeter to the actual dose delivered to the dosimeter was calculated. The results are shown in Table 2.2.

The requirement for linearity (or accuracy) is given in ANSI N13.27 as $\pm 20\%$ over the range 0.1 R/h to 1 R/h. The results of the testing indicate that the PD-4 dosimeter response is within the accuracy limits over the range 10 mR/h to 600 R/h and thus meets the requirement. A second requirement states that the exposure rate dependence shall be within $\pm 20\%$ over the useful range. The exposure rate range of the dosimeter is 0.01 R/h to 999 R/h. At exposure rates greater than 650 R/h, the dosimeter overresponds by more than 20%; hence, the dosimeter does not meet this requirement. However, it is highly unlikely that the dosimeter would ever be used in fields greater than 600 R/h. Thus, the dosimeter is considered acceptable with the limitation that it may not be used in fields that exceed 600 R/h.

FIGURE 2.3. Linearity of SAIC PD-4 Electronic Dosimeter

TABLE 2.2. Linearity (Accuracy) of SAIC PD-4 Electronic Dosimeters

Serial Number	Exposure Rate, R/h	Ratio of Recorded Dose to True Dose
RT1005	0.1	1.05
	1	1.03
	10	1.02
RT1006	0.1	1.07
	1	1.03
	10	1.02

3.0 TESTING FOR NONMANDATORY REQUIREMENTS

This section describes the results of testing performed to demonstrate compliance with the requirements of ANSI N13.27. Since ANSI N13.27 is not a mandatory standard, these are nonmandatory requirements.

3.1 PHYSICAL CHARACTERISTICS

The PD-4 dosimeter's physical dimensions and limits from ANSI N13.27 are shown in Table 3.1.

3.2 DISPLAY

The dose, rate, and alarm settings are read out on a liquid crystal display consisting of a three-digit numeric display and 12 icons. The icons indicate battery condition, dose and rate alarms, units (R, mR, and h), and a y icon that flashes each time a pulse is detected. Additional icons are used with the PDE-4 dosimeter, which is a PD-4 equipped with up to four extremity dosimeters. The display is backlit by four green light emitting diodes.

American National Standards Institute Publication N13.27 requires the maximum exposure display be retained until the device is manually reset. The display can only be reset using the PDR-4 reader. The display cannot be reset

TABLE 3.1. PD-4 Electronic Dosimeter Physical Dimensions and ANSI N13.27 Limits

Dimension	SAIC PD-4 Measurement	ANSI N13.27 Limit
Max. Width, cm	9.5	8
Max. Length, cm	Without antenna: 15.5 With antenna: 25.0	16
Max. Thickness, cm	3.3	4
Max. Width plus Max. Thickness, cm	12.8	11
Weight, g	392	300

at the dosimeter and is not reset when the battery is removed. During testing, the battery on an exposed dosimeter was removed for 3 hours. When the battery was reinstalled, the dosimeter correctly displayed the accumulated dose.

3.3 CLIP

The current version of the dosimeter does not have a clip. The dosimeter is worn in a pouch which is hung around the neck of the individual and then strapped to the body. According to SAIC, future versions of the dosimeter will have clips, but the clip is not available for evaluation at this time.

3.4 EXTERNAL CONTROLS

The dosimeter has four external controls. Three recessed buttons with membrane covers control the display mode (dose, rate, or confirmation mode), acknowledge, and turn on the display light. The recessed buttons are level with the surface of the dosimeter case and are difficult to feel when wearing gloves. Also, the pouch provided to wear the dosimeter interferes with locating the buttons. When the dosimeter is in the pouch, the user must either look at the case to locate the buttons or randomly press on the case until he/she hits the desired button.

A fourth control, a recessed power switch, is located on the side of the dosimeter.

3.5 RANGE

The PD-4 has a dose rate range of 0.01 mR/h to 999 R/h and accumulated dose range of 0.01 mR to 999 R. During testing, the dosimeter was exposed to dose rates in excess of the maximum displayed rate and the dosimeter continued to accumulate dose as expected.

3.6 ALARMS

The PD-4 has five alarm conditions: low battery, dose alarm, rate alarm, loss of communication with the remote computer, and detector failure.

Low battery conditions are indicated by a two-step visual display and by an audible alarm. The visual alarm is a battery icon that blinks for an intermediate low-battery condition and then is solidly lit for a final low-battery condition. The audible alarm resets after about 5 seconds.

The dose and rate alarms have visual and audible alarms. The visual alarm is a blinking dose or rate icon. The audible alarms are identical and consist of two tones, pause, and repeat (beep-beep, pause, beep-beep, etc.). The audible alarm is reset by pressing the mode button. The dose alarm has a range of 0.01 mR to 100 R. The rate alarm has a range of 0.1 mR/h to 999 R/h. The dose and rate alarms can only be set using the RadStar program and the radio link.

Loss of communication with the remote computer is indicated by audible alarm at a continuous frequency of four beeps per second. The audible alarm is reset by pressing the call button. The loss-of-communication alarm can be disabled.

The dosimeter alarms on detector failure if it does not detect a pulse from the Geiger-Müller (GM) tube during a sample period. The sample period is adjustable based on the number of pulses seen by the detector and, for low-count-rate conditions, is 1024 seconds. Therefore, 17 minutes may pass before the dosimeter will alarm for the loss of detector. This was tested by disconnecting the high voltage supply from the GM tube and then operating the dosimeter until it alarmed.

The sound pressure level of the alarm tones from four dosimeters was measured with a decibel meter. The requirement is that the alarm have a minimum sound pressure level of 75 dBA at a distance of 30 cm. The alarm tones were measured at a distance of 30 cm above the display and 30 cm from the speaker. In both cases, the average alarm volume was 78 dBA.

Under ANSI N13.27, the rate alarm shall continue to operate in fields up to 10^3 times the highest alarm setpoint. Since the highest rate alarm set

point is 999 R/h, testing this requirement would require an exposure rate of 999,000 R/h. The highest exposure rate achievable in the 318 Building is only 17,917 R/h; therefore, the dosimeter was tested at 17000 R/h. With the rate alarm set at 1000 R/h and the dosimeter exposed to a 17000-R/h field, the dosimeter alarmed within 3 seconds and remained in alarm for the duration of the exposure, which was 5 minutes. This test was repeated with a dosimeter in the low-battery condition (battery voltage = 7.5 V) and the results were the same.

3.7 POWER

The SAIC PD-4 electronic dosimeter operates on a 9-V alkaline battery. The batteries are easily accessed through a sliding door on the back of the dosimeter.

The current drain of the dosimeter was measured using a Fluke multimeter placed in series between the positive terminal of the battery and the battery connector. The battery was a 9-V industrial alkaline battery. The current drain of four dosimeters was measured under numerous conditions, and the average current drain is shown in Table 3.2.

3.8 BATTERY LIFE

Since the transmitter draws a relatively large current, the battery life of the PD-4 dosimeter is highly dependent on the transmission frequency. The

TABLE 3.2. Current Drain of SAIC PD-4 Electronic Dosimeters

Condition	Current Drain
Ambient background	9.2
Ambient background with light	13.1
During transmissions	~100 for 1 sec
Exposed to 10-mR/h source	9.1
During audible alarms	Cycles between 20 to 60

battery life as a function of transmission frequency was estimated by installing fresh batteries in four dosimeters, setting each dosimeter for a different transmission frequency, and recording the time at which the dosimeter reached the low-battery condition. The test was performed twice and the observed range of battery lives for different transmission intervals is shown in Table 3.3. The battery life is defined as the number of hours the dosimeter and transmitter operate. After the battery voltage falls below the level required to operate the transmitter, the dosimeter continues to operate. ANSI N13.27 requires a battery life of 100 hours when the dosimeter is used continuously in a 1 mR/h field. The PD-4 does not meet this requirement because of the transmitter.

American National Standards Institute Publication N13.27 requires that the dosimeter is required to function correctly for 8 hours after reaching a low-battery condition and to retain exposure data for an additional 2 hours. This was tested by operating a dosimeter until the solid low-battery icon was indicated. The dosimeter was then zeroed and placed in a 100-mR/h field for 8 hours. The dose recorded at the end of the 8 hours was compared to the actual dose delivered. The dosimeter was then allowed to operate an additional 2 hours. The dosimeter functioned correctly while in the low-battery condition.

TABLE 3.3. Range of Observed Battery Lives for PD-4 Transmitter at Various Transmission Intervals

Transmission Interval, s		Time to loss of Transmitter, h
10		5 to 9
20		15
30		14
60		14

3.9 ENVIRONMENTAL CONDITIONS

Temperature, humidity and dew point testing was performed on four SAIC PD-4 dosimeters.^(a) The purpose of the testing was to verify that the dosimeters met the requirements of ANSI N13.27. The requirement states that the dosimeter shall operate properly over the relative humidity (RH) range of 20% to 90% and over the temperature range specified by the manufacturer and when cycled through the dew point at 20°C.

The PD-4s were tested over the temperature ranges 22°C to 60°C and 22°C to -20°C in 10°C increments. Twenty readings of each dosimeter were taken at each temperature and the averages and standard deviations were calculated. The average reading for each temperature was compared to the reference readings taken at 22°C. In no cases did the instrument responses vary significantly from the reference reading.

For the humidity test, the reference readings were taken at 40% RH. The RH was then increased to 95%. The dosimeter responses at 95% RH were recorded every hour for 8 hours by recording 20 instrument readings and calculating the average and standard deviation. None of the instrument readings varied significantly from the reference readings.

The dosimeters were cycled through the dew point and left in the condensing atmosphere for a period of time. The condensing atmosphere did not cause a significant change in the dosimeter readings.

Based on the testing conducted, the PD-4 meets the environmental requirement given in ANSI N13.27.

(a) Sisk, D. R., May 4, 1993, memo to M. L. Johnson, "Results of SAIC Pocket Dosimeter Testing." Pacific Northwest Laboratory, Richland, Washington.

4.0 CALIBRATION

The PD-4 dosimeter is calibrated with a two-step calibration. During the first step, the dosimeter is exposed to a field of 10 mR/h to 1.0 R/h until a total dose of 10 mR to 1.0 R is accumulated. The dosimeter is then placed on the reader and the calibration software establishes the linear calibration factor ($\mu\text{R/pulse}$) and the rate calibration factor ($\mu\text{R/h/pulse}$). Next, the dosimeter is exposed to a 100 R/h to 500 R/h field until a total dose of 100 mR to 10 R is accumulated. The dosimeter is placed on the calibrator and the calibration software establishes the dead-time correction factor ($\mu\text{sec/pulse}$). The calibration can be performed using the facilities available in the 318 Building.

5.0 REFERENCES

American National Standards Institute (ANSI). 1981. "American National Standard Performance Requirements for Pocket-sized Alarm Dosimeters and Alarm Ratemeters." ANSI N13.27, American National Standards Institute, New York.

American National Standards Institute (ANSI). 1989. "Performance Specifications for Health Physics Instrumentation - Portable Instrumentation for Use in Normal Environmental Conditions." ANSI N42.17A-1989, American National Standards Institute, New York.

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