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Performance Testing of Personnel Dosimetry Services: Procedures Manual

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University of Michigan

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PERFORMANCE TESTING OF

PERSONNEL DOSIMETRY SERVICES:

PROCEDURES MANUAL

ABSTRACT

The University of Michigan conducted a two-year pilot study of the Health Physics Society Standards Committee (HPSSC) Standard titled, "Criteria for Testing Personnel Dosimetry Performance." During the pilot study, 59 dosimetry processors volunteered to submit dosimeters for test irradiations according to the requirements and restraints described in the HPSSC Standard.

The objective of the Procedures Manual is to describe the operational conditions of the pilot study. The Manual describes source calibrations (which were done or supervised by the National Bureau of Standards), irradiation geometries, quality control, record keeping, data analysis, and methods of receiving, handling, and returning large numbers of dosimeters.

The pilot study was conducted using the procedures and radiation sources required by the draft of the HPSSC Standard dated November 30, 1977. The Procedures Manual was prepared prior to the preparation of

the Final Report on the pilot study, which contains recommendations for changes in the HPSSC Standard. Other interested groups are also expected to recommend changes in the Standard after the Final Report is issued. Thus, the reader of the Procedures Manual is cautioned that the HPSSC Standard will undoubtedly have changed between the time the Manual was prepared and the time it will first be used.

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I. INTRODUCTION

From October, 1977 to September, 1979, The University of Michigan conducted a pilot study of the Health Physics Society Standards Committee (HPSSC) Standard titled CRITERIA FOR TESTING PERSONNEL DOSIMETRY PERFORMANCE.[1*] The Standard was given tentative approval by the American National Standards Institute as ANSI N13.11. Table 1 summarizes the radiation categories and statistical criteria required by the Standard.

During the two-year pilot study, 59 dosimetry processors volunteered to send us dosimeters for irradiation according to the requirements and restraints described in the HPSSC Standard. Once a processor evaluated their dosimeters, they reported their estimates of the delivered dose equivalents to us. We then determined if the processor passed or failed the Standard and sent the processor a computer printout of their results.

Each processor was permitted to be tested twice during the pilot study. Test #1 was conducted from May through October, 1978, and Test #2 was conducted from November, 1978 through April, 1979. For each test, a processor could choose to be tested in any or all of the eight radiation categories defined in the Standard. The average processor participated in six categories. During the two-year pilot study, we administered a total of 700 category tests among all the processors. These tests required the irradiation of approximately 21,000 dosimeters.

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*The version of the HPSSC Standard used for the pilot study was dated November 30, 1977. This verision of the Standard is included in Appendix D. Following the pilot study, the Standard was revised extensively.

Table 1. Summary of HPSSC Standard prepared by The University of Michigan

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:

$$P = \frac{H' - H}{H}$$ where: H = delivered quantity, H' = 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

In addition to the open tests, we blind-tested seven of the large commercial processors. The blind testing program involved a total of 70 category tests and 1,680 dosimeters.

The objective of this Procedures Manual is to describe the operational conditions of the pilot study in sufficient detail to permit another laboratory to duplicate our procedures. The Manual describes our source calibrations, irradiation geometries, quality control, record keeping, data analysis, and method of receiving, handling, and returning large numbers of dosimeters.

This Procedures Manual was prepared prior to the preparation of the Final Report on the pilot study, which will contain our recommendations for changes in the HPSSC Standard. Other interested groups are also expected to recommend changes in the Standard after the Final Report is issued. Thus, the reader of this Procedures Manual is cautioned that the HPSSC Standard will undoubtedly have changed between the time this Manual was prepared and the time it will first be used.

II. SOURCES, CALIBRATIONS, EQUIPMENT, AND INSTRUMENTS

A. General

Table 2 summarizes the six radiation sources that were used for each interval of the five radiation categories that require a single source. The remaining three c... ries involve appropriate combinations of the sources used for the first five categories.

All calibrations were done with ionization chambers placed free in air, but all dosimeters were irradiated while mounted on a phantom. Six phantoms were constructed for convenience, so one phantom could be left with each of the six radiation sources throughout the pilot study. Each phantom is a Plexiglas box, 30 x 30 cm by 15 cm deep, filled with water. Six dosimeters, one from each of six different processors, were attached to a phantom and irradiated at the same time to the same quantity of radiation. The six irradiation positions on the front face of each phantom are shown in Figure 1. Calibration of each radiation source involved exposure (or absorbed dose) rate measurements at each of the six positions at which dosimeters were placed on a phantom. The irradiation geometry for dosimeters attached to a phantom is illustrated in Figure 1.

At each source, a phantom was placed on a permanent stand. The height of each stand was fixed in order to keep the phantom in the center of the radiation beam. A platform was mounted on top of each stand, and a phantom was placed on the platform. Each platform had the same surface dimensions

Table 2. Summary of radiation sources and irradiation conditions for the five categories that require a single source.

Radiation Category	Interval	Radiation Source	NBS Technique	Irradiation Conditions: Dist. (cm)	Irradiation Conditions: Approx. Rate[d]	$\bar{C}_{x_{air}}$[e] Shallow	$\bar{C}_{x_{air}}$[e] Deep	$\bar{E}$[f] (keV)
I. Gamma	10-200 rad[a]	Co-60, teletherapy		200	15 R/min	1.01	1.01	1250
	201-800 rad[a]	" "		100	60 R/min	"	"	"
	30-100 mrem	Co-60, Irradiator		200	25 mR/min	"	"	"
	101-300 mrem	" "		100	100 mR/min	"	"	"
	301-10,000 mrem	" "		100	100 mR/min	"	"	"
II. X-Ray (30-300 keV)	10-800 rad	X-ray machine[b]	MFK, 20mA	100	10 R/min	1.34	1.34	91
	30-100 mrem	" "	HFK, 5mA	100	15 mR/min	1.26	1.26	204
	101-300 mrem	" "	HFG, 10mA	100	50 mR/min	1.35	1.35	118
	301-10,000 mrem	" "	MFG, 5mA	100	750 mR/min	1.28	1.23	54
III. X-Ray (15-30 keV)	150-300 mrem	X-ray machine[c]	L-G, 1mA	200	100 mR/min	0.81	0.26	20
	301-10,000 mrem	" "	L-G, 4mA	200	300 mR/min	"	"	"
IV. Beta	150-300 mrem	Sr-90 irradiator		35	150 mrad/min			
	301-10,000 mrem	" "		35	150 mrad/min			
V. Neutron	100-300 mrem	Cf-252 irradiator		100	25 mrem/min			
	301-5,000 mrem	" "		50	100 mrem/min			

(a) The single interval from 10 to 800 rad was subdivided for ease of irradiation at two distances.

(b) A General Electric Maxitron 300 X-ray machine was used for all intervals of Category II.

(c) A General Electric XRD-5 X-ray machine was used for both intervals of Category III.

(d) Exact exposure rates and absorbed dose rates were measured with appropriate ionization chambers.

(e) Values of C_x are given in Table 2 of the HPSSC Standard. They are used to convert from exposure to dose equivalent index at shallow (7 mg/cm^2) and deep (1000 mg/cm^2) depths in tissue. Values of $\bar{C}_x$ are weighted averages for each complete fluence spectrum.

(f) Values of $\bar{E}$, the average energy of a photon spectrum, were measured by GSF[2].

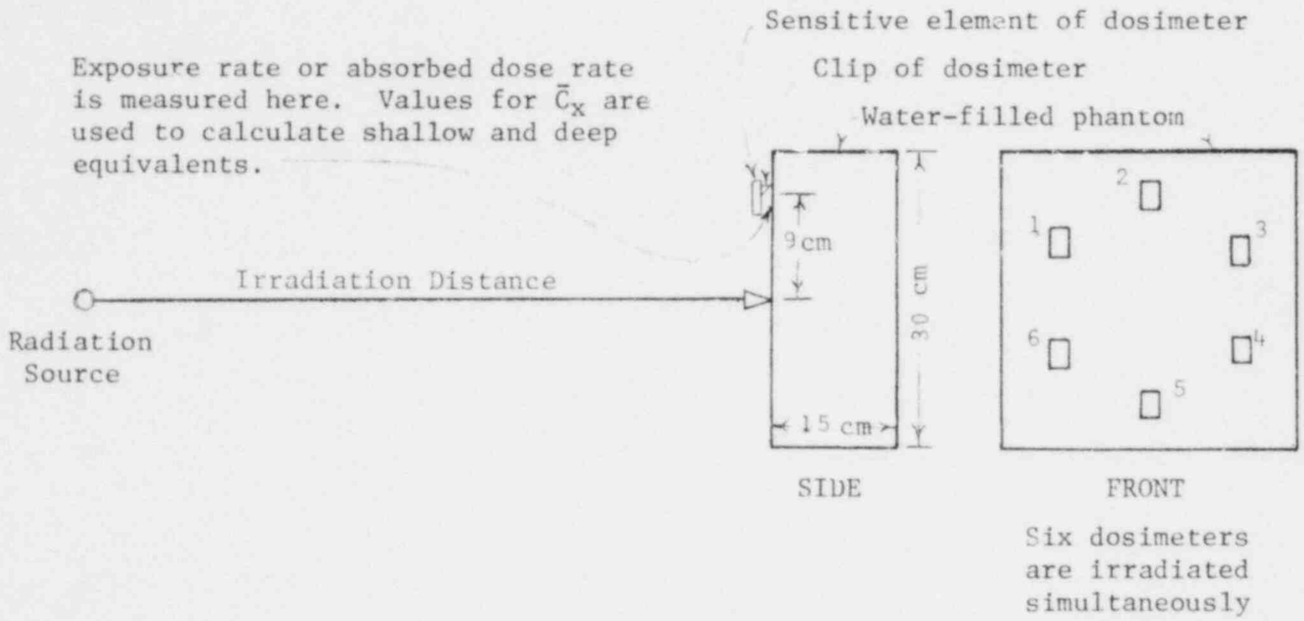

Figure 1. Irradiation geometry for dosimeters attached to a water-filled phantom.

as the bottom of a phantom, 30 cm x 15 cm. The front of the phantom was aligned with the front of the platform for dosimeter irradiations. The phantom was pushed back a distance equal to the radius of an ionization chamber for calibrations so the ionization chamber could be properly positioned before the phantom was removed.

Two methods were used to determine the proper alignment of a phantom in a radiation beam. First, for all photon sources, ionization chamber measurements were made repetitively at the six irradiation positions on the face of a phantom. The phantom was moved vertically or horizontally until the mean exposure rates among the six positions differed by less than 1%. Second, for every source including the californium-252 source, a piece of chest-size X-ray film was placed on the face of the phantom and irradiated. A Welch densitometer was used to examine the uniformity of the radiation beam among the six irradiation positions.

Once a phantom was properly aligned in a radiation beam, plumb bobs were suspended from permanent mountings in the ceiling to align with markings on the top of the phantom. Measurements were made relative to the phantom from the walls, the floor, and the source and were recorded on a schematic drawing of each room. A schematic drawing was posted at each source to make alignment quality control checks simple and consistent. Levels were placed on the phantom to be sure the face of the phantom was always perpendicular to the radiation beam. A rigid bar was cut for each source so the distance from the source to the phantom would be measured exactly the same each time. Each measuring bar was labeled beta source, gamma source, etc., to provide each source with the same bar each time.

All of the radiation sources, except the neutron source, were calibrated with an electrometer and a Leeds and Northrup Student Potentiometer. When operated in the capacitance mode, the electrometer was used with a 10,381.3 x 10^{-12} farad capacitor calibrated by the National Bureau of Standards (NBS).

The X-ray and cobalt-60 sources were calibrated with either a 3 cm^3 or a 100 cm^3 Shonka-Wyckoff ionization chamber manufactured by Exradin, Inc. Both chambers were calibrated by NBS for specific NBS X-ray techniques (specific combinations of kilovoltage and filtration) and for cobalt-60.

The strontium-90 source was calibrated first by NBS and then with The University of Michigan's extrapolation chamber.

The californium-252 source was calibrated by NBS.

Throughout the pilot study, close ties were maintained between the testing laboratory and NBS. Before Test #1 began, NBS calibrated the two ionization chambers that were to be used to calibrate all the photon sources required for the pilot study. At the conclusion of Test #2, the ionization chambers were again calibrated by NBS. A team of five people from NBS visited the testing laboratory before Test #1 began to review all calibration and irradiation procedures. This close cooperation with NBS was essential to insure that the delivered exposures and absorbed doses were as accurate as possible.

The following parts of Section II describe the procedures developed to calibrate and use the six radiation sources required for the pilot study. Floor plans of the irradiation facilities and specific calibration data are given in the Preliminary Phase Report prepared in April, 1978.

B. Cobalt-60 Irradiator

A 5-curie cobalt-60 irradiator with a 30° beam port was purchased from J.L. Shephard and Associates. Irradiation distances of 1 and 2 meters were chosen for the protection intervals of Category I. At each distance, a Plexiglas phantom was placed on a stand and aligned in the center of the beam. Once the correct alignment was determined, two permanent plumb bobs (110 g each) were hung from the ceiling with nylon lines so the alignment of the phantom could be reproduced. Also, a plumb bob was hung from the ceiling above the source so that any movement could be detected. The beam extended approximately 50 cm beyond the edges of the front face of the phantom. Rigid bars 1 and 2 meters long were fabricated to assure reproducible distance measurements. The 3 cm^3 ionization chamber with a plastic buildup cap to produce electronic equilibrium was used for calibration.

The following procedures were used for calibration. Four different measuring systems were used to determine which ones would be most accurate and to determine the agreement among the systems. The systems were: Keithley model 610B electrometer, Keithley model 610B electrometer with Leeds and Northrup Potentiometer, Cary model 31 electrometer, and Cary model 31 electrometer with Leeds and Northrup Potentiometer. At a later time, a Keithley model 616 electrometer was also used. It was determined that the Cary model 31 and the Keithley model 616 systems were the most accurate and reliable. However, there was fair agreement when the Keithley model 610B electrometer was used together with the potentiometer. It is felt that using different techniques enabled the testing laboratory to have some redundancy in the measurement systems.

Calibration measurements were made repeatedly at each of the six phantom positions at the 1 meter distance. The variation in the average exposure rates among all six phantom positions was no larger than the variations in individual readings at any one position. Therefore, the exposure rate was computed from a mean among all six phantom positions. At the 2 meter distance, only three phantom positions (#2, #3, and #5) were calibrated as above. The exposure rate was again computed from a mean rate among the three positions.

Personnel at NBS calculated that back-scatter from the walls of the room was less than 0.1%. The electronics were removed as far as possible from the direct and scattered radiation. Two line frequency timers, two barometers, two thermometers, low-noise cables, and proper connectors were used to insure accuracy of the measurements.

To check the effect of source-shutter functions, the source was raised and lowered several times with the timer, which is activated when the source is in the irradiation position, used to record the total source-on time. The actual irradiation time, computed from the steady-state ionization current determined in earlier measurements, was compared to the time on the irradiator's timer. The difference, if any, in the times was corrected for in the calibration.

Since the irradiator was manually operated, all the personnel involved in the pilot study were used to determine the shutter time. This was done several times and an average time was calculated. It was determined that, for the shortest times (on the order of 1 minute) used to irradiate dosimeters, an error of about 0.2% could result. Thus, it was concluded that shutter time errors were insignificant.

The linearity of the exposure rate was also checked by measuring the exposure rate as a function of exposure time. It was determined that the exposure rate was constant for times greater than 0.5 minute.

Leakage current of the electrometer system was measured after each set of six measurements. The leakage current averaged about 1×10^{-14} ampere and was corrected for in the calibration measurements.

C. Cobalt-60 Teletherapy Unit

The University of Michigan Hospital's 2700-curie cobalt-60 teletherapy unit was used to deliver the high absorbed doses required for the accident interval of Category I. Irradiation distances of 100 cm and 200 cm were chosen for convenience. At each distance, the phantom was placed on a stand and aligned in the center of the gamma-ray beam with the aid of the internal light source in the head of the teletherapy unit. The aperture of the source was adjusted so the beam extended beyond the edges of the phantom by a few centimeters. The phantom was then pushed back on the platform a distance equal to the radius of the 3 cm^3 ionization chamber. The chamber with a plastic buildup cap to produce electronic equilibrium was placed at Position 1 (see Figure 1). The phantom was then removed, and the exposure rate was measured with the Cary electrometer, or its equivalent, operated in the capacitance mode. The procedure was repeated for each of the other five positions on the phantom. The average exposure rate among the six positions was then calculated.

D. High-Energy X-Ray Machine

A General Electric Maxitron 300 X-ray machine was used to irradiate dosimeters for Category II. The machine has an inherent filtration of 4.75 mm Be. Four NBS X-ray techniques were used for Category II, one for each of the four intervals. The filtration and kilovoltage used for these four techniques are shown in Table 3.

A Plexiglas phantom was mounted on a stand and aligned in the center of the X-ray beam. Two commercial plumb bobs were permanently suspended with nylon line from the ceiling so the alignment of the phantom could

Table 3. X-ray techniques used for The University of Michigan dosimetry performance pilot study.

X-Ray Machine	Category	Interval	kVp	Filtration (mm) Be	Al	Cu	Sn	Pb	NBS Technique	GSF* Measured $\bar{E}$ (keV)	UM Calculated $\bar{E}$ (keV)	UM Calculated Avg. $\bar{C}_x$-shallow	$\bar{C}_x$-deep
G.E. Maxitron 300	II	1	200	4.75	4.85	5.00			MFK	91.1	107.5	1.342	1.338
G.E. Maxitron 300	II	2	250	4.75	3.97	0.60	1.03	2.65	HFK	204.2	205.3	1.262	1.262
G.E. Maxitron 300	II	3	150	4.75	4.00	4.00	1.46		HFG	117.5	118.5	1.349	1.349
G.E. Maxitron 300	II	4	100	4.75	6.31				MFG	53.9	57.5	1.283	1.233
G.E. XRD-5	III	1 and 2	30	0.25	0.37				L-G	19.7	19.0	0.813	0.259

*GSF: Gesellschaft für Strahlen-und Umweltforschung mbH, (reference 2).

be reproduced. The beam was collimated with lead so that it extended beyond the edges of the phantom by approximately 5 cm. A rigid aluminum bar was cut to a length of 1 meter so that measurements from the X-ray tube head to the phantom face were reproducible for all irradiations. Two elapsed timers, driven by power line frequency, were used to time all irradiations.

Calibrations at the six positions on the face of the phantom were made with the 100 cm^3 ionization chamber. The Cary electrometer was used with the Leeds and Northrup Student Potentiometer in the null mode to measure exposure rates for each NBS technique. The Cary electrometer was also used in the capacitance mode to measure exposure rates, and these measurements were compared to exposure rates obtained with the potentiometer. The Keithley model 616 was also used as a redundant check. Redundant calibration measurements made with several different systems were made at only one of the dosimeter positions. The exposure rates measured among the systems differed by about 0.5%.

The exposure rates were then determined repeatedly (5 to 6 measurements) at each phantom position. It was concluded that the variations in the average rates for all six phantom positions were no larger than the variations in the individual measurements at any one position.

When dosimeters were to be irradiated, the following procedure was followed. The ionization chamber was placed at one of the six phantom positions, and the phantom was removed. The ionization chamber was placed so that the center of the spherical chamber was in the same plane as the front face of the phantom would be when the phantom was returned to the stand for dosimeter irradiations. Five measurements of exposure rate were then made. The ionization chamber was then removed and the phantom placed on the stand. Dosimeters were irradiated during the working day with a beam monitor in continuous operation. The output of the beam monitor was recorded on a strip chart recorder. At the end of the day, the beam was calibrated again with the ionization chamber.

If the beam monitor showed no significant changes in the output of the X-ray machine during the day, then the initial and final exposure rates were averaged. The average exposure rate was combined with the recorded irradiation times for the dosimeters to calculate the exposure to each dosimeter. At no time during the pilot study did the initial and final calibrations differ by more than 2%.

The electronic equipment was placed in a small room next to the X-ray room with a cable leading through a lead-covered opening in the wall. This eliminated scattered radiation from affecting the electronics. Low noise cable, automatic timing, a Data Precision and a Keithley digital voltmeter, two thermometers, and two barometers were used for the measurements.

The quality of the beams was determined by measuring the first half value layer (HVL_1) and the homogeneity coefficient (h) defined as the ratio of the first and second half value layers. Type 1100 aluminum filters were used for these measurements. The quality of the beam was determined to be acceptable only if the measured value for HVL_1 was within 5% of the HVL_1 measured by NBS, and if the measur . value for h was within 10% of the h measured by NBS.

Timing errors were examined by measuring exposure rates for irradiation times that varied from 0.1 minute to 10.0 minutes. It was determined that there was no significant difference in the exposure rate for 1.0 minute to 10 minutes irradiations. Therefore, the minimum time used to irradiate dosimeters was 1.0 minute.

The leakage current of each system was monitored periodically during the calibrations, and corrections were made for leakage. The leakage current averaged about $1x10^{-14}$ ampere.

The rem/roentgen conversion factor ($\bar{C}_x$) for each X-ray technique was computed by weighing the factors given in Table 2 of the HPSSC Standard by the approximate exposure spectrum of each technique. The spectra were obtained by Kramers' calculational method. Energy absorption coefficients required for the calculations were obtained from the Radiological Health Handbook. Calculated values for $\bar{C}_x$ at shallow and deep depths in tissue are shown in Table 3.

An upper estimate of room scatter was made by shielding the ionization chamber from the primary beam. This experimental measurement showed that the maximum room scatter was approximately 1.6% at 1 m from the tube head.

E. Low-Energy X-Ray Machine

A General Electric XRD-5 X-ray machine was used to irradiate dosimeters for Category III. The machine has an inherent filtration of approximately 0.25 mm Be. A single NBS technique L-G, with different tube currents, was used for the two intervals of Category III. The filtration and kilovoltage required for the L-G technique are shown in Table 3.

A Plexiglas phantom was mounted on a stand and aligned in the X-ray beam. Two commercial plumb bobs were permanently suspended with nylon line from the ceiling so the alignment of the phantom could be reproduced. The beam was collimated with lead so that it extended beyond the edges of the phantom by approximately 5 cm. A rigid aluminum bar was cut to the appropriate length so that the measurement from the X-ray tube head to the phantom was reproducible for all irradiations.

The same calibration and irradiation procedures were used for the XRD-5 X-ray machine as were used for the Maxitron 300. These procedures and the equipment used are described in Section II D above.

An upper estimate of room scatter was made in the same manner described for the high-energy X-ray machine and found to be 1.2% at 200 cm. The quality of the beam was determined by measuring the first half value layer (HVL_1) and the homogeneity coefficient (h).

F. Strontium-90 Irradiator

The HPSSC Standard requires a sealed $^{90}Sr/^{90}Y$ beta-particle source equipped with a 100 mg/cm^2 filter of low atomic number. A 40-mCi strontium-90 source was lent to The University of Michigan by NBS for the pilot study. The active portion of the source is a disk, 1.27 cm in diameter by 0.635 cm thick. The source was mounted in a custom-made irradiator constructed of 1.27 cm thick Plexiglas surrounded by 0.32 cm lead. The irradiator, shown in Figure 2, was equipped with a solenoid-activated shutter controlled by a precision digital timer.

The source was encapsulated in 60 mg/cm^2 stainless steel. It was calibrated by NBS at a distance of 35 cm and found to produce 189.0 mrad/min in tissue (water). However, the HPSSC Standard requires an encapsulation of 100 mg/cm^2. Therefore, when the source arrived at The University of Michigan, it was first calibrated with the University's extrapolation chamber at 35 cm with the original 60 mg/cm^2 encapsulation. An absorbed dose rate of 188.9 mrad/min in tissue (water) was measured. This result compared favorably with the beta-particle measurements made by NBS. Finally, an additional 40 mg/cm^2 Mylar were added to the encapsulation of the source.

An extensive investigation of the beam showed that although beta particles were emerging from the source at nearly a 2π solid angle, the beam was not uniform. At a distance of 35 cm from the source, an area of only 3 cm in radius at the center of the beam showed uniform absorbed dose rates. At 5 cm from the center of the beam, the absorbed dose rate

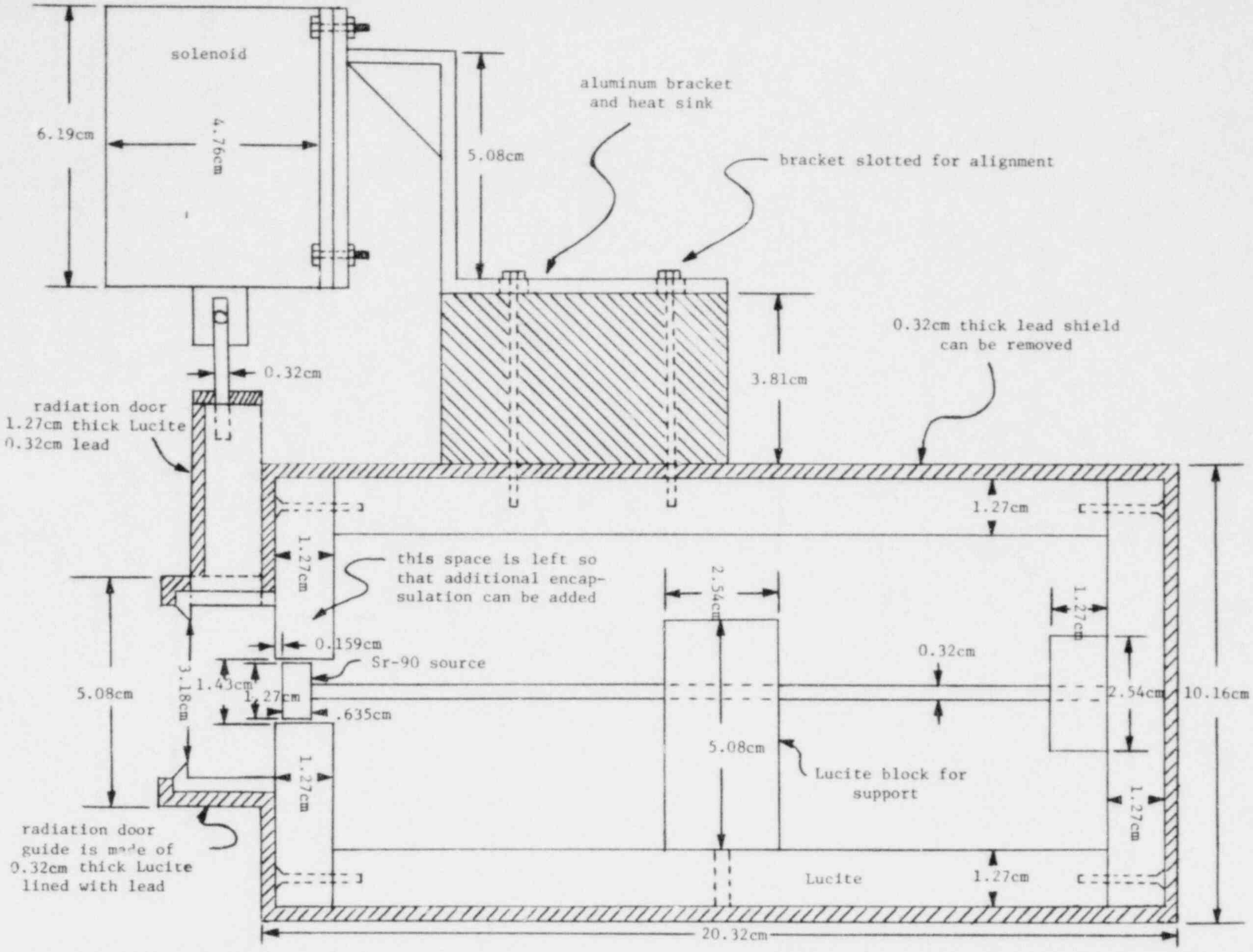

Figure 2. Strontium-90 irradiator used for Categories IV and VII.

was 2% less than at the center. Therefore, only one dosimeter at a time could be irradiated with the strontium-90 source, instead of the six dosimeters which could be irradiated simultaneously with the other five sources.

The extrapolation chamber was positioned 35 cm from the source (the closest irradiation distance permitted by the HPSSC Standard) and the absorbed dose rate was measured. Additional layers of Mylar were then added to the source to determine the absorbed dose rate at a depth of 7 mg/cm^2 from a source encapsulated in 100 cm/cm^2. A difference of 3.35% was found between absorbed dose rate measurements made at 100 and 107 mg/cm^2.

G. Californium-252 Irradiator

The HPSSC Standard requires a californium-252 neutron source with such an activity that the required irradiations can be performed at a distance of not less than 35 cm. A 0.7 mg californium-252 source was lent to The University of Michigan by NBS for the pilot study. The source had an emission rate of 1.56×10^9 n/sec on March 4, 1978 as measured by NBS. It has a height and diameter of approximately 0.8 cm.

The source was stored and used in the University's Willow Run Laboratory, located approximately 24 km from the School of Public Health. The building is a moderately sized storage room with a floor space of approximately 7.5 x 33 meters and a height of 6 meters. When not in use, the source was stored in the same 91 cm diameter, 91 cm deep shipping cask used to deliver the source. The cask was placed in a 122 cm diameter, 122 cm deep pit in the floor. The source was screwed into a hollow aluminum wand 0.9 cm in diameter and 46 cm long. The hollow wand was attached to a solid aluminum shaft 1.3 cm in diameter and 163 cm long. The solid shaft slid inside two hollow aluminum guide tubes, one mounted to the floor above the cask and one mounted to the ceiling. There was an air space of about 130 cm between the ends of the two guide tubes.

The source was raised from the cask for use, and moved up through the lower guide tube to a reproducible point midway between the two guide tubes. The reproducibility of positioning was checked using a high-power telescope and a mirror so that a movement of 0.5 mm could be observed. Binoculars were also used to monitor the source on the wand.

A steel cable attached to the top of the solid aluminum shaft permitted the source to be raised and lowered manually from the control room located about 23 meters from the storage pit. The pit was covered so that if the source should drop off the wand it would not fall into the pit. Proper handling devices and survey meters were in the building at all times. Figure 3 shows the guide tubes used to position the californium-252 source for the required irradiations.

Equation (3) in Section III C of this Manual shows the method used to calculate a delivered neutron dose equivalent produced by this source. The gamma-ray exposure rate was estimated by NBS to be 7.033% of the neutron dose equivalent rate. Equation (4) in Section III C of this Manual shows the method used to calculate a delivered gamma-ray dose equivalent produced by this californium-252 source. The gamma-ray exposure rate was accounted for in Category VIII.

When the source was used, a phantom was mounted on a stand and positioned at either 50 cm or 100 cm from the source, depending on the dose equivalent rate desired. Radiographic film exposed to gamma rays emitted from the source was used to determine proper alignment of the phantom. Permanent plumb bobs and reference distances were used as described for the other radiation sources to insure that phantom alignments were reproducible. The phantoms remained in their fixed position throughout the pilot study. The operator mounted a ladder to place and remove the dosimeters.

A concrete-block wall 19.3 cm thick and a shielded area for dosimeter storage, of the same thickness, were built in the control room to protect the operator and dosimeters. Shielding information was obtained from the Californium-252 Shielding Guide.[3]

The National Bureau of Standards calculated that room-scattered neutrons would increase the calculated neutron dose equivalent rate by 1.5% for dosimeters irradiated at 50 cm from the source, and by 6.0% for dosimeters irradiated at 100 cm. An effort was made to irradiate all dosimeters at 50 cm to minimize the effect of room-scattered neutrons.

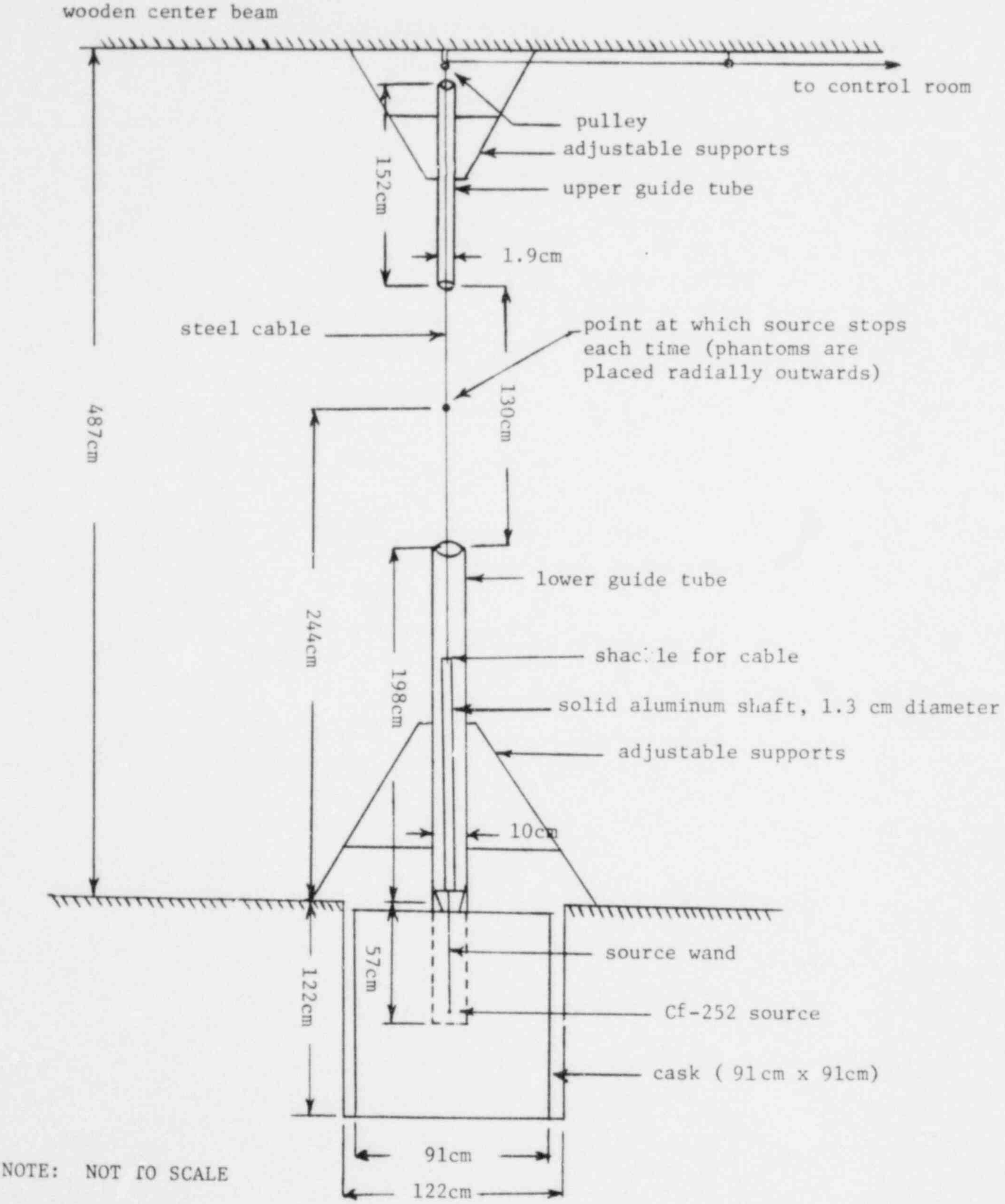

Figure 3. Guide tubes used tc position the californium-252 source.

III. CALCULATION OF DOSE EQUIVALENTS

A. Photon Sources

The two X-ray machines and the two cobalt-60 sources were calibrated with the ionization chambers positioned free in air. The dose equivalent delivered to a given dosimeter was calculated by:

$$H = \bar{C}_{x_{air}} \dot{X}_{air} t \qquad (1)$$

where:

H = delivered dose equivalent at either the shallow or deep depth (mrem)

$\bar{C}_{x_{air}}$ = average conversion factor for either the shallow or deep depth calculated from the HPSSC Standard (mrem/mR)

$\dot{X}_{air}$ = exposure rate measured free in air and corrected for temperature and pressure (mR/min)

t = irradiation time (min)

B. Beta Source

As discussed in Section II F of this report, the dose equivalent at 7 mg/cm^2 delivered to a dosimeter was calculated by:

$$H = 0.9665 \cdot \dot{D}_{tissue} \cdot Q \cdot t \qquad (2)$$

where:

H = delivered dose equivalent at 7 mg/cm^2 (mrem)

$\dot{D}_{tissue}$ = absorbed dose rate measured at the surface of a tissue equivalent material (mrad/min)

Q = quality factor for beta particles, assumed to be unity (mrem/mrad)

t = irradiation time (min)

C. Neutron Source

As discussed in Section II G of this report, the neutron dose equivalent rate produced by this source at 100 cm is calculated as:

$$H = \frac{3.4 \times 10^{-5} \cdot N \cdot RS \cdot t \cdot 60}{4\pi x^2} \quad (3)$$

where:

H = delivered dose equivalent produced by neutrons (mrem)

N = neutron emission rate at the time of irradiation as determined by NBS based on a half life of 2.65 years (n/sec)

RS = room scatter correction factor, determined by NBS to be 1.015 at x = 50 cm and 1.060 at x = 100 cm

t = irradiation time (min)

x = irradiation distance (cm)

3.4×10^{-5} = dose equivalent conversion factor given in the HPSSC Standard (mrem-cm^2/n)

60 = time conversion factor (sec/min)

The gamma-ray dose equivalent rate was calculated as:

$$H_i = \frac{3.4 \times 10^{-5} \cdot N \cdot t \cdot 60 \cdot 0.07033}{4\pi x^2} \quad (4)$$

Where:

0.07033 = fraction of primary neutron dose equivalent rate (exclusive of room-scattered neutrons) calculated by NBS to define the gamma-ray dose equivalent rate

All other parameters and constants in equation (4) are the same as those defined in equation (3).

IV. OUTLINE OF PROCEDURES

A. Scheduling Test Irradiations

On the average, each processor submitted 150 dosimeters for each of the two tests, plus a few extra dosimeters for controls and in case some irradiations were voided by errors made by the testing laboratory. One-third of these dosimeters were mailed to the testing laboratory once per month for three months for each test. Each processor had three months between Test #1 and Test #2 to make any adjustments in their procedures they believed to be necessary as a result of their performance in the first test.

Each of the two tests was completed in six calendar months. The 59 participating processors were divided into two groups for convenience. One group participated in the first three months and the other group participated in the second three months of a testing period.

Great care was taken to insure confidentiality between the testing laboratory and each processor. A randomly chosen code number was assigned to each processor. If a processor submitted more than one type of dosimeter, each type was assigned a different code number. With the code numbers, a processor's results could be discussed with the NRC and other interested groups without revealing the identity of the processor.

B. Receiving and Cataloging Dosimeters

When the dosimeters were received, the arrival date, processor name, code number, and extra dosimeter numbers were recorded in the Administrative Log Book. Appendix A shows sample pages from this log book. The arrival of a monthly shipment was also noted on a list of expected participants. If the dosimeters were not received by the arrival deadline (the fifth day of the month), telephone calls were made to the processor regarding the status of the shipment.

The shipping container in which the dosimeters arrived was labeled with the processor's code number. The dosimeters were placed in envelopes labeled with the processor name, code number, category number and interval number. There were ten lines on the envelope numbered 1 to 10. The dosimeter numbers were recorded on these lines as they were placed in the envelopes. These lines corresponded to the numbered lines on the data sheets (see Appendix B) kept in the Irradiation Log Books for each interval of each category. The dosimeter number on line 1 of an envelope also appeared on line 1 of the corresponding data sheet. Dosimeter numbers were limited to five digits; no dashes or letters were recorded. These and other restrictions were adopted to enable the testing laboratory to use a computer code to evaluate the processors' performance.

When an envelope was filled with the dosimeters to be irradiated, it was placed in the appropriate storage box. Eight storage boxes were kept in a low-background room, one box for each of the eight radiation categories. Each storage box was divided into sections, one section for each interval within a category. The storage boxes made it convenient to carry the dosimeters to the appropriate radiation source.

When a processor's dosimeters were irradiated sometime during the month, the irradiation date was recorded next to the dosimeter number on the envelope. This system of a box for each category, a section within a box for each interval, and individual envelopes that were dated at the time of irradiation, make it easy to determine the number of irradiations still to be done at any time during the month.

Irradiations were evenly distributed over the three months of a test. For each interval, four dosimeters were usually irradiated during the first month, three dosimeters during the second month, and three dosimeters during the third month.

Controls were left in the shipping box, and their numbers were not recorded. Shipping boxes were placed in numerical order on storage shelves located in the low-background room with the storage boxes. Letters of special instruction accompanying the dosimeters and shipping receipts were placed in a folder labeled by month.

C. Irradiations

Dose equivalents to be delivered were chosen before the start of each test. A random number table was used to select the delivered dose equivalents according to the specifications of the HPSSC Standard. The procedures followed on the day of irradiation were:

1. The radiation source room to be used was checked with a survey meter to determine if any radiation sources had been left out in the room.

2. Processor envelopes were selected six at a time.

3. Actual dosimeter numbers were checked against dosimeter numbers written on the envelopes.

4. Dosimeter numbers were recorded on data pages of the Irradiation Log Book shown in Appendix B in the same order as they appeared on an envelope.

5. As irradiations were completed, irradiation date, time of day, irradiation time, etc., were recorded on the data page, and the dosimeters were returned to their envelope.

6. The date of irradiation was recorded on the envelope. For mixed categories, there were two columns on each envelope for the date, one column for each source.

7. In mixed categories both data pages were checked to assure correct numerical order of dosimeter numbers. Numbers were written on both pages of a mixed category when the first irradiations were made for the month.

8. All data were printed, large and neat, in black or blue ink with no erasures.

9. Daily exposure rates were listed in the back of the Irradiation Log Books kept for each radionuclide source.

10. Quality control data and exposure rates for the X-ray machines were recorded in the back of the Irradiation Log Books kept for each X-ray machine.

11. Misirradiated or lost dosimeters were recorded in the Administrative Log Book, together with dosimeter number, processor number, error committed, and replacement dosimeter number. If a dosimeter was lost, the processor was notified. If a misirradiation demanded extra dosimeters from a processor, the processor was notified by phone as soon as possible.

D. Returning Dosimeters

Approximately two man-days were required at e end of each month to prepare the dosimeters for return to the processors. The procedures followed at this time were:

1. Dosimeters were removed from the envelopes and placed in the correct shipping box.

2. The envelopes were checked for irradiation dates and correct number of dosimeters.

3. A list of dosimeters irradiated in the accident intervals was enclosed in the shipping box with the dosimeters.

4. After all the shipping boxes were filled, they were sealed, labeled and stamped first class.

5. Special instructions for mailing were checked at this time.

E. Evaluating and Reporting Test Irradiation Results

When a processor sent all of the reported dose equivalents to the testing laboratory, a computer program was run for each category in which the processor participated. A copy of the printout was placed in the processor's file, and a second copy was sent to the processor.

Use of the computer program made evaluation quick, neat, and accurate. A copy of the program in Fortran and a sample output are included in Appendix C.

F. Maintaining Documented Records

A separate Irradiation Log Book was kept for each radiation category. One section of each notebook was devoted to calibration procedures and results for the particular radiation source, and a second section was devoted to quality control checks of the source. A third section contained the actual irradiation data for the test dosimeters. In this third section, a separate data page was assigned to each processor who chose to be tested in that category. Appendix B shows a sample data page for each of the 8 radiation categories. The Administrative Log Book contained the following lists:

1. processor names in alphabetical order to provide a quick reference for code numbers.

2. addresses, telephone numbers and contact persons for each processor.

3. processors by code number, the categories in which they participate, type of dosimeter, number of dosimeters required each month, and testing schedule.

4. shipping data including arrival date, processor name, code number, and a comment column for remarks regarding holders, controls, and mailing problems.

5. extra badge numbers each month for each processor.

6. daily environmental checks such as room temperature, atmospheric pressure and relative humidity. These checks showed that environmental conditions did not change significantly during the pilot study. The data were not used beyond the documentation of environmental conditions.

Also included in the Administrative Log Book was a section where daily items were recorded such as phone calls to processors, problems with shipping, mistakes and corrections made, equipment failure, lost dosimeters or envelopes, changes in status of processors, and any other item of possible consequence.

A file folder for each processor was also maintained. Each file contained correspondence, copies of results, and data pages at the completion of a test.

G. Quality Controls

The most powerful quality control procedure was the simultaneous irradiation of dosimeters from six different processors. Any dosimeter with a reported dose equivalent that differed significantly from the delivered quantity could be compared to five other simultaneously irradiated dosimeters from five other processors. If the testing laboratory made a mistake in the positioning of the phantom relative to the radiation source, in the timing of the irradiations, etc., all or most of the six dosimeters should reflect the error. Because the time of day and date of irradiation were recorded for each dosimeter, and a list of participating processors was available for each category, it was a simple procedure to trace a dosimeter in question.

This procedure worked extremely well for questions by processors of the dose equivalents delivered. However, a problem resulted when some of the other five processors had not reported their results and a comparison could be made only with the few processors which had reported. Bad or erratic performance by another processor involved also weakens this procedure. However, it proved to be helpful because the check was provided by the processors and not just the testing laboratory.

Once the radionuclide sources (strontium-90, californium-252, and two cobalt-60 sources) were calibrated, their output remained constant throughout the pilot study except for radioactive decay, for which corrections were made.

The two X-ray machines were expected to show slight daily variations in their output. Calibrations were performed before and after irradiations on the day of irradiation as discussed in Sections II D and II E.

V. BLIND TESTING

Seven commercial processors were blind-tested during the pilot study. A utility company was asked to subscribe to each of the seven processors ostensibly to use the dosimeters in and around their nuclear power plant. The utility company then shipped the dosimeters they received to the testing laboratory to be irradiated with the same procedures applied to the open tests. At the end of the month, the dosimeters were returned to the utility company which mailed them to the seven commercial processors. All questions, problems, and answers regarding dosimetry, results, and radiation sources were relayed through the utility company to preserve the blind tests. The utility company was not shown the pass/fail results of the processors. The seven processors were blind-tested during the same months in which they were tested openly. Although this method was effective for blind testing large commercial processors, it would not work to blind test small or in-house processors.

VI. RECOMMENDATIONS

The two-year pilot study represented the first attempt to conduct a dosimetry testing program according to the requirements of the HPSSC Standard. Some of the methods and procedures that seemed reasonable when the pilot study began were later found to be less than satisfactory. The following are recommendations to improve the general operation of a future testing program. These recommendations do not include suggested changes in the Standard since those recommendations will be discussed in the Final Report of the pilot study.

1. Phantoms. The use of water-filled phantoms occasionally proved to be troublesome. Some of the phantoms leaked, distilled water had to be used since tap water discolored the Plexiglas boxes and promoted algal growth, and when one phantom was accidently dropped, it virtually exploded. Solid slabs of acrylic and other plastics are no more expensive than the labor required to build a Plexiglas box that can be filled with water.

2. Shipping Containers. Only a few processors ship dosimeters regularly through the mail. Many processors shipped dosimeters in weak containers, such as shoe boxes, and they continued to use the containers until they literally fell apart. Consequently, some dosimeters were lost during shipment. The testing laboratory should replace substandard shipping containers with sturdy containers.

3. Time Limit for Receiving Dosimeters. Throughout the pilot study, a great effort was made to complete all irradiations required during a given month at least two days before the end of that month so the last days could be used for packaging and mailing the dosimeters. Since an average of 2,000 dosimeters were irradiated each month, it was imperative that all the dosimeters arrive at the testing laboratory at or before the beginning of the month. During the early part of Test #1, several processors were very casual about shipping their dosimeters; some dosimeters did not arrive at the testing laboratory until the 15th or 20th of the month. We adopted a rule that any dosimeters arriving after the 5th of the month would be returned unirradiated. This solved the problem except for an occasional oversight by a processor.

4. Beam Monitors. A beam monitor connected to a strip chart recorder was used to monitor the output of each of the two X-ray machines while dosimeters were being irradiated. The irradiation date and time of day were recorded for each dosimeter. Thus, if a processor challenged the delivered dose to a particular dosimeter irradiated with X rays, the calibration and irradiation information could be checked including the actual irradiation time recorded on strip-chart paper. Some method should be available for the radioisotope sources to verify that the irradiation time recorded was, in fact, the true irradiation time. Perhaps beam monitors and strip chart recorders should be used with all radiation sources.

REFEPENCES

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. (Same as proposed standard ANSI N13.11).

2. Seelentag, W.W., Panzer, W., Drexler, G., Platz, L., and Santner, F. A catalogue of spectra for the calibration of dosimeters. Gesellschaft für Strahlen-und Umweltforschung mbH, D-8042 Neuherberg, Ingolstadter Landstr. 1, West Germany, March, 1979.

3. Stoddard, D.H. and H.E. Hootman. ^{252}Cf Shielding Guide. TID-4500, UC-41, March 1971.

APPENDIX A

Format of data pages kept in Administrative Log Book.

DAILY ENVIRONMENTAL CHECK

DATE	BAROMETRIC PRESSURE	% HUMIDITY	TEMPERATURE

	ARRIVAL DATE	PROCESSOR	CODE NO.	NO. OF DOSIMETERS	SHIPPING DATE	COMMENTS

EXTRA DOSIMETERS

MONTH	PROCESSOR	NUMBER

APPENDIX B

Format of data pages kept in the Irradiation Log Book. Processor's name and code number have been omitted. Computer printout for this processor is shown in Appendix C.

CATEGORY: 1, Gamma

INTERVAL: 1, 10-800 rad

Source: Cobalt-60 teletherapy

Irradiation Distance: shown below

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (R/min)	Irra. Time (min)	Phantom Position	Irra. Dist.(cm)	Reference Time	Reported Dose (rad) Deep
1	34	022079	54.54	3.82	4	100	1740	195.
2	11	022079	54.54	9.86	4	100	1750	550.
3	52	022079	54.54	13.81	4	100	1800	600.
4	2	022079	54.54	12.91	4	100	1810	650.
5	154	032079	53.99	11.83	3	100	1830	620.
6	182	032079	53.99	10.40	3	100	1840	600.
7	170	032079	53.99	1.95	3	100	1850	130.
8	304	041879	53.43	3.57	3	100	1200	255.
9	342	041879	53.43	6.15	3	100	1210	800.
10	322	041879	53.43	8.45	3	100	1220	600.

CATEGORY: 1, Gamma

INTERVAL: 2, 30-100 mrem

Source: Cobalt-60 irradiator

Irradiation Distance: 200 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (sec)	Phantom Position	Reference Time	Reported Dose (mrem) Deep
1	4	021579	22.49	140.5	2	1010	70.
2	33	021579	22.49	252.5	2	1014	100.
3	51	021579	22.49	196.5	2	1020	90.
4	163	032679	22.18	214.6	2	1200	97.
5	137	032679	22.18	259.6	2	1210	122.
6	194	032679	22.18	90.0	2	1215	38.
7	171	032679	22.18	103.8	2	1220	45.
8	305	042079	21.98	233.6	2	1200	107.
9	321	042079	21.98	117.2	2	1201	60.
10	340	042079	21.98	225.6	2	1202	107.

CATEGORY: 1, Gamma

INTERVAL: 3, 101-300 mrem

Source: Cobalt-60 irradiator

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (sec)	Phantom Position	Reference Time	Reported Dose (mrem) Deep
1	35	022679	88.73	163.5	2	1325	290.
2	3	022679	88.73	99.4	2	1328	165.
3	27	022679	88.73	160.5	2	1331	270.
4	172	032279	87.97	115.3	3	1015	186.
5	162	032279	87.97	121.2	3	1016	200.
6	138	032279	87.97	103.3	3	1017	187.
7	192	032279	87.97	141.2	3	1018	240.
8	308	041879	87.11	148.2	6	1000	260.
9	349	041879	87.11	93.5	6	1001	135.
10	323	041879	87.11	72.6	6	1002	135.

CATEGORY: 1, Gamma

INTERVAL: 4, 301-10,000 mrem

Source: Cobalt-60 irradiator

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (sec)	Phantom Position	Reference Time	Reported Dose (mrem) Deep
1	25	022079	88.92	4258.	3	0832.	7400.
2	53	022079	88.92	631.5	3	0945	1100.
3	36	022079	88.92	694.3	3	0956	1100.
4	5	022079	88.92	477.2	3	1007	760.
5	195	032779	87.81	3426.	3	1500	5100.
6	141	032779	87.81	599.8	3	1600	1000.
7	174	032779	87.81	473.5	3	1610	750.
8	352	040879	87.43	3261.	3	1700	6300.
9	334	040879	87.43	360.0	3	1800	600.
10	306	040879	87.43	6160.	3	1900	10000.

CATEGORY: 2, X Ray

INTERVAL: 1, 10-800 rad

NBS Technique: MFK

Machine Settings: 200 kV, 20 mA

Added Filtration: 4.85 mm Al, 0.5 mm Cu

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (R/min)	Irra. Time (min)	Phantom Position	Reference Time	Reported Dose (rad) Deep
1	37	022379	8.83	46.58	2	1200	675.
2	55	022379	8.83	20.09	2	1230	385.
3	6	022379	8.83	3.83	2	1300	27.
4	26	022379	8.83	50.41	2	1330	613.
5	166	032679	10.83	48.10	1	1200	675.
6	161	032679	10.83	7.14	1	1300	79.
7	193	032679	10.83	52.33	1	1310	625.
8	360	042579	10.54	32.66	3	1301	750.
9	345	042579	10.54	25.26	3	1302	610.
10	311	042579	10.54	11.71	3	1303	355.

CATEGORY: 2, X Ray

INTERVAL: 2, 30-100 mrem

NBS Technique: HFK

Machine Settings: 250 kV, 5 mA

Added Filtration: 3.97 mm Al, 0.60 mm Cu, 1.03 mm Sn, 2.65 mm Pb

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (min)	Phantom Position	Reference Time	Reported Dose (mrem)	
							Shallow	Deep
1	24	022179	20.44	1.69	2	1215	60.	60.
2	38	022179	20.44	2.225	2	1220	75.	75.
3	7	022179	20.44	3.395	2	1225	116.	116.
4	191	032379	20.46	3.19	1	1120	106.	106.
5	167	032379	20.46	3.815	1	1125	120.	120.
6	160	032379	20.46	1.81	1	1130	60.	60.
7	140	032379	20.46	1.23	1	1135	50.	50.
8	303	042579	21.30	2.44	3	1301	105.	105.
9	313	042579	21.30	2.71	3	1302	107.	107.
10	351	042579	21.30	3.10	3	1303	110.	110.

CATEGORY: 2, X Ray

INTERVAL: 3, 101-300 mrem

NBS Technique: HFG

Machine Settings: 150 kV, 10 mA

Added Filtration: 4.00 mm Al, 4.00 mm Cu, 1.46 mm Sn

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (min)	Phantom Position	Reference Time	Reported Dose (mrem) Shallow	Deep
1	39	022079	62.55	1.87	1	1215	170.	170.
2	23	022079	62.55	1.305	1	1220	121.	121.
3	56	022079	62.55	2.95	1	1225	248.	248.
4	190	032179	65.6	3.04	1	1930	256.	256.
5	168	032179	65.6	1.52	1	1935	165.	165.
6	180	032179	65.6	1.97	1	1940	197.	197.
7	142	032179	65.6	2.31	1	1950	263.	263.
8	335	042479	66.13	2.41	3	1301	225.	225.
9	316	042479	66.13	3.28	3	1302	337.	337.
10	359	042479	66.13	1.79	3	1303	170.	170.

CATEGORY: 2, X Ray

INTERVAL: 4, 301-10,000 mrem

NBS Technique: MFG

Machine Settings: 100 kV, current shown below

Added Filtration: 6.31 mm Al

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: [illegible]

Line	Dosimeter Number	Date Irra.	Current (A)	Exposure Rate (mR/min)	Irra. Time (min)	Phantom Position	Reference Time	Reported Dose (mrem) Shallow	Reported Dose (mrem) Deep
1	22	021479	5	877.2	5.085	2	1115	6400.	6150.
2	40	021379	1	105.2	3.11	2	1215	490.	480.
3	57	021479	5	877.2	2.34	2	1120	3000.	2900.
4	8	021379	1	105.2	3.49	2	1220	524.	504.
5	159	032179	5	860.3	6.30	1	1215	7125.	7135.
6	143	032179	5	860.3	5.93	1	1220	6900.	6550.
7	175	031979	1	102.9	5.685	1	1225	640.	615.
8	317	042479	5	896.3	3.69	3	1008	4095.	3936.
9	331	042479	1	73.27	3.82	3	1009	400.	384.
10	356	042479	1	73.21	6.67	3	1010	595.	572.

CATEGORY: 3, X Ray

INTERVAL: 1, 150-300 mrem

NBS Technique: L-G

Machine Settings: 30 kV, 1 mA

Added Filtration: 0.37 mm Al

Irradiation Distance: 200 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (min)	Phantom Position	Reference Time	Reported Dose (mrem) Shallow	Deep
1	41	022679	114.5	1.89	4	1100	190.	59.
2	58	022679	114.5	2.92	4	1105	348.	108.
3	9	022679	114.5	2.26	4	1110	210.	65.
4	21	022679	114.5	1.78	4	1115	184.	55.
5	176	031379	116.8	2.66	1	1600	284.	88.
6	189	031379	116.8	2.77	1	1605	340.	105.
7	144	031379	116.8	3.01	1	1610	315.	97.
8	353	042879	116.0	2.51	4	1100	320.	100.
9	338	042879	116.0	1.88	4	1101	2[illegible]5.	65.
10	325	042879	116.0	1.93	4	1102	230.	71.

CATEGORY: 3, X Ray

INTERVAL: 2, 301-10,000 mrem

NBS Technique: L-G

Machine Settings: 30 kV, 4 mA

Added Filtration: 0.37 mm Al

Irradiation Distance: 200 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (min)	Phantom Position	Reference Time	Reported Dose (mrem) Shallow	Deep
1	42	022679	286.4	18.15	6	1530	2835.	875.
2	59	022679	286.4	37.46	6	1600	7500.	2300.
3	28	022679	286.4	2.98	6	1630	830.	220.
4	10	022679	286.4	15.92	6	1700	2150.	850.
5	177	031479	288.6	1.66	1	1700	405.	125.
6	145	031479	288.6	11.84	1	1705	2700.	750.
7	157	031479	288.6	1.88	1	1710	526.	162.
8	357	042979	288.8	29.90	4	1350	6975.	2150.
9	336	042979	288.8	3.61	4	1400	1377.	425.
10	310	042979	288.8	1.77	4	1410	508.	157.

53

CATEGORY: 4, Beta

INTERVAL: 1, 150-300 mrem

Source: Strontium-90

Irradiation Distance: 35 cm

Pr cessor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Absorbed Dose Rate (mrad/min)	Irra. Time (min)	Reported Dose (mrem) Shallow
1	43	021879	152.3	1.86	320.
2	60	021879	152.3	1.08	207.
3	12	021879	152.3	1.58	260.
4	29	021879	152.3	1.78	300.
5	156	030979	152.0	1.70	275.
6	188	030979	152.0	1.29	213.
7	149	030979	152.0	1.32	208.
8	502	051079 ~~042~~	151.3	1.67	275.
9	503	051079	151.3	1.22	215.
10	504	051079	151.3	1.90	310.

CATEGORY: 4, Beta

INTERVAL: 2, 301-10,000 mrem

Source: Strontium-90

Irradiation Distance: 35 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Absorbed Dose Rate (mrad/min)	Irra. Time (min)	Reported Dose (mrem) Shallow
1	44	020679	152.3	46.80	6700.
2	13	020679	152.3	4.89	850.
3	30	020679	152.3	12.19	2575.
4	183	032179	152.0	3.71	680.
5	152	032179	152.0	17.66	2960.
6	169	032179	152.0	6.74	875.
7	139	032179	152.0	9.22	1600.
8	354	042379	151.6	3.54	740.
9	314	042379	151.6	53.60	8536.
10	327	042379	151.6	5.69	975.

CATEGORY: 5, Neutron

INTERVAL: 1, 100-300 mrem

Source: Californium-252

Irradiation Distance: shown below

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Dose Eq. Rate (mrem/min)	Irra. Time (min)	Phantom Position	Irra. Dist.(cm)	Reference Time	Reported Dose (mrem) Deep
1	75	022179	78.45	1.336	2	050	1900	150.
2	64	022179	78.45	2.543	2	050	1901	275.
3	72	022179	78.45	3.733	2	050	1902	358.
4	62	022179	78.45	2.383	2	050	1903	235.
5	208	031379	77.33	2.335	1	050	1700	142.
6	199	031379	77.33	3.600	1	050	1701	380.
7	205	031379	77.33	3.446	1	050	1702	290.
8	374	042679	74.93	2.223	3	050	1500	436.
9	368	042679	74.93	1.530	3	050	1501	310.
10	363	042679	74.93	2.339	3	050	1502	356.

CATEGORY: 5, Neutron

INTERVAL: 2, 301-5,000 mrem

Source: Californium-252

Irradiation Distance: shown below

Processor Name:

Processor Code No.:

Type of Dosimeter: FiLM

Line	Dosimeter Number	Date Irra.	Dose Eq. Rate (mrem/min)	Irra. Time (min)	Phantom Position	Irra. Dist.(cm)	Reference Time	Reported Dose (mrem) Deep
1	70	022579	78.22	49.66	2	050	1700	5050
2	63	022579	78.22	4.448	2	050	1701	510
3	65	022579	78.22	23.55	2	050	1702	2215
4	74	022579	78.22	11.69	2	050	1703	1240
5	201	031579	77.22	57.50	1	050	1000	5020
6	198	031579	77.22	10.32	1	050	1001	1000
7	203	031579	77.22	39.50	1	050	1002	3480
8	365	041879	75.36	11.40	3	050	1700	1065
9	369	041879	75.36	32.00	3	050	1701	3180
10	373	041879	75.36	6.636	3	050	1702	590

CATEGORY: 6, Gamma component of gamma plus X ray

INTERVAL: 1, 50-100 mrem

Source: Cobalt-60 irradiator

Irradiation Distance: 200 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: [illegible]

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (sec)	Phantom Position	Reference Time
1	45	021379	22.51	169.3	6	1900
2	14	021379	22.51	63.2	6	1901
3	19	021379	22.51	124.4	6	1902
4	173	031479	22.27	38.5	3	1300
5	151	031479	22.27	138.5	3	1301
6	187	031479	22.27	45.6	3	1302
7	158	031479	22.27	213.6	3	1303
8	350	040179	22.13	55.6	2	1200
9	332	040179	22.13	104.7	2	1203
10	302	040179	22.13	39.8	2	1208

CATEGORY: 6, X ray component of gamma plus X ray

INTERVAL: 1, 50-100 mrem

NBS Technique: HFK

Machine Settings: 250 kV, 5 mA

Added Filtration: 3.7 mm Al, 0.60 mm Cu, 1.03 mm Sn, 2.65 mm Pb

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (min)	Phantom Position	Reference Time	Reported Dose (mrem) Shallow	Reported Dose (mrem) Deep
1	45	022179	20.44	.98	1	1115	125.	125.
2	14	022179	20.44	2.62	1	1120	110.	110.
3	19	022179	20.44	.73	1	1125	90.	90.
4	173	032379	20.46	1.54	4	1000	65.	65.
5	151	032379	20.46	.78	4	1001	98.	98.
6	187	032379	20.46	.81	4	1002	38.	38.
7	158	032379	20.46	1.04	4	1003	130.	130.
8	350	042579	21.30	2.11	1	1301	45.	45.
9	332	042579	21.30	.67	1	1302	115.	115.
10	302	042579	21.30	1.67	1	1303	80.	80.

CATEGORY: 6, Gamma component of gamma plus X ray

INTERVAL: 2, 101-300 mrem

Source: Cobalt-60 irradiator

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (sec)	Phantom Position	Reference Time
1	54	021379	22.51	156.4	4	1800
2	15	021379	22.51	318.4	4	1801
3	46	021379	22.51	421.6	4	1802
4	178	031479	22.27	281.4	5	1700
5	186	031479	22.27	203.7	5	1701
6	147	031479	22.27	209.4	5	1702
7	153	031479	22.27	289.0	5	1703
8	315	040179	22.13	135.6	2	1230
9	324	040179	22.13	241.7	2	1235
10	346	040179	22.13	151.3	2	1240

CATEGORY: 6, X ray component of gamma plus X ray

INTERVAL: 2, 101-300 mrem

NBS Technique: HFG

Machine Settings: 150 kV, 10 mA

Added Filtration: 4.00 mm Al, 4.00 mm Cu, 1.46 mm Sn

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (min)	Phantom Position	Reference Time	Reported Dose (mrem) Shallow	Deep
1	54	022079	62.55	1.78	1	1045	194.	194.
2	15	022079	62.55	.95	1	1050	153.	153.
3	46	022079	62.55	1.185	1	1055	162.	162.
4	178	032179	65.6	.48	2	1700	81.	81.
5	186	032179	65.6	2.21	2	1701	529.	529.
6	147	032179	65.6	.42	2	1702	170.	170.
7	153	032179	65.6	.48	2	1703	235.	235.
8	315	042479	66.13	1.40	1	1900	185.	185.
9	324	042479	66.13	.41	1	1901	81.	81.
10	346	042479	66.13	1.59	1	1902	195.	195.

CATEGORY: 6, Gamma component of gamma plus X ray

INTERVAL: 3, 301-10,000 mrem

Source: Cobalt-60 irradiator

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (sec)	Phantom Position	Reference Time
1	50	020679	89.37	97.5	2	1200
2	16	020679	89.37	3387.	2	1201
3	18	020679	89.37	92.7	2	1300
4	32	020679	89.37	3147.	2	1301
5	155	031379	88.25	253.2	5	1300
6	179	031379	88.25	362.4	5	1305
7	148	031379	88.25	178.6	5	1310
8	10	040279	87.65	1179.	2	1500
9	49	040279	87.65	73.9	2	1600
10	24	040179	87.68	2771.	2	1200

CATEGORY: 6, X ray component of gamma plus X ray

INTERVAL: 3, 301-10,000 mrem

NBS Technique: MFG

Machine Settings: 100 kV, current shown below

Added Filtration: 6.31 mm Al

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Current (A)	Exposure Rate (mR/min)	Irra. Time (min)	Phantom Position	Reference Time	Reported Dose (mrem) Shallow	Reported Dose (mrem) Deep
1	50	021379	1	105.2	2.695	1	[illegible]	500	485
2	16	021479	5	877.2	1.785	1	1215	8000	7900
3	18	021379	1	105.2	2.42	1	[illegible]	371	357
4	32	021479	5	877.2	1.55	1	1220	7140	7100
5	155	031979	1	102.9	1.13	4	1100	418	418
6	179	032179	5	860.3	1.23	4	1105	1472	1415
7	148	031979	1	102.9	5.015	4	1110	705	675
8	90010	042479	5	896.3	3.82	1	1130	not reported	
9	90049	042479	1	73.27	2.78	1	1131	not reported	
10	90024	042479	5	896.3	1.405	1	1132	not reported	

CATEGORY: 7, Gamma component of beta plus gamma

INTERVAL: 1, 200-300 mrem

Source: Cobalt-60

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter:

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (sec)	Phantom Position	Reference Time
1	31	020679	89.37	48.75	2	0925
2	17	020679	89.37	115.2	2	0930
3	48	020679	89.37	41.5	2	0933
4	181	031079	88.35	135.4	1	1106
5	150	031079	88.35	49.7	1	1108
6	165	031079	88.35	129.3	1	1110
7	146	031079	88.35	121.8	1	1112
8	347	040179	87.65	42.2	2	1400
9	309	040179	87.65	49.3	2	1405
10	320	040179	87.65	126.6	2	1410

CATEGORY: 7, Beta component of beta plus gamma

INTERVAL: 1, 200-300 mrem

Source: Strontium-90

Irradiation Distance: 35 cm

Processor Name:

Processor Code No.:

Type of Dosimeter:

Line	Dosimeter Number	Date Irra.	Absorbed Dose Rate (mrad/min)	Irra. Time (min)	Reported Dose (mrem) Shallow	Reported Dose (mrem) Deep
1	31	022679	152.3	1.18	282.	92.
2	17	022679	152.3	.42	240.	240.
3	48	022679	152.3	1.01	241.	84.
4	181	031379	152.0	.53	310.	210.
5	150	031379	152.0	1.20	263.	70.
6	165	031379	152.0	.51	372.	197.
7	146	031379	152.0	.47	350.	230.
8	347	041679	151.6	1.03	250.	80.
9	309	041679	151.6	1.12	275.	95.
10	320	041679	151.6	.49	365.	190.

CATEGORY: 7, Gamma component of beta plus gamma

INTERVAL: 2, 301-10,000 mrem

Source: Cobalt-60 irradiator

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (sec)	Phantom Position	Reference Time
1	47	020679	89.37	1036.	3	1107
2	20	020679	89.37	99.5	3	1126
3	49	020679	89.37	935.3	3	1337
4	185	031379	88.25	128.2	2	1910
5	184	031379	88.25	1128.	2	1930
6	164	031379	88.25	406.2	2	1945
7	344	040179	87.65	993.3	2	1590
8	358	040179	87.65	100.4	2	1600
9	312	040179	87.65	670.6	2	1610
10	333	040179	87.65	170.3	2	1620

CATEGORY: 7, Beta component
of beta plus gamma

INTERVAL: 2, 301-10,000 mrem

Source: Strontium-90

Irradiation Distance: 35 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Absorbed Dose Rate (mrad/min)	Irra. Time (min)	Reported Dose (mrem) Shallow	Deep
1	47	022479	152.3	25.53	3270.	2220.
2	20	022479	152.3	2.44	530.	258.
3	49	022479	152.3	3.63	1900.	1700.
4	185	031479	152.0	.75	428.	518.
5	184	031479	152.0	27.77	3350.	2000.
6	164	031479	152.0	1.58	680.	680.
7	344	040279	151.6	3.88	1980.	1700.
8	358	040279	151.6	2.51	595.	165.
9	312	040279	151.6	16.66	2300.	1300.
10	333	040279	151.6	.68	415.	295.

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CATEGORY: 8, Gamma component of gamma plus neutron

INTERVAL: 1, 150-300 mrem

Source: Cobalt-60 irradiator

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (sec)	Phantom Position	Reference Time
1	66	020679	89.37	42.5	3	1730
2	90068	020679	89.37	82.2	3	1731
3	71	020679	89.37	55.3	3	1732
4	209	031079	88.35	113.2	1	0930
5	204	031079	88.35	43.1	1	0932
6	197	031079	88.35	79.9	1	0934
7	201	031079	88.35	52.9	1	0936
8	375	041079	87.37	94.6	4	1100
9	371	041079	87.37	36.7	4	1101
10	362	041079	87.37	119.1	4	1102

CATEGORY: 8, Neutron component of gamma plus neutron

INTERVAL: 1, 150-300 mrem

Source: Californium-252

Irradiation Distance: shown below

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Dose Eq. Rate (mrem/min)	Irra. Time (min)	Phantom Position	Irra. Dist. (cm)	Reference Time	Reported Dose (mrem) Deep
1	66	022379	78.34	2.000	1	050	1829	300
2	90068							
3	71	022579	78.22	2.613	1	050	1547	349
4	209	032279	19.25	3.482	1	100	1700	255
5	204	032279	76.83	2.070	1	050	1701	344
6	197	032279	19.25	2.443	1	100	1702	225
7	201	032279	76.83	2.536	1	050	1703	385
8	375	042679	18.73	2.930	1	100	1715	210
9	371	042679	74.93	1.810	1	050	1716	284
10	362	042679	18.73	3.739	1	100	1717	263

CATEGORY: 8, Gamma component
of gamma plus neutron

INTERVAL: 2, 301-5,000 mrem

Source: Cobalt-60 irradiator

Irradiation Distance: 100 cm

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Exposure Rate (mR/min)	Irra. Time (sec)	Phantom Position	Reference Time
1	67	020879	89.31	905.5	2	1510
2	73	020879	89.31	150.7	2	1525
3	69	020879	89.31	1653.	2	1530
4	200	031279	88.28	428.3	1	1328
5	202	031279	88.28	777.3	1	1338
6	206	031279	88.28	66.1	1	1355
7	210	031279	88.28	739.5	1	1400
8	364	040979	87.4	204.2	5	1200
9	372	040979	87.4	790.4	5	1205
10	367	040979	87.4	162.4	5	1215

CATEGORY: 8, Neutron component of gamma plus neutron

INTERVAL: 2, 301-5,000 mrem

Source: Californium-252

Irradiation Distance: shown below

Processor Name:

Processor Code No.:

Type of Dosimeter: FILM

Line	Dosimeter Number	Date Irra.	Dose Eq. Rate (mrem/min)	Irra. Time (min)	Phantom Position	Irra. Dist.(cm)	Reference Time	Reported Dose (mrem) Deep
1	67	022479	78.28	41.38	1	050	1729	3186
2	73	022479	78.28	7.15	1	050	1815	970
3	69	022479	78.28	12.55	1	050	1826	4210
4	200	032779	76.56	3.320	1	050	1635	990
5	202	032779	76.56	37.98	1	050	1636	4465
6	206	032779	76.56	2.9100	1	050	1637	475
7	210	032779	76.56	36.15	1	050	1638	4460
8	364	041979	75.36	1.601	1	050	1445	469
9	372	041979	75.36	9.485	1	050	1446	2180
10	367	041979	75.36	8.485	1	050	1447	1035

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APPENDIX C

Computer program used to evaluate processor performance and a sample report. Processor's name and code number have been omitted. Raw data for this processor are shown in Appendix B.

```
      COMMON TYPE,NCAT,REF(10),FINISH,CODE(10)
      COMMON RATE(10),TIME(10),EXPOS(10),P(10),CX,RESULT,PBAR,HBAR,S
      COMMON NUMBER(10),IMONTH(10),IDAY(10),IYEAR(10),IPOS(10),IDIST(10
      DIMENSION RSHAL(10),DSHAL(10),RDEEP(10),DDEEP(10),STATE(10),NUMX(
     110),DSHALX(10),DDEEPX(10),RAT(10),TIM(10),JMONTH(10),JDAY(10),JYEAR
     2(10),JPOS(10),CLO(10),J(10),FIN(10),K(10),M(10),PP(10)
      REAL *8 PRO,CESSOR,TYPE,PR,CE,TY,OK8/'           '/
      DATA PASS/'PASS'/,FAIL/'FAIL'/,VOID/'VOID'/,OK/'     '/
      DATA STAR/'*    '/,STARR/'**  '/
      READ (5,300) NAME
  300 FORMAT (I1)
      READ (5,20) NCAT,INTER,PRO,CESSOR,NUM,TYPE
      NC = NCAT
      IN = INTER
      PR = PRO
      CE = CESSOR
      NU = NUM
      TY = TYPE
      WRITE (6,200)
  200 FORMAT (1H1///////19X,'PERSONAL DOSIMETRY PERFORMANCE TESTING'//33
     1X,'A PILOT STUDY'/////32X,'SPONSORED BY :'/22X,'U.S. NUCLEAR REGUL
     2ATORY COMMISSION'/////32X,'CONDUCTED BY :'/17X,'DEPT. OF ENVIRONME
     3NTAL AND INDUSTRIAL HEALTH'/28X,'SCHOOL OF PUBLIC HEALTH'/28X,'UNI
     4VERSITY OF MICHIGAN'/30X,'ANN ARBOR, MICHIGAN'/////18X,'**********
     4  RESULTS OF TEST #2  **********'/////)
      IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,201) PRO,CESSOR,NUM,TYPE
  201 FORMAT (23X,'PROCESSOR NAME : ',A8,A7//23X,'PROCESSOR CODE NO. : '
     1,I2//23X,'TYPE OF DOSIMETER : ',A8)
      WRITE (6,202)
  202 FORMAT (1H1///////3X,'FOR EACH DOSIMETER, A PERFORMANCE INDEX IS C
     1ALCULATED BY :',////32X,'P = (H* - H)/H'////4X,'WHERE :  H = DELIV
     2ERED QUANTITY'/13X,'H* = REPORTED QUANTITY'////4X,'FOR EACH DEPTH
     3OF EACH INTERVAL OF A CATEGORY, AN AVERAGE PERFORMANCE'//4X,'INDEX
     4, (P AVERAGE), AND ITS STANDARD DEVIATION, S, ARE CALCULATED.'////
     54X,'A PROCESSOR PASSES A CATEGORY IF, FOR EACH DEPTH OF EACH INTER
     6VAL,'//4X,'THE ABSOLUTE VALUE OF (P AVERAGE) PLUS 2S IS LESS THAN
     7OR EQUAL TO'//4X,'THE TOLERANCE LIMIT, L.'////)
      WRITE (6,207)
  207 FORMAT (4X,'FOR CATEGORY I, INTERVAL 1, AND FOR CATEGORY II, INTER
     1VAL 1, L = 0.3.  FOR'//4X,'CATEGORY I, INTERVALS 2, 3, AND 4, L =
     20.3 OR 6/SQRT(H AVERAGE), WHICHEVER'//4X,'IS LARGER.  FOR ALL OTHE
     3R CATEGORIES, L = 0.5 OR 15/SQRT(H AVERAGE), WHICHEVER'//4X,'IS LA
     4RGER.')
      WRITE (6,226)
  226 FORMAT (////4X,'IF A DOSIMETER IS LOST, NOT REPORTED BY THE PROCES
     1SOR, IRRADIATED IMPROPERLY,'//4X,'ETC., THE WORD VOID APPEARS NEXT
     2 TO THE DOSIMETER NUMBER.  VOIDED DOSIMETERS'//4X,'ARE NOT INCLUDE
     3D IN THE PASS/FAIL CALCULATIONS.')
      DO 174 I = 1,8
      K(I) = 0
  174 J(I) = 0
      M(1) = 4
      M(2) = 7
      M(3) = 4
      M(4) = 2
      M(5) = 2
      M(6) = 6
      M(7) = 4
      M(8) = 2
      GO TO 152
  100 READ (5,20) NCAT,INTER,PRO,CESSOR,NUM,TYPE
   20 FORMAT (2I5,A8,A7,I5,A8)
```

```
      DO 500 I = 1,10
500   CODE(I) = 0.0
      IF (NCAT.NE.0) GO TO 152
      DO 204 I = 1,8
      IF (K(I).GT.0) FIN(I)=STAR
      IF (J(I).EQ.M(I)) FIN(I)=PASS
      IF (J(I).LT.M(I).AND.K(I).EQ.M(I)) FIN(I)=FAIL
204   IF (J(I).EQ.0.AND.K(I).EQ.0) FIN(I)=STARR
      WRITE (6,205)
205   FORMAT (1H1///////17X,'**********  SUMMARY OF RESULTS  **********'
     1/////)
      IF (NAME.EQ.1) PR=OK8
      IF (NAME.EQ.1) CE=OK8
      WRITE (6,201) PR,CE,NU,TY
      WRITE (6,206) (FIN(I), I = 1,8)
206   FORMAT (/////17X,'CATEGORY I,     GAMMA',24X,': ',A4,//17X,'CATEGOR
     1Y II,   HIGH-ENERGY X RAY',12X,': ',A4//17X,'CATEGORY III,  LOW-EN
     2ERGY X RAY',13X,': ',A4//17X,'CATEGORY IV,    BETA',25X,': ',A4//17
     3X,'CATEGORY V,     NEUTRON',22X,': ',A4//17X,'CATEGORY VI,    GAMMA
     4PLUS HIGH-ENERGY X RAY : ',A4//17X,'CATEGORY VII,  GAMMA PLUS BETA
     5',14X,': ',A4//17X,'CATEGORY VIII, GAMMA PLUS NEUTRON',11X,': ',A4
     6////)
      LL = 0
      MM = 0
      DO 221 I = 1,8
      IF (FIN(I).EQ.STAR) LL=I
      IF (FIN(I).EQ.STARR) MM=1
221   CONTINUE
      IF (LL.EQ.0) GO TO 222
      WRITE (6,220)
220   FORMAT (17X,'*  = RESULTS ARE INCOMPLETE FOR THIS CATEGORY'//)
222   IF (MM.EQ.0) GO TO 224
      WRITE (6,223)
223   FORMAT (17X,'** = PROCESSOR DID NOT PARTICIPATE IN THIS CATEGORY')
224   WRITE (6,225)
225   FORMAT (1H1)
      GO TO 100
152   GO TO (1,2,3,4,5,6,7,8), NCAT
  1   GO TO (9,10,10,10), INTER
  9   READ (5,21) (NUMBER(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I),TIME(I),
     1IPOS(I),IDIST(I),REF(I),RDEEP(I), I = 1,10)
 21   FORMAT (I5,3I2,2F5.0,I1,I3,F4.0,F10.0)
      DO 502 I = 1,10
      IF (NUMBER(I).LT.90000) GO TO 502
      CODE(I) = 9.0
      NUMBER(I) = NUMBER(I) - 90000
502   CONTINUE
      CX = 1.01
      CALL TEST (RDEEP,DDEEP)
      WRITE (6,22)
 22   FORMAT (1H1,9X,'CATEGORY I, GAMMA'//10X,'INTERVAL 1, 10 - 800 RAD'
     1)
 40   IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO, CESSOR, NUM, TYPE
 23   FORMAT (47X,'PROCESSOR NAME : ',A8,A7//47X,'PROCESSOR CODE NO. : '
     1,I2,//47X,'TYPE OF DOSIMETER : ',A8)
      WRITE (6,24)
 24   FORMAT (10X,'SOURCE : COBALT-60 IRRADIATOR'//10X,'IRRADIATION DIST
     1ANCE : SHOWN BELOW'////)
      IF (INTER.GT.1) GO TO 29
      TOLER = 0.3
      WRITE (6,25) CX
 25   FORMAT (23X,'EXPOS.  IRRA. ',10X,'IRRA.  DEEP ABSORBED DOSE, CX =
     1',F4.2)
      WRITE (6,62)
```

```
 62  FORMAT (1X,'DOSIMETER',4X,'DATE',6X,'RATE',3X,'TIME   EXPOSURE DIS
    'T.   DELIV.   REPORT.')
     WRITE (6,63)
 63  FORMAT (2X,'NUMBER   IRRADIATED (R/MIN)  (MIN)    (R)    (CM)    (
    1RAD)    (RAD)    P=(H*-H)/H'//)
     GO TO 31
 29  TOLER = 6.0/SQRT(HBAR)
     IF (TOLER.LT.0.3) TOLER=0.3
     WRITE (6,30) CX
 30  FORMAT (23X,'EXPOS.  IRRA. ',10X,'IRRA.  DEEP DOSE EQUIVALENT, CX=
    1',F4.2)
     WRITE (6,62)
     WRITE (6,32)
 32  FORMAT (2X,'NUMBER   IRRADIATED (MR/MIN) (MIN)    (MR)   (CM)    (
    1MREM)    (MREM)   P=(H*-H)/H'//)
 31  DO 33 I = 1,10
     STATE(I) = OK
     IF (CODE(I).EQ.9.0) STATE(I)=VOID
     GO TO (33,43,44,44), INTER
 43  IDIST(I) = 200
     GO TO 33
 44  IDIST(I) = 100
 33  CONTINUE
     IF (INTER.GT.1) GO TO 400
     WRITE (6,26) (NUMBER(I),STATE(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I
    1),TIME(I),EXPOS(I),IDIST(I),DDEEP(I),RDEEP(I),P(I), I = 1,10)
 26  FORMAT (1X,I5,1X,A4,1X,I2,'-',I2,'-',I2,2X,F6.2,F8.3,F9.2,3X,I3,F9
    1.0,F10.3,3X,F9.4/)
     GO TO 401
400  WRITE (6,82) (NUMBER(I),STATE(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I
    1),TIME(I),EXPOS(I),IDIST(I),DDEEP(I),RDEEP(I),P(I), I = 1,10)
 82  FORMAT (1X,I5,1X,A4,1X,I2,'-',I2,'-',I2,2X,F6.2,F8.3,F9.2,3X,I3,2F
    19.0,4X,F9.4/)
401  WRITE (6,27) PBAR, S, HBAR, RESULT, TOLER
 27  FORMAT   (///62X,'P AVERAGE = ',F8.4//70X,'S = ',F8.4//62X,'H AVER
    1AGE = ',F8.1//52X,'ABS(P AVERAGE) + 2S = ',F8.4//70X,'L = ',F8.4//
    2/)
     FINISH = PASS
     IF (RESULT.GT.TOLER) FINISH=FAIL
     WRITE (6,28) FINISH
 28  FORMAT (52X,'**********  ',A4,'  ************')
     K(1) = K(1) + 1
     IF (FINISH.EQ.PASS) J(1)=J(1)+1
     GO TO 100
 10  READ (5,34) (NUMBER(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I),  ME(I),
    1IPOS(I),REF(I),RDEEP(I), I = 1,10)
 34  FORMAT (I5,3I2,2F5.0,I1,F4.0,F10.0)
     DO 521 I = 1,10
     IF (NUMBER(I).LT.90000) GO   521
     CODE(I) = 9.0
     NUMBER(I) = NUMBER(I) - 90000
521  CONTINUE
     DO 725 I = 1,10
725  TIME(I) = TIME(I)/60.0
     CX = 1.01
     CALL TEST (RDEEP,DDEEP)
     WRITE (6,35)
 35  FORMAT (1H1,9X,'CATEGORY I, GAMMA  )
     IF (INTER - 3) 36, 37, 38
 36  WRITE (6,39)
 39  FORMAT (10X,'INTERVAL 2, 30 - 100 MREM')
     GO TO 40
 37  WRITE (6,41)
 41  FORMAT (10X,'INTERVAL 3, 101 - 300 MREM')
     GO TO 40
 38  WRITE (6,42)
```

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42  FORMAT (10X,'INTERVAL 4. 301 - 10,000 MREM')
    GO TO 40
 2  IF (INTER.GT.1) GO TO 46
    READ (5,34) (NUMBER(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I),TIME(I),
   1IPOS(I),REF(I),RDEEP(I), I = 1,10)
    DO 503 I = 1,10
    IF (NUMBER(I).LT.90000) GO TO 503
    CODE(I) = 9.0
    NUMBER(I) = NUMBER(I) - 90000
503 CONTINUE
    CX = 1.33
    CALL TEST (RDEEP,DDEEP)
    WRITE (6,47)
47  FORMAT (1H1,9X,'CATEGORY II, HIGH-ENERGY X RAY'//10X,'INTERVAL 1,
   110 - 800 RAD')
    IF (NAME.EQ.1) PRO=OK8
    IF (NAME.EQ.1) CESSOR=OK8
    WRITE (6,23) PRO,CESSOR,NUM,TYPE
    WRITE (6,48)
48  FORMAT (10X,'NBS TECHNIQUE : MFK'//10X,'IRRADIATION DISTANCE : 100
   1 CM'////)
    WRITE (6,49) CX
49  FORMAT (23X,'IRRA.   IRRA. ',11X,'DEEP ABSORBED DOSE, Cx = ',F4.2)
    CALL ANSWER (RDEEP,DDEEP,1)
    K(2) = K(2) + 1
    IF (FINISH.EQ.PASS) J(2)=J(2)+1
    GO TO 100
46  READ (5,58) (NUMBER(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I),TIME(I),
   1IPOS(I),REF(I),RSHAL(I),RDEEP(I), I = 1,10)
58  FORMAT (I5,3I2,2F5.0,I1,F4.0,2F10.0)
    DO 520 I = 1,10
    IF (NUMBER(I).LT.90000) GO TO 520
    CODE(I) = 9.0
    NUMBER(I) = NUMBER(I) - 90000
520 CONTINUE
    GO TO (59,59,60,61), INTER
59  CX = 1.26
    CALL TEST (RSHAL,DSHAL)
    WRITE (6,50)
50  FORMAT (1H1,9X,'CATEGORY II, HIGH-ENERGY X RAY'//10X,'INTERVAL 2,
   130 - 100 MREM')
    IF (NAME.EQ.1) PRO=OK8
    IF (NAME.EQ.1) CESSOR=OK8
    WRITE (6,23) PRO,CESSOR,NUM,TYPE
    WRITE (6,52)
52  FORMAT (10X,'NBS TECHNIQUE : HFK'//10X,'IRRADIATION DISTANCE : 100
   1 CM'////)
    WRITE (6,54) CX
54  FORMAT (23X,'IRRA.   IRRA. ',11X,'SHALLOW DOSE EQUIV., CX=',F5.3)
    CALL ANSWER (RSHAL,DSHAL,2)
    K(2) = K(2) + 1
    IF (FINISH.EQ.PASS) J(2)=J(2)+1
    CALL TEST(RDEEP,DDEEP)
    WRITE (6,50)
    IF (NAME.EQ.1) PRO=OK8
    IF (NAME.EQ.1) CESSOR=OK8
    WRITE (6,23) PRO,CESSOR,NUM,TYPE
    WRITE (6,52)
    WRITE (6,55) CX
55  FORMAT (23X,'IRRA.   IRRA. ',11X,'DEEP DOSE EQUIVALENT, CX=',F5.3)
    CALL ANSWER (RDEEP,DDEEP,2)
    K(2) = K(2) + 1
    IF (FINISH.EQ.PASS) J(2)=J(2)+1
    GO TO 100
60  CX = 1.35
    CALL TEST (RSHAL,DSHAL)
```

```
      WRITE (6,56)
   56 FORMAT (1H1,9X,'CATEGORY II, HIGH-ENERGY X RAY'//10X,'INTERVAL 3,
     1101 - 300 MREM')
      IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,57)
   57 FORMAT (10X,'NBS TECHNIQUE : MFG'//10X,'IRRADIATION DISTANCE : 100
     1 CM'////)
      WRITE (6,54) CX
      CALL ANSWER (RSHAL,DSHAL,2)
      K(2) = K(2) + 1
      IF (FINISH.EQ.PASS) J(2)=J(2)+1
      CALL TEST (RDEEP,DDEEP)
      WRITE (6,56)
      IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,57)
      WRITE (6,55) CX
      CALL ANSWER (RDEEP,DDEEP,2)
      K(2) = K(2) + 1
      IF (FINISH.EQ.PASS) J(2)=J(2)+1
      GO TO 100
   61 CX = 1.28
      CALL TEST (RSHAL,DSHAL)
      WRITE (6,65)
   65 FORMAT (1H1,9X,'CATEGORY II, HIGH-ENERGY X RAY'//10X,'INTERVAL 4,
     1301 - 10,000 MREM')
      IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,66)
   66 FORMAT (10X,'NBS TECHNIQUE : MFG'//10X,'IRRADIATION DISTANCE : 100
     1 CM'////)
      WRITE (6,54) CX
      CALL ANSWER (RSHAL,DSHAL,2)
      K(2) = K(2) + 1
      IF (FINISH.EQ.PASS) J(2)=J(2)+1
      CX = 1.23
      CALL TEST (RDEEP,DDEEP)
      WRITE (6,65)
      IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,66)
      WRITE (6,55) CX
      CALL ANSWER (RDEEP,DDEEP,2)
      K(2) = K(2) + 1
      IF (FINISH.EQ.PASS) J(2)=J(2)+1
      GO TO 100
    3 READ (5,58) (NUMBER(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I),TIME(I),
     1IPOS(I),REF(I),RSHAL(I),RDEEP(I), I = 1,10)
      DO 504 I = 1,10
      IF (NUMBER(I).LT.90000) GO TO 504
      CODE(I) = 9.0
      NUMBER(I) = NUMBER(I) - 90000
  504 CONTINUE
      IF (ITER.GT.1) GO TO 68
      CX = 0.81
      CALL TEST (RSHAL,DSHAL)
      WRITE (6,67)
   67 FORMAT (1H1,9X,'CATEGORY III, LOW-ENERGY X RAY'//10X,'INTERVAL 1,
     1150 - 300 MREM')
      IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
```

```
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,69)
   69 FORMAT (10X,'NHS TECHNIQUE : L-G'//10X,'IRRADIATION DISTANCE : 200
     1 CM'////)
      WRITE (6,54) CX
      CALL ANSWER (RSHAL,DSHAL,2)
      K(3) = K(3) + 1
      IF (FINISH.EQ.PASS) J(3)=J(3)+1
      CX = 0.25
      CALL TEST (RDEEP,DDEEP)
      WRITE (6,67)
      IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,69)
      WRITE (6,55) CX
      CALL ANSWER (RDEEP,DDEEP,2)
      K(3) = K(3) + 1
      IF (FINISH.EQ.PASS) J(3)=J(3)+1
      GO TO 100
   68 CX = 0.81
      CALL TEST (RSHAL,DSHAL)
      WRITE (6,70)
   70 FORMAT (1H1,9X,'CATEGORY III, LOW-ENERGY X RAY'//10X,'INTERVAL 2,
     1301 - 10,000 MREM')
      IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,69)
      WRITE (6,54) CX
      CALL ANSWER (RSHAL,DSHAL,2)
      K(3) = K(3) + 1
      IF (FINISH.EQ.PASS) J(3)=J(3)+1
      CX = 0.25
      CALL TEST (RDEEP,DDEEP)
      WRITE (6,70)
      IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,69)
      WRITE (6,55) CX
      CALL ANSWER (RDEEP,DDEEP,2)
      K(3) = K(3) + 1
      IF (FINISH.EQ.PASS) J(3)=J(3)+1
      GO TO 100
    4 READ (5,11) (NUMBER(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I),TIME(I),
     1RSHAL(I), I = 1,10)
   11 FORMAT (I5,3I2,2F5.0,F10.0)
      DO 505 I = 1,10
      IF (NUMBER(I).LT.90000) GO TO 505
      CODE(I) = 9.0
      NUMBER(I) = NUMBER(I) - 90000
  505 CONTINUE
      CX = 0.9665
      CALL TEST (RSHAL,DSHAL)
      IF (INTER.GT.1) GO TO 72
      WRITE (6,71)
   71 FORMAT (1H1,9X,'CATEGORY IV, BETA'//10X,'INTERVAL 1, 150 - 300 MRE
     1M')
      GO TO 75
   72 WRITE (6,74)
   74 FORMAT (1H1,9X,'CATEGORY IV, BETA'//10X,'INTERVAL 2, 301 - 10,000
     1MREM')
   75 IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
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      WRITE (6,73)
 73   FORMAT (10X,'SOURCE : STRONTIUM-90'//10X,'IRRADIATION DISTANCE : 3
     15 CM'////)
      WRITE (6,54) CX
      CALL ANSWER (RSHAL,DSHAL,2)
      K(4) = K(4) + 1
      IF (FINISH.EQ.PASS) J(4)=J(4)+1
      GO TO 100
  5   READ (5,21) (NUMBER(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I),TIME(I),
     1IPOS(I),IDIST(I),REF(I),RDEEP(I), I = 1,10)
      DO 506 I = 1,10
      IF (NUMBER(I).LT.90000) GO TO 506
      CODE(I) = 9.0
      NUMBER(I) = NUMBER(I) - 90000
506   CONTINUE
      CALL TEST (RDEEP,DDEEP)
      IF (INTER.GT.1) GO TO 99
      WRITE (6,77)
 77   FORMAT (1H1,9X,'CATEGORY V. NEUTRON'//10X,'INTERVAL 1, 100 - 300 M
     1REM')
      GO TO 78
 99   WRITE (6,80)
 80   FORMAT (1H1,9X,'CATEGORY V. NEUTRON'//10X,'INTERVAL 2, 301 - 5,000
     1 MREM')
 78   IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,79)
 79   FORMAT (10X,'SOURCE : CALIFORNIUM-252'//10X,'IRRADIATION DISTANCE
     1: SHOWN BELOW'//)
      WRITE (6,81)
 81   FORMAT (10X,'NOTE : DELIVERED DOSE EQUIVALENT INCLUDES THE'/17X,'R
     1OOM RETURN (SCATTER) CORRECTION FACTOR'/17X,'SHOWN BELOW'///)
      WRITE (6,83)
 83   FORMAT (23X,'DOSE EQ.  IRRA. IRRA.',15X,'DEEP DOSE EQUIVALENT')
      WRITE (6,84)
 84   FORMAT (1X,'DOSIMETER    DATE',7X,'RATE    TIME  DIST. SCATTER   D
     1ELIV.   REPORT.')
      WRITE (6,85)
 85   FORMAT (2X,'NUMBER   IRRADIATED (MREM/MIN) (MIN) (CM)   C.F.      (
     1MREM)   (MREM)   P=(H*-H)/H'//)
      DO 86 I = 1,10
      STATE(I) = OK
      IF (CODE(I).EQ.9.0) STATE(I)=VOID
 86   CONTINUE
      WRITE (6,87) (NUMBER(I),STATE(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I
     1),TIME(I),IDIST(I),EXPOS(I),DDEEP(I),RDEEP(I),P(I), I = 1,10)
 87   FORMAT (1X,I5,1X,A4,1X,I2,'-',I2,'-',I2,3X,F6.2,F9.3,I5,F8.3,2F9.0
     1,4X,F9.4/)
      TOLER = 15.0/SQRT(HBAR)
      IF (TOLER.LT.0.5) TOLER=0.5
      WRITE (6,27) PBAR,S,HBAR,RESULT,TOLER
      FINISH = PASS
      IF (RESULT.GT.TOLER) FINISH=FAIL
      WRITE (6,28) FINISH
      K(5) = K(5) + 1
      IF (FINISH.EQ.PASS) J(5)=J(5)+1
      GO TO 100
  6   READ (5,88) (NUMBER(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I),TIME(I),
     1IPOS(I),REF(I), I = 1,10)
 88   FORMAT (I5,3I2,2F5.0,I1,F4.0)
      READ (5,20) NCAT,INTER,PRO,CESSOR,NUM,TYPE
      READ (5,58) (NUMX(I),JMONTH(I),JDAY(I),JYEAR(I),RAT(I),TIM(I),JPOS
     1(I),CLO(I),RSHAL(I),RDEEP(I), I = 1,10)
      DO 507 I = 1,10
      IF (NUMBER(I).LT.90000) GO TO 508
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      CODE(I) = 9.0
      NUMBER(I) = NUMBER(I) - 90000
508   IF (NUMX(I).LT.90000) GO TO 507
      CODE(I) = 9.0
      NUMX(I) = NUMX(I) - 90000
507   CONTINUE
      DO 726 I = 1,10
726   TIME(I) = TIME(I)/60.0
      CX = 1.01
      CALL TEST (RDEEP,DDEEP)
      WRITE (6,94)
 94   FORMAT (1H1,9X,'CATEGORY VI, GAMMA COMPONENT',32X,'PAGE 1 OF 3'/23
     1X,'OF GAMMA PLUS HIGH-ENERGY X RAY'/)
      GO TO (91,92,93), INTER
 91   WRITE (6,95)
 95   FORMAT (10X,'INTERVAL 1, 50 - 100 MREM')
      GO TO 110
 92   WRITE (6,111)
111   FORMAT (10X,'INTERVAL 2, 101 - 300 MREM')
      GO TO 110
 93   WRITE (6,112)
112   FORMAT (10X,'INTERVAL 3, 301 - 10,000 MREM')
110   IF (NAME.EQ.1) PRO=OKB
      IF (NAME.EQ.1) CESSOR=OKB
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,96)
 96   FORMAT (10X,'SOURCE : COBALT-60 IRRADIATOR'//)
      GO TO (124,125,125), INTER
124   WRITE (6,127)
127   FORMAT (10X,'IRRADIATION DISTANCE : 200 CM'////)
      GO TO 126
125   WRITE (6,128)
128   FORMAT (10X,'IRRADIATION DISTANCE : 100 CM'////)
126   WRITE (6,97)
 97   FORMAT (57X,'DELIVERED DOSE EQUIVALENT',/28X,'IRRA.     IRRA.',20X,
     1'SHALLOW',6X,'DEEP')
      WRITE (6,98) CX, CX
 98   FORMAT (1X,'DOSIMETER      DATE',9X,'RATE      TIME     EXPOSURE',9X,
     1'CX=',F4.2,'      CX=',F4.2)
      WRITE (6,101)
101   FORMAT (2X,'NUMBER     IRRADIATED     (MR/MIN)    (MIN)      (MR)',12X
     1,'(MREM)      (MREM)'//)
      DO 102 I = 1,10
      STATE(I) = OK
      IF (CODE(I).EQ.9.0) STATE(I)=VOID
102   CONTINUE
      WRITE (6,103) (NUMBER(I),STATE(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(
     1I),TIME(I),EXPOS(I),DDEEP(I),DDEEP(I), I = 1,10)
103   FORMAT (1X,I5,1X,A4,2X,I2,'-',I2,'-',I2,4X,F8.2,F10.3,F10.2,8X,F8.
     10,4X,F7.0/)
      WRITE (6,107)
107   FORMAT (1H1,9X,'CATEGORY VI, X RAY COMPONENT',33X,'PAGE 2 OF 3'/23
     1X,'OF GAMMA PLUS HIGH-ENERGY X RAY'/)
      GO TO (104,105,106), INTER
104   WRITE (6,95)
      CXSHAL = 1.26
      CXDEEP = 1.26
      GO TO 113
105   WRITE (6,111)
      CXSHAL = 1.35
      CXDEEP = 1.35
      GO TO 113
106   WRITE (6,112)
      CXSHAL = 1.28
      CXDEEP = 1.23
113   CX = CXSHAL
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      DO 109 I = 1,10
      RATE(I) = RAT(I)
      TIME(I) = TIM(I)
      STATE(I) = OK
      IF (CODE(I).EQ.9.0) STATE(I)=VOID
  109 CONTINUE
      CALL TEST (RSHAL,DSHALX)
      CX = CXDEEP
      CALL TEST (RDEEP,DDEEPX)
      IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      GO TO (129,130,131), INTER
  129 WRITE (6,132)
  132 FORMAT (10X,'NBS TECHNIQUE : HFK'//)
      GO TO 108
  130 WRITE (6,133)
  133 FORMAT (10X,'NBS TECHNIQUE : HFG'//)
      GO TO 108
  131 WRITE (6,134)
  134 FORMAT (10X,'NBS TECHNIQUE : MFG'//)
  108 WRITE (6,135)
  135 FORMAT (10X,'IRRADIATION DISTANCE : 100 CM'////)
      WRITE (6,97)
      WRITE (6,98) CXSHAL, CXDEEP
      WRITE (6,101)
      WRITE (6,103)    (NUMX(I),STATE(I),JMONTH(I),JDAY(I),JYEAR(I),RATE(
     1I),TIME(I),EXPOS(I),DSHALX(I),DDEEPX(I), I = 1,10)
      DO 89 I = 1,10
      DSHAL(I) = DDEEP(I) + DSHALX(I)
      DDEEP(I) = DDEEP(I) + DDEEPX(I)
      IF (NUMBER(I).EQ.NUMX(I)) GO TO 89
      WRITE (6,90) NCAT, INTER
   90 FORMAT (1H1,4X,'WARNING *** DOSIMETER NUMBERS IN CATEGORY ',I1,' I
     1NTERVAL ',I1//17X,'DO NOT MATCH BETWEEN THE TWO RADIATION SOURCES
     2USED')
      GO TO 100
   89 CONTINUE
      CX = 6.0
      CALL TEST (RSHAL,DSHAL)
      TOLER = 15.0/SQRT(HBAR)
      IF (TOLER.LT.0.5) TOLER=0.5
      DO 114 I = 1,10
      TIME(I) = DSHAL(I)
      EXPOS(I) = RSHAL(I)
  114 REF(I) = P(I)
      PAVG = PBAR
      SAVG = S
      HAVG = HBAR
      GAMRES = RESULT
      GAMTOL = TOLER
      GAMFIN = PASS
      IF (RESULT.GT.TOLER) GAMFIN=FAIL
      CX = 6.0
      CALL TEST (RDEEP,DDEEP)
      TOLER = 15.0/SQRT(HBAR)
      IF (TOLER.LT.0.5) TOLER=0.5
      FINISH = PASS
      IF (RESULT.GT.TOLER) FINISH=FAIL
      WRITE (6,115)
  115 FORMAT (1H1,9X,'CATEGORY VI, TOTAL OF GAMMA PLUS X RAY',22X,'PAGE
     13 OF 3'//)
      GO TO (116,117,118), INTER
  116 WRITE (6,95)
      GO TO 119
  117 WRITE (6,111)
```

```
      GO TO 119
118   WRITE (6,112)
119   IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,120)
120   FORMAT (////18X,'TOTAL SHALLOW DOSE EQUIVALENT',7X,'TOTAL DEEP DOS
     1E EQUIVALENT'/3X,'DOSIMETER',6X,'DELIVERED REPORTED',16X,'DELIVERE
     2D REPORTED'/4X,'NUMBER',10X,'(MREM)    (MREM)  P=(H*-H)/H',7X,'(MRE
     4M)    (MREM) P=(H*-H)/H'//)
      WRITE (6,121) (NUMBER(I),STATE(I),TIME(I),EXPOS(I),REF(I),DDEEP(I)
     1,RDEEP(I),P(I), I = 1,10)
121   FORMAT (4X,I5,1X,A4,5X,F7.0,2X,F7.0,2X,F9.4,7X,F7.0,2X,F7.0,2X,F9.
     14/)
      WRITE (6,122) PAVG,PBAR,SAVG,S,HAVG,HBAR,GAMRES,RESULT,GAMTOL,TOLE
     1R
122   FORMAT (///28X,'P AVERAGE =',F8.4,12X,'P AVERAGE =',F8.4//36X,'S =
     1',F8.4,20X,'S =',F8.4//28X,'H AVERAGE =',F8.1,12X,'H AVERAGE =',F8
     2.1//18X,'ABS(P AVERAGE) + 2S =',F8.4,2X,'ABS(P AVERAGE) + 2S =',F8
     3.4//36X,'L =',F8.4,20X,'L =',F8.4//)
      WRITE (6,123) GAMFIN, FINISH
123   FORMAT (18X,'**********  ',A4,'  ***********',2X,'**********  ',A4
     1,'  ************')
      K(6) = K(6) + 2
      IF (FINISH.EQ.PASS) J(6)=J(6)+1
      IF (GAMFIN.EQ.PASS) J(6)=J(6)+1
      GO TO 100
    7 READ (5,88) (NUMBER(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I),TIME(I),
     1EXPOS(I),REF(I), I = 1,10)
      READ (5,20) NCAT,INTER,PRO,CESSOR,NUM,TYPE
      READ (5,141) (NUMX(I),JMONTH(I),JDAY(I),JYEAR(I),RAT(I),TIM(I),RSH
     1AL(I),RDEEP(I), I = 1,10)
141   FORMAT (I5,3I2,2F5.0,2F10.0)
      DO 509 I = 1,10
      IF (NUMBER(I).LT.90000) GO TO 510
      CODE(I) = 9.0
      NUMBER(I) = NUMBER(I) - 90000
510   IF (NUMX(I).LT.90000) GO TO 509
      CODE(I) = 9.0
      NUMX(I) = NUMX(I) - 90000
509   CONTINUE
      DO 727 I = 1,10
727   TIME(I) = TIME(I)/60.0
      CX = 1.01
      CALL TEST (RDEEP,DDEEP)
      TOLER = 15.0/SQRT(HBAR)
      IF (TOLER.LT.0.5) TOLER=0.5
      PAVG = PBAR
      SAVG = S
      HAVG = HBAR
      GAMRES = RESULT
      GAMTOL = TOLER
      GAMFIN = PASS
      IF (RESULT.GT.TOLER) GAMFIN=FAIL
      WRITE (6,136)
136   FORMAT (1H1,9X,'CATEGORY VII, GAMMA COMPONENT',32X,'PAGE 1 OF 3'/2
     14X,'OF BETA PLUS GAMMA'/)
      IF (INTER.GT.1) GO TO 139
      WRITE (6,137)
137   FORMAT (10X,'INTERVAL 1, 200 - 300 MREM')
      GO TO 138
139   WRITE (6,140)
140   FORMAT (10X,'INTERVAL 2, 301 - 10,000 MREM')
138   IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
```

```
      WRITE (6,96)
      WRITE (6,128)
      IF (NCAT.NE.8) GO TO 197
      WRITE (6,175)
175   FORMAT (10X,'NOTE : DELIVERED DOSE EQUIVALENT INCLUDES A GAMMA-RAY
     1'/17X,'CONTRIBUTION FROM THE CF-252 SOURCE EQUAL TO'/17X,'7.033 PE
     2RCENT OF THE NEUTRON DOSE EQUIVALENT'///)
197   WRITE (6,97)
      WRITE (6,98) CX, CX
      WRITE (6,101)
      DO 154 I = 1,10
      PP(I) = P(I)
      STATE(I) = OK
      IF (CODE(I).EQ.9.0) STATE(I)=VOID
154   CONTINUE
      WRITE (6,103) (NUMBER(I),STATE(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(
     1I),TIME(I),EXPOS(I),DDFEP(I),DDEEP(I), I = 1,10)
      IF (NCAT.EQ.8) GO TO 165
      WRITE (6,142)
142   FORMAT (1H1,9X,'CATEGORY VII, BETA COMPONENT',32X,'PAGE 2 OF 3'/24
     1X,'OF BETA PLUS GAMMA'/)
      IF (INTER.GT.1) GO TO 143
      WRITE (6,137)
      GO TO 144
143   WRITE (6,140)
144   IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,73)
      CX = 0.9665
      DO 147 I = 1,10
      RATE(I) = RAT(I)
      TIME(I) = TIM(I)
      REF(I) = 0.0
      STATE(I) = OK
      IF (CODE(I).EQ.9.0) STATE(I)=VOID
147   CONTINUE
      CALL TEST (RSHAL,DSHAL)
      WRITE (6,97)
      WRITE (6,146)
146   FORMAT (1X,'DOSIMETER',5X,'DATE',8X,'RATE',7X,'TIME',3X,'ABS. DOSE
     1',9X,'CX=.9665',4X,'CX=0.00'/2X,'NUMBER',4X,'IRRADIATED',3X,'(MRAD
     2/MIN)',3X,'(MIN)',4X,'(MRAD)',11X,'(MREM)',6X,'(MREM)'//)
      WRITE (6,103)    (NUMX(I),STATE(I),JMONTH(I),JDAY(I),JYEAR(I),RATE(
     1I),TIME(I),EXPOS(I),DSHAL(I),REF(I), I = 1,10)
      DO 148 I = 1,10
      DSHAL(I) = DSHAL(I) + DDEEP(I)
      IF (NUMBER(I).EQ.NUMX(I)) GO TO 148
      WRITE (6,90) NCAT,INTER
      GO TO 100
148   CONTINUE
      CX = 6.0
      CALL TEST (RSHAL,DSHAL)
      TOLER = 15.0/SQRT(HBAR)
      IF (TOLER.LT.0.5) TOLER=0.5
      FINISH = PASS
      IF (RESULT.GT.TOLER) FINISH=FAIL
      WRITE (6,149)
149   FORMAT (1H1,9X,'CATEGORY VII, TOTAL OF BETA PLUS GAMMA',23X,'PAGE
     13 OF 3'//)
      IF (INTER.GT.1) GO TO 150
      WRITE (6,137)
      GO TO 151
150   WRITE (6,140)
151   IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
```

```
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,120)
      WRITE (6,121) (NUMBER(I),STATE(I),DSHAL(I),RSHAL(I),P(I),UDEEP(I),
     1RDEEP(I),PP(I), I = 1,10)
      WRITE (6,122) PBAR,PAVG,S,SAVG,HBAR,HAVG,RESULT,GAMRES,TOLER,GAMTO
     1L
      WRITE (6,123) FINISH, GAMFIN
      K(7) = K(7) + 2
      IF (FINISH.EQ.PASS) J(7)=J(7)+1
      IF (GAMFIN.EQ.PASS) J(7)=J(7)+1
      GO TO 100
    8 READ (5,88) (NUMBER(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I),TIME(I),
     1IPOS(I),REF(I), I = 1,10)
      READ (5,20) NCAT,INTER,PRO,CESSOR,NUM,TYPE
      READ (5,21) (NUMX(I),JMONTH(I),JDAY(I),JYEAR(I),RAT(I),TIM(I),JPOS
     1(I),IDIST(I),CLO(I),RDEEP(I), I = 1,10)
      DO 511 I = 1,10
      IF (NUMBER(I).LT.90000) GO TO 512
      CODE(I) = 9.0
      NUMBER(I) = NUMBER(I) - 90000
  512 IF (NUMX(I).LT.90000) GO TO 511
      CODE(I) = 9.0
      NUMX(I) = NUMX(I) - 90000
  511 CONTINUE
      CX = 1.01
      DO 160 I = 1,10
      TIME(I) = TIME(I)/60.0
      EXPOS(I) = RATE(I)*TIME(I)
      DDEEP(I) = EXPOS(I)*CX + 0.07033*RAT(I)*TIM(I)
      IDEL = UDEEP(I)
      XDEL = IDEL
      DIFF = UDEEP(I) - XDEL
      IF (DIFF.GT.0.5) GO TO 173
      DDEEP(I) = XDEL
      GO TO 160
  173 DDEEP(I) = XDEL + 1.0
  160 CONTINUE
      WRITE (6,161)
  161 FORMAT (1H1,9X,'CATEGORY VIII, GAMMA COMPONENT',32X,'PAGE 1 OF 3'/
     125X,'OF NEUTRON PLUS GAMMA'/)
      IF (INTER.GT.1) GO TO 162
      WRITE (6,163)
  163 FORMAT (10X,'INTERVAL 1, 150 - 300 MREM')
      GO TO 138
  162 WRITE (6,164)
  164 FORMAT (10X,'INTERVAL 2, 301 - 5,000 MREM')
      GO TO 138
  165 WRITE (6,166)
  166 FORMAT (1H1,9X,'CATEGORY VIII, NEUTRON COMPONENT',30X,'PAGE 2 OF 3
     1'/25X,'OF NEUTRON PLUS GAMMA'/)
      IF (INTER.GT.1) GO TO 167
      WRITE (6,163)
      GO TO 168
  167 WRITE (6,164)
  168 IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,79)
      WRITE (6,81)
      DO 191 I = 1,10
      RATE(I) = RAT(I)
      TIME(I) = TIM(I)
      STATE(I) = OK
      IF (CODE(I).EQ.9.0) STATE(I)=VOID
  191 CONTINUE
      CX = 8.0
```

```
      CALL TEST (RDEEP,DDEEPX)
      WRITE (6,169)
169   FORMAT (23X,'DOSE EQ.  IRRA. IRRA.',14X,'DELIVERED DOSE EQUIVALENT
     1'/1X,'DOSIMETER    DATE',7X,'RATE    TIME  DIST. SCATTER',9X,'SHAL
     2LOW   DEEP')
      WRITE (6,170)
170   FORMAT (2X,'NUMBER   IRRADIATED (MREM/MIN) (MIN) (CM)    C.F.',12X,
     1'(MREM)   (MREM)'//)
      WRITE (6,172)   (NUMX(I),STATE(I),JMONTH(I),JDAY(I),JYEAR(I),RAT(I
     1),TIM(I),IDIST(I),EXPOS(I),DDEEPX(I),DDEEPX(I), I = 1,10)
172   FORMAT (1X,I5,1X,A4,1X,I2,'-',I2,'-',I2,3X,F6.2,F9.3,I5,F8.3,8X,2F
     19.0/)
      DO 183 I = 1,10
      DDEEP(I) = DDEEP(I) + DDEEPX(I)
      IF (NUMBER(I).EQ.NUMX(I)) GO TO 183
      WRITE (6,90) NCAT,INTER
      GO TO 100
183   CONTINUE
      CX = 6.0
      CALL TEST (RDEEP,DDEEP)
      TOLER = 15.0/SQRT(HBAR)
      IF (TOLER.LT.0.5) TOLER=0.5
      FINISH = PASS
      IF (RESULT.GT.TOLER) FINISH = FAIL
      WRITE (6,198)
198   FORMAT (1H1,9X,'CATEGORY VIII, NEUTRON PLUS GAMMA',29X,'PAGE 3 OF
     13'//)
      IF (INTER.GT.1) GO TO 176
      WRITE (6,163)
      GO TO 177
176   WRITE (6,164)
177   WRITE (6,178)
178   FORMAT (///)
      IF (NAME.EQ.1) PRO=OK8
      IF (NAME.EQ.1) CESSOR=OK8
      WRITE (6,23) PRO,CESSOR,NUM,TYPE
      WRITE (6,179)
179   FORMAT (///29X,'TOTAL DEEP DOSE EQUIVALENT'/10X,'DOSIMETER',8X,'DE
     1LIVERED REPORTED'/11X,'NUMBER',12X,'(MREM)    (MREM) P=(H0-H)/H'//)
      WRITE (6,180) (NUMBER(I),STATE(I),DDEEP(I),RDEEP(I),P(I), I=1,10)
180   FORMAT (11X,I5,1X,A4,6X,F7.0,2X,F7.0,2X,F9.4/)
      WRITE (6,181) PBAR,S,HBAR,RESULT,TOLER
181   FORMAT (///36X,'P AVERAGE =',F8.4//44X,'S =',F8.4//36X,'H AVERAGE
     1=',F8.1//26X,'ABS(P AVERAGE) + 2S =',F8.4//44X,'L =',F8.4//)
      WRITE (6,182) FINISH
182   FORMAT (26X,'***********  ',A4,'  **********')
      K(8) = K(8) + 1
      IF (FINISH.EQ.PASS) J(8)=J(8)+1
      GO TO 100
      END
```

```
      SUBROUTINE TEST (REP,DEL)
      COMMON TYPE,NCAT,REF(10),FINISH,CODE(10)
      COMMON RATE(10),TIME(10),EXPOS(10),P(10),CX,RESULT,PBAR,HBAR,S
      COMMON NUMBER(10),IMONTH(10),IDAY(10),IYEAR(10),IPOS(10),IDIST(10)
      DIMENSION REP(10),DEL(10)
      REAL *8 ALBEDO,TYPE
      DATA ALBEDO/'ALBEDO  '/
      TDEL = 0.0
      TP = 0.0
      DENOM = 10.0
      IF (CX.EQ.6.0) GO TO 50
      IF (CX.EQ.8.0) GO TO 24
      DO 22 I = 1,10
      EXPOS(I) = RATE(I)*TIME(I)
   22 DEL(I) = EXPOS(I)*CX
      IF (NCAT.NE.5) GO TO 50
   24 IF (TYPE.EQ.ALBEDO) GO TO 51
      CF50 = 1.015
      CF100 = 1.06
      GO TO 52
   51 CF50 = 1.04
      CF100 = 1.17
   52 DO 53 I = 1,10
      IF (IDIST(I).EQ.100) GO TO 54
      EXPOS(I) = CF50
      DEL(I) = RATE(I)*TIME(I)*CF50
      GO TO 53
   54 DEL(I) = RATE(I)*TIME(I)*CF100
      EXPOS(I) = CF100
   53 CONTINUE
   50 DO 34 I = 1,10
      P(I) = 0.0
      IDEL = DEL(I)
      XDEL = IDEL
      DIFF = DEL(I) - XDEL
      IF (DIFF - 0.5) 30, 30, 31
   30 DEL(I) = XDEL
      GO TO 32
   31 DEL(I) = XDEL + 1.0
   32 IF (DEL(I).EQ.0.0) GO TO 70
      P(I) = (REP(I) - DEL(I))/DEL(I)
   70 IF (CODE(I).LT.9.0) GO TO 33
      DENOM = DENOM - 1.0
      GO TO 34
   33 TDEL = TDEL + DEL(I)
      TP = TP + P(I)
   34 CONTINUE
      PBAR = TP/DENOM
      HBAR = TDEL/DENOM
      HOLD = 0.0
      DO 23 I = 1,10
      IF (CODE(I).EQ.9.0) GO TO 23
      HOLD = HOLD + (P(I) - PBAR)**2
   23 CONTINUE
      S = SQRT(HOLD/(DENOM - 1.0))
      RESULT = ABS(PBAR) + 2.0*S
      RETURN
      END
```

```
      SUBROUTINE ANSWER (REP,DEL,N)
      COMMON TYPE,NCAT,REF(10),FINISH,CODE(10)
      COMMON RATE(10),TIME(10),EXPOS(10),P(10),CX,RESULT,PBAR,HBAR,S
      COMMON NUMBER(10),IMONTH(10):IDAY(10),IYEAR(10),IPOS(10),IDIST(10)
      DIMENSION DEL(10),REP(10),STATE(10)
      REAL *8 TYPE
      DATA PASS/'PASS'/,FAIL/'FAIL'/,VOID/'VOID'/,OK/'    '/
      IF (NCAT.NE.4) GO TO 22
      WRITE (6,52)
   52 FORMAT (1X,'DOSIMETER',4X,'DATE',6X,'RATE',3X,'TIME',5X,'DOSE',5X,
     1'DELIV.',3X,'REPORT.')
      WRITE (6,53)
   53 FORMAT (2X,'NUMBER   IRRADIATED (MRAD/M) (MIN)',3X,'(MREM)    (MRE
     1M)    (MREM)    P=(H*-H)/H'//)
      TOLER = 15.0/SQRT(HBAR)
      IF (TOLER.LT.0.5) TOLER=0.5
      GO TO 23
   22 WRITE (6,51)
   51 FORMAT (1X,'DOSIMETER',4X,'DATE',6X,'RATE',3X,'TIME   EXPOSURE',3X
     1,'DELIV.   REPORT.')
      GO TO (20,21), N
   20 TOLER = 0.3
      WRITE (6,64)
   64 FORMAT (2X,'NUMBER   IRRADIATED (R/MIN)  (MIN)     (R)',6X,'(RAD)
     1  (RAD)     P=(H*-H)/H'//)
      GO TO 23
   21 TOLER = 15.0/SQRT(HBAR)
      IF (TOLER.LT.0.5) TOLER=0.5
      WRITE (6,65)
   65 FORMAT (2X,'NUMBER   IRRADIATED (MR MIN) (MIN)     (MR)',5X,'(MREM)
     1    (MREM)    P=(H*-H)/H'//)
   23 DO 10 I = 1,10
      STATE(I) = OK
      IF (CODE(I).EQ.9.0) STATE(I)=VOID
   10 CONTINUE
      GO TO (30,31), N
   30 WRITE (6,13) (NUMBER(I),STATE(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I
     1),TIME(I),EXPOS(I),DEL(I),REP(I),P(I), I = 1,10)
   13 FORMAT (1X,I5,1X,A4,1X,I2,'-',I2,'-',I2,1X,F7.2,F8.3,F9.2,F9.0,F10
     1.3,3X,F9.4/)
      GO TO 32
   31 WRITE (6,11) (NUMBER(I),STATE(I),IMONTH(I),IDAY(I),IYEAR(I),RATE(I
     1),TIME(I),EXPOS(I),DEL(I),REP(I),P(I), I = 1,10)
   11 FORMAT (1X,I5,1X,A4,1X,I2,'-',I2,'-',I2,1X,F7.2,F8.3,F9.2,2F9.0,4X
     1,F9.4/)
   32 WRITE (6,12) PRAR,S,HBAR,RESULT,TOLER
   12 FORMAT (///56X,'P AVERAGE = ',F8.4//64X,'S = ',F8.4//50X,'H AVERAG
     1E = ',F8.1//46X,'ABS(P AVERAGE) + 2S = ',F8.4//64X,'L = ',F8.4//)
      FINISH = PASS
      IF (RESULT.GT.TOLER) FINISH=FAIL
      WRITE (6,57) FINISH
   57 FORMAT (47X,'***********  ',A4,'  **********')
      RETURN
      END
```

PERSONAL DOSIMETRY PERFORMANCE TESTING

A PILOT STUDY

SPONSORED BY :
U.S. NUCLEAR REGULATORY COMMISSION

CONDUCTED BY :
DEPT. OF ENVIRONMENTAL AND INDUSTRIAL HEALTH
SCHOOL OF PUBLIC HEALTH
UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

********** RESULTS OF TEST #2 **********

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

FOR EACH DOSIMETER, A PERFORMANCE INDEX IS CALCULATED BY :

$$P = (H^* - H)/H$$

WHERE : H = DELIVERED QUANTITY
H* = REPORTED QUANTITY

FOR EACH DEPTH OF EACH INTERVAL OF A CATEGORY, AN AVERAGE PERFORMANCE INDEX, (P AVERAGE), AND ITS STANDARD DEVIATION, S, ARE CALCULATED.

A PROCESSOR PASSES A CATEGORY IF, FOR EACH DEPTH OF EACH INTERVAL, THE ABSOLUTE VALUE OF (P AVERAGE) PLUS 2S IS LESS THAN OR EQUAL TO THE TOLERANCE LIMIT, L.

FOR CATEGORY I, INTERVAL 1, AND FOR CATEGORY II, INTERVAL 1, L = 0.3. FOR CATEGORY I, INTERVALS 2, 3, AND 4, L = 0.3 OR 6/SQRT(H AVERAGE), WHICHEVER IS LARGER. FOR ALL OTHER CATEGORIES, L = 0.5 OR 15/SQRT(H AVERAGE), WHICHEVER IS LARGER.

IF A DOSIMETER IS LOST, NOT REPORTED BY THE PROCESSOR, IRRADIATED IMPROPERLY, ETC., THE WORD VOID APPEARS NEXT TO THE DOSIMETER NUMBER. VOIDED DOSIMETERS ARE NOT INCLUDED IN THE PASS/FAIL CALCULATIONS.

CATEGORY I, GAMMA

INTERVAL 1, 10 - 800 RAD

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	EXPOS. RATE (R/MIN)	IRRA. TIME (MIN)	EXPOSURE (R)	IRRA. DIST. (CM)	DEEP ABSORBED DOSE, CX = 1.01 DELIV. (RAD)	REPORT. (RAD)	P=(H*-H)/H
34	2-20-79	54.54	3.820	208.34	100	210.	195.000	-0.0714
11	2-20-79	54.54	9.860	537.76	100	543.	550.000	0.0129
52	2-20-79	54.54	13.810	753.20	100	761.	600.000	-0.2116
2	2-20-79	54.54	12.910	704.11	100	711.	650.000	-0.0858
154	3-20-79	53.99	11.830	638.70	100	645.	620.000	-0.0388
182	3-20-79	53.99	10.400	561.50	100	567.	600.000	0.0582
170	3-20-79	53.99	1.950	105.28	100	106.	130.000	0.2264
304	4-18-79	53.43	3.570	190.75	100	193.	255.000	0.3212
342	4-18-79	53.43	6.150	328.59	100	332.	800.000	1.4096
322	4-18-79	53.43	8.450	451.48	100	456.	600.000	0.3158

P AVERAGE = 0.1937

S = 0.4629

H AVERAGE = 452.4

ABS(P AVERAGE) + 2S = 1.1195

L = 0.3000

********** FAIL ***********

CATEGORY I. GAMMA

INTERVAL 2, 30 - 100 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	EXPOS. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	IRR DIST. (CM)	DEEP DOSE EQUIVALENT, CX=1.01 DELIV. (MREM)	REPORT. (MREM)	P=(H°-H)/H
4	2-15-79	22.49	2.342	52.66	200	53.	70.	0.3208
33	2-15-79	22.49	4.208	94.65	200	96.	100.	0.0417
51	2-15-79	22.49	3.275	73.65	200	74.	90.	0.2162
163	3-26-79	22.18	3.577	79.33	200	80.	97.	0.2125
137	3-26-79	22.18	4.327	95.97	200	97.	122.	0.2577
194	3-26-79	22.18	1.500	33.27	200	34.	38.	0.1176
171	3-26-79	22.18	1.730	38.37	200	39.	45.	0.1538
305	4-20-79	21.98	3.893	85.58	200	86.	107.	0.2442
321	4-20-79	21.98	1.953	42.93	200	43.	60.	0.3953
340	4-20-79	21.98	3.760	82.64	200	83.	107.	0.2892

P AVERAGE = 0.2249

S = 0.1023

H AVERAGE = 68.5

ABS(P AVERAGE) + 2S = 0.4295

L = 0.7249

********** PASS ***********

CATEGORY I, GAMMA

INTERVAL 3, 101 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	EXPOS. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	IRRA. DIST. (CM)	DEEP DOSE DELIV. (MREM)	EQUIVALENT, CX=1.0 REPORT. (MREM)	P=(H°-H)/H
35	2-26-79	88.73	2.725	241.79	100	244.	290.	0.1885
3	2-26-79	88.73	1.657	147.00	100	148.	165.	0.1149
27	2-26-79	88.73	2.675	237.35	100	240.	270.	0.1250
172	3-22-79	87.97	1.922	169.05	100	171.	186.	0.0877
162	3-22-79	87.97	2.020	177.70	100	179.	200.	0.1173
138	3-22-79	87.97	1.722	151.45	100	153.	187.	0.2222
192	3-22-79	87.97	2.353	207.02	100	209.	240.	0.1483
308	4-18-79	87.11	2.470	215.16	100	217.	260.	0.1982
349	4-18-79	87.11	1.558	135.75	100	137.	135.	-0.0146
323	4-18-79	87.11	1.210	105.40	100	106.	135.	0.2736

P AVERAGE = 0.1461

S = 0.0803

H AVERAGE = 180.4

ABS(P AVERAGE) + 2S = 0.3067

L = 0.4467

********** PASS ************

CATEGORY I, GAMMA

INTERVAL 4, 301 - 10,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	EXPOS. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	IRRA. DIST. (CM)	DEEP DOSE EQUIVALENT, CX=1.01 DELIV. (MREM)	REPORT. (MREM)	P=(H°-H)/H
25	2-20-79	88.92	70.967	6310.35	100	6373.	7400.	0.1611
53	2-20-79	88.92	10.525	935.88	100	945.	1100.	0.1640
36	2-20-79	88.92	11.572	1028.95	100	1039.	1100.	0.0587
5	2-20-79	88.92	7.953	707.21	100	714.	760.	0.0644
195	3-27-79	87.81	57.100	5013.95	100	5064.	5100.	0.0071
141	3-27-79	87.81	9.997	877.81	100	887.	1000.	0.1274
174	3-27-79	87.81	7.892	692.97	100	700.	750.	0.0714
352	4- 8-79	87.43	54.350	4751.82	100	4799.	6300.	0.3128
334	4- 8-79	87.43	6.000	524.58	100	530.	600.	0.1321
306	4- 8-79	87.43	102.667	8976.14	100	9066.	10000.	0.1030

P AVERAGE = 0.1202

S = 0.0838

H AVERAGE = 3011.7

ABS(P AVERAGE) + 2S = 0.2878

L = 0.3000

********** PASS ************

CATEGORY II, HIGH-ENERGY X RAY

INTERVAL 1, 10 - 800 RAD

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

NBS TECHNIQUE : MFK

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (R/MIN)	IRRA. TIME (MIN)	EXPOSURE (R)	DEEP ABSORBED DOSE, CX = 1.33 DELIV. (RAD)	REPORT. (RAD)	P=(H*-H)/H
37	2-23-79	8.83	46.580	411.30	547.	675.000	0.2340
55	2-23-79	8.83	20.090	177.39	236.	385.000	0.6314
6	2-23-79	8.83	3.830	33.82	45.	27.000	-0.4000
26	2-23-79	8.83	50.410	445.12	592.	613.000	0.0355
166	3-26-79	10.83	48.100	520.92	693.	675.000	-0.0260
161	3-26-79	10.83	7.140	77.33	103.	79.000	-0.2330
193	3-26-79	10.83	52.330	566.73	754.	625.000	-0.1711
360	4-25-79	10.54	32.660	344.24	458.	750.000	0.6376
345	4-25-79	10.54	25.260	266.24	354.	610.000	0.7232
311	4-25-79	10.54	11.710	123.42	164.	355.000	1.1646

P AVERAGE = 0.2596

S = 0.5067

H AVERAGE = 394.6

ABS(P AVERAGE) + 2S = 1.2730

L = 0.3000

*********** FAIL **********

CATEGORY II, HIGH-ENERGY X RAY

INTERVAL 2, 30 - 100 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

NBS TECHNIQUE : HFK

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	SHALLOW DOSE EQUIV., CX=1.260 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
24	2-21-79	20.44	1.690	34.54	44.	60.	0.3636
38	2-21-79	20.44	2.225	45.48	57.	75.	0.3158
7	2-21-79	20.44	3.395	69.39	87.	116.	0.3333
191	3-23-79	20.46	3.190	65.27	82.	106.	0.2927
167	3-23-79	20.46	3.815	78.05	98.	120.	0.2245
160	3-23-79	20.46	1.810	37.03	47.	60.	0.2766
140	3-23-79	20.46	1.230	25.17	32.	50.	0.5625
303	4-25-79	21.30	2.440	51.97	65.	105.	0.6154
313	4-25-79	21.30	2.710	57.72	73.	107.	0.4658
351	4-25-79	21.30	3.100	66.03	83.	110.	0.3253

P AVERAGE = 0.3775

S = 0.1283

H AVERAGE = 66.8

ABS(P AVERAGE) + 2S = 0.6341

L = 1.8353

*********** PASS **********

CATEGORY II. HIGH-ENERGY X RAY

INTERVAL 2. 30 - 100 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

NBS TECHNIQUE : HFK

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DEEP DOSE EQUIVALENT, CX=1.260 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
24	2-21-79	20.44	1.690	34.54	44.	60.	0.3636
38	2-21-79	20.44	2.225	45.48	57.	75.	0.3158
7	2-21-79	20.44	3.395	69.39	87.	116.	0.3333
191	3-23-79	20.46	3.190	65.27	82.	106.	0.2927
167	3-23-79	20.46	3.815	78.05	98.	120.	0.2245
160	3-23-79	20.46	1.810	37.03	47.	60.	0.2766
140	3-23-79	20.46	1.230	25.17	32.	50.	0.5625
303	4-25-79	21.30	2.440	51.97	65.	105.	0.6154
313	4-25-79	21.30	2.710	57.72	73.	107.	0.4658
351	4-25-79	21.30	3.100	66.03	83.	110.	0.3253

P AVERAGE = 0.3775

S = 0.1283

H AVERAGE = 66.8

ABS(P AVERAGE) + 2S = 0.6341

L = 1.8353

*********** PASS **********

CATEGORY II, HIGH-ENERGY X RAY

INTERVAL 3, 101 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

NBS TECHNIQUE : HFG

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	SHALLOW DOSE EQUIV., CX=1.350 DELIV. (MREM)	REPORT. (MREM)	P=(H°-H)/H
39	2-20-79	62.55	1.870	116.97	158.	170.	0.0759
23	2-20-79	62.55	1.305	81.63	110.	121.	0.1000
56	2-20-79	62.55	2.950	184.52	249.	248.	-0.0040
190	3-21-79	65.60	3.040	199.42	269.	256.	-0.0483
168	3-21-79	65.60	1.520	99.71	135.	165.	0.2222
180	3-21-79	65.60	1.970	129.23	174.	197.	0.1322
142	3-21-79	65.60	2.310	151.54	205.	263.	0.2829
335	4-24-79	66.13	2.410	159.37	215.	225.	0.0465
316	4-24-79	66.13	3.280	216.91	293.	337.	0.1502
359	4-24-79	66.13	1.790	118.37	160.	170.	0.0625

P AVERAGE = 0.1020

S = 0.0998

H AVERAGE = 196.8

ABS(P AVERAGE) + 2S = 0.3015

L = 1.0692

*********** PASS **********

CATEGORY II, HIGH-ENERGY X RAY

INTERVAL 3. 101 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

NBS TECHNIQUE : HFG

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DEEP DOSE EQUIVALENT, CX=1.350 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
39	2-20-79	62.55	1.870	116.97	158.	170.	0.0759
23	2-20-79	62.55	1.305	81.63	110.	121.	0.1000
56	2-20-79	62.55	2.950	184.52	249.	248.	-0.0040
190	3-21-79	65.60	3.040	199.42	269.	256.	-0.0483
168	3-21-79	65.60	1.520	99.71	135.	165.	0.2222
180	3-21-79	65.60	1.970	129.23	174.	197.	0.1322
142	3-21-79	65.60	2.310	151.54	205.	263.	0.2829
335	4-24-79	66.13	2.410	159.37	215.	225.	0.0465
316	4-24-79	66.13	3.280	216.91	293.	337.	0.1502
359	4-24-79	66.13	1.790	118.37	160.	170.	0.0625

P AVERAGE = 0.1020

S = 0.0998

H AVERAGE = 196.8

ABS(P AVERAGE) + 2S = 0.3015

L = 1.0692

*********** PASS **********

CATEGORY II, HIGH-ENERGY X RAY

INTERVAL 4, 301 - 10,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

NBS TECHNIQUE : MFG

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	SHALLOW DOSE EQUIV., CX=1.280 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
22	2-14-79	877.20	5.085	4460.56	5710.	6400.	0.1208
40	2-13-79	105.20	3.110	327.17	419.	490.	0.1695
57	2-14-79	877.20	2.340	2052.65	2627.	3000.	0.1420
8	2-13-79	105.20	3.490	367.15	470.	524.	0.1149
159	3-21-79	860.30	6.300	5419.89	6937.	7425.	0.0703
143	3-21-79	860.30	5.930	5101.58	6530.	6900.	0.0567
175	3-19-79	102.90	5.685	584.99	749.	640.	-0.1455
317	4-24-79	896.30	3.690	3307.35	4233.	4095.	-0.0326
331	4-24-79	73.27	3.820	279.89	358.	400.	0.1173
356	4-24-79	73.27	6.670	488.71	626.	595.	-0.0495

P AVERAGE = 0.0564

S = 0.1008

H AVERAGE = 2865.9

ABS(P AVERAGE) + 2S = 0.2580

L = 0.5000

*********** PASS **********

CATEGORY II. HIGH-ENERGY X RAY

INTERVAL 4, 301 - 10,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

NBS TECHNIQUE : MFG

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DEEP DOSE EQUIVALENT, CX=1.230 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
22	2-14-79	877.20	5.085	4460.56	5486.	6150.	0.1210
40	2-13-79	105.20	3.110	327.17	402.	480.	0.1940
57	2-14-79	877.20	2.340	2052.65	2525.	2900.	0.1485
8	2-13-79	105.20	3.490	367.15	452.	504.	0.1150
159	3-21-79	860.30	6.300	5419.89	6666.	7135.	0.0704
143	3-21-79	860.30	5.930	5101.58	6275.	6550.	0.0438
175	3-19-79	102.90	5.685	584.99	720.	615.	-0.1458
317	4-24-79	896.30	3.690	3307.35	4068.	3936.	-0.0324
331	4-24-79	73.27	3.820	279.89	344.	384.	0.1163
356	4-24-79	73.27	6.670	488.71	601.	572.	-0.0483

P AVERAGE = 0.0583

S = 0.1047

H AVERAGE = 2753.9

ABS(P AVERAGE) + 2S = 0.2677

L = 0.5000

*********** PASS **********

CATEGORY III, LOW-ENERGY X RAY

INTERVAL 1, 150 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

NBS TECHNIQUE : L-G

IRRADIATION DISTANCE : 200 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	SHALLOW DOSE EQUIV., CX=0.810 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
41	2-26-79	114.50	1.890	216.41	175.	190.	0.0857
58	2-26-79	114.50	2.920	334.34	271.	348.	0.2841
9	2-26-79	114.50	2.260	258.77	210.	210.	0.0
21	2-26-79	114.50	1.780	203.81	165.	184.	0.1152
176	3-13-79	116.80	2.660	310.69	252.	284.	0.1270
189	3-13-79	116.80	2.770	323.54	262.	340.	0.2977
144	3-13-79	116.80	3.010	351.57	285.	315.	0.1053
353	4-28-79	116.00	2.510	291.16	236.	320.	0.3559
338	4-28-79	116.00	1.880	218.08	177.	205.	0.1582
325	4-28-79	116.00	1.930	223.88	181.	230.	0.2707

P AVERAGE = 0.1800

S = 0.1146

H AVERAGE = 221.4

ABS(P AVERAGE) + 2S = 0.4092

L = 1.0081

*********** PASS **********

CATEGORY III, LOW-ENERGY X RAY

INTERVAL 1, 150 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

NBS TECHNIQUE : L-G

IRRADIATION DISTANCE : 200 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DEEP DOSE EQUIVALENT, CX=0.250 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
41	2-26-79	114.50	1.890	216.41	54.	59.	0.0926
58	2-26-79	114.50	2.920	334.34	84.	108.	0.2857
9	2-26-79	114.50	2.260	258.77	65.	65.	0.0
21	2-26-79	114.50	1.780	203.81	51.	55.	0.0784
176	3-13-79	116.80	2.660	310.69	78.	88.	0.1282
189	3-13-79	116.80	2.770	323.54	81.	105.	0.2963
144	3-13-79	116.80	3.010	351.57	88.	97.	0.1023
353	4-28-79	116.00	2.510	291.16	73.	100.	0.3699
338	4-28-79	116.00	1.880	218.08	55.	65.	0.1818
325	4-28-79	116.00	1.930	223.88	56.	71.	0.2679

P AVERAGE = 0.1803

S = 0.1190

H AVERAGE = 68.5

ABS(P AVERAGE) + 2S = 0.4184

L = 1.8124

*********** PASS **********

CATEGORY III. LOW-ENERGY X RAY

INTERVAL 2. 301 - 10,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

NBS TECHNIQUE : L-G

IRRADIATION DISTANCE : 200 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	SHALLOW DOSE EQUIV., CX=0.810 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
42	2-26-79	286.40	18.150	5198.16	4211.	2835.	-0.3268
59	2-26-79	286.40	37.460	10728.54	8690.	7500.	-0.1369
28	2-26-79	286.40	2.980	853.47	691.	830.	0.2012
10	2-26-79	286.40	15.920	4559.48	3693.	2750.	-0.2553
177	3-14-79	288.60	1.660	479.08	388.	405.	0.0438
145	3-14-79	288.60	11.840	3417.03	2768.	2700.	-0.0246
157	3-14-79	288.60	1.880	542.57	439.	526.	0.1982
357	4-29-79	288.80	29.900	8635.12	6994.	6975.	-0.0027
336	4-29-79	288.80	3.610	1042.57	844.	1377.	0.6315
310	4-29-79	288.80	1.770	511.18	414.	508.	0.2271

P AVERAGE = 0.0555

S = 0.2774

H AVERAGE = 2913.2

ABS(P AVERAGE) + 2S = 0.6103

L = 0.5000

*********** FAIL **********

CATEGORY III, LOW-ENERGY X RAY

INTERVAL 2, 301 - 10,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

NBS TECHNIQUE : L-G

IRRADIATION DISTANCE : 200 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DEEP DOSE EQUIVALENT, CX=0.250 DELIV. (MREM)	REPORT. (MREM)	P=(H@-H)/H
42	2-26-79	286.40	18.150	5198.16	1300.	875.	-0.3269
59	2-26-79	286.40	37.460	10728.54	2682.	2300.	-0.1424
28	2-26-79	286.40	2.980	853.47	213.	220.	0.0329
10	2-26-79	286.40	15.920	4559.48	1140.	850.	-0.2544
177	3-14-79	288.60	1.660	479.08	120.	125.	0.0417
145	3-14-79	288.60	11.840	3417.03	854.	750.	-0.1218
157	3-14-79	288.60	1.880	542.57	136.	162.	0.1912
357	4-29-79	288.80	29.900	8635.12	2159.	2150.	-0.0042
336	4-29-79	288.80	3.610	1042.57	261.	425.	0.6284
310	4-29-79	288.80	1.770	511.18	128.	157.	0.2266

P AVERAGE = 0.0271

S = 0.2759

H AVERAGE = 899.3

ABS(P AVERAGE) + 2S = 0.5788

L = 0.5002

*********** FAIL **********

CATEGORY IV, BETA

INTERVAL 1, 150 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : STRONTIUM-90

IRRADIATION DISTANCE : 35 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MRAD/M)	IRRA. TIME (MIN)	DOSE (MREM)	SHALLOW DOSE EQUIV., CX=0.966 DELIV. (MREM)	REPORT. (MREM)	P=(H°-H)/H
43	2-18-79	152.30	1.860	283.28	274.	320.	0.1679
[illegible]	2-18-79	152.30	1.080	164.48	159.	207.	0.3019
12	2-18-79	152.30	1.580	240.63	233.	260.	0.1159
29	2-18-79	152.30	1.780	271.09	262.	300.	0.1450
156	3- 9-79	152.00	1.700	258.40	250.	275.	0.1000
188	3- 9-79	152.00	1.290	196.08	190.	213.	0.1211
149	3- 9-79	152.00	1.320	200.64	194.	208.	0.0722
502	5-10-79	151.30	1.670	252.67	244.	275.	0.1270
503	5-10-79	151.30	1.220	184.59	178.	215.	0.2079
504	5-10-79	151.30	1.900	287.47	278.	310.	0.1151

P AVERAGE = 0.1474

S = 0.0658

H AVERAGE = 226.2

ABS(P AVERAGE) + 2S = 0.2790

L = 0.9973

*********** PASS **********

CATEGORY IV, BETA

INTERVAL 2, 301 - 10,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : STRONTIUM-90

IRRADIATION DISTANCE : 35 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MRAD/M)	IRRA. TIME (MIN)	DOSE (MREM)	SHALLOW DOSE EQUIV., CX=0.966 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
44	2- 6-79	152.30	46.800	7127.64	6889.	6700.	-0.0274
13	2- 6-79	152.30	4.890	744.75	720.	850.	0.1806
30	2- 6-79	152.30	12.190	1856.54	1794.	2575.	0.4353
183	3-21-79	152.00	3.710	563.92	545.	680.	0.2477
152	3-21-79	152.00	17.660	2684.32	2594.	2960.	0.1411
169	3-21-79	152.00	6.740	1024.48	990.	875.	-0.1162
139	3-21-79	152.00	9.220	1401.44	1354.	1600.	0.1817
354	4-23-79	151.60	3.540	536.66	519.	740.	0.4258
314	4-23-79	151.60	53.600	8125.76	7854.	8536.	0.0868
327	4-23-79	151.60	5.690	862.60	834.	975.	0.1691

P AVERAGE = 0.1725

S = 0.1734

H AVERAGE = 2409.3

ABS(P AVERAGE) + 2S = 0.5193

L = 0.5000

*********** FAIL **********

CATEGORY V, NEUTRON

INTERVAL 1, 100 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : CALIFORNIUM-252

IRRADIATION DISTANCE : SHOWN BELOW

NOTE : DELIVERED DOSE EQUIVALENT INCLUDES THE
ROOM RETURN (SCATTER) CORRECTION FACTOR
SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	DOSE EQ. RATE (MREM/MIN)	IRRA. TIME (MIN)	IRRA. DIST. (CM)	SCATTER C.F.	DEEP DOSE EQUIVALENT DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
75	2-21-79	78.45	1.336	50	1.015	106.	150.	0.4151
64	2-21-79	78.45	2.543	50	1.015	202.	275.	0.3614
72	2-21-79	78.45	3.733	50	1.015	297.	358.	0.2054
52	2-21-79	78.45	2.383	50	1.015	190.	235.	0.2368
208	3-13-79	77.33	2.335	50	1.015	183.	142.	-0 [illegible]240
199	3-13-79	77.33	3.600	50	1.015	283.	380.	0.3428
205	3-13-79	77.33	3.446	50	1.015	270.	290.	0.0741
374	4-26-79	74.93	2.223	50	1.015	169.	436.	1.5799
368	4-26-79	74.93	1.530	50	1.015	116.	310.	1.6724
363	4-26-79	74.93	2.339	50	1.015	178.	356.	1.0000

P AVERAGE = 0.5664

S = 0.6377

H AVERAGE = 199.4

ABS(P AVERAGE) + 2S = 1.8417

L = 1.0623

********** FAIL ************

CATEGORY V, NEUTRON

INTERVAL 2, 301 - 5,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : CALIFORNIUM-252

IRRADIATION DISTANCE : SHOWN BELOW

NOTE : DELIVERED DOSE EQUIVALENT INCLUDES THE ROOM RETURN (SCATTER) CORRECTION FACTOR SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	DOSE EQ. RATE (MREM/MIN)	IRRA. TIME (MIN)	IRRA. DIST. (CM)	SCATTER C.F.	DEEP DOSE EQUIVALENT DELIV. (MREM)	DEEP DOSE EQUIVALENT REPORT. (MREM)	P=(H*-H)/H
70	2-25-79	78.22	49.660	50	1.015	3943.	5050.	0.2808
63	2-25-79	78.22	4.443	50	1.015	353.	510.	0.4448
65	2-25-79	78.22	23.550	50	1.015	1870.	2215.	0.1845
74	2-25-79	78.22	11.690	50	1.015	928.	1240.	0.3362
207	3-15-79	77.22	57.500	50	1.015	4507.	5020.	0.1138
198	3-15-79	77.22	10.320	50	1.015	809.	1000.	0.2361
203	3-15-79	77.22	39.500	50	1.015	3096.	3480.	0.1240
365	4-18-79	75.36	11.400	50	1.015	872.	1065.	0.2213
369	4-18-79	75.36	32.000	50	1.015	2448.	3180.	0.2990
373	4-18-79	75.36	6.636	50	1.015	508.	590.	0.1614

P AVERAGE = 0.2402

S = 0.1029

H AVERAGE = 1933.4

ABS(P AVERAGE) + 2S = 0.4460

L = 0.5000

*********** PASS ************

CATEGORY VI. GAMMA COMPONENT
OF GAMMA PLUS HIGH-ENERGY X RAY

INTERVAL 1. 50 - 100 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : 200 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DELIVERED DOSE EQUIVALENT SHALLOW CX=1.01 (MREM)	DEEP CX=1.01 (MREM)
45	2-13-79	22.51	2.822	63.52	64.	64.
14	2-13-79	22.51	1.053	23.71	24.	24.
19	2-13-79	22.51	2.073	46.67	47.	47.
173	3-14-79	22.27	0.642	14.29	14.	14.
151	3-14-79	22.27	2.308	51.41	52.	52.
187	3-14-79	22.27	0.760	16.93	17.	17.
158	3-14-79	22.27	3.560	79.28	80.	80.
350	4- 1-79	22.13	0.927	20.51	21.	21.
332	4- 1-79	22.13	1.745	38.62	39.	39.
302	4- 1-79	22.13	0.663	14.68	15.	15.

CATEGORY VI. X RAY COMPONENT
OF GAMMA PLUS HIGH-ENERGY X RAY

INTERVAL 1. 50 - 100 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

NBS TECHNIQUE : HFK

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DELIVERED DOSE EQUIVALENT SHALLOW CX=1.26 (MREM)	DEEP CX=1.26 (MREM)
45	2-21-79	20.44	0.980	20.03	25.	25.
14	2-21-79	20.44	2.620	53.55	67.	67.
19	2-21-79	20.44	0.730	14.92	19.	19.
173	3-23-79	20.46	1.540	31.51	40.	40.
151	3-23-79	20.46	0.780	15.96	20.	20.
187	3-23-79	20.46	0.810	16.57	21.	21.
158	3-23-79	20.46	1.040	21.28	27.	27.
350	4-25-79	21.30	2.110	44.94	57.	57.
332	4-25-79	21.30	0.670	14.27	18.	18.
302	4-25-79	21.30	1.670	35.57	45.	45.

INTERVAL 1, 50 - 100 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

DOSIMETER NUMBER	TOTAL SHALLOW DOSE EQUIVALENT DELIVERED (MREM)	REPORTED (MREM)	P=(H*-H)/H	TOTAL DEEP DOSE EQUIVALENT DELIVERED (MREM)	REPORTED (MREM)	P=(H*-H)/H
45	89.	125.	0.4045	89.	125.	0.4045
14	91.	110.	0.2088	91.	110.	0.2088
19	66.	90.	0.3636	66.	90.	0.3636
173	54.	65.	0.2037	54.	65.	0.2037
151	72.	98.	0.3611	72.	98.	0.3611
187	38.	38.	0.0	38.	38.	0.0
158	107.	130.	0.2150	107.	130.	0.2150
350	78.	45.	-0.4231	78.	45.	-0.4231
332	57.	115.	1.0175	57.	115.	1.0175
302	60.	80.	0.3333	60.	80.	0.3333

	Shallow		Deep
P AVERAGE =	0.2684	P AVERAGE =	0.2684
S =	0.3594	S =	0.3594
H AVERAGE =	71.2	H AVERAGE =	71.2
ABS(P AVERAGE) + 2S =	0.9872	ABS(P AVERAGE) + 2S =	0.9872
L =	1.7777	L =	1.7777

********** PASS ***********   ********** PASS ***********

CATEGORY VI, GAMMA COMPONENT
OF GAMMA PLUS HIGH-ENERGY X RAY

INTERVAL 2, 101 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DELIVERED DOSE EQUIVALENT SHALLOW CX=1.01 (MREM)	DEEP CX=1.01 (MREM)
54	2-13-79	22.51	2.607	58.68	59.	59.
15	2-13-79	22.51	5.307	119.45	121.	121.
46	2-13-79	22.51	7.027	158.17	160.	160.
178	3-14-79	22.27	4.690	104.45	105.	105.
186	3-14-79	22.27	3.395	75.61	76.	76.
147	3-14-79	22.27	3.490	77.72	78.	78.
153	3-14-79	22.27	4.817	107.27	108.	108.
315	4- 1-79	22.13	2.260	50.01	51.	51.
324	4- 1-79	22.13	4.028	89.15	90.	90.
346	4- 1-79	22.13	2.522	55.80	56.	56.

CATEGORY VI. X RAY COMPONENT
OF GAMMA PLUS HIGH-ENERGY X RAY

INTERVAL 2, 101 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

NBS TECHNIQUE : HFG

IRRADIATION DISTANCE : 100 CM

					DELIVERED DOSE EQUIVALENT	
DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	SHALLOW CX=1.35 (MREM)	DEEP CX=1.35 (MREM)
54	2-20-79	62.55	1.780	111.34	150.	150.
15	2-20-79	62.55	0.950	59.42	80.	80.
46	2-20-79	62.55	1.185	74.12	100.	100.
178	3-21-79	65.60	0.480	31.49	43.	43.
186	3-21-79	65.60	2.210	144.98	196.	196.
147	3-21-79	65.60	0.420	27.55	37.	37.
153	3-21-79	65.60	0.480	31.49	43.	43.
315	4-24-79	66.13	1.400	92.58	125.	125.
324	4-24-79	66.13	0.410	27.11	37.	37.
346	4-24-79	66.13	1.590	105.15	142.	142.

CATEGORY VI. TOTAL OF GAMMA PLUS X RAY

INTERVAL 2, 101 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

DOSIMETER NUMBER	TOTAL SHALLOW DOSE EQUIVALENT DELIVERED (MREM)	REPORTED (MREM)	P=(H*-H)/H	TOTAL DEEP DOSE EQUIVALENT DELIVERED (MREM)	REPORTED (MREM)	P=(H*-H)/H
54	209.	194.	-0.0718	209.	194.	-0.0718
15	201.	153.	-0.2388	201.	153.	-0.2388
46	260.	162.	-0.3769	260.	162.	-0.3769
178	148.	81.	-0.4527	148.	81.	-0.4527
186	272.	529.	0.9449	272.	529.	0.9449
147	115.	170.	0.4783	115.	170.	0.4783
153	151.	235.	0.5563	151.	235.	0.5563
315	176.	185.	0.0511	176.	185.	0.0511
324	127.	81.	-0.3622	127.	81.	-0.3622
346	198.	195.	-0.0152	198.	195.	-0.0152

	Shallow		Deep
P AVERAGE =	0.0513	P AVERAGE =	0.0513
S =	0.4652	S =	0.4652
H AVERAGE =	185.7	H AVERAGE =	185.7
ABS(P AVERAGE) + 2S =	0.9817	ABS(P AVERAGE) + 2S =	0.9817
L =	1.1007	L =	1.1007

*********** PASS *********** ********** PASS ***********

CATEGORY VI, GAMMA COMPONENT
OF GAMMA PLUS HIGH-ENERGY X RAY

INTERVAL 3, 301 - 10,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DELIVERED DOSE EQUIVALENT SHALLOW CX=1.01 (MREM)	DEEP CX=1.01 (MREM)
50	2- 6-79	89.37	1.625	145.23	147.	147.
16	2- 6-79	89.37	56.450	5044.93	5095.	5095.
18	2- 6-79	89.37	1.545	138.08	139.	139.
32	2- 6-79	89.37	52.450	4687.45	4734.	4734.
155	3-13-79	88.25	4.220	372.41	376.	376.
179	3-13-79	88.25	6.040	533.03	538.	538.
148	3-13-79	88.25	2.977	262.69	265.	265.
10 VOID	4- 2-79	87.65	19.650	1722.32	1740.	1740.
49 VOID	4- 2-79	87.65	1.232	107.96	109.	109.
24 VOID	4- 1-79	87.68	46.183	4049.35	4090.	4090.

CATEGORY VI, X RAY COMPONENT
OF GAMMA PLUS HIGH-ENERGY X RAY

INTERVAL 3, 301 - 10,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

NBS TECHNIQUE : MFG

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DELIVERED DOSE EQUIVALENT SHALLOW CX=1.28 (MREM)	DEEP CX=1.23 (MREM)
50	2-13-79	105.20	2.695	283.51	363.	349.
16	2-14-79	877.20	1.785	1565.80	2004.	1926.
18	2-13-79	105.20	2.420	254.58	326.	313.
32	2-14-79	877.20	1.550	1359.66	1740.	1672.
155	3-19-79	102.90	1.130	116.28	149.	143.
179	3-21-79	860.30	1.230	1058.17	1354.	1302.
148	3-19-79	102.90	5.015	516.04	661.	635.
10 VOID	4-24-79	896.30	3.820	3423.87	4383.	4211.
49 VOID	4-24-79	73.27	2.780	203.69	261.	251.
24 VOID	4-24-79	896.30	1.405	1259.30	1612.	1549.

INTERVAL 3, 301 - 10,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

DOSIMETER NUMBER	TOTAL SHALLOW DOSE EQUIVALENT DELIVERED (MREM)	REPORTED (MREM)	P=(H*-H)/H	TOTAL DEEP DOSE EQUIVALENT DELIVERED (MREM)	REPORTED (MREM)	P=(H*-H)/H
50	510.	500.	-0.0196	496.	485.	-0.0222
16	7099.	8000.	0.1269	7021.	7900.	0.1252
18	465.	371.	-0.2022	452.	357.	-0.2102
32	6474.	7140.	0.1029	6406.	7100.	0.1083
155	525.	418.	-0.2038	519.	418.	-0.1946
179	1892.	1472.	-0.2220	1840.	1415.	-0.2310
148	926.	705.	-0.2387	900.	675.	-0.2500
10 VOID	6123.	0.	-1.0000	5951.	0.	-1.0000
49 VOID	370.	0.	-1.0000	360.	0.	-1.0000
24 VOID	5702.	0.	-1.0000	5639.	0.	-1.0000

	Shallow		Deep
P AVERAGE =	-0.0938	P AVERAGE =	-0.0963
S =	0.1603	S =	0.1637
H AVERAGE =	2555.9	H AVERAGE =	2519.1
ABS(P AVERAGE) + 2S =	0.4144	ABS(P AVERAGE) + 2S =	0.4238
L =	0.5000	L =	0.5000

********** PASS ********** ********** PASS **********

CATEGORY VII, GAMMA COMPONENT
OF BETA PLUS GAMMA

INTERVAL 1, 200 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DELIVERED DOSE EQUIVALENT SHALLOW CX=1.01 (MREM)	DELIVERED DOSE EQUIVALENT DEEP CX=1.01 (MREM)
31	2- 6-79	89.37	0.813	72.61	73.	73.
17	2- 6-79	89.37	1.920	171.59	173.	173.
48	2- 6-79	89.37	0.692	61.81	62.	62.
181	3-10-79	88.35	2.257	199.38	201.	201.
150	3-10-79	88.35	0.828	73.18	74.	74.
165	3-10-79	88.35	2.155	190.39	192.	192.
146	3-10-79	88.35	2.030	179.35	181.	181.
347	4- 1-79	87.65	0.703	61.65	62.	62.
309	4- 1-79	87.65	0.822	72.02	73.	73.
320	4- 1-79	87.65	2.110	184.94	187.	187.

CATEGORY VII, BETA COMPONENT
OF BETA PLUS GAMMA

INTERVAL 1, 200 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : STRONTIUM-90

IRRADIATION DISTANCE : 35 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MRAD/MIN)	IRRA. TIME (MIN)	ABS. DOSE (MRAD)	DELIVERED DOSE EQUIVALENT SHALLOW CX=.9665 (MREM)	DEEP CX=0.00 (MREM)
31	2-26-79	152.30	1.180	179.71	174.	0.
17	2-26-79	152.30	0.420	63.97	62.	0.
48	2-26-79	152.30	1.010	153.82	149.	0.
181	3-13-79	152.00	0.530	80.56	78.	0.
150	3-13-79	152.00	1.200	182.40	176.	0.
165	3-13-79	152.00	0.510	77.52	75.	0.
146	3-13-79	152.00	0.470	71.44	69.	0.
347	4-16-79	151.60	1.030	156.15	151.	0.
309	4-16-79	151.60	1.120	169.79	164.	0.
320	4-16-79	151.60	0.490	74.28	72.	0.

INTERVAL 1, 200 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

DOSIMETER NUMBER	TOTAL SHALLOW DOSE EQUIVALENT DELIVERED (MREM)	REPORTED (MREM)	P=(H*-H)/H	TOTAL DEEP DOSE EQUIVALENT DELIVERED (MREM)	REPORTED (MREM)	P=(H*-H)/H
31	247.	282.	0.1417	73.	92.	0.2603
17	235.	240.	0.0213	173.	240.	0.3873
48	211.	241.	0.1422	62.	84.	0.3548
181	279.	310.	0.1111	201.	210.	0.0448
150	250.	263.	0.0520	74.	70.	-0.0541
165	267.	372.	0.3933	192.	197.	0.0260
146	250.	350.	0.4000	181.	230.	0.2707
347	213.	250.	0.1737	62.	80.	0.2903
309	237.	275.	0.1603	73.	95.	0.3014
320	259.	365.	0.4093	187.	190.	0.0160

	Shallow		Deep
P AVERAGE =	0.2005	P AVERAGE =	0.1898
S =	0.1460	S =	0.1626
H AVERAGE =	244.8	H AVERAGE =	127.8
ABS(P AVERAGE) + 2S =	0.4925	ABS(P AVERAGE) + 2S =	0.5149
L =	0.9587	L =	1.3269

********** PASS ********** ********** PASS **********

CATEGORY VII, GAMMA COMPONENT OF BETA PLUS GAMMA

INTERVAL 2, 301 - 10,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DELIVERED DOSE EQUIVALENT SHALLOW CX=1.01 (MREM)	DELIVERED DOSE EQUIVALENT DEEP CX=1.01 (MREM)
47	2- 6-79	89.37	17.267	1543.12	1559.	1559.
20	2- 6-79	89.37	1.658	148.21	150.	150.
49	2- 6-79	89.37	15.588	1393.13	1407.	1407.
185	3-13-79	88.25	3.137	276.81	280.	280.
184	3-13-79	88.25	18.800	1659.10	1676.	1676.
164	3-13-79	88.25	6.770	597.45	603.	603.
344	4- 1-79	87.65	16.555	1451.04	1466.	1466.
358	4- 1-79	87.65	1.673	146.67	148.	148.
312	4- 1-79	87.65	11.177	979.63	989.	989.
333	4- 1-79	87.65	2.838	248.78	251.	251.

CATEGORY VII, BETA COMPONENT OF BETA PLUS GAMMA

INTERVAL 2, 301 - 10,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : STRONTIUM-90

IRRADIATION DISTANCE : 35 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MRAD/MIN)	IRRA. TIME (MIN)	ABS. DOSE (MRAD)	DELIVERED DOSE EQUIVALENT SHALLOW CX=.9665 (MREM)	DEEP CX=0.00 (MREM)
47	2-24-79	152.30	25.530	3888.22	3758.	0.
20	2-24-79	152.30	2.440	371.61	359.	0.
49	2-24-79	152.30	3.630	552.85	534.	0.
185	3-14-79	152.00	0.750	114.00	110.	0.
184	3-14-79	152.00	27.770	4221.04	4080.	0.
164	3-14-79	152.00	1.580	240.16	232.	0.
344	4- 2-79	151.60	3.880	588.21	569.	0.
358	4- 2-79	151.60	2.510	380.52	368.	0.
312	4- 2-79	151.60	16.660	2525.66	2441.	0.
333	4- 2-79	151.60	0.680	103.09	100.	0.

INTERVAL 2. 301 - 10,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

DOSIMETER NUMBER	TOTAL SHALLOW DOSE EQUIVALENT DELIVERED (MREM)	REPORTED (MREM)	P=(H*-H)/H	TOTAL DEEP DOSE EQUIVALENT DELIVERED (MREM)	REPORTED (MREM)	P=(H*-H)/H
47	5317.	3270.	-0.3850	1559.	2220.	0.4240
20	509.	530.	0.0413	150.	258.	0.7200
49	1941.	1900.	-0.0211	1407.	1700.	0.2082
185	390.	428.	0.0974	280.	318.	0.1357
184	5756.	3350.	-0.4180	1676.	2000.	0.1933
164	835.	680.	-0.1856	603.	680.	0.1277
344	2035.	1980.	-0.0270	1466.	1700.	0.1596
358	516.	595.	0.1531	148.	165.	0.1149
312	3430.	2300.	-0.3294	989.	1300.	0.3145
333	351.	415.	0.1823	251.	295.	0.1753

	Shallow		Deep
P AVERAGE =	-0.0892	P AVERAGE =	0.2573
S =	0.2249	S =	0.1885
H AVERAGE =	2108.0	H AVERAGE =	852.9
ABS(P AVERAGE) + 2S =	0.5391	ABS(P AVERAGE) + 2S =	0.6343
L =	0.5000	L =	0.5136

********** FAIL *********** ********** FAIL ***********

CATEGORY VIII. GAMMA COMPONENT
OF NEUTRON PLUS GAMMA

INTERVAL 1. 150 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : 100 CM

NOTE : DELIVERED DOSE EQUIVALENT INCLUDES A GAMMA-RAY CONTRIBUTION FROM THE CF-252 SOURCE EQUAL TO 7.033 PERCENT OF THE NEUTRON DOSE EQUIVALENT

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DELIVERED DOSE EQUIVALENT SHALLOW CX=1.01 (MREM)	DELIVERED DOSE EQUIVALENT DEEP CX=1.01 (MREM)
66	2- 6-79	89.37	0.708	63.30	75.	75.
68 VOID	2- 6-79	89.37	1.370	122.44	124.	124.
71	2- 6-79	89.37	0.922	82.37	98.	98.
209	3-10-79	88.35	1.887	166.69	173.	173.
204	3-10-79	88.35	0.718	63.46	75.	75.
197	3-10-79	88.35	1.332	117.65	122.	122.
201	3-10-79	88.35	0.882	77.90	92.	92.
375	4-10-79	87.37	1.577	137.75	143.	143.
371	4-10-79	87.37	0.612	53.44	64.	64.
362	4-10-79	87.37	1.985	173.43	180.	180.

CATEGORY VIII, NEUTRON COMPONENT
OF NEUTRON PLUS GAMMA

INTERVAL 1, 150 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : CALIFORNIUM-252

IRRADIATION DISTANCE : SHOWN BELOW

NOTE : DELIVERED DOSE EQUIVALENT INCLUDES THE ROOM RETURN (SCATTER) CORRECTION FACTOR SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	DOSE EQ. RATE (MREM/MIN)	IRRA. TIME (MIN)	IRRA. DIST. (CM)	SCATTER C.F.	DELIVERED DOSE EQUIVALENT SHALLOW (MREM)	DEEP (MREM)
66	2-23-79	78.34	2.000	50	1.015	159.	159.
68 VOID	0- 0- 0	0.0	0.0	0	1.015	0.	0.
71	2-25-79	78.22	2.613	50	1.015	207.	207.
209	3-22-79	19.25	3.482	100	1.060	71.	71.
204	3-22-79	76.83	2.070	50	1.015	161.	161.
197	3-22-79	19.25	2.443	100	1.060	50.	50.
201	3-22-79	76.83	2.536	50	1.015	198.	198.
375	4-26-79	18.73	2.930	100	1.060	58.	58.
371	4-26-79	74.93	1.810	50	1.015	138.	138.
362	4-26-79	18.73	3.739	100	1.060	74.	74.

INTERVAL 1, 150 - 300 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

DOSIMETER NUMBER	TOTAL DEEP DOSE EQUIVALENT DELIVERED (MREM)	REPORTED (MREM)	P=(H*-H)/H
66	234.	300.	0.2821
68 VOID	124.	0.	-1.0000
71	305.	349.	0.1443
209	244.	255.	0.0451
204	236.	344.	0.4576
197	172.	225.	0.3081
201	290.	385.	0.3276
375	201.	210.	0.0448
371	202.	284.	0.4059
362	254.	263.	0.0354

P AVERAGE = 0.2279

S = 0.1639

H AVERAGE = 237.6

ABS(P AVERAGE) + 2S = 0.5556

L = 0.9732

*********** PASS **********

CATEGORY VIII, GAMMA COMPONENT
OF NEUTRON PLUS GAMMA

INTERVAL 2. 301 - 5,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : 100 CM

NOTE : DELIVERED DOSE EQUIVALENT INCLUDES A GAMMA-RAY CONTRIBUTION FROM THE CF-252 SOURCE EQUAL TO 7.033 PERCENT OF THE NEUTRON DOSE EQUIVALENT

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DELIVERED DOSE EQUIVALENT SHALLOW CX=1.01 (MREM)	DELIVERED DOSE EQUIVALENT DEEP CX=1.01 (MREM)
67	2- 8-79	89.31	15.092	1347.84	1589.	1589.
73	2- 8-79	89.31	2.512	224.32	266.	266.
69	2- 8-79	89.31	27.550	2460.49	2554.	2554.
200	3-12-79	88.28	7.138	630.17	654.	654.
202	3-12-79	88.28	12.955	1143.67	1360.	1360.
206	3-12-79	88.28	1.102	97.26	114.	114.
210	3-12-79	88.28	12.325	1088.05	1294.	1294.
364	4- 9-79	87.40	3.403	297.45	309.	309.
372	4- 9-79	87.40	13.173	1151.35	1213.	1213.
367	4- 9-79	87.40	2.707	236.56	284.	284.

CATEGORY VIII, NEUTRON COMPONENT
OF NEUTRON PLUS GAMMA

INTERVAL 2, 301 - 5,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

SOURCE : CALIFORNIUM-252

IRRADIATION DISTANCE : SHOWN BELOW

NOTE : DELIVERED DOSE EQUIVALENT INCLUDES THE
ROOM RETURN (SCATTER) CORRECTION FACTOR
SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	DOSE EQ. RATE (MREM/MIN)	IRRA. TIME (MIN)	IRRA. DIST. (CM)	SCATTER C.F.	DELIVERED DOSE EQUIVALENT SHALLOW (MREM)	DEEP (MREM)
67	2-24-79	76.28	41.380	50	1.015	3288.	3288.
73	2-24-79	78.28	7.150	50	1.015	568.	568.
69	2-24-79	78.28	12.550	50	1.015	997.	997.
200	3-27-79	76.56	3.320	50	1.015	258.	258.
202	3-27-79	76.56	37.980	50	1.015	2951.	2951.
206	3-27-79	76.56	2.910	50	1.015	226.	226.
210	3-27-79	76.56	36.150	50	1.015	2809.	2809.
364	4-19-79	75.36	1.601	50	1.015	122.	122.
372	4-19-79	75.36	9.485	50	1.015	726.	726.
367	4-19-79	75.36	8.485	50	1.015	649.	649.

INTERVAL 2, 301 - 5,000 MREM

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

DOSIMETER NUMBER	TOTAL DEEP DOSE EQUIVALENT DELIVERED (MREM)	REPORTED (MREM)	P=(H*-H)/H
67	4877.	3186.	-0.3467
73	834.	970.	0.1631
69	3551.	4210.	0.1856
200	912.	990.	0.0855
202	4311.	4465.	0.0357
206	340.	475.	0.3971
210	4103.	4460.	0.0870
364	431.	469.	0.0882
372	1939.	2180.	0.1243
367	933.	1035.	0.1093

P AVERAGE = 0.0929

S = 0.1838

H AVERAGE = 2223.1

ABS(P AVERAGE) + 2S = 0.4604

L = 0.5000

*********** PASS **********

********** SUMMARY OF RESULTS **********

PROCESSOR NAME :

PROCESSOR CODE NO. :

TYPE OF DOSIMETER : FILM

CATEGORY I.	GAMMA	: FAIL
CATEGORY II.	HIGH-ENERGY X RAY	: FAIL
CATEGORY III.	LOW-ENERGY X RAY	: FAIL
CATEGORY IV.	BETA	: FAIL
CATEGORY V.	NEUTRON	: FAIL
CATEGORY VI.	GAMMA PLUS HIGH-ENERGY X RAY	: PASS
CATEGORY VII.	GAMMA PLUS BETA	: FAIL
CATEGORY VIII.	GAMMA PLUS NEUTRON	: PASS

Appendix D

Proposed Standard: Draft American National Standard Criteria for Testing Personnel Dosimetry Performance, July, 1978.

Draft American National Standard Criteria for Testing Personnel Dosimetry Performance

TRIAL USE AND COMMENT

Publication of this draft standard for trial use and comment has been approved by the Health Physics Society Standards Committee. The trial use period shall not continue beyond 12 months from the date of publication. It is expected that following this 12-month period, the draft, revised as necessary, will be submitted to the American National Standards Institute for approval as an American National Standard. Suggestions for revision should be directed to Edward J. Vallario, Chairman, Health Physics Society Standards Committee, U.S. Department of Energy, Division of Operational and Environmental Safety, Mail Station E201, Washington, D.C. 20545.

Secretariat: Health Physics Society

Published July 1978

american national standards institute, inc
1430 broadway, new york, new york 10018

American National Standard

An American National Standard implies a consensus of those substantially concerned with its scope and provisions. An American National Standard is intended as a guide to aid the manufacturer, the consumer, and the general public. The existence of an American National Standard does not in any respect preclude anyone, whether he has approved the standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the standard. American National Standards are subject to periodic review and users are cautioned to obtain the latest editions.

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Foreword

(This Foreword is not a part of Draft American National Standard Criteria for Testing Personnel Dosimetry Performance, N13.11.)

This Draft American National Standard provides a procedure for testing the performance of the suppliers of dosimetry services for personnel potentially exposed to ionizing radiation. The initial thrust for work on this draft standard came from the Conference of Radiation Control Program Directors, which, in 1973, constituted a task force with state and federal participation, for the purpose of implementing the Conference's recommendation to establish a continuing testing program of personnel-dosimetry performance throughout the United States, under the supervision of an impartial federal agency, such as the National Bureau of Standards. Subsequently, after studying the feasibility of using existing testing standards as the basis for this proposed testing service, the task force decided that a new standard was required and approached the Health Physics Society Standards Committee, which, in August 1976, assigned the task of writing such a document to a work group constituted for this purpose. The present draft standard, formerly known as N716, was developed in cooperation with such groups as users, commercial and in-house suppliers of personnel-dosimetry services, and regulatory agencies. Furthermore, comments received as a result of a public meeting of all interested parties were taken into account.

The testing criteria specified in this draft standard are based in part on acceptable limits of inaccuracy recommended by the National Council on Radiation Protection and Measurements and the International Commission on Radiation Units and Measurements, and in part on the results of a baseline study carried out in 1974 by Battelle-Northwest. This baseline study was designed to establish the accuracy limitations imposed by the current state of the art of personnel dosimetry.

This draft standard is published for the limited period of one year, for the purpose of encouraging trial use and comments. Comments should be sent to:

Edward J. Vallario, Chairman
Health Physics Society Standards Committee
U.S. Department of Energy
Division of Operational and Environmental Safety
Mail Station E201
Washington, D.C. 20545

This draft standard was prepared under the direction of the Health Physics Society Standards Committee, which had the following members:

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Vernon T. Chilson
Eric L. Geiger
Richard V. Griffith
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The Working Group responsible for the development of this draft standard had the following members:

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(Bureau of Radiological Health, FDA)
Phillip Plato
(University of Michigan School of Public Health)
Bernard Weiss
(Nuclear Regulatory Commission)

The Committee is grateful to the Literary Executor of the late Sir Ronald A. Fisher, F.R.S., to Dr Frank Yates, F.R.S., and to Longman Group Ltd, London, for permission to reprint Table III from their book *Statistical Tables for Biological, Agricultural and Medical Research* (6th ed. 1974).

Contents

Draft American National Standard Criteria for Testing Personnel Dosimetry Performance

1. Purpose and Scope

1.1 Purpose. The purpose of this standard is to provide a procedure for testing routine personnel dosimetry performance under controlled conditions of dosimeter irradiation with photons, electrons (beta particles), fast neutrons, and mixtures thereof, originating from external sources.

1.2 Scope. Specifications are given for:

(1) Minimum number of dosimeters required for testing, and test schedule

(2) Radiation categories and ranges of irradiation levels

(3) Types of radiation sources and irradiation geometry

(4) Performance criteria to be applied to the test results

The choice of ranges of irradiation levels and the choice of the performance criteria are based on considerations of radiation protection, as expressed in current NCRP, ICRP, and ICRU publications [1-4],[1] and modified where necessary to accommodate the limitations of practical instrumentation. Covered are tests of personnel dosimetry performance with any type of dosimeter whose reading is used to provide a personal irradiation record of an individual. It does not cover tests of dosimetry performance in the intermediate and thermal neutron ranges. No consideration is given to administrative aspects of performance, such as adequacy of dosimeter identification, and promptness or format of reports. (See Appendix A.)

2. Definitions

NOTE: In this standard, the definitions given in 2.1 through 2.15 shall apply.

2.1 Absorbed Dose (D). The energy absorbed per unit mass at a specific place in a material. The special unit of absorbed dose is the rad, equal to 10 millijoules per kilogram (100 ergs per gram). 1 rad = 0.01 Gray. As used in this standard, "absorbed dose" stands for the absorbed dose in the material of interest, that is, in soft tissue or in a phantom approximating soft tissue in composition.

2.2 Dose Equivalent (H). The product of D, Q, and N, at the point of interest in tissue, where D is the absorbed dose, Q is the quality factor, and N is the product of any other modifying factors. The special unit of dose equivalent is the rem. When D is expressed in rads, H is in rems.

2.3 Absorbed Dose Index (D_I) or Dose Equivalent Index (H_I) at a Point. Maximum absorbed dose or dose equivalent within a 30-cm diameter sphere centered at this point and consisting of material equivalent to soft tissue with a density of 1 gram cm^{-3}.

NOTE: In the case of radiation of low penetrating power, it is recommended to divide the sphere into two shells (from the surface to a depth of 0.007 cm and from 0.007 cm to 1 cm) and a core (from a depth of 1 cm to the center), and to determine the so-called "restricted" index quantities, called the "shallow" and the "deep" absorbed dose or dose equivalent indices (see also definition 2.4). For the sake of simplicity, the terms "restricted absorbed dose index" and "restricted dose equivalent index" will not be employed in this standard.

2.4 Protection Dosimetry. Routine estimation of the maximum dose equivalent near the surface (shallow dose equivalent index) and beyond a depth of 1 cm in the human body or phantom (deep dose equivalent index), for the purpose of ascertaining the effectiveness of radiation protection measures in a given radiation facility. For the purpose of this standard, the shallow and deep dose equivalent indices will be considered equal to the dose equivalents in the human body or phantom at depths of 0.007 cm and 1.0 cm, respectively. (See also Section C1 of Appendix C.)

2.5 Accident Dosimetry. Determination of single high absorbed doses, occurring as a consequence of uncontrolled conditions.

2.6 Dosimeter. A radiation sensitive element (or elements) in a holder, the holder being considered a part of the dosimeter.

[1] Bracketed numbers refer to corresponding listings given in Section 5, References to the Text.

2.7 Processor. Supplier of personnel dosimetry services. These services include:

(1) Furnishing dosimeters to the user

(2) Evaluating the reading of the dosimeters after their return in terms of the dose equivalent index (shallow or deep, or both) as prescribed in this standard

(3) Recording the results

(4) Reporting them to the user

2.8 Test. Procedure with the following sequence:

(1) Submission of dosimeters of a processor's current stock to a testing laboratory, in numbers sufficient for the specified irradiations in all radiation categories covered by a processor's service

(2) Irradiation of the dosimeters by personnel of the testing laboratory in all radiation categories covered by a processor's service, using the type(s) of radiation specified for each of these radiation categories (see 3.2)

(3) Evaluation by the processor of the response of the returned dosimeters in terms of dose equivalent index for tests of protection monitoring, or in terms of absorbed dose index for tests of accident monitoring, as specified in 4.2.1

(4) Submission of these evaluations to the testing laboratory

(5) Analysis of the submitted evaluations by the testing laboratory

(6) Reporting the results of this analysis (also referred to as "test results") to the processor

2.9 Testing Laboratory. A group independent of the processor's operation that is carrying out the procedures outlined in this standard.

2.10 Radiation Category. Each type and energy range of radiation (or of a radiation mixture) for which separate tests are performed.

2.11 Interval of Dose Equivalent (or Absorbed Dose) Index. Range of dose equivalent (or absorbed dose) indices in a given category and for a given type of radiation, for which performance criteria are applied separately.

2.12 Performance Index (P_i). For tests of protection dosimetry, the performance index for the ith dosimeter is defined as

$$P_i \equiv [(H_I')_i - (H_I)_i]/(H_I)_i$$

where $(H_I)_i$ is the dose equivalent index, assigned by the testing laboratory to the irradiated dosimeter, and $(H_I')_i$ the corresponding dose equivalent index reported by the processor.

For tests of accident dosimetry the same definition applies, with the absorbed dose index, D_I, replacing the dose equivalent index, H_I.

2.13 Bias (B). The bias of the values of the performance index, P_i, is

$$B \equiv \bar{P} \equiv (1/n) \sum_{i=1}^{n} P_i$$

where the sum is extended over all n values of P_i for a particular test in a given radiation category, interval of dose equivalent indices, and phantom depth.

2.14 Standard Deviation (S). The standard deviation of the values of the performance index, P_i, is:

$$S \equiv \left[\frac{\Sigma_{i=1}^{n} (P_i - \bar{P})^2}{n-1} \right]^{1/2}$$

where the sum is extended over all n values of P_i for a particular test in a given radiation category, interval of dose equivalent indices, and phantom depth.

2.15 Consistency of Performance. Uniformity of work quality of a processor over extended periods of time. (See also Section D3 of Appendix D.)

3. Test Procedure

3.1 Administrative Procedure

3.1.1 Information to Be Supplied to the Testing Laboratory. The processor shall certify that the dosimeters submitted for each test are representative of those supplied routinely to his users.

3.1.2 Number of Test Dosimeters. For every test, the number of dosimeters to be irradiated in a given radiation category shall be 10 for each of the applicable intervals specified in 4.1.2, or a total of 30 per test and category. At least one additional dosimeter that is not to be irradiated (a shipping control) shall be included with each dosimeter shipment.

3.1.3 Test Schedule. Each test shall extend over a period ranging from three to six months. The test dosimeters shall be submitted in at least three separate groups per radiation category. Each group shall be returned to the processor within one month from receipt, and within two weeks after the start of irradiations of dosimeters in the group. (See also Section D3 of Appendix D.)

3.1.4 Dissemination of Test Results. All test results on dosimeters supplied by a given processor shall be reported to that processor at the completion of each test. An estimate for the uncertainty of the assigned values of the dose equivalent (or absorbed dose) index shall be included in the report.

3.2 Radiation Categories and Test Ranges. The radiation categories in which tests shall be performed and

Table 1
Radiation Categories, Test Ranges, and Tolerance Levels

	Radiation	Test Range		Tolerance Level, L (Note 1)	
		Protection (rem)	Accident (rad)	Shallow	Deep
I	Photons, 300 keV < $\bar{E}$ ≤ 3 MeV (Note 2)	0.03 to 10	10 to 800	no test	protection: 0.3 or $6/(\bar{H}_I)^{1/2}$ accident: 0.3
II	Photons, 30 keV < $\bar{E}$ ≤ 300 keV (Notes 2 and 3)	0.03 to 10	10 to 800	protection: 0.5 or $15/(\bar{H}_I)^{1/2}$ accident: no test	protection: 0.5 or $15/(\bar{H}_I)^{1/2}$ accident: 0.3
III	Photons, 15 keV < $\bar{E}$ ≤ 30 keV (Notes 2 and 4)	0.15 to 10 (Note 5)	no test	0.5 or $15/(\bar{H}_I)^{1/2}$	0.5 or $15/(\bar{H}_I)^{1/2}$
IV	Beta particles	0.15 to 10	no test	0.5 or $15/(\bar{H}_I)^{1/2}$	no test
V	Fast neutrons	0.10 to 5	no test	no test	0.5 or $15/(\bar{H}_I)^{1/2}$
VI	Photon mixtures (any combination of categories I and II) (Note 5)	0.05 to 10	no test	0.5 or $15/(\bar{H}_I)^{1/2}$	0.5 or $15/(\bar{H}_I)^{1/2}$
VII	Mixtures, photons, and beta particles (combination of category I or II, and category IV) (Note 5)	0.20 to 10	no test	0.5 or $15/(\bar{H}_I)^{1/2}$	0.5 or $15/(\bar{H}_I)^{1/2}$
VIII	Mixtures, photons, a[illegible] [illegible]st neutrons (combinations of categories I and V) (Note 6)	0.15 to 5	no test	no test	0.5 or $15/(\bar{H}_I)^{1/2}$

NOTES:

(1) See also [illegible] 1.1, 4.2.1, and Appendix C. When two limits are given, the larger one applies. $\bar{H}_I$ is in mrem in the protection range.
(2) See Section A1 of Appendix A for explanation of the symbol, $\bar{E}$.
(3) For narrow bremsstrahlung spectra, NBS calibration techniques specifying heavily filtered X rays are applicable. For broad bremsstrahlung spectra, NBS calibration techniques specifying lightly or moderately filtered X rays generated at > 60 kVcp are applicable. [5]
(4) For bremsstrahlung spectra, NBS calibration techniques specifying X rays generated at ≤ 30 kVcp are applicable. [5]
(5) Control on range based on shallow dose equivalent index.
(6) Control on range based on deep dose equivalent index.

the test ranges are given in Table 1 and are further discussed in Appendix A. Each processor shall be tested in the radiation categories covered by his service. If tests in the mixed radiation categories, VI, VII, or VIII, are performed, tests shall be performed also in the categories of the individual types of radiation components. For photon irradiations, the radiation category and the radiation energy within the category in which test irradiations are administered shall not be divulged to the processor for a test of protection dosimetry until after the test has been completed. The photon sources and energies used for tests of accident dosimetry shall be identified for the processor at the time the irradiated dosimeters are returned to him for evaluation. The individual dosimeters receiving radiation from a particular source (or sources) in a particular radiation category shall not be identified, with the exception of those irradiated for tests of accident dosimetry. In categories II and III, at least two different radiation spectra shall be used per test and category, but not more than one per interval.

3.3 Radiation Sources

3.3.1 The following radiation sources shall be available in the testing laboratory:

(1) At least one gamma-ray source (^{60}Co or ^{137}Cs). The source may be used either in a beam-type irradiator equipped with a collimator or free in air.

(2) At least one X-ray machine operable in the range between about 20 and 300 kV constant potential. Among the accessories shall be beam filters of compositions and thicknesses appropriate to produce continuous X-ray spectra using the techniques specified by the National Bureau of Standards [5]. An attachment

for the production of K-fluorescence X rays may be of advantage.

(3) A sealed $^{90}Sr/^{90}Y$ beta-particle source equipped with a 100-mg/cm^2 filter of low atomic number.

(4) A ^{252}Cf fast neutron source approximating an isolated point fission source.

3.3.2 The calibration of all radiation sources and dosimetry instruments shall be carried out either at the National Bureau of Standards or with instruments or sources calibrated at the National Bureau of Standards for use in the calibration of other instruments or sources. Calibration of all neutron sources shall be carried out at the National Bureau of Standards, and the recalibration schedule shall be based upon recommendations by the National Bureau of Standards. Suggested procedures for the use of calibrated instruments and sources for determining test irradiation levels are given in Appendix B.

3.4 Irradiation Conditions. The test dosimeters shall be irradiated under ambient laboratory conditions on a phantom at perpendicular radiation incidence. The total scatter contribution from the walls, ceiling, and floor of the irradiation room shall amount to not more than 5% of the assigned dose equivalent index. See Section C 3 of Appendix C for recommendations on phantom construction and on minimal interference between simultaneously irradiated dosimeters.

3.5 Selection of Irradiation Levels. In each interval of each category, the irradiation levels shall be chosen at random. In categories involving irradiations simulating those in mixed radiation fields, the total assigned dose equivalent index and the component ratios shall be selected at random. In categories VII and VIII, the assigned dose equivalent index of the larger component shall not be greater than three times that of the smaller component. (See also Section A3 of Appendix A.)

3.6 Assignment of Dose Equivalent Index Values. The testing laboratory shall assign to each dosimeter values for the shallow or deep dose equivalent index (H_I), or for both. The uncertainty in these values shall not exceed 5%.

3.6.1 For photons, values for the shallow and the deep dose equivalent index shall be assigned in the following way:

(1) When the photon source is calibrated in terms of exposure free in air (X_{air}) and the personnel dosimeters are irradiated with phantom backing:

$$H_I = c_{X_{air}} X_{air}$$

(2) When the photon source is calibrated in terms of exposure in the presence of a phantom (X_{ph}), and the personnel dosimeters are irradiated with phantom backing,

$$H_I = c_{X_{ph}} X_{ph}$$

Table 2
Conversion Factors for Computing the Dose Equivalent Index from Exposure

Photon Energy (MeV)	$c_{X_{air}}$, rem R^{-1}		$c_{X_{ph}}$, rem R^{-1}
	Deep	Shallow	
0.015	0.16	0.79	0.88
0.02	0.45	0.87	0.87
0.03	0.94	1.07	0.87
0.04	1.18	1.25	0.88
0.05	1.28	1.32	0.90
0.08	1.38	1.38	0.94
0.10	1.37	1.37	0.95
0.20	1.27	1.27	0.97
0.30	1.18	1.18	0.97
0.40	1.14	1.14	0.98
0.50	1.09	1.09	0.98
0.60	1.07	1.07	0.97
0.67	1.05	1.05	0.97
0.80	1.03	1.03	0.97
1.0	1.01	1.01	0.97
1.5	1.01	1.01	0.97
2.0	1.01	1.01	0.98
3.0	1.01	1.01	0.98

When the photon spectra can be adequately characterized by average energy (see Section A1 of Appendix A), or are sufficiently well known, the values for $c_{X_{air}}$ and $c_{X_{ph}}$ shall be taken from Table 2. When the spectral characterization is in terms of half-value layers, conversion methods described elsewhere may be used [6]. For average photon energies above 0.05 MeV, X_{ph} shall be determined only at a depth of 1 cm, while for lower average photon energies it shall be determined both at depths of 0.007 cm and 1 cm in the phantom.

3.6.2 For beta particles from a source calibrated in terms of absorbed dose in phantom, values for the shallow dose equivalent index shall be assigned as

$$H_I \equiv D_I$$

where D_I is the absorbed dose in the phantom at a depth of 0.007 cm.

3.6.3 For fast neutrons from a source calibrated in terms of fluence, ϕ, free in air, values for the deep dose equivalent index shall be assigned as

$$H_I = \bar{c}_\phi \phi$$

where the dose equivalent per unit fluence, $\bar{c}_\phi$, shall be taken as 3.4×10^{-8} rem cm^2 for ^{252}Cf [7].

3.7 Consistency of Performance. The testing laboratory shall provide in each report to the processor information on the consistency of his performance. (See Section D3 of Appendix D.)

3.8 Study of Angular Dependence of Response. For each dosimeter design submitted for test by a processor, a study of the angular dependence of the response in the presence of a phantom shall be carried out by the testing laboratory with each type of radiation in the categories for which dosimeter performance is tested. Procedures for such a study are suggested in Section D6 of Appendix D.

4. Characterizing the Performance

4.1 Performance Criterion. Performance in a given category shall be considered adequate if, in all applicable intervals and for the applicable phantom depths,

$$|B| + 2S \leq L \qquad (4.1)$$

where B and S designate, respectively, the bias and standard deviation of the performance index, and L is the tolerance level. (See also Section D1 of Appendix D.)

4.1.1 The value of L in the inequality (4.1) shall be

(1) 0.3 or $6/(H_I)^{1/2}$, whichever is larger, for tests of protection dosimetry in radiation category I

(2) 0.5 or $15/(H_I)^{1/2}$, whichever is larger, for all other tests of protection dosimetry

(3) 0.3 for all tests of accident dosimetry

where H_I is the average value of the dose equivalent index in mrem chosen in the applicable interval (1), (2), or (3) of 4.1.2 for a particular test in a given radiation category. (See also 3.5.)

4.1.2 The values for S and B shall be obtained from values of the performance index in the following intervals:

(1) $H_I \leq 100$ mrem (where applicable)

(2) 100 mrem $< H_I \leq 300$ mrem

(3) $H_I > 300$ mrem

(4) 10 rad $\leq D_I < 800$ rad

4.2 Performance Evaluation. A processor's performance shall be evaluated by determining conformance with inequality (4.1) (see Table 1):

(1) In categories II, III, VI, and VII for estimates of the shallow and the deep dose equivalent index

(2) In category IV only for estimates of the shallow dose equivalent index

(3) In categories I, V, and VIII only for estimates of the deep dose equivalent index

5. References to the Text

[1] Basic Radiation Protection Criteria. Washington, D.C.: National Council on Radiation Protection and Measurements; 1971; Report No. 39.

[2] General Principles of Monitoring for Radiation Protection of Workers. International Commission on Radiological Protection. Elmsford, N.Y.: Pergamon Press; 1969; Publication 12.

[3] Radiation Protection Instrumentation and Its Application. Washington, D.C.: International Commission on Radiation Units and Measurements; 1971; Report 20.

[4] Conceptual Basis for the Determination of Dose Equivalent. Washington, D.C.: International Commission on Radiation Units and Measurements; 1976; Report 25.

[5] Calibration and Test Services of the National Bureau of Standards. Washington, D.C.: National Bureau of Standards; 1977 April; Special Publication 250; Section 8.3, Appendix.

[6] For a discussion of suitable measurement techniques see, for example, Measurement of Absorbed Dose in a Phantom Irradiated by a Single Beam of X or Gamma Rays. Washington, D.C.: International Commission on Radiation Units and Measurements; 1973; Report No. 23.

[7] Stoddard, D. H.; Hootman, H. E. ^{252}Cf Shielding Guide. Oak Ridge, Tenn.: Technical Information Division; 1971; TID-450, DP-1245, UC-41.

Appendixes

(These Appendixes are not a part of Draft American National Standard Criteria for Testing Personnel Dosimetry Performance, N13.11, but are included for information purposes only.)

Appendix A

Radiation Categories and Test Irradiations

A1. Types of Radiation Included in Table 1

Listed in this table are the categories of radiation most likely to contribute significantly to the dose equivalent received by radiation workers in the United States, with the omission of intermediate energy neutrons, for which calibration beams are not generally available. Also omitted from the table is a category for thermal neutrons, since thermal neutrons contribute a relatively small portion to the total dose equivalent received by radiation workers in most situations involving potential thermal neutron irradiation [A1].[2]

In Table 1, symbol $\bar{E}$ stands for the weighted average energy of the photons emitted from the source used for the test irradiations:

$$\bar{E} = \int_0^{E_{max}} \phi(E)\, E\, dE \Big/ \int_0^{E_{max}} \phi(E)\, dE$$

where $\phi(E)$ is the fluence of the photons with energies between E and $E + dE$. For the purpose of specifying the radiation category for a particular photon beam of narrow spectral width, $\bar{E}$ is an adequate approximation to the "effective energy" of the beam. Effective energy may be defined as the energy of a monoenergetic photon beam associated with the total (good geometry) attenuation coefficient obtained from the attenuation curve of the photon beam in question in a suitable absorber (for example, Al or Cu), extrapolated to zero absorber thickness. Neither the concept of weighted average energy nor the concept of effective energy provides a good description of beam quality for wide, multipeaked bremsstrahlung spectra. Therefore, in Table 1, the applicable NBS techniques, specified in terms of first and second half-value layers, are listed in footnotes to categories II and III.

A2. Test Ranges

The test ranges specified in Table 1 represent a compromise between considerations based on the principles of personnel dosimetry for radiation protection recommended by the NCRP [A2], and technical limitations imposed by currently employed personnel dosimetry systems. The NCRP recommends personnel dosimetry when the annual maximum dose equivalent is likely to exceed one-fourth of the recommended annual limit. One-fourth of the annual limit is not exceeded when all individual dosimeter readings for biweekly or longer monitoring periods are below the lower limits of the test ranges specified in Table 1. One-fourth of the annual limit could be exceeded for weekly monitoring periods; however, weekly monitoring periods are not used normally except when high dose equivalents or excessive fading of dosimeter response are expected. Tests of accident monitoring are presently specified only for photons in the energy range from 30 keV to 3 MeV. Tests of dosimetry associated with criticality accidents [A3] are not included in this standard.

Consideration was given as to whether it was desirable to extend the test ranges to lower dose equivalent index levels, in view of the NCRP recommendation to limit the dose equivalent from occupational exposure to the embryo-fetus of the expectant mother to 0.5 rem during the entire gestation period [A4]. A dose equivalent index of 30 mrem, which is the lower test limit for penetrating photons in Table 1 (categories I and II), is adequate for measuring a prospective value of 0.5 rem with quarterly or longer monitoring periods, but not with shorter monitoring periods. Nevertheless, it was decided not to lower the test limits because the limitations in the present state of personnel monitoring technique would result in an unacceptably large error at dose equivalent index levels below 30 mrem.

A3. Random Selection of Irradiation Levels and Composition of Mixtures

A number of different methods may be used for selecting random irradiation levels with equal probability within any one of the test intervals given in 4.1.2. One suitable method would be to select random num-

[2] Bracketed numbers refer to corresponding listings given in Section A6, References to Appendix A.

bers, ρ, between 0 and 1 from a random number table [A5], and represent the dose equivalent index, H_I, as

$$H_I = (H_I)_\ell + \rho[(H_I)_u - (H_I)_\ell]$$

where $(H_I)_\ell$ and $(H_I)_u$ are the lower and upper limits, respectively, of the test interval in question. If this method is chosen, it is recommended that, in the interval $H_I > 300$ mrem, the formula be applied separately to select five values of H_I above 1000 mrem and, in order to ensure adequate coverage of this important region, five between 300 and 1000 mrem.

Restricting the ratio of the dose equivalent indices of the two radiation components in category VIII to values not larger than 3:1 is motivated mainly by considerations of technical limitations. This restriction is reasonable in the light of the recommendation of the International Commission on Radiological Protection (ICRP) to use personnel dosimetry for neutrons "only if the likely neutron dose equivalent is a substantial portion of the gamma dose equivalent, say more than about a third" [A6]. For the sake of simplicity, the same ratio was adopted for category VII.

A4. Irradiation Geometry

Consideration was given to whether test irradiations should be carried out in the presence or absence of a phantom. If test irradiations were performed with the dosimeters suspended free in air while, in actual use, they are carried on the human body, a correction would have to be applied to the value (or values) of the dose equivalent index (or absorbed dose index) assigned to each dosimeter, equal to the quotient of dosimeter response with and without phantom backing. This quantity would have to be measured by the testing laboratory for each type of dosimeter submitted and for each type and energy of the test radiation used. It was decided instead to require that test irradiations be made with the dosimeters backed by a phantom. No such restrictions are made regarding the presence or absence of a phantom during calibration. (See also Section B2 of Appendix B.)

A5. Blind Testing

Blind testing is recognized as a valuable technique for determining the capability of a dosimetry service in a realistic manner. However, there are some inherent difficulties in providing test dosimeters without the knowledge of the processor, particularly in the case of in-house dosimetry operations. It is suggested that, where feasible, some blind testing be conducted, and a final decision on whether or not to make blind testing an integral part of the compulsory testing program be deferred until sufficient results from blind tests have been accumulated to determine if there exist significant differences between the performance on open and blind tests.

A6. References to Appendix A

[A1] See, for example, Becker, K. Preliminary Results of the 1975 International Personnel Monitoring Survey. U.S. Department of Commerce, National Technical Information Service; 1975; ORNL-TM-5102.

[A2] See, for example, Basic Radiation Protection Criteria. Washington, D.C.: National Council on Radiation Protection and Measurements; 1971; Report No. 39; paragraph 219.

[A3] American National Standard Dosimetry for Criticality Accidents, ANSI N13.3-1969. Available from American National Standards Institute, 1430 Broadway, New York, N.Y. 10018.

[A4] Basic Radiation Protection Criteria. Washington, D.C.: National Council on Radiation Protection and Measurements; 1971; Report No. 39; paragraph 240.

[A5] See, for example, The Rand Corporation. *A Million Random Digits with 100 000 Normal Deviates.* Glencoe, Ill.: Free Press Publishers; 1952.

[A6] General Principles of Monitoring for Radiation Protection of Workers. International Commission on Radiological Protection. Elmsford, N.Y.: Pergamon Press; 1969; Publication 12; paragraph 82.

Appendix B

Use of Calibrated Radiation Sources and Instruments

B1. Activity of Isotope Sources

It was felt unnecessary to specify source activities in the standard since they are intimately tied to the specified ranges of irradiation levels (see, for example, Table 1), to the on-phantom irradiation geometry (see 3.4) and to the accuracy of assignment of the dose equivalent indices (see 3.6). Distances of not less than 1 meter are desirable, particularly for irradiation with ^{60}Co photons from uncollimated sources, which produce considerable electron scatter in the air at shorter irradiation distances. This electron scatter may simulate nonnegligible beta particle irradiations of the personnel dosimeters. Distances of less than 35 cm as a rule will prove unsatisfactory for test irradiations in any radiation category.

B2. Beam Calibration at the Location of the Test Dosimeters

B2.1 Photons. Photon radiation fields both from low energy continuous x-radiation or K fluorescence and from radioisotope sources usually are calibrated in terms of exposure (X), a quantity related to ionization in air, measured in units of roentgens (R). The exposure calibrations may be carried out either free in air or at the specified "shallow" and "deep" depths in a phantom. Since the quantity, dose equivalent index per unit exposure in the presence of a phantom ($c\chi_{ph}$ of Table 2), depends only little on photon energy while the quantity, dose equivalent index per unit exposure free in air ($c\chi_{air}$ of Table 2), varies strongly with energy for low photon energies, it would be of advantage to measure exposure due to low energy photons in the presence of a phantom when the photon spectrum is not well known. However, in-phantom measurements require specially designed ionization chambers [B1].[3] For in-air measurements, a calibrated laboratory standard instrument may be used. This is an instrument having a performance and stability sufficient for it to be employed in the calibration of other instruments. It is further recommended that a field exposure meter, equipped with suitable ionization chambers, be available. This is an instrument having a performance and stability sufficient for it to be used for routine calibration checks at the location of the test dosimeters to be calibrated.

B2.2 Beta Particles. Beta particle beams may be calibrated directly in terms of absorbed dose in the phantom by means of an extrapolation ionization chamber equipped with close to phantom-equivalent walls of variable thickness, or by a similarly equipped fixed-volume "thin" ionization chamber [B2].

B2.3 Fast Neutrons. Fast neutron sources usually are calibrated in terms of neutron emission rates, from which neutron fluences may be deduced for use of the sources in a low scatter 4-π geometry.

B3. References to Appendix B

[B1] For a discussion of suitable measurement techniques see, for example, Measurement of Absorbed Dose in a Phantom Irradiated by a Single Beam of X or Gamma Rays. Washington, D.C.: International Commission on Radiation Units and Measurements; 1973; Report No. 23.

[B2] For a discussion of suitable measurement techniques, see, for example, Radiation Dosimetry: Electrons with Initial Energies between 1 and 50 MeV. Washington, D.C.: International Commission on Radiation Units and Measurements; 1972; Report No. 21.

[3] Bracketed numbers refer to corresponding listings in Section B3, References to Appendix B.

Appendix C

Interpretation of the Response of Personnel Monitoring Dosimeters

C1. Use of the Dose Equivalent Index (or Absorbed Dose Index)

Recommendations have been made for the maximum permissible levels of occupational exposure to ionizing radiation for the skin and the extremities, for the lens of the eye, and for the gonads and deep-seated organs [C1].[4] A direct determination of dose equivalent for each of these organs is usually impossible [C2], or at least impractical. In this standard, the values of the shallow or deep dose equivalent index, or both (or absorbed dose index) are used to quantify the irradiation of each test dosimeter. Although the depth at which the maximum dose equivalent (or maximum absorbed dose) is attained varies with radiation energy, using depths of 0.007 cm and 1.0 cm to approximate the modified index quantities is justified for the test irradiations and test conditions specified in this standard for the following reasons:

(1) For beta particles from the specified $^{90}Sr/^{90}Y$ source and for photons of energies below 0.05 MeV, the maximum dose equivalent is attained close to the surface of the body. Therefore, the shallow dose equivalent index is essentially equal to the dose equivalent to the skin.

(2) For photons of energies between 0.05 and 3 MeV, and for neutrons from the specified ^{252}Cf source (for which less than 2% of the neutrons are below 0.1 MeV and less than 2% above 7 MeV [C3]), the maximum dose equivalent for the majority of the incident photons or neutrons is attained in the vicinity of 1.0 cm in the body. Therefore, the deep dose equivalent index, as a rule, overestimates the dose equivalent to deep-seated organs and never underestimates significantly the dose equivalent at a depth of 1 cm in tissue [C4].

C2. Assignment of Values of the Dose Equivalent Index for Photons

The factors $c\chi_{air}$ and $c\chi_{ph}$ for computing the shallow and deep dose equivalent indices are listed in Table 2 as a function of photon energy. They were obtained in the following way:

(1) $c\chi_{ph}$: Absorbed dose per unit exposure determined in the presence of a phantom [C5].

(2) $c\chi_{air}$:

(a) Above 0.10 MeV and between 0.04 and 0.10 MeV for computing the shallow dose equivalent index: obtained as the product of $c\chi_{ph}$ and the back scatter factor [C5].

(b) Below 0.04 MeV, both for computing the shallow and the deep dose equivalent index: computed by the Health Physics Division of the Oak Ridge National Laboratory for the anterior trunk of the modified MIRD phantom [C6], irradiated by a broad parallel beam incident on the phantom's anterior [C7].

(c) Between 0.04 and 0.10 MeV, for computing the deep dose equivalent index: estimated with the aid of the Oak Ridge data and available depth dose data for bremsstrahlung [C8], for a depth of 1 cm in water.

C3. Phantom Construction

It is recommended that the phantom be constructed of a material simulating soft tissue in composition [C9] sufficiently to result in dosimeter readings deviating from those in soft tissue by less than 5% for irradiations in all categories. Slabs of this phantom material of dimensions 30 cm × 30 cm by a thickness of 15 cm may be used. In the case of beta particle or low energy photon irradiations, the slab thickness may be reduced to about twice the range of the most energetic electrons incident upon (or created within) the slab. If several dosimeters are to be irradiated simultaneously, it is recommended that precautions be taken to keep the mutual interference to less than 5% of the dosimeter response.

C4. References to Appendix C

[C1] See, for example, Review of the Current State of Radiation Protection Philosophy. Washington, D.C.: National Council on Radiation Protection and Measurements; 1975; Report No. 43; Appendixes A and B.

[C2] Conceptual Basis for the Determination of Dose Equivalent. Washington, D.C.: International Commission on Radiation Units and Measurements; 1976; Report No. 25.

[C3] Grundl, J. A.; Spiegel, V.; Eisenhauer, C. M.; and others. A Californium-252 Fission Spectrum Irradiation Facility for Neutron Reaction Rate Measurements.

[4] Bracketed numbers refer to corresponding listings in Section C4, References to Appendix C.

Nuclear Technology 32:315; 1977; supplemented by Grundl, J. A.; private communication.

[C4] Protection against Neutron Radiation. Washington, D.C.: National Council on Radiation Protection and Measurements; 1971; Report No. 38; Figs. 10 through 20.

[C5] Data for Protection against Ionizing Radiation from External Sources: Supplement to ICRP Publication 15; International Commission on Radiological Protection. Elmsford, N.Y.: Pergamon Press, 1969; Publication 21; Table and Fig. 9.

[C6] Snyder, W. S.; Ford, M. R.; Warner, G. G.; Watson, S. B. A Tabulation of Dose Equivalent per Microcurie-Day for Source and Target Organs of an Adult for Various Radionuclides. Oak Ridge, Tenn.: Oak Ridge National Laboratory; 1974; ORNL-5000.

[C7] Poston, J.; Warner, G. C.; unpublished data. See also Jones, T. D.; Auxier, J. A.; Snyder, W. S.; Warner, G. G. Dose to Standard Reference Man from External Sources of Monoenergetic Photons. *Health Physics* 24: 241; 1973.

[C8] Cohen, M.; Jones, D. E. A.; Greene, D., eds. Central Axis Depth Dose Data for Use in Radiotherapy. *British Journal of Radiology*; Supplement No. 11. London: British Institute of Radiology; 1972.

[C9] Report of the Task Group on Reference Man. International Commission on Radiological Protection. Elmsford, N.Y.: Pergamon Press; 1975; Report No. 23.

Appendix D

Performance Criterion and Performance Evaluation

D1. Dependence of Performance Index on Dose Equivalent Level

The uncertainty of dosimeter readings usually increases at dose levels close to the lower limit of a dosimeter's useful range. Previous tests have shown [D1][5] that, for photographic dosimeters, the ratio of the standard deviations of the performance index at the 30-mrem and the 300-mrem levels may be as much as 2.5 for irradiations with Ra gamma rays, and as much as 2.0 for irradiations with fast neutrons. Similar results have been obtained for photon irradiations of thermoluminescence dosimeters. Therefore, it was decided to divide the dose equivalent ranges for testing in each category into several intervals, and to carry out all tests separately for each interval.

D2. Significance of Testing over an Extended Period

It is the purpose of performance testing to gain information on the quality of a processor's total work output during a given time period. Inasmuch as the sample from which this information is to be gathered is of necessity relatively small, it is important that fluctuations in a supplier's process be reflect in the test data to the largest extent possible. For this reason, procedures are adopted for evaluating dosimeter performance on a protracted basis throughout each test period. Also, to achieve an equitable distribution of dose equivalent index (or absorbed dose index) levels, it is stipulated that these levels be chosen at random in each interval.

A further aid for increasing the amount of information gained on a processor's performance is to compare present and past test results. This may be done by checking for trends in the quantities of bias and standard deviation from a series of successive tests, either by examining plots of these quantities or by comparing them by statistical means (see Section D3 of Appendix D). Consistency provides some degree of ensurance that the performance test results are indicative of a processor's total work output.

Testing for consistency is of necessity limited to categories I through V. Categories VI through VIII are not readily amenable to consistency testing because the difference in the evaluation process for different types of radiation makes it difficult to devise a fair test procedure. This standard requires that consistency evaluations be performed on the data for each complete test series in categories I through V, and that a processor be provided with the results of this evaluation. When a

[5] Bracketed numbers refer to corresponding listings in Section D7, References to Appendix D.

Table D1
F Values, 0.1% Probability Level*

$N-1$† \ $n-1$†	1	2	3	4	5	6	7	[illegible]	9	10	12	15	20	24	30	40	60	120	∞
1	4053‡	5000‡	5404‡	5625‡	5764‡	5859‡	5929‡	5981‡	6023‡	6056‡	6107‡	6158‡	6209‡	6235‡	6261‡	6287‡	6313‡	6340‡	6366‡
2	998.5	999.0	999.2	999.2	999.3	999.3	999.4	999.4	999.4	999.4	999.4	999.4	999.4	999.5	999.5	999.5	999.5	999.5	999.5
3	167.0	148.5	141.1	137.1	134.6	132.8	131.6	130.6	129.9	129.2	128.3	127.4	126.4	125.9	125.4	125.0	124.5	124.0	123.5
4	74.14	61.25	56.18	53.44	51.71	50.53	49.66	49.00	48.47	48.05	47.41	46.76	46.10	45.77	45.43	45.09	44.75	44.40	44.05
5	47.18	37.12	33.20	31.09	29.75	28.84	28.16	27.64	27.24	26.92	26.42	25.91	25.39	25.14	24.87	24.60	24.33	24.06	23.79
6	35.51	27.00	23.70	21.92	20.81	20.03	19.46	19.03	18.69	18.41	17.99	17.56	17.12	16.89	16.67	16.44	16.21	15.99	15.75
7	29.25	21.69	18.77	17.19	16.21	15.52	15.02	14.63	14.33	14.08	13.71	13.32	12.93	12.73	12.53	12.33	12.12	11.91	11.70
8	25.42	18.49	15.83	14.39	13.49	12.86	12.40	12.04	11.77	11.54	11.19	10.84	10.48	10.30	10.11	9.92	9.73	9.53	9.33
9	22.86	16.39	13.90	12.56	11.71	11.13	10.70	10.37	10.11	9.89	9.57	9.24	8.90	8.72	8.55	8.37	8.19	8.00	7.81
10	21.04	14.91	12.55	11.28	10.48	9.92	9.52	9.20	8.96	8.75	8.45	8.13	7.80	7.64	7.47	7.30	7.12	6.94	6.76
11	19.69	13.81	11.56	10.35	9.58	9.05	8.66	8.35	8.12	7.92	7.63	7.32	7.01	6.85	6.68	6.52	6.35	6.17	6.00
12	18.64	12.97	10.80	9.63	8.89	8.38	8.00	7.71	7.48	7.29	7.00	6.71	6.40	6.25	6.09	5.93	5.76	5.59	5.42
13	17.81	12.31	10.21	9.07	8.35	7.86	7.49	7.21	6.98	6.80	6.52	6.23	5.93	5.78	5.63	5.47	5.30	5.14	4.97
14	17.14	11.78	9.73	8.62	7.92	7.43	7.08	6.80	6.58	6.40	6.13	5.85	5.56	5.41	5.25	5.10	4.94	4.77	4.60
15	16.59	11.34	9.34	8.25	7.57	7.09	6.74	6.47	6.26	6.08	5.81	5.54	5.25	5.10	4.95	4.80	4.64	4.47	4.31
16	16.12	10.97	9.00	7.94	7.27	6.81	6.46	6.19	5.98	5.81	5.55	5.27	4.99	4.85	4.70	4.54	4.39	4.23	4.06
17	15.72	10.66	8.73	7.68	7.02	6.56	6.22	5.96	5.75	5.58	5.32	5.05	4.78	4.63	4.48	4.33	4.18	4.02	3.85
18	15.38	10.39	8.49	7.46	6.81	6.35	6.02	5.76	5.56	5.39	5.13	4.87	4.59	4.45	4.30	4.15	4.00	3.84	3.67
19	15.08	10.16	8.28	7.26	6.62	6.18	5.85	5.59	5.39	5.22	4.97	4.70	4.43	4.29	4.14	3.99	3.84	3.68	3.51
20	14.82	9.95	8.10	7.10	6.46	6.02	5.69	5.44	5.24	5.08	4.82	4.56	4.29	4.15	4.00	3.86	3.70	3.54	3.38
21	14.59	9.77	7.94	6.95	6.32	5.88	5.56	5.31	5.11	4.95	4.70	4.44	4.17	4.03	3.88	3.74	3.58	3.42	3.26
22	14.38	9.61	7.80	6.81	6.19	5.76	5.44	5.19	4.99	4.83	4.58	4.33	4.06	'.92	3.78	3.63	3.48	3.32	3.15
23	14.19	9.47	7.67	6.69	6.08	5.65	5.33	5.09	4.89	4.73	4.48	4.23	3.96	3.82	3.68	3.53	3.38	3.22	3.05
24	14.03	9.34	7.55	6.59	5.98	5.55	5.23	4.99	4.80	4.64	4.39	4.14	3.87	3.74	3.59	3.45	3.29	3.14	2.97
25	13.88	9.22	7.45	6.49	'88	5.46	5.15	4.91	4.71	4.56	4.31	4.06	3.79	3.66	3.52	3.37	3.22	3.06	2.89
26	13.74	9.12	7.36	6.41	5.80	5.38	5.07	4.83	4.64	4.48	4.24	3.99	3.72	3.59	3.44	3.30	3.15	2.99	2.82
27	13.61	9.02	7.27	6.33	5.73	5.31	5.00	4.76	4.57	4.41	4.17	3.92	3.66	3.52	3.38	3.23	3.08	2.92	2.75
28	13.50	8.93	7.19	6.25	5.66	5.24	4.93	4.69	4.50	4.35	4.11	3.86	3.60	3.46	3.32	3.18	3.02	2.86	2.69
29	13.39	8.85	7.12	6.19	5.59	5.18	4.87	4.64	4.45	4.29	4.05	3.80	3.54	3.41	3.27	3.12	2.97	2.81	2.64
30	13.29	8.77	7.05	6.12	5.53	5.12	4.82	4.58	4.39	4.24	4.00	3.75	3.49	3.36	3.22	3.07	2.92	2.76	2.59
40	12.61	8.25	6.60	5.70	5.13	4.73	4.44	4.21	4.02	3.87	3.64	3.40	3.15	3.01	2.87	2.73	2.57	2.41	2.23
60	11.97	7.76	6.17	5.31	4.76	4.37	4.09	3.87	3.69	3.54	3.31	3.08	2.83	2.69	2.55	2.41	2.25	2.08	1.89
120	11.38	7.32	5.79	4.95	4.42	4.04	3.77	3.55	3.38	3.24	3.02	2.78	2.53	2.40	2.26	2.11	1.95	1.76	1.54
∞	10.83	6.91	5.42	4.62	4.10	3.74	3.47	3.27	3.10	2.96	2.74	2.51	2.27	2.13	1.99	1.84	1.66	1.45	1.00

*From Pearson, E. S.; Hartley, H. O., eds. *Biometrika Tables for Statisticians.* Vol 1. Cambridge: University Press; 1956; p 163.

†*n*: Number of *P* values used to obtain current value of *S*
N: Total number of *P* values used to obtain *σ*

‡Multiply these entries by 100.

trend or other sign of lack of consistency is noticed in a process :'s test parameters for successive tests, it is important that the reasons for such behavior be determined, since lack of consistency may foreshadow future failure of performance tests.

D3. Statistical Procedure for Evaluating Consistency

Following is an acceptable statistical procedure for checking for inconsistency in the results of successive tests:

The test data for a given category and dose equivalent interval are considered to be consistent with previous data if the test parameters, S and B, meet the following two conditions:

$$S < \sqrt{F(n-1, N-1, 0.001)}\ \bar{\sigma} \qquad \text{(D3.1)}$$

where S is the standard deviation obtained from n dosimeters for the current test, $\bar{\sigma}$ is the standard deviation obtained from N dosimeters for all past successive tests that were consistent, and F is obtained from the 0.001-level of the F distribution. Pertinent values of F are given in Table D1.

$$|B - \bar{B}| \leq t_{0.001}\ \bar{\sigma} \sqrt{(n+N)/nN} \qquad \text{(D3.2)}$$

where B is the bias obtained from n dosimeters for the current test, $\bar{B}$ is the bias obtained from N dosimeters for all past successive tests that were consistent, and t is the value of the t-statistic for the degrees of freedom in $\bar{\sigma}$,[6] exceeded with probability 0.001. Applicable values of t are shown in Table D2. If inequality (D3.1) is not fulfilled, the validity of inequality (D3.2) need not be determined.

D4. Choice of Tolerance Level, L

The values chosen for the tolerance limit represent a compromise between the recommendations of international authorities in the field of radiation protection and radiation measurements, and the limitations dictated by available measurement techniques. In ICRU Report No. 20 [D2], a 30% limit is recommended for the uncertainty in the maximum dose equivalent in the vicinity of the maximum permissible levels, while an uncertainty of as much as a factor of three is considered acceptable for maximum dose equivalents smaller by an order of magnitude. In ICRP Report No. 12 [D3], on the other hand, a limit of 50% is recommended in the vicinity of maximum permissible levels under field conditions, when errors caused by unknown irradiation geometry or ambient conditions are taken into account. In this standard, a fixed irradiation geometry and laboratory ambient conditions are specified for the test irradiations. Because of limitations in measurement technique, the tolerance limit is set at 0.5 (50%) in the vicinity of maximum permissible levels or above, except for accident dosimetry and protection dosimetry of high energy photons, where it is set at 0.3 (30%). At lower levels, the tolerance limit is relaxed on a graded scale.

[6] Total number of observations minus the number of constants (for example, averages) fitted to the data.

D5. Sources of Uncertainty Not Included in the Performance Evaluation

This standard does not include provisions for testing a supplier's performance under the various possible conditions of practical use of the personnel dosimeters. Among the common sources of uncertainty not included are:

(1) Dependence of response on ambient temperature, including storage temperatures before, during, and after irradiations, up to the time of processing or readout.

(2) Dependence of response on ambient humidity, including storage humidity, before, during, and after irradiation, up to the time of processing or readout

(3) Time intervals between dosimeter issue, irradiation, and processing or readout

Table D2
Distribution of t*

Degrees of Freedom	Probability 0.001	Degrees of Freedom	Probability 0.001
1	636.62	18	3.92
2	31.60	19	3.88
3	12.92	20	3.85
4	8.61	21	3.82
5	6.87	22	3.79
6	5.96	23	3.77
7	5.41	24	3.75
8	5.04	25	3.73
9	4.78	26	3.71
10	4.59	27	3.69
11		28	3.67
12	4.32	29	3.66
13	4.22	30	3.65
14	4.14	40	3.55
15	4.07	60	3.46
16	4.02	120	3.37
17	3.97	∞	3.29

*Table D2 is taken from Table III, p 46, of Fisher and Yates: *Statistical Tables for Biological, Agricultural and Medical Research*, published by Longman Group Ltd, London (previously published by Oliver and Boyd, Edinburgh), and by permission of the authors and publishers.

(4) Dependence of response on visible and ultraviolet light prior to, during, and after irradiation, up to the time of processing or readout

(5) Position of the badge on the human body relative to the point of maximum irradiation on the body surface, and relative to the location of the organs of interest

(6) Influence upon dosimeter response of the angle of radiation incidence for the different types of radiation and different radiation energies

(7) A possible bias in the performance on an open test, that is, a test carried out with the knowledge of the processor, introduced by the processor's awareness of being tested

The extent to which any one of these factors may contribute to a given interpretation of dosimeter response varies widely, depending on dosimeter design and processing or readout techniques. It is suggested that the testing laboratory be in a position to evaluate the supplied dosimeter designs for the influence on interpretation of dosimeter response of any of these factors. Methods of carrying out some of the required test procedures may be found in the literature [D4].

Because of the magnitude of the potential errors associated with angular dependence of dosimeter response, consideration was given to incorporating into the standard performance requirements related to response characteristics of test dosimeters as a function of angle of radiation incidence for different radiation energies and types of radiation. However, an adequate data base for the angular dependence of the response of most personnel dosimeters irradiated on a phantom was not available. Therefore, it was impossible to select appropriate performance criteria.[7] It was decided to include requirements in the standard for the development of such a data base so that, in future reviews and revisions of this standard, suitable performance criteria can be specified. Section D6 gives an acceptable procedure for determining the dependence of dosimeter response on the angle of radiation incidence.

D6 Measurement of Dependence of On-Phantom Dosimeter Response on Angle of Radiation Incidence

Irradiations are carried out with the dosimeters mounted on the phantom used for all other test irradiations, for each radiation type and energy range included in the categories of Table 1 of this standard for which the dosimeters are used by the particular processor.

Mixed radiation categories are excluded. Angle of incidence is varied in two planes perpendicular to each other and to the plane of the dosimeter in contact with the phantom. At least seven different angles of incidence from −85 to +85 degrees, and including zero degrees (perpendicular incidence), are used in each of the two planes. Irradiations are made with at least three different radiation spectra in category II, and one in each of the other categories. At least two dosimeters are irradiated identically. Values for the dose equivalent index for each irradiation condition are selected from between 300 and 600 mrem for photons and beta particles, and from between 500 and 1000 mrem for fast neutrons. They are determined for perpendicular incidence of the radiation on the phantom by the methods outlined in the standard for the depths (or depth) of interest for the particular type of radiation. Dosimeter response for any angle of radiation incidence and any type and energy of the incident radiation then is given by the quotient of the dosimeter reading for these irradiation conditions and the dose equivalent index for perpendicular radiation incidence.

D7. References to Appendix D

[D1] See, for example, Unruh, C. M.; Larson, H. V.; Beetle, T. M.; Keene, A. R. The Establishment and Utilization of Film Dosimeter Performance Criteria. Richland, Wash.: Battelle Memorial Northwest Laboratory; 1967; BNWL-542, UC-48.

[D2] Radiation Protection Instrumentation and Its Application. Washington, D.C.: International Commission on Radiation Units and Measurements; 1971; Report No. 20; Section I(C).

[D3] General Principles of Monitoring for Radiation Protection of Workers. International Commission on Radiological Protection. Elmsford, N.Y.: Pergamon Press; 1968; Publication 12; paragraph 101.

[D4] See, for example, Personal Photographic Dosimeters, ISO/R 1757-1971, available from the American National Standards Institute, 1430 Broadway, New York, N.Y. 10018.[8]

[7] It may be noted here that dosimeters with isotropic response would overestimate the dose equivalent index when irradiated under a 90-degree angle of incidence (parallel to the phantom surface), while dosimeters having a response that strongly varies with angle of incidence may underestimate the dose equivalent index when irradiated in the same geometry.

[8] A related Health Physics Society standard, Standard for Performance of Thermoluminescence Dosimetry Systems, will be forthcoming.

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16. ABSTRACT (200 words or less)

The Procedures Manual describe, the operational conditions of the 2-year pilot study conducted by the University of Michigan of the Health Physics Society Standards Committee (HPSSC) Standard titled, "Criteria for Testing Personnel Dosimetry Performance." The Manual describes source calibrations (which were done or supervised by the National Bureau of Standards), irradiation geometries, quality control, record keeping, data analysis, and methods of receiving, handling, and returning large numbers of dosimeters.

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