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Performance Testing of Personnel Dosimetry Services

Supplementary Report of a Two-Year Pilot Study
October 1977 - December 1979

Prepared by P. Plato, G. Hudson

The University of Michigan

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Prepared by
P. Plato, G. Hudson

The Department of Environmental and Industrial Health
School of Public Health
The University of Michigan
Ann Arbor, MI 48109

Prepared for
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U.S. Nuclear Regulatory Commission
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PERFORMANCE TESTING OF
PERSONNEL DOSIMETRY SERVICES:
SUPPLEMENTARY REPORT

ABSTRACT

The University of Michigan conducted a two-year pilot study of the Health Physics Society Standards Committee (HPSSC) Standard, "Criteria for Testing Personnel Dosimetry Performance." After the pilot study was concluded on September 27, 1979, the HPSSC Standard was revised based, in part, on experiences and recommendations derived from the pilot study. The Nuclear Regulatory Commission extended the contract under which the pilot study was conducted primarily so the data produced during the pilot study could be examined using the revised HPSSC Standard.

The results of this extension to the pilot study show that the passing rate increases substantially when the revised version of the Standard is used instead of the original version. Data are also given that show the percent of dosimeters used in the United States that are being processed by processors that passed the revised version of the HPSSC Standard. Finally, data are given that show that the production of bremsstrahlung is negligible for the strontium-90 source used during the pilot study, but that a processor that uses a deep depth considerably less than 1000 mg/cm^2 will over estimate deep doses for beta-plus-gamma irradiations.

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OBJECTIVES

The University of Michigan conducted a two-year pilot study of the Health Physics Society Standards Committee (HPSSC) Standard, CRITERIA FOR TESTING PERSONNEL DOSIMETER PERFORMANCE.¹ The pilot study was sponsored by the U.S. Nuclear Regulatory Commission under contract number NRC-01-77-180. The pilot study was completed on schedule on September 27, 1979. The primary documents that describe the operation and results of the pilot study are the Procedures Manual² and the Final Report.³

On October 16 and 17, 1979, Working Group 1.4 of the Health Physics Society met in Denver, Colorado to consider changes in the HPSSC Standard based, in part, on experiences and recommendations derived from the two-year pilot study. Immediately following the Denver meeting, the Nuclear Regulatory Commission extended contract number NRC-01-77-180 until December 31, 1979. The objectives of the extension were:

1. Using the criteria as modified by the HPSSC Working Group on ANSI N13.11 during its meeting of October 16-17, 1979, determine the percentage of radiation categories that were passed in the pilot study conducted under this contract.
2. Using both the original and modified HPSSC criteria, determine, or provide the best estimate of, the percentage of personnel dosimeters in the United States that are being processed by dosimetry processors who performed well in the pilot study. If an estimate is used, provide the basis for the estimate.
3. Determine by physical measurement the dose rate at 35 cm due to photons (bremsstrahlung) from the strontium-90 source used in the performance of this contract.

RESULTS

1. Performance Under Revised Standard

Table 1 is a summary of the radiation categories, dose intervals, number of dosimeters, and tolerance limits specified in the HPSSC Standard as the Standard was used during the pilot study. Table 2 is a summary of the radiation categories, test ranges, number of dosimeters, and tolerance limits as revised at the Denver meeting.* Several major changes in the HPSSC Standard were made:

1. The high-energy photon source was changed from cobalt-60 to cesium-137.
2. Accident doses (>10 rad) were placed in separate categories from protection doses for test purposes.
3. The mixed-photon category was changed from gamma rays plus high-energy photons to gamma rays plus low-energy photons.
4. The neutron source was changed from unmoderated to moderated californium-252.
5. The dose interval concept was eliminated. Instead, each category has only one dose range.
6. Fifteen dosimeters were required for each category instead of 20 to 40 dosimeters required in the original Standard.
7. The tolerance limit, L, was changed from a variable that depended on the delivered dose (see the bottom of Table 1), to a constant of 0.3 for the accident categories and 0.5 for the protection categories.
3. The statistical test was changed from $|\bar{P}| + 2S \leq L$ to $|\bar{P}| + S \leq L$.

* Although the changes shown in Table 2 were adopted by Working Group 1.4 in Denver, these changes have not been finalized as of this date. However, this report is based on the assumption that the changes shown in Table 2 will be adopted. Specific NBS X-ray techniques for Category III of Table 2 have not been selected as of this date.

Table 1. Summary of the HPSSC Standard used in the pilot study

Radiation Category	Interval	Test Range	Number of Dosimeters Per Test	Tolerance Level (L) (see footnotes)	
				Shallow (7 mg/cm ²)	Deep (1000 mg/cm ²)
I. Gamma (Co-60)	1 Accident:	10-800 rad	10	no test	a
	2 Protection:	30-100 mrem	10	no test	b
	3	101-300 mrem	10	no test	b
	4	301-10,000 mrem	10	no test	b
II. X Ray (30-300 keV)	1 Accident:	10-800 rad	10	no test	a
	2 Protection:	30-100 mrem	10	c	c
	3	101-300 mrem	10	c	c
	4	301-10,000 mrem	10	c	c
III. X Ray (15-30 keV)	Accident:	no test			
	1 Protection:	150-300 mrem	10	c	c
	2	301-10,000 mrem	10	c	c
IV. Beta (Sr-90)	Accident:	no test			
	1 Protection:	150-300 mrem	10	c	no test
	2	301-10,000 mrem	10	c	no test
V. Neutrons (Cf-252)	Accident:	no test			
	1 Protection:	100-300 mrem	10	no test	c
	2	301-5,000 mrem	10	no test	c
VI. Photon Mixtures (Cat. I & II)	Accident:	no test			
	1 Protection:	50-100 mrem	10	c	c
	2	101-300 mrem	10	c	c
	3	301-10,000 mrem	10	c	c
VII. Photon and Beta Mixtures (Cat. I or II & IV)	Accident:	no test			
	1 Protection:	200-300 mrem	10	c	c
	2	301-10,000 mrem	10	c	c
VIII. Photon and Neutron Mixtures (Cat. I & V)	Accident:	no test			
	1 Protection:	150-300 mrem	10	no test	c
	2	301-5,000 mrem	10	no test	c

For each dosimeter, a performance index is calculated by:

$$P = \frac{H' - H}{H} \quad \text{where: } H = \text{delivered quantity} \\ H' = \text{reported quantity}$$

For each depth of each interval, an average performance index, $\bar{P}$, and its standard deviation, S , are calculated.

A processor passes a category if, for each depth of each interval:

$$|\bar{P}| + 2S \leq L$$

where:

- a: $L = 0.3$
- b: $L = 0.3$ or $6/\sqrt{H}$ whichever is larger
- c: $L = 0.5$ or $15/\sqrt{H}$ whichever is larger

Table 2. Summary of the revised HPSSC Standard following the pilot study

Radiation Category*	Test Range	Tolerance Level, L, for	
		Deep Depth	Shallow Depth
I. Accidents, low-energy photons (NBS technique MFI)	10 - 500 rad	0.3	no test
II. Accidents, high-energy photons (^{137}Cs gamma radiation)	10 - 500 rad	0.3	no test
III. Low-energy photons (NBS techniques to be selected or K-fluorescence radiation of energy ≥ 20 KeV)	0.03 to 10 rem	0.5	0.5
IV. High-energy photons (^{137}Cs gamma radiation)	0.03 to 10 rem	0.5	no test
V. Beta particles (^{90}Sr - ^{90}Y)	0.15 to 10 rem	no test	0.5
VI. Photon mixtures (any combination of categories III and IV)	0.05 to 5 rem	0.5	0.5
VII. Mixtures, photons and beta particles (any combination of categories IV and V)	0.20 to 5 rem	0.5	0.5
VIII. Mixtures, neutrons and photons (^{252}Cf moderated by 15 cm of D_2O , either by itself or combined with category IV)	0.15 to 5 rem	0.5	no test

*All radiation categories except the first two which are specifically marked "accidents" apply to protection dosimetry. A processor passes a category if, for each depth, $|P| + S \leq L$ for 15 dosimeters

Table 3 compares the revised Standard to the original Standard used in the pilot study. In revised Categories I, III, and V, the comparison is exact except for the number of dosimeters required. The revised Standard requires 15 dosimeters for each category whereas the original Standard requires 10 dosimeters for each dose interval and a total of 20 to 40 dosimeters for each category. Thus, the analyses shown in Table 3 were done with as few as 10 dosimeters for some revised categories (e.g., Category I) and with as many as 30 dosimeters for others (e.g., Category IV).

In revised Categories II, IV, and VII, the only differences are the change from cobalt-60 to cesium-137 and the number of dosimeters required. In revised Category VI, low-energy photons instead of high-energy photons are mixed with gamma rays, the gamma-ray source is changed, and the number of dosimeters is changed. In revised Category VIII, a moderated instead of an unmoderated neutron source is required, the gamma-ray source is changed, and the number of dosimeters is changed. Thus, three of the revised categories have not been changed except for the number of dosimeters required, three have been changed slightly, and two (Categories VI and VIII) have been changed drastically.

The results from Test #1 and Test #2 of the pilot study were analyzed according (as much as possible) to the new radiation categories defined

Table 3. Analysis of pilot-study data for the revised HPSSC Standard

Revised Radiation Categories	Corresponding Original Radiation Categories and Dose Intervals	Results of Test #1				Results of Test #2			
		Processors		Dosimeters		Processors		Dosimeters	
		Number ¹	Passing ²	Number ³	Passing ⁴	Number ¹	Passing ²	Number ³	Passing ⁴
I. Accidents, low-energy photons (NBS technique MFI, E=60 keV)	Category II, interval 1 (NBS technique MPK, E=91 keV)	44	23%	571,000	42%	37	39%	516,000	51%
II. Accidents, high-energy photons (Cs-137 gamma radiation)	Category I, interval 1 (Co-60 gamma radiation)	61	46%	640,000	54%	53	62%	586,000	66%
III. Low-energy photons (20 keV ≤ E ≤ 100 keV)	Category III, intervals 1&2 (NBS technique L-C, E=20 keV)	35	14%	571,000	26%	34	53%	520,000	70%
IV. High-energy photons (Cs-137 gamma radiation)	Category I, intervals 2,3,&4 (Co-60 gamma radiation)	62	77%	648,000	84%	54	87%	594,000	92%
V. Beta particles (Sr/Y-90)	Category IV, intervals 1&2 (Sr/Y-90)	42	60%	585,000	87%	39	69%	533,000	87%
VI. Photon mixtures (Cs-137 + low-energy photons)	Category VI, intervals 1,2,&3 (Co-60 + high-energy photons)	42	56%	576,000	49%	36	65%	518,000	70%
VII. Photon + beta mixtures (Cs-137 + Sr/Y-90)	Category VII, intervals 1&2 (Co-60 + Sr/Y-90)	40	45%	557,000	81%	39	47%	530,000	85%
VIII. Photon + neutron mixtures (Cs-137 + moderated Cf-252)	Category VIII, intervals 1&2 (Co-60 + unmoderated Cf-252)	30	48%	382,000	42%	29	66%	335,000	65%
Average weighted by number of processors or dosimeters as appropriate			48%		59%		62%		74%

1 This column shows the number of processors that participated in each category.

2 This column shows the percent of processors that passed each category.

3 This column shows the approximate number of dosimeters processed each month by the processors that participated in each category.

4 This column shows the percent of dosimeters in the United States being processed by processors that passed each category.

Table 4. Analysis of pilot-study data for the original FPSSC Standard

Original Category	Results of Test #1				Results of Test #2			
	Processors		Dosimeters		Processors		Dosimeters	
	Number ¹	Passing ²	Number ³	Passing ⁴	Number ¹	Passing ²	Number ³	Passing ⁴
I	62	18%	632,000	15%	54	35%	576,000	40%
II	46	4%	581,000	5%	37	16%	512,000	27%
III	35	3%	571,000	3%	34	32%	519,000	49%
IV	42	38%	574,000	52%	39	51%	533,000	75%
V	30	20%	360,000	6%	32	31%	366,000	33%
VI	42	40%	576,000	58%	36	44%	518,000	34%
VII	40	33%	557,000	38%	39	26%	530,000	32%
VIII	30	<u>27%</u>	383,000	<u>33%</u>	29	<u>41%</u>	334,000	<u>37%</u>
Average weighted by number of processors or dosimeters as appropriate		23%		27%		35%		41%

1 This column shows the number of processors that participated in each category during the pilot study.

2 This column shows the percent of processors that passed each category.

3 This column shows the approximate number of dosimeters processed each month by the processors that participated in each category.

4 This column shows the percent of dosimeters being processed in the United States by processors that passed each category.

in the revised Standard. Table 3 shows the percent of category-tests^{*} passed by processors using the revised Standard and Table 4 shows similar information for the original Standard used during the pilot study. A comparison of these two tables indicates the effect of changing from 2S to S in the test formula and the effect of changing from a variable L to a constant L. The first change results in a more lenient test formula, while the second change results in a more stringent test formula than the one used in the original Standard. The net result is that the percent of category-tests passed increases from 23% to 48% for Test #1 and from 35% to 62% for Test #2 with the revised statistical formula.

2. Percent of Dosimeters that Pass

At the beginning of the two-year pilot study, a questionnaire was sent to each participating processor to determine how and why each processor calibrated their dosimeters. One question on the questionnaire asked for an estimate of the size of the processor in terms of the number of dosimeters processed each month. Tables 3 and 4 show the approximate number of dosimeters processed each month by the processors that chose to be tested in each category of the revised and original Standard, respectively. Also shown is the percent of U.S. dosimeters being processed by

* A category-test is one radiation category tested for one processor for one type of dosimeter. For example, if a processor elected to submit two types of dosimeters, each to be tested in three of the eight categories, the processor would have participated in a total of six category-tests. The results of all the category-tests indicate an average performance among all processors, but they do not indicate the fraction of processors that can pass all the categories in which they elect to be tested.

processors that passed a category in which they chose to participate. By weighting these percents by the number of dosimeters represented in each category, it is possible to estimate the percent of dosimeters in the United States that are being handled by dosimetry processors that were able to pass the original and revised HPSSC Standard.* These values are 27% and 41% for Tests #1 and #2, respectively, using the original Standard and 59% and 74% for Tests #1 and #2, respectively, using the revised Standard.

Appendix A contains bar graphs showing the distribution of the quality of individual dosimeters as determined from the results of Test #1 of the pilot study using the original version of the HPSSC Standard. A performance index was calculated as $(|\bar{P}| + 2S)/L$ for each dose interval of each category. Thus, if $(|\bar{P}| + 2S)/L \leq 1$, the dosimeters are being handled by a processor that passes the test in question. If this performance index is slightly larger than unity (perhaps as high as 2 or 3), the processor could probably pass with some minor adjustments in procedures. If the performance index is much larger than unity (the bar graphs end at 8, but some processors had a performance index as high as 3,000), then, at best, the processor probably requires major changes in procedures to pass and, at worst, the processor will never be able to pass the Standard.

*The total number of dosimeters processed each month by the 59 processors that participated in the pilot study is approximately 700,000. Since there are approximately 800,000 radiation workers in the United States, the pilot study included processors that handle about 90% of all radiation workers in the U.S.

Appendix B contains bar graphs showing performance in Test #2 of the pilot study using the original version of the Standard. Appendices C and D contain similar bar graphs for Test #1 and Test #2, respectively, using the revised HPSSC Standard.

In the original Standard, an interval is passed only if the required depths are passed, and a category is passed only if all the intervals are passed. The revised Standard has no dose intervals within each category, but a processor must pass the required depths of a category in order to pass the category. Thus, Tables 3 and 4 reflect the ability of the processors to meet all test requirements whereas the bar graphs shown in the Appendices reflect the ability of the processors to pass the various components of a category-test.

In the analyses discussed above, some processors failed a radiation category when only one dosimeter was considerably out of control (for example, some dosimeters were in error by a factor of ten due to clerical problems) even though each of the other dosimeters tested for that category had a reported dose within a few percent of the delivered dose. As an alternate method of analyzing the performance of the processors, and therefore the fraction of dosimeters in the United States being processed within acceptable limits, the performance index, P , of each of the 23,000 dosimeters irradiated for the pilot study was examined. Table 5 shows the results of this analysis. The left-hand column in Table 5 shows several tolerance levels used to test individual dosimeters irradiated

Table 5. Performance of individual dosimeters irradiated during the pilot study, and an estimate of the performance of all dosimeters in use in the United States.

Tolerance Level	Test #1		Test #2	
	Dosimeters Within the Indicated Tolerance Level		Dosimeters Within the Indicated Tolerance Level	
	Pilot Study ¹	United States ²	Pilot Study ¹	United States ²
±10%	27%	23%	37%	44%
±30%	62%	65%	73%	84%
±50%	78%	81%	86%	93%
±70%	86%	88%	92%	97%
±90%	91%	96%	95%	98%
L ³	85%	89%	90%	95%

¹ This column shows the percent of all the dosimeters irradiated for the pilot study that had reported doses within the indicated tolerance level.

² This column shows an estimate of all dosimeters processed in the United States that have accuracies within the tolerance levels shown. Values for this column were calculated by weighting the results of each dosimeter by the number of dosimeters processed each month by the processor that submitted the dosimeter.

³ The performance index (P) for each dosimeter was compared to the appropriate tolerance level (L) as defined in the HPSSC Standard. Definitions of P and L are given in Table 1. The criterion used for this analysis was $P \leq L$ although values of L were not intended to be used with individual values of P.

for the pilot study instead of the statistical tests applied to all the dosimeters in a category. The last line in Table 5 refers to the tolerance levels, L , defined in the original version of the HPSSC Standard used for the pilot study and shown in Table 1.

The columns labeled "Pilot Study" show the percent of dosimeters irradiated for the pilot study that were within the corresponding tolerance levels. The results show that 78% of the dosimeters irradiated for Test #1 and 86% of the dosimeters irradiated for Test #2 had a reported dose that was within $\pm 50\%$ of the delivered dose. In addition, Table 5 shows that 85% and 90% of the individual dosimeters irradiated during Tests #1 and #2, respectively, were within the tolerance levels required by the Standard. However, Table 4 shows that the passing rate for the category-tests was 23% and 35% for Tests #1 and #2, respectively. These results suggest that the low passing rates of the category-tests are due to the poor response of a relatively small (10% to 20%) number of dosimeters. The outlier dosimeters appear to be distributed somewhat uniformly among most of the processors and are not the exclusive problem of only a few processors.

In an attempt to use the results shown in Table 5 to estimate the accuracy of all dosimeters processed in the United States, the performance for each dosimeter was weighted by the number of dosimeters processed each month by the processor that submitted the dosimeter in question. The results are shown in Table 5 under the columns labeled "United States." This weighting procedure does not change the results appreciably.

Extrapolation from the test results of the pilot study to the performance of all dosimeters in use throughout the United States contains three possible sources of error. First, the pilot study represented a test conducted under well-defined conditions of irradiation. It did not include an evaluation of the variety of problems produced when dosimeters are actually used by people. Second, the pilot study followed the calibration requirements specified in the HPSSC Standard. Many processors use different calibration procedures that, at least in some cases, they believe satisfy the needs of the radiation workers they serve. Third, some uncertainties exist in the number of dosimeters processed each month by a given processor.

3. Contribution of Bremsstrahlung from Strontium-90 Source

At the beginning of the pilot study, the National Bureau of Standards (NBS) estimated that the contribution of bremsstrahlung from the strontium-90 source used for the pilot study would be negligible at the deep depth of 1000 mg/cm^2 . However, since no direct measurements were made at the beginning of the pilot study, it was decided to make such measurements to confirm the estimates by NBS.

Bremsstrahlung measurements were made using two independent methods. First, a Panasonic model UD-710A automatic thermoluminescent dosimeter (TLD) reader was used with UD-301A dosimeters. One element within the dosimeter is a $\text{Li}_2\text{B}_4\text{O}_7:\text{Cu}$ tissue-equivalent ($\bar{Z} = 7.4$) chip covered with

14 mg/cm² of Teflon. Several UD-801A dosimeters were placed 35 cm (the irradiation distance used during the pilot study) from the strontium-90 source used during the pilot study and were irradiated one at a time to 300 mrad of beta radiation. Additional layers of Mylar were added to the dosimeters to produce a depth-response curve from 14 to approximately 1000 mg/cm². Second, an Ionex electrometer together with a 300 cm³ thin-wall ionization chamber was used at 35 cm with aluminum filters to produce a depth-response curve from 0 to approximately 1000 mg/cm².

The results, shown in Table 6 and Figure 1, indicate that at 1000 mg/cm², a thickness that will absorb essentially all the beta particles from the strontium-90 source, the contribution of bremsstrahlung is less than 1% of the surface dose rate which had been found to be about 150 mrad/min.² Therefore, the contribution from bremsstrahlung is approximately 1 mrad/min throughout the first 1000 mg/cm² of an absorber.

Table 6. Results of measurements to determine the percent contribution of b. emsstrahlung at the deep (1000 mg/cm²) depth from the Sr/Y-90 source used for the pilot study.

Depth in Mylar (mg/cm ²)	Percent Response of TLD ¹ (%)	Depth in Aluminum (mg/cm ²)	Percent Response of Ionization Chamber ² (%)
0	100	0	100
14	98	19	97
63	90	81	72
112	74	130	55
209	44	173	46
307	25	228	35
405	15	275	26
502	7	342	16
600	3	440	9
697	0.6	495	6
795	0.2	550	3
990	0.3	678	2
		835	1
		960	0.9
		1090	0.7

¹ Panasonic UD-801A thermoluminescent dosimeters (TLDs) used with a Panasonic UD-710A Automatic TLD reader.

² Ionex electrometer used with an Ionex 600 cm³ thin-wall ionization chamber.

CONCLUSIONS

1. Performance Under Revised Standard

If the revised HPSSC Standard had been used during the pilot study, approximately half the category-tests would have been passed for Test #1 and approximately two-thirds of the category-tests would have been passed for Test #2. This represents a substantial increase in the passing rate compared to the results observed with the original HPSSC Standard.

2. Percent of Dosimeters that Pass

Table 4 shows an estimate of personnel dosimeters in the United States that are being processed by dosimetry processors that passed the original version of the HPSSC Standard for Test #1 and #2 of the pilot study. When the results for each radiation category are weighted by the number of dosimeters processed each month by processors that chose to be tested in that category, 27% and 41% of the dosimeters in the United States are being processed by processors that passed Test #1 and Test #2, respectively, of the pilot study.

Table 3 shows an estimate of the percent of personnel dosimeters that are being processed by dosimetry processors that would pass the revised version of the HPSSC Standard. The results given in Table 3 indicate that 59% and 74% of the dosimeters in the United States are being processed by processors that would have passed Test #1 and Test #2, respectively, if the revised Standard had been used during the pilot study.

The results shown in Tables 3 and 4 indicate that the percent of dosimeters processed by processors that passed the original or revised HPSSC Standard are approximately the same as the percent of category-tests that were passed in Tests #1 and #2. Thus, on the average, large and small processors appear to be about equal in their ability to pass the original and revised versions of the HPSSC Standard.

Table 5 shows that 78% and 86% of the dosimeters irradiated for Tests #1 and #2, respectively, had a reported dose that was within $\pm 50\%$ of the delivered dose. When the results of individual dosimeters are weighted by the size of each processor, Table 5 shows that the passing rates do not change appreciably. This further confirms that, on the average, large and small processors are about equal in their ability to process dosimeters accurately.

3. Contribution of Bremsstrahlung from Strontium-90 Source

Two different measurement methods were used to estimate the contribution of bremsstrahlung from the strontium-90 source used during the pilot study. The results shown in Table 6 and Figure 1 indicate that at 1000 mg/cm^2 the contribution from bremsstrahlung is less than 1% of the surface dose rate. Based on surface dose rate measurements made for the pilot study, it is estimated that the contribution from bremsstrahlung is approximately 1 mrad/min throughout the first 1000 mg/cm^2 of an absorber. This represents a negligible addition to the shallow doses assigned for beta-particle irradiations and the shallow and deep doses assigned for beta-plus-gamma irradiations during the pilot study.

Processors could create a problem for themselves if they determined the deep dose at a depth considerably less than 1000 mg/cm^2 . In fact, many processors use as little as 300 mg/cm^2 to measure deep doses. For beta-plus-gamma irradiations, the contribution of bremsstrahlung is negligible at any depth. But Figure 1 shows that the dose rate from beta particles at 300 mg/cm^2 is about 25% of the surface dose rate. Thus, a processor that used 300 mg/cm^2 will over estimate the deep dose due to the contribution of beta particles that reach this depth.

REFERENCES

1. Criteria for testing personnel dosimetry performance. Proposed standard prepared by the Health Physics Society Standards Committee, 4720 Montgomery Lane, Suite 506, Bethesda, MD 20014, November 30, 1977. This Standard is also published by the American National Standards Institute as Draft ANSI N13.11.
- * 2. Plato, P. and Hudson, G. Procedures manual for performance testing of personnel dosimetry services, NUREG/CR-1063, National Technical Information Service, Springfield, Virginia 22161, January, 1980.
- * 3. Plato, P. and Hudson, G. Final report for performance testing of personnel dosimetry services, NUREG/CR-1064, National Technical Information Service, Springfield, Virginia 22161, January, 1980.

*Available from the NRC/GPO Sales Program, Washington, D. C. 20555
and the National Technical Information Service, Springfield, VA 22161.

APPENDIX A

Distribution of the quality of individual dosimeters for Test #1 of the pilot study using the original version of the HPSSC Standard.

TEST 1
 CATEGORY I
 GAMMA
 10-800 RADS
 DEEP

TEST 1
 CATEGORY I
 GAMMA
 30-100 MREM
 DEEP

TOTAL BADGES PROCESSED=632020.

PERCENT OF BADGES PASSING=56.6

TEST 1
 CATEGORY I
 GAMMA
 101-300 MREM
 DEEP

TOTAL BADGES PROCESSED=632020.

PERCENT OF BADGES PASSING=59.9

TEST 1
 CATEGORY I
 GAMMA
 301-10,000 MREM
 DEEP

TEST 1
 CATEGORY II
 HIGH ENERGY X RAY
 10-800 RAD
 DEEP

TEST 1
 CATEGORY II
 HIGH ENERGY X RAY
 30-100 MREM
 SHALLOW

TOTAL BADGES PROCESSED=580895.

PERCENT OF BADGES PASSING=99.7

TEST I
 CATEGORY II
 HIGH ENERGY X RAY
 30-100 MREM
 DEEP

TOTAL BADGES PROCESSED=580895.

PERCENT OF BADGES PASSING=99.9

TEST 1
 CATEGORY II
 HIGH ENERGY X RAY
 101-300 MREM
 SHALLOW

TOTAL BADGES PROCESSED=580895.

PERCENT OF BADGES PASSING=96.4

TEST I
 CATEGORY II
 HIGH ENERGY X RAY
 101-300 MREM
 DEEP

TEST 1
 CATEGORY II
 HIGH ENERGY X RAY
 301-10,000 MREM
 SHALLOW

TOTAL BADGES PROCESSED=580895.

PERCENT OF BADGES PASSING=54.6

TEST 1
 CATEGORY III
 LOW ENERGY X RAY
 150-300 MREM
 SHALLOW

TOTAL BADGES PROCESSED=571175.

PERCENT OF BADGES PASSING=69.1

TEST 1
 CATEGORY III
 LOW ENERGY X RAY
 150-300 MREM
 DEEP

TEST 1
 CATEGORY III
 LOW ENERGY X RAY
 301-10,000 MREM
 SHALLOW

TOTAL BADGES PROCESSED=571185.

PERCENT OF BADGES PASSING=39.8

TEST 1
 CATEGORY III
 LOW ENERGY X RAY
 301-10,000 MREM
 DEEP

TEST 1
 CATEGORY IV
 BETA
 150-300 MREM
 SHALLOW

TEST 1
 CATEGORY IV
 BETA
 301-10,000 MREM
 SHALLOW

TOTAL BADGES PROCESSED=573050.

PERCENT OF BADGES PASSING=51.5

TEST 1
 CATEGORY V
 NEUTRON
 100-300 MREM
 DEEP

TEST 1
 CATEGORY V
 NEUTRON
 301-5000 MREM
 DEEP

TOTAL BADGES PROCESSED=359950.

PERCENT OF BADGES PASSING=6.8

TEST 1

CATEGORY VI

GAMMA PLUS X RAY

50-100 MREM

SHALLOW

TOTAL BADGES PROCESSED=576050.

PERCENT OF BADGES PASSING=97.3

TEST 1
 CATEGORY VI
 GAMMA PLUS X RAY
 50-100 MREM
 DEEP

TOTAL BADGES PROCESSED=576050.

PERCENT OF BADGES PASSING=97.3

TEST 1
 CATEGORY VI
 GAMMA PLUS X RAY
 101-300 MREM
 SHALLOW

TOTAL BADGES PROCESSED=576050.

PERCENT OF BADGES PASSING=95.7

TEST 1
 CATEGORY VI
 GAMMA PLUS X RAY
 101-300 MREM
 DEEP

TEST 1
 CATEGORY VI
 GAMMA PLUS X RAY
 301-10,000 MREM
 SHALLOW

TEST 1
 CATEGORY VI
 GAMMA PLUS X RAY
 301-10,000 MREM
 DEEP

TEST 1
 CATEGORY VII
 GAMMA PLUS BETA
 200-300 MREM
 DEEP

TEST 1
 CATEGORY VII
 GAMMA PLUS BETA
 301-10,000 MREM
 SHALLOW

TEST 1
 CATEGORY VII
 GAMMA PLUS BETA
 301-10,000 MREM
 DEEP

TEST 1
 CATEGORY VIII
 GAMMA PLUS NEUTRON
 150-300 MREM
 SHALLOW

TOTAL BADGES PROCESSED=382720.

PERCENT OF BADGES PASSING=80.7

TEST 1
 CATEGORY VIII
 GAMMA PLUS NEUTRON
 301-5,000 MREM
 DEEP

APPENDIX B

Distribution of the quality of individual
dosimeters for Test #2 of the pilot study
using the original version of the HPSSC
Standard

TEST 2
 CATEGORY I
 GAMMA
 10-800 RAD
 DEEP

TOTAL BADGES PROCESSED=568280.

PERCENT OF BADGES PASSING=51.9

TEST 2
 CATEGORY I
 GAMMA
 30-100 MREM
 DEEP

TOTAL BADGES PROCESSED=576300.

PERCENT OF BADGES PASSING=87.6

TEST 2
 CATEGORY I
 GAMMA
 101-300 MREM
 DEEP

TOTAL BADGES PROCESSED=576290.

PERCENT OF BADGES PASSING=92.7

TEST 2
 CATEGORY I
 GAMMA
 301-10,000 MREM
 DEEP

TOTAL BADGES PROCESSED=576280.

PERCENT OF BADGES PASSING=63.2

TEST 2
 CATEGORY II
 HIGH ENERGY X RAY
 10-800 RAD
 DEEP

TOTAL BADGES PROCESSED=502370.

PERCENT OF BADGES PASSING=52.0

TEST 2
 CATEGORY II
 HIGH ENERGY X RAY
 30-100 MREM
 SHALLOW

TOTAL BADGES PROCESSED=512370.

PERCENT OF BADGES PASSING=99.2

TEST 2
 CATEGORY II
 HIGH ENERGY X RAY
 30-100 MREM
 DEEP

TOTAL BADGES PROCESSED=512370.

PERCENT OF BADGES PASSING=99.2

TEST 2
 CATEGORY II
 HIGH ENERGY X RAY
 101-300 MREM
 SHALLOW

TEST 2
 CATEGORY II
 HIGH ENERGY X RAY
 101-300 MREM
 DEEP

09

TOTAL BADGES PROCESSED=512370.

PERCENT OF BADGES PASSING=75.3

TEST 2
 CATEGORY II
 HIGH ENERGY X RAY
 301-10,000 MREM
 SHALLOW

TOTAL BADGES PROCESSED=512370.

PERCENT OF BADGES PASSING=63.3

TEST 2
 CATEGORY II
 HIGH ENERGY X RAY
 301-10,000 MREM
 DEEP

TEST 2
 CATEGORY III
 LOW ENERGY X RAY
 150-300 MREM
 SHALLOW

CATEGORY III
LOW ENERGY X RAY
150-300 MREM
DEEP

NUMBER OF BADGES PER MONTH

10⁷
5
10⁶
5
10⁵
5
10⁴
5
10³
5
10²
5
10¹

0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00 8.00

$((\bar{P})+2S)/L$

Bin Range ($((\bar{P})+2S)/L$)	Number of Badges per Month
0.00 - 0.25	~10 ^{5.5}
0.25 - 0.50	~10 ^{5.2}
0.50 - 0.75	~10 ^{4.8}
0.75 - 1.00	~10 ^{4.2}
1.00 - 1.25	~10 ^{3.8}
1.25 - 1.50	~10 ^{3.2}
1.50 - 1.75	~10 ^{2.8}
1.75 - 2.00	~10 ^{2.2}
2.00 - 2.25	~10 ^{1.8}
2.25 - 2.50	~10 ^{1.2}
2.50 - 2.75	~10 ^{0.8}
2.75 - 3.00	~10 ^{0.2}
3.00 - 3.25	~10 ^{-0.2}
3.25 - 3.50	~10 ^{-0.8}
3.50 - 3.75	~10 ^{-1.2}
3.75 - 4.00	~10 ^{-1.8}
4.00 - 4.25	~10 ^{-2.2}
4.25 - 4.50	~10 ^{-2.8}
4.50 - 4.75	~10 ^{-3.2}
4.75 - 5.00	~10 ^{-3.8}
5.00 - 5.25	~10 ^{-4.2}
5.25 - 5.50	~10 ^{-4.8}
5.50 - 5.75	~10 ^{-5.2}
5.75 - 6.00	~10 ^{-5.8}
6.00 - 6.25	~10 ^{-6.2}
6.25 - 6.50	~10 ^{-6.8}
6.50 - 6.75	~10 ^{-7.2}
6.75 - 7.00	~10 ^{-7.8}
7.00 - 7.25	~10 ^{-8.2}
7.25 - 7.50	~10 ^{-8.8}
7.50 - 7.75	~10 ^{-9.2}
7.75 - 8.00	~10 ^{-9.8}

PERCENT OF BADGES PASSING=99.7

TEST 2
 CATEGORY III
 LOW ENERGY X RAY
 301-10,000 MREM
 SHALLOW

TOTAL BADGES PROCESSED=519350.

PERCENT OF BADGES PASSING=63.1

CATEGORY III
LOW ENERGY X RAY
301-10,000 MREM
DEEP

NUMBER OF BADGES PER MONTH

$(|F|+2S)/L$

$(F +2S)/L$ Range	Number of Badges per Month (approx.)
0.25 - 0.50	10,000
0.50 - 0.75	10,000
0.75 - 1.00	1,000
1.00 - 1.25	10,000
1.25 - 1.50	1,000
1.50 - 1.75	1,000
2.00 - 2.25	10,000
2.25 - 2.50	1,000
2.75 - 3.00	1,000
4.50 - 4.75	1,000
6.50 - 6.75	100
8.00 - 8.25	10,000

PERCENT OF BADGES PASSING=69.0

TEST 2
 CATEGORY IV
 BETA
 150-300 MREM
 SHALLOW

TOTAL BADGES PROCESSED=532850.

PERCENT OF BADGES PASSING=97.5

TEST 2
 CATEGORY IV
 BETA
 301-10,000 MREM
 SHALLOW

TOTAL BADGES PROCESSED=532050.

PERCENT OF BADGES PASSING=76.6

TEST 2
CATEGORY V
NEUTRONS
100-300 MREM
DEEP

TEST 2
 CATEGORY V
 NEUTRONS
 301-10,000 MREM
 DEEP

TEST 2

CATEGORY VI

GAMMA PLUS X RAY

50-100 MREM

SHALLOW

TEST 2
 CATEGORY VI
 GAMMA PLUS X RAY
 50-100 MREM
 DEEP

72

TEST 2
 CATEGORY VI
 GAMMA PLUS X RAY
 101-300 MREM
 SHALLOW

TOTAL BADGES PROCESSED=517985.

PERCENT OF BADGES PASSING=95.1

TEST 2
 CATEGORY VI
 GAMMA PLUS X RAY
 101-300 MREM
 DEEP

TOTAL BADGES PROCESSED=517985.

PERCENT OF BADGES PASSING=95.4

TEST 2
 CATEGORY VI
 GAMMA PLUS X RAY
 301-10,000 MREM
 SHALLOW

TEST 2
 CATEGORY VI
 GAMMA PLUS X RAY
 301-10,000 MREM
 DEEP

TOTAL BADGES PROCESSED=517985.

PERCENT OF BADGES PASSING=43.2

TEST 2
 CATEGORY VII
 GAMMA PLUS BETA
 200-300 MREM
 SHALLOW

TEST 2
 CATEGORY VII
 GAMMA PLUS BETA
 200-300 MREM
 DEEP

TEST 2
 CATEGORY VII
 GAMMA PLUS BETA
 301-10,000 MREM
 SHALLOW

TEST 2

CATEGORY VIII

GAMMA PLUS NEUTRON

150-300 MREM

DEEP

TEST 2
 CATEGORY VIII
 GAMMA PLUS NEUTRON
 301-5,000 MREM
 DEEP

APPENDIX C

Distribution of the quality of individual dosimeters for Test #1 of the pilot study using the revised version of the HPSSC Standard.

TEST 1
 CATEGORY I
 LOW-ENERGY PHOTONS
 10-500 RAD
 DEEP

TOTAL BADGES PROCESSED=570895.

PERCENT OF BADGES PASSING=41.8

TEST 1
 CATEGORY II
 HIGH-ENERGY PHOTONS
 10-500 RAD
 DEEP

TOTAL BADGES PROCESSED=639645.

PERCENT OF BADGES PASSING=53.5

TEST I
 CATEGORY III
 LOW-ENERGY PHOTONS
 30-10,000 MREM
 SHALLOW

TOTAL BADGES PROCESSED=571185.

PERCENT OF BADGES PASSING=56.3

TEST 1
 CATEGORY III
 LOW-ENERGY PHOTONS
 30-10,000 MREM
 DEEP

TOTAL BADGES PROCESSED=571185.

PERCENT OF BADGES PASSING=44.1

TEST 1
 CATEGORY IV
 HIGH-ENERGY PHOTONS
 30-10,000 MREM
 DEEP

TOTAL BADGES PROCESSED=647645.

PERCENT OF BADGES PASSING=84.1

TEST 1
CATEGORY V
BETA
150-10,000 MREM
SHALLOW

TOTAL BADGES PROCESSED=585375.

PERCENT OF BADGES PASSING=86.6

TEST 1
 CATEGORY VI
 GAMMA PLUS X RAY
 50-5,000 MREM
 SHALLOW

TEST 1
 CATEGORY VI
 GAMMA PLUS X RAY
 50-5,000 MREM
 DEEP

TEST 1
 CATEGORY VII
 GAMMA PLUS BETA
 200-5,000 MREM
 SHALLOW

TEST 1
 CATEGORY VII
 GAMMA PLUS BETA
 200-5,000 MREM
 DEEP

TOTAL BADGES PROCESSED=557135.

PERCENT OF BADGES PASSING=86.6

TEST 1
 CATEGORY VIII
 GAMMA PLUS NEUTRON
 150-5,000 MREM
 DEEP

APPENDIX D

Distribution of the quality of individual dosimeters for Test #2 of the pilot study using the revised version of the HPSSC Standard.

TEST 2
 CATEGORY I
 LOW-ENERGY PHOTONS
 10-500 RAD
 DEEP

TEST 2
 CATEGORY II
 HIGH-ENERGY PHOTONS
 10-500 RAD
 DEEP

TOTAL BADGES PROCESSED=586120.

TEST 2
 CATEGORY III
 LOW-ENERGY PHOTONS
 30-10,000 MREM
 SHALLOW

TOTAL BADGES PROCESSED=519850.

PERCENT OF BADGES PASSING=71.9

TEST 2
 CATEGORY III
 LOW-ENERGY PHOTONS
 30-10,000 MREM
 DEEP

TEST 2
 CATEGORY IV
 HIGH-ENERGY PHOTONS
 30-10,000 MREM
 DEEP

TEST 2
 CATEGORY V
 BETA
 150-10,000 MREM
 SHALLOW

TOTAL BADGES PROCESSED=533350.

PERCENT OF BADGES PASSING=89.7

TEST 2
 CATEGORY VI
 GAMMA PLUS X RAY
 50-5,000 MREM
 SHALLOW

TEST 2
 CATEGORY VI
 GAMMA PLUS X RAY
 50-5,000 MREM
 DEEP

TOTAL BADGES PROCESSED=518485.

PERCENT OF BADGES PASSING=84.4

TEST 2
 CATEGORY VII
 GAMMA PLUS BETA
 200-5,000 MREM
 SHALLOW

TOTAL BADGES PROCESSED=530110.

PERCENT OF BADGES PASSING=94.2

TEST 2
CATEGORY VII
GAMMA PLUS BETA
200-5,000 MREM
DEEP

TOTAL BADGES PROCESSED=530110.

PERCENT OF BADGES PASSING=89.2

TEST 2
 CATEGORY VIII
 GAMMA PLUS NEUTRON
 150-5,000 MREM
 DEEP

TOTAL BADGES PROCESSED=334860.

PERCENT OF BADGES PASSING=65.4