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Further Testing of Pocket-Sized Electronic Dosimeters

R. A. Fox
C. D. Hooker
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April 1980

Prepared for
the U.S. Nuclear Regulatory Commission

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

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POCKET-SIZED ELECTRONIC
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ABSTRACT

The experiences of industrial radiographers have indicated that electronic radiation-warning devices become inoperative when they are used under some types of ambient conditions. This report, as a follow-up to NUREG/CR-0554, documents the nature of tests performed on several additional commercially available models. None of the three models tested passed the tests for ruggedness and severe environmental conditions. However, all models passed most of the requirements of a Health Physics Society draft standard of performance specifications for these devices. The test procedures used in the project and the results obtained are discussed. Conclusions from the tests and recommendations concerning potentially useful modifications to existing devices are presented.

CONTENTS

ABSTRACT	iii
INTRODUCTION.	1
MODELS TESTED	2
TEST METHODS.	3
RESULTS AND DISCUSSION	4
GENERAL RESULTS	4
RELATION TO HPSSC STANDARD	5
CONCLUSIONS	8
REFERENCES	9
APPENDICES	
A. TEST MODEL DESCRIPTION	A.1
B. TEST PROCEDURES.	B.1
C. TABULATED TEST RESULTS	C.1
ACKNOWLEDGMENTS	

FURTHER TESTING OF POCKET-SIZED ELECTRONIC DOSIMETERS

INTRODUCTION

Pocket-sized electronic dosimeters are being used to provide radiological protection information to industrial radiographers. Because the industrial situation may involve rugged work conditions and harsh environments, users of these dosimeters have expressed concern to regulatory agencies about the overall reliability of the devices. In response to this concern, the Pacific Northwest Laboratory (PNL)^(a) received a contract from the Nuclear Regulatory Commission to test the capabilities of commercially available pocket-sized electronic dosimeters and to identify the generic characteristics that limit their ability to operate satisfactorily under severe conditions.

The Radiation Calibrations Laboratory staff at PNL originally tested the electrical, mechanical, and radiological capabilities of 70 units (five each of 14 dosimeter models). The results of the study were reported in NUREG/CR-0554 (PNL-2548, Mulhern 1979). A follow-up testing program was undertaken later to test three models (five units of each, or a total of 15 units) that had not been tested during the original project. This report contains a description of the models tested in the follow-up program, an explanation of the tests, the results obtained, and observations on the reliability of component items used in the construction of the dosimeters. Comments are also included relating these results to a draft standard (Health Physics Society Standards Committee 1979) on procurement specifications for electronic pocket-sized dosimeters.

^(a) Operated for the Department of Energy by Battelle Memorial Institute.

MODELS TESTED

The three models tested were divided into two categories, as in the previous testing: 1) two chirpers, i.e., devices that emit a burst of sound at rates that vary in direct relation to the intensity of the detected radiations, and 2) one digital device, i.e., a device that indicates an accumulated dose^(a) via visual display. (The names and manufacturers of the models tested are listed in Appendix A, along with cost and delivery information.)

All of the models tested use miniature Geiger-Mueller (GM) tubes to detect photon radiation. Geiger-Mueller tubes are not usually desirable as quantifiers of radiation dose for two reasons. First, they have nonlinear exposure rate properties; GM tubes used in portable survey instruments have shown dose rate problems in photon fields as low as a few hundred mR/hr. Second, they have a nonlinear energy response; however, measures have been taken by some manufacturers of the digital devices to correct this problem in uncompensated GM tubes. Because users may be inclined to rely on the readout of digital units for accountable dose information, rather than on a system of TLD, film, or pocket ion-chamber devices, we tested the energy dependence and exposure rate characteristics of the digital readout units.

The digital model tested in this study uses a remote light-emitting diode (LED) display and emits a short sound each time 1.5 mR is registered, or more frequently. The presettable alarm on each digital display unit was tested to verify that the alarms sounded at the preselected levels.

For two models, the use of an alkaline cell 9-volt battery is recommended by the manufacturers, while for the third, a TR-133R 4.05-volt battery is required.

(a) In this report, the terms "dose" and "mR" are used in the same way the manufacturers use them. The use of this terminology does not imply that these dosimeters are capable of measuring either "dose" or "exposure (mR)." The terms are used in a casual manner rather than according to their strict definitions.

TEST METHODS

The three types of tests^(a) performed relate to the physical, electrical, and radiological properties of the dosimeters. The characteristics analyzed are listed below. A more detailed description of the tests appears in Appendix B.

Physical Properties

Mass
Dimensions
Strength of mounting clip
Switch access

Resistance to:

Vibration
Mechanical shock
Temperature variations
Humidity variations
Water immersion
Salt water

Electrical Properties

Battery life
Speaker volume
Geotropism
Alarm point accuracy

Radiological Properties

Rate of chirp repetition
Accuracy
Energy dependence
Exposure rate dependence
Response at high exposure rates

^(a) The tests used were developed by O. R. Mulhern, currently at Eberline Instrument Corporation, Santa Fe, New Mexico, for the original dosimeter testing project. Attempts were made to follow his testing procedures as closely as possible in order to relate the results of this project to those reported previously (Mulhern 1979).

RESULTS AND DISCUSSION

The tabulated results of the tests are presented in Appendix C for use in conjunction with the discussion below. The order in which the dosimeter models are presented in Appendix A has no relation to the order of the models listed in the test results.

GENERAL RESULTS

The most detrimental effects on performance of the dosimeters were noted during the water immersion test series. In all cases, the presence of internal moisture completely disabled the unit, which then had to be opened, disassembled, and dried overnight or longer--in other words, a major repair effort was required. About one-third of the units failed permanently as a result of internal moisture and could not be revived to continue the test sequence.

A variety of components failed during the moisture tests.

- Batteries. The battery often failed and required replacement. Units with replaceable batteries were at a distinct advantage in this respect.
- Power supply. Often the components in the high-voltage power supply failed when moisture was introduced while the units were operating.
- Speaker volume. Moisture decreased all of the volume levels.

Units could be made less sensitive to moisture effects if major portions of the internal circuits were enclosed in a potting compound or some other waterproof material. None of the cases were designed to keep all moisture out of the internal components.

Generally speaking, the mechanical shock test was about as hard on the units as was the moisture test. Fourteen units were dropped onto concrete from 1.2 meters (4 feet). (One unit had failed permanently in a previous test.) The units that survived the 1.2-meter drop were dropped from heights increasing by 0.3 meter (1 foot) up to a maximum of

2.4 meters (8 feet). Components that failed during this test were (in the order of frequency of occurrence) battery holders, switches that jammed or broke, speakers, and solder connections on circuit boards. In some cases we suspected that the GM tube was the failing component. Protecting the GM tube by mounting it in a foam rubber sheath and connecting it to the rest of the circuit by means of flexible wires would probably assure its continued operation during any of the mechanical shock tests.

The salt water test was conducted on units that had already failed an earlier test. Corrosion was noted on exposed metal surfaces and on nearly all interfaces between dissimilar metals. The conductors on circuit boards also showed the effects of corrosion. We concluded that salt water immersion would ruin an operational unit.

Some pleasant discoveries also resulted from these tests. The exposure rate response test, performed only on the five digital display units, showed that the model tested responds reasonably accurately up to photon fields of 15 R/hr, even though it uses GM tubes. Both digital and chirper models were tested in a 500-R/hr field and all continued to respond.

All of the units withstood the "polite abuse" presented by the Boerner shaker and crushing tests. In temperature extreme tests, although all the units continued to operate at all test points, cold had a larger detrimental effect than heat on the instrument's accuracy. The battery life tests indicated that a majority of the units can be operated for well over 2 months' worth of 8-hour working days without needing to have the batteries replaced. Finally, the speaker volume level did not seem to be affected by the use of a battery that had been discharged to 90% of its nominal terminal voltage.

RELATION TO HPSSC STANDARD

In 1979, a working group commissioned by the Health Physics Society's Standards Committee (HPSSC) issued a draft set of performance specifications

for pocket-sized alarming dosimeters and ratemeters, including chirpers and digital display dosimeters (1979).^(a) The specifications are designed to apply to devices for both heavy industrial uses and less severe uses.

The HPSSC's standard deals with properties similar to those tested during this project. As listed in the draft of May 11, 1979, they include: 1) physical requirements (size, clip strength, mechanical shock resistance, and switch access); 2) power requirements; 3) controls and features (reset devices, calibration adjustments, speaker volume, multiple alarm requirements, and remote alarm capability); and 4) response characteristics (accuracy, energy dependence, exposure rate dependence, temperature response, and humidity response). Because the draft standard was developed independently of this project, some of our tests were only marginally appropriate in assessing how useful the standard would be to someone procuring dosimeters for rugged applications. However, other tests we used did give a preliminary assessment of how well current models meet HPSSC's proposed performance specifications.

With infrequent exceptions, our test population met or exceeded the minimum HPSSC specifications. The exceptions are noted as follows:

- Only one of the units tested did not pass a single drop test onto concrete from 1.2 meters (4 feet). (The HPSSC standard requires that devices for industrial use be able to withstand three such falls.) Our results indicated that two of the three models tested would have better than a 90% survival rate after three drops from 1.2 meters.
- One model averaged less than the minimum HPSSC requirement for sound pressure level of 75 dB (A-weighted). However, our measurements were made at a distance of 0.3 meter (1 foot) from the speaker in an orientation simulating the actual ear-to-speaker alignment that occurs when the unit is worn in the breast pocket. The standard does not specify a particular orientation, and this model would

^(a) The U.S. Nuclear Regulatory Commission, Office of Standards Development, has issued a draft regulatory guide for industrial radiography (1979) based on the HPSSC draft standard.

have passed a test in which the speaker was aimed toward the microphone.

- Energy dependence was tested using a 167-keV filtered x-ray spectrum similar to that used in the National Bureau of Standards' Technique HFI (1976), and using the isotopic sources Cs-137 (662 keV), Ra-226 + daughters (830 keV) and Co-60 (1250 keV). The digital display model overestimated the x-ray exposure by more than 30%, but responded to within 20% of the true exposure to the three isotopic sources. (The standard does not require that chirpers pass an energy dependence test.)
- The standard requires that access-limiting devices be used to minimize the risk of accidentally changing a switch's position. Two models offered little or no protection against this possibility, and units representing these models failed a test designed to determine resistance to accidental position changes.

CONCLUSIONS

A review of the test results for these pocket-sized electronic dosimeters and those tested earlier indicates that no instrument on the market at this time is capable of withstanding severe industrial or environmental conditions. With a little creative engineering and ingenuity, however, some of the instruments could be made rugged enough for use under severe conditions.

Several of the problems found could be corrected easily, e.g., low chirper volume, battery contacts that release the battery on impact, and switches that are subject to change by bumping or dropping. Other problems, like speaker breakage and the overresponse of most digital units to low-energy radiation, would require a fair amount of effort to resolve. However, no technological breakthroughs would be needed to enable the instruments to meet all the criteria tested in this project.

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APPENDIX A

TEST MODEL DESCRIPTION

APPENDIX A
TEST MODEL DESCRIPTION

Two chirper models were tested:

- RAW-II, acquired from Dosimeter Corporation of America. The price was \$125.00 in August 1979 and delivery time was about 4 months.
- Model 95/0023 - 1/6 Personal Gamma Dose-Rate Alarm, acquired from Nuclear Enterprises, Incorporated. The chirper contains a test source for an operational check, and a safety-pin and chain back-up for the clip. The price was \$310.00 in October 1978 and delivery time was about 8 weeks.

One digital display model was tested:

- PRIMADOSE II, Model 05-153 Integrating Alarm Dosimeter and Model 05-154 Reader, acquired from Nuclear Associates. The Primadose II has two audible response ranges, seven alarm levels, and a remote read-out capability. It also has an audible test. The price of the Primadose II dosimeter was \$225.00 and the price of the optional reader was \$390.00 in August 1979. Delivery time for five units and a reader was about 2 weeks.

APPENDIX B

TEST PROCEDURES

APPENDIX B TEST PROCEDURES

This section describes the types of tests performed on the test population. The section is divided into those tests which measured various properties of the units and those tests which evaluated the performance characteristics of the units under different conditions.

PHYSICAL PROPERTY TESTS

Mass: The mass of each unit was measured and recorded.

Dimensions: The maximum values of three major dimensions (length, width, and thickness) were measured and recorded.

Switch Access: Units were visually inspected for the presence of access-limiting devices. Switches were bumped and rubbed in a manner which tended to change their state. Adverse effects of bumping or rubbing casually were recorded.

Geotropism: The response to a constant field of radiation was noted with the dosimeter oriented in all six different positions with respect to gravity.

Speaker Volume Level: The sound pressure level was measured using a meter calibrated in decibels (A-weighted scale). Additional measurements were made on units having low batteries. This was done to determine whether or not lowering the battery potential would have any effect on the user's ability to hear the device. (No significant changes in the volume levels were noted.)

Battery Life: With fresh batteries in place, units were placed in a constant field of 2.5 mR/hr. Units were checked at 50, 150, 250, and 500 hours after the start of the test to see when they ceased to function.

With 90% of the nominal terminal voltage on the battery, units were placed in a 100-mR/hr field for a period of 8 hours. If a visual non-constant display was present, it was operated manually 20 times. At the end of 8 hours, each unit was checked to assure that it was still operating.

Alarm Point Accuracy: For units with presettable alarm points, this test was designed to assure that the alarm indications actuated only at the proper value as indicated by the digital readout. The point to be tested was selected by switch combinations, and the unit was exposed to radiation until the alarm sounded. The digital display was compared to the alarm point selected.

Chirp Repetition Rate: Units were placed in a constant radiation field where the exposure rate was known. Chirps from the unit were counted, and the chirp/mR factor was calculated based on time, chirps and radiation intensity.

PERFORMANCE CHARACTERISTICS TESTS

Mounting Clip Strength: A force equal to twice the weight of the unit was exerted on a unit attached to cotton duck material, in a manner which would remove the unit from the material.

Vibration: Units were placed in a Boerner shaker and vibrated for a total of 15 minutes. Units were removed every 5 minutes and checked for adverse effects.

Temperature: Units were subjected to the temperatures of -10°C and $+40^{\circ}\text{C}$. Their response to a constant radiation field at those temperatures was compared to their response at $20-25^{\circ}\text{C}$.

Temperature Shock: Units were heated to $+40^{\circ}\text{C}$ and allowed to stabilize for at least 15 minutes. Their ambient temperature was rapidly lowered to -10°C and the response to a constant radiation field was measured at 10-minute intervals for the next 30 minutes. The temperature was raised rapidly to $+40^{\circ}\text{C}$ and the response to the constant radiation field was again measured at 10-minute intervals for 30 minutes.

Humidity: Response of the unit to a constant radiation field was measured at both high and low relative humidities at both -10°C and $+40^{\circ}\text{C}$. Units were not cycled through the dew point.

Water Immersion and Moisture: Unpowered units were submerged in 1 foot of water for 10 minutes, opened, blow dried with room temperature air, and operated in a constant radiation field to which the pre-test response was known.

Operating units were sprayed with water at a rate which approximated a 3-inch per hour accumulation rate for 10 minutes. Changes in response were noted.

Units with power applied were submerged in 1 foot of water for 30 seconds, removed and inspected for internal moisture and/or damage.

Mechanical Shock: Units were dropped from heights of 1.2, 1.5, 1.8, 2.1, and 2.4 meters onto concrete. After each drop, units were tested in a radiation field to see if there was continued response. In the case of no response, effort was made to identify the failing component.

Surviving units were tossed into a metal tool box from a distance of 8 feet.

Surviving units were attached to a sand bag and allowed to impact on a concrete wall after swinging freely through 45° on an 8-foot radius.

Salt Water: Unpowered units were submerged in salt water for a period of 1 minute and set out in air for 10 minutes. The units were opened and rinsed with copious amounts of fresh water. Areas of corrosion damage were noted.

Accuracy (to ^{137}Cs): For digital display units, 6 minutes' exposure to 100 mR/hr of Cs-137 provided 10 mR of accumulated total dose with which to compare the unit's individual response.

Energy Dependence: (Digital Display Units) Units were placed in photon fields from Co-60, Ra-226 + daughters, Cs-137, and the filtered x-ray spectrum which approximates NBS' technique HFI (167 keV). After an exposure at the rate of 100 mR/hr, the indicated exposure in the dosimeter's display was compared to the actual value delivered.

Exposure Rate Error: (Digital Display Units) Using Technique HFI, dosimeters were exposed to photon radiation fields of 1.5, 3, 6, 9, 12, and 15 R/hr. (Corrections were made for any energy dependence identified in the previous test.) The response of the unit was compared to the actual exposure delivered after a predetermined time in the radiation field.

Response at High Exposure Rates: All units were placed in a photon field where the exposure rate was 500 R/hr. The ability to respond at this radiation intensity was noted for all units.

APPENDIX C

TABULATED TEST RESULTS

APPENDIX C
TABULATED TEST RESULTS

C.1. Physical Properties Tests

<u>Model</u>	<u>Mass, gm</u>	<u>Dimensions, mm</u>	<u>Mounting Clip Strength Test</u>	<u>Resistance to Switch Change</u>
Chirpers				
7C	188	139 x 45 x 25	5 Pass	0 Pass-5 Fail
8C	260	118 x 66 x 25	5 Pass	5 Pass-0 Fail
Digital Units				
9D	131	91 x 62 x 21	5 Pass	0 Pass-5 Fail

<u>Model</u>	<u>Temperature</u>			<u>Temperature Shock</u>		<u>Humidity</u>	<u>Water Immersion</u>
	<u>-10°C</u>	<u>+20°C</u>	<u>+40°C</u>	<u>Temp↑</u>	<u>Temp↓</u>		
Chirpers							
7C	Pass	Pass	Pass	Pass	1 Fail	Pass	Fail
8C	Pass	Pass	1 Fail	Pass	1 Fail	Pass	Fail
Digital Units							
9D	2 Fail	Pass	Pass	Pass	Pass	Pass	Fail

<u>Model</u>	<u>Number Tested</u>	<u>Mechanical Shock</u>						
		<u>Number Passing Drop From</u>						
		<u>1.2m</u>	<u>1.5m</u>	<u>1.8m</u>	<u>2.1m</u>	<u>2.4m</u>	<u>Toss</u>	<u>Crush</u>
Chirpers								
7C	5	4	3	2	1	1	--	--
8C	4	4	4	3	1	1	1	1
Digital Units								
9D	5	5	5	5	4	4	4	4

C.2. Electrical Properties Tests

<u>Model</u>	<u>Battery Life</u>		<u>Speaker Volume, dBA</u>	<u>Geotropism Effects</u>	<u>Alarm Point Accuracy</u>
	<u>8 Hours in a 100-mR/hr field</u>	<u>Duration in 2.5-mR/hr field</u>			
Chirpers					
7C	Pass	>500 hr	75	Pass	--
8C	1 Pass-3 Fail	>250 hr	71	Pass	--
Digital Units					
9D	Pass	>500 hr	78	Pass	Pass

C.3. Radiological Properties Tests

<u>Model</u>	<u>Chirps/mR ¹³⁷Cs</u>	<u>Accuracy to 100 mR/hr ¹³⁷Cs</u>
Chirpers		
7C	804	N/A
8C	522	N/A
Digital Units		
9D	754	Within 10%

<u>Model</u>	<u>Energy Response, % Deviation from Actual Exposure</u>			
	<u>167 keV (x-ray)</u>	<u>662 keV (¹³⁷Cs)</u>	<u>830 keV (²²⁶Ra)</u>	<u>1250 keV (⁶⁰Co)</u>
Digital Units				
9D	+33	-5	-5	+8

C.3. Radiological Properties Tests (Continued)

<u>Model</u>	Exposure Rate Response, % Deviation from Actual Exposure						
	<u>1.5</u> <u>R/hr</u>	<u>3.0</u> <u>R/hr</u>	<u>6.0</u> <u>R/hr</u>	<u>9.0</u> <u>R/hr</u>	<u>12.0</u> <u>R/hr</u>	<u>15.0</u> <u>R/hr</u>	<u>500</u> <u>R/hr</u>
Chirpers							
7C	N/A	N/A	N/A	N/A	N/A	N/A	Pass
8C	N/A	N/A	N/A	N/A	N/A	N/A	Pass
Digital Units							
9D	+20	+22	+7	+1	-4	-10	Pass

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