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Radiation-Hardness Testing of Electronic Devices: A Survey of Facility Dosimetry Practices

J. C. Humphreys and S. E. Chappell

Center for Radiation Research
Institute for Basic Standards
National Bureau of Standards
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RADIATION-HARDNESS TESTING OF ELECTRONIC DEVICES: A SURVEY OF FACILITY DOSIMETRY PRACTICES

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ABSTRACT

As part of a program to develop better quality assurance in the measurement of total dose in the field of radiation-hardness testing of electronic devices, a survey was conducted at twelve radiation test facilities. The survey was carried out through personal visits during which various characteristics of the test facilities and dosimetry procedures were noted. This report summarizes the results of the survey. Particular attention is given to the types of dosimetry problems perceived by the dosimetry personnel at the facilities as well as to general observations by the surveyor.

The observations and information obtained through this survey led to some conclusions on where problems in total-dose measurements may occur. Some specific recommendations result and give direction to the program plan for developing more consistent measurement procedures within the radiation-hardness testing community.

1. INTRODUCTION

At the present time, many different radiation sources and dosimetry systems are used in the radiation-hardness testing of electronic devices and systems, and, in many instances, considerable disagreement and lack of consistency in the experimental results have been observed. This state of affairs has led to confusion and uncertainty about the dosimetry results among users of radiation-hardness testing facilities. Results of an earlier survey on this problem have been reported by D.C. Lewis [1]. In order to help establish more uniform, accurate, and consistent measurements of total dose, the National Bureau of Standards is engaged in a program which is expected to lead to the establishment of reliable dosimetry systems. This survey represents a first step in this program. In this report, the term "total dose" means the energy absorbed per unit mass in a specific material as a result of irradiation by photons or electrons. This report does not address measurements of dose rate resulting from irradiation by photons or electrons, or measurements of dose resulting from neutron irradiation.

2. FACILITIES VISITED

Table 1 lists the facilities visited. Although this is not a comprehensive listing of all facilities of the radiation-hardness testing community, these are considered to be fairly representative. Thoughout the remainder of this report, the observations and conclusions on radiation sources and dosimetry will be based on a compilation of information gathered from all these facilities. The purpose here is to identify the dosimetry practices and problems that may be experienced by the radiation-hardness testing community in general. Therefore, no attempt will be made to identify the dosimetry practices of a particular facility. A checklist of the type of information sought at each facility is given in the Appendix.

TABLE 1

Facilities Visited

Facility	Location
Air Force Weapons Laboratory	Albuquerque, New Mexico
White Sands Missile Range	New Mexico
Harry Diamond Laboratories	Adelphi, Maryland
Naval Surface Weapons Center	White Oak, Maryland
Jet Propulsion Laboratory	Pasedena, California
Sandia Laboratories	Albuquerque, New Mexico
Boeing Radiation Effects Laboratory	Seattle, Washington
Hughes Aircraft	Los Angeles, California
IRT Corporation	San Diego, California
Northrop Corporation	Los Angeles, California
Rockwell International	Los Angeles, California
TRW Systems Group	Los Angeles, California

3. RADIATION SOURCES

A variety of radiation sources was seen at the facilities visited. These sources ranged from low-activity γ-ray isotope sources to the very large flash accelerators. Table 2 gives a summary of the number of various kinds of sources observed and, where applicable, the basis of calibration of the sources. Some of the ^{60}Co and ^{137}Cs sources were used only for dosimeter calibration while others were used for both dosimeter calibration and electronic device irradiation. In general, the accelerators of all types were used only for irradiation of electronic devices and systems.

3.1 Isotope Sources

The isotope γ-ray sources (^{60}Co or ^{137}Cs) observed can be grouped into four basic geometry categories:

(1) lead-shielded well irradiator, with the specimen to be irradiated placed inside a cylindrical array of source tubes;

(2) collimated-beam irradiator, with the irradiated specimen in air on the axis of a beam port in the lead housing that shields the source;

TABLE 2

Radiation Sources

Type	Total Number	Number of Calibrated Sources	Calibration Instrument Used	
			Type	For Specified Number of Sources
^{60}Co γ-Ray Source	20	21	Ion Chamber	18
			TLD and ion chamber	2
^{137}Cs γ-Ray Source	3		Fricke* dosimeter and ion chamber	1
Flash Accelerator	13	4	Calorimeter	4
Linac	4	3	Calorimeter	2
			Fricke* dosimeter	1
D.C. Accelerator	3	2	Calorimeter	1
			Faraday cup	1

*ferrous sulfate

(3) open-air source, with the irradiated specimen either in the center or to one side of a cylindrical or planar array of sources; and

(4) pool source, which is usually a cylindrical array of sources at the bottom of a water well, with the specimen placed in the center of the array inside a watertight can.

The γ-ray spectrum from a particular isotope source varies depending upon the specific activity of the source, the details of the source encapsulation, and the material surrounding the source capsule. Some general comments can be made, however, about the various source geometries described above. The lead-shielded well-type irradiators will have more low-energy scattered photons in their spectrum than the other three types; the open-air source geometry usually has the "cleanest" spectrum. Because of the scatter introduced by shielding materials, source capsules, etc., knowledge of the scattered photon energy spectrum is an important parameter. This is because a dosimeter or device whose radiation response is energy dependent will be affected differently by equal exposures with a source having a "dirty" spectrum than with a "clean" source. Therefore, errors can be introduced in the source calibration as well as in the use of the source for dosimeter calibration and device irradiation if the photon energy spectrum of the source is not taken into account. In only one of the 12 facilities visited was any knowledge expressed of the energy spectra of the isotope sources used. The activities of the isotope sources seen ranged from 50 Ci to 50 kCi, with corresponding maximum dose rates of 100 rad/h to 8 Mrad/h in silicon. In this report, the quantity, absorbed dose in silicon in units of rads or kilorads, will be abbreviated as rad (Si) or krad (Si).*

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*The International Committee of Weights and Measures (CIPM) has recently adopted new special names for SI units in the field of ionizing radiations. The SI unit for absorbed dose, the joule per kilogram, is called the gray with the symbol Gy; 1 Gy = 100 rad = $J\ kg^{-1}$. The SI unit for activity, the reciprocal second (one per second), is called the becquerel, symbol Bq; 1 Bq = $1\ s^{-1} \approx 2.703 \times 10^{-11}$ Ci [2].

3.2 Flash Accelerators

The fast-pulse (flash) accelerators used at the facilities visited have maximum electron-beam energies varying from about 0.8 Mev for the smaller machines up to 12 MeV for the largest machines. These machines are used primarily in the x-ray (bremsstrahlung) mode; only a few utilize the primary electron beam for irradiations. Generally, in the x-ray mode, the maximum deliverable total dose per pulse to a specimen is about 10 krad (Si) for the lower output machines up to about 100 krad (Si) for the higher output machines. Maximum dose rates available in the x-ray mode are of the order of 10^{11}-10^{12} rad (Si)/s. The facilities use either PIN diodes or scintillator-photodiodes, or both, as photon-beam monitors for every irradiation pulse. None of the facilities reported detailed knowledge of the bremsstrahlung energy spectra mainly because of the difficulty involved in making direct spectral measurements during the fast output pulse (typically 100 ns full width at half maximum). Several facilities do have approximations of the available photon energy spectra derived from calculations and indirect measurements.

3.3 Linacs and D.C. Accelerators

The linacs observed ranged from a single-section machine (10-MeV maximum electron energy), to a four-section machine (60-MeV maximum energy). Most of the multisection machines are used with a varying number of accelerating sections to give several different electron-beam energy and current combinations. All of the linacs are used primarily in the electron-beam mode although most are readily convertible to the x-ray mode with the addition of a bremsstrahlung converter. With direct electron beams, the linacs can give doses per pulse from less than one rad (Si) up to 100 krad (Si). Dose rates up to about 10^{11} rad (Si)/s can be obtained. Beam monitors used are PIN diodes and secondary-electron emission devices.

In addition to the linacs, three d.c. accelerators were observed. The maximum electron energy is 1 MeV for one of these and 2.5 MeV for the other two machines. Two of the machines use electron beams only while the other machine is used either in an electron or a positive-ion acceleration mode. The dose rates available from electron beams are in the range of 10^6-10^9 rad (Si)/s. Most of the time, a Faraday cup is used as a beam monitor on these d.c. accelerators.

4. CALIBRATION OF THE RADIATION SOURCES

In order to make measurements of the effects of irradiation on an electronic device, it is necessary to calibrate the output of the radiation source. At the facilities surveyed, the methods of source-output calibration fall into two general categories: those used for γ-ray isotope sources and those used for accelerators (flash, linac, or d.c.). See Table 2 for a summary of the methods.

4.1 γ-Ray Isotope Source Calibration

Nearly all of the facilities visited used air-ionization chambers as the primary method of γ-ray source-output calibration. In some facilities, these chambers were used in conjunction with other dosimeters. Only three of the sources were calibrated by other methods: one by a Fricke (ferrous sulfate) system, and two others by a TLD (CaF_2:Mn) system that had been calibrated at another source which, in turn, had been calibrated with an ion chamber. Table 3 gives details on the instruments used for source calibrations. Of the ion chambers used, 75 percent had been periodically calibrated at NBS, and the remainder had been calibrated by their manufacturer. The frequency of source calibration varied from one to four years. Most of the facilities have had their ion chambers recalibrated at one-to-two year intervals. The quantity usually measured by an air-ionization chamber irradiated by photons is exposure in units of roentgens (R). For radiation-hardness testing of electronic devices, the quantity of interest is dose in units of rads in silicon (rad (Si)). Therefore, a conversion factor is necessary to convert exposure (R) to dose (rad (Si)).

TABLE 3

Dosimeters used for Calibration of γ-ray Sources

Number of Sources	Model of Ionization Chamber*	Other type of Dosimeter
6	Landsverk L-64	none
4	Victoreen 570	none
3	EG&G IC-17	none
2	Landsverk L-64 + EG&G IC-17	none
1	Farmer 2505	none
2	NRL graphite + EG&G IC-17	none
1	Victoreen 570	Fricke dosimeter
2	EG&G IC-17	TLD (CaF_2:Mn)

*Throughout this report, the identity of the manufacturer or type of dosimeters and other equipment is revealed in order to make explicit the results of this survey. It does not in anyway imply an endorsement or recommendation by the NBS.

4.2 Accelerator Calibration

As can be seen from Table 2, the radiation output from the flash accelerators has been calibrated in only a few cases. Calorimeters of various types were used to measure the output of the four calibrated machines. The characteristics of these calorimeters were as follows:

(1) Four designs employed thin foils of materials such as C, Al, Ta, and Au. One design used a single foil, and the rest employed multiple stacks of foils. Foil thicknesses were of the order of 25 to 100 μm.

(2) Four designs used thick C or Al elements to totally absorb the irradiation beam.

(3) Two designs utilized single silicon wafers with dimensions of about 3 x 3 mm by 250 μm thick.

(4) Generally, the associated temperature sensors were thermocouples soldered or welded to the foils or the silicon wafers; however, a few employed thermistors which permitted measurements at lower dose levels.

(5) One design consisted of a spherical silicon core surrounded by a hollow spherical silicon shield and employed a thermistor temperature sensor in the core [3]. In this case, the spherical geometry eliminated directional effects on the calorimeter response for nonplanar photon beams.

In most facilities using electron beams from the linacs and d.c. accelerators, the beam output was calibrated by means of calorimeters similar to those employed for the flash x-ray machines. However, in one case, a Fricke (ferrous sulfate) dosimeter system was employed to calibrate both the electron and x-ray beams from a linac, and, in another instance, the electron beam from a d.c. accelerator was characterized by the charge collected with a Faraday cup in vacuum.

5. DOSIMETRY SYSTEMS EMPLOYED DURING DEVICE IRRADIATION

As had been expected, the survey revealed that thermoluminescence dosimetry (TLD) is employed by nearly all of the facilities as the principal method of dosimetry for electronic-device irradiations. A few facilities occasionally employ other methods, such as cobalt glass and plastic dye films, but these are generally used only to supplement TLD measurements.

5.1. Thermoluminescence Dosimeters

The TLDs utilized by the facilities visited are shown in Table 4. They are listed by manufacturer, type, physical form, and the number of facilities that used the specific physical form listed. The most commonly used type was CaF_2:Mn which was seen in a total of 13 systems in five physical forms. The next most popular was LiF in six systems and in four forms. $Li_2B_4O_7$:Mn was employed in a single system and form. Most facilities used only one, or at most two, types of TLDs, with only two facilities using as many as three types.

5.2 Dosimeter Calibration

All facilities visited calibrated their TLDs with γ rays from either ^{60}Co or ^{137}Cs sources. The calibration procedures varied greatly from facility to facility. In some cases, where relatively few dosimeters were used in a given time period, each dosimeter was calibrated and given an identity that was maintained throughout its useful life. In other cases, where TLDs were used in large quantities (e.g., as many as 15 000 per year), only a few dosimeters from each batch were selected and calibrated to obtain a calibration factor which characterized the entire batch. Most facilities used the batch-calibration procedure with batch sizes varying from 1000 to 15 000. In one facility, all new batches were 100 percent screened initially to eliminate any "mavericks," i.e., dosimeters whose responses deviated significantly from the batch average. This facility used CaF_2:Mn in the form of solid rods with

TABLE 4

Thermoluminescence Dosimeters

Manufacturer	Type	Physical Form	No. of Facilities Using Specified Form
Teledyne	CaF_2:Mn	Pressed chips	1
		Teflon discs	3
	LiF	Teflon discs	2
		Teflon rods	1
	$Li_2B_4O_7$:Mn	Teflon discs	1
EG&G	CaF_2:Mn	Pressed chips in bulbs	2
		Pressed chips	1
		Powder in glass tubes	1
	LiF	Powder in glass tubes	1
Harshaw	CaF_2:Mn	Pressed chips	4
		Square rods	1
	LiF	Loose powder in thick Teflon capsule	1
		Loose powder in thin gelatin capsule	1

square cross sections and annealed the dosimeters after each irradiation and readout.

Typically, most facilities generate a calibration curve that covers a dose range of about 1 rad to about 200 krad with the dose generally specified in silicon or in the TLD material. This curve characterizes an entire batch, or, in some cases, all batches of the same TLD type and manufacturer. Subsequent batches generally are checked at only one dose (e.g., 2 krad (Si)), in order to obtain the calibration factor for this entire new batch. In some cases, different types or forms of TLDs were used for different dose ranges. For example, CaF_2:Mn chips were used to cover the range of 0.05 to 10 rad (Si), and LiF-in-Teflon discs from 1 rad to 50 krad (Si).

The geometrical arrangements of the TLDs with respect to the γ-ray source during calibration irradiations varied among the facilities. In about half the cases, material of sufficient thickness to achieve electron equilibrium conditions surrounded the sensitive elements of the dosimeters during irradiation. This material generally was Lucite or aluminum. However, in some cases, Lucite or other plastic material whose thickness was only 20 percent (or less) of the thickness required for equilibrium conditions encased the dosimeters.

In a number of facilities, the dosimeters were discarded after a single irradiation. Generally, this was the procedure for the TLD forms consisting of the TL phosphor powder uniformly distributed in a Teflon matrix. Most facilities that used CaF_2:Mn in solid or powder forms, and a few that used LiF powder, annealed the dosimeters after irradiation and readout for reuse. The annealing procedure varied greatly among the facilities. Those using LiF powder and some employing CaF_2:Mn used carefully timed and well-controlled heating and cooling cycles while others were quite casual about the time-temperature cycle during annealing.

5.3 Dosimeter Readout Devices

The reader is an integral part of a TLD system. Therefore, its characteristics and performance with a given TLD must be well understood. The manufacturer and model of the various TLD readers seen at the facilities visited are shown in Table 5, along with the types of TLDs that were read out with a given model. A given reader generally was used to read out only one or two types or forms of TLDs. All the readers, except for one model, produced an output that indicated the integral light sum from a TLD. The exception, the EG&G units, indicated the peak light output from a dosimeter on a built-in chart recorder. A majority of the readers used a factory preset heating cycle appropriate for a particular TLD. However, several facilities have adjusted or modified their readers to give heating cycles which, the facility staff felt, produced more reliable data. The heating cycles varied with reader models, their modification, and type of TLD. Some used linear heating ramps while others brought the TLDs quickly up to a constant temperature for readout. All of the readers are equipped with some type of check light source to enable the operator to verify that the instrument is operating in a stable and reproducible manner. At most of the facilities, the check light sources were used at the beginning of the day (or TLD batch) and then again at intervals of a few minutes to several hours.

5.4 Dosimeter Handling Procedures

Observations of dosimeter handling procedure and environmental conditions during irradiation and readout were made at all facilities. In all cases, bare TLDs were handled either with tweezers or, in two facilities, with vacuum-pickup probes. None of the facilities consciously attempted to shield the dosimeters from exposure to UV light from either fluorescent lamps or sunlight. In nearly half of the laboratories, dry nitrogen gas was flowed over the TLDs during readout. Some of the other facilities used readers that had no provision for using inert gas during readout. The elapsed time between irradiation and readout varied widely. In most cases, elapsed times varied from five minutes to a few hours. None of the facilities using LiF or $Li_2B_4O_7$ and only a few of those using CaF_2 TLDs kept an accurate record of elapsed time; consequently, most facilities made no attempt

TABLE 5

TLD Readers

Manufacturer	Model	No. of facilities using specified reader model	TLD Types	No. of facilities using specified TLD type
Harshaw	2000	6	CaF_2:Mn	6
			LiF	1
Teledyne	7300	4	CaF_2:Mn	3
			LiF	3
			$Li_2B_4O_7$:Mn	1
Con-Rad (now Teledyne)	7100	1	LiF	1
EG&G	TL-3*	4	CaF_2:Mn	4
			LiF	1
Eberline	TLR-5	1	CaF_2:Mn	1

*This model now manufactured by Victoreen.

to correct for fading of the TLD response. One facility waited overnight to read all of their CaF_2 TLDs in order to minimize errors associated with fading effects. However, in two labs the elapsed time was accurately measured, and a fading-correction factor was applied to each CaF_2 dosimeter reading.

5.5 Use of Dosimeters During Device Irradiation

The TLDs were arranged in a variety of geometrical configurations when they served as radiation monitors during irradiation of electronic components or systems. Two of the most commonly employed configurations are discussed here. One method was to place essentially bare dosimeters (i.e., TLDs that were neither encapsulated nor encased in material thick enough to produce electron equilibrium conditions) next to, or in front of, the electronic devices being tested. Sometimes these dosimeters were held in place by thin gelatin capsules or similar material. Irradiation of this configuration supposedly would produce approximately the same absorbed dose in the TLDs as in the device. In another arrangement, the TLDs, located inside equilibrium build-up material of Lucite, aluminum, tantalum, or combinations of these and other materials, were placed in the vicinity of the devices being tested. This latter arrangement supposedly made possible a prediction of the absorbed dose in silicon per unit incident photon fluence under equilibrium conditions as a result of irradiation by the particular radiation source used. Some of the facilities made measurements in both configurations. Most of the dosimeters were used to measure doses up to about 100 krad (Si) with only a few being exposed to higher dose levels.

6. COMMENTS FROM FACILITY PERSONNEL

A significant number of the facility staff interviewed expressed some dissatisfaction with their TLDs or readers and sometimes with both. Several mentioned that from five to ten percent of a large batch of TLDs gave responses as much as 50 percent different from the rest of the batch. This was true especially for the TLDs in a Teflon matrix, where the problem was thought to be caused by a non-uniformity of the TL powder-Teflon mixture. This same type of dosimeters also produced erratic readout results in some types of readers, apparently because of poor thermal contact with the heating planchet. Another difficulty observed with the Teflon-matrix type of TLD was the production of a greasy residue if the TLD was overheated during the readout cycle. When this occurred the residue was deposited on the optical surfaces in the reader and reduced the light received by the photomultiplier tube. Other difficulties mentioned include electronic instabilities in the readers in the form of drifts and sudden shifts in sensitivity or in temperature readings. As might be expected, facilities with heavy work schedules have had problems with mechanical and electrical failures of their TLD readers. When asked about the overall accuracy and reproducibility of their dosimetry measurements, some facility personnel did not attempt to estimate an overall accuracy, but felt that their reproducibility was about 5-10 percent. Others stated an accuracy and a reproducibility of about 10 percent.

7. OBSERVATIONS ON DOSIMETRY PRACTICES

A number of practices were observed during the survey that could have adverse effects on the reproducibility and/or the accuracy of the dosimetry results. These are summarized as follows:

(1) Lack of sufficient equilibrium build-up material around the TLDs, either during calibration (by γ-ray sources) or during irradiation (by flash x-ray beams). This may not be a serious problem in all cases, but the magnitude of this effect should be experimentally verified.

(2) Possible incorrect conversion from exposure (in roentgens) to absorbed dose (in rads) in the material of interest.

(3) Inadequate annealing techniques of TLDs such as poor temperature control of the annealing oven, erratic annealing periods, annealing periods that were too short, and erratic cooling rates.

(4) Poor control of heating and cooling rates during TLD readout caused either by erratic reader performance, or by inconsistent dosimeter-handling techniques during readout, or both.

(5) Lack of attention to elapsed time between irradiation and readout of TLDs with resultant lack of correction for fading of the response.

(6) Neglect of possible need for correction for nonlinearity of the TLD response at high doses.

(7) Exposure to UV light that can cause spurious responses or enhanced fading of TLDs (particularly CaF_2:Mn) used for low dose measurements.

8. RECOMMENDATIONS

Guidance is needed for workers in the radiation-hardness testing community on how to eliminate difficulties and inconsistencies in the measurement practices and procedures used for determining total dose. It has been decided that an efficient and effective way to do this would be through the voluntary consensus standards process in ASTM. With this goal in mind, work is underway to prepare (1) guidelines on how to use presently available TLD systems effectively, and (2) guidelines on how to calibrate photon sources which in turn are used to calibrate TLDs. In addition, plans are being made to study, on a pilot basis, the feasibility of developing a measurement-assurance program for the radiation-hardness testing facilities.

An approach needs to be developed to solve the "maverick" dosimeter problem. One possibility would be to obtain better quality control of both TLDs and their readers from the manufacturers of these products. This is of particular importance to facilities in which the TLDs are used only once and then discarded. Another possible solution would be the development of a simple 100 percent screening technique for large TLD batches. One possible configuration of such a screening technique would involve the calibration of every TLD in a batch and reuse only those found to have suitable responses. Still another alternative would be to avoid using the types of TLDs that have a "maverick" problem. Appropriate attention also should be given to developing automated handling-readout systems to the maximum extent possible for users of large quantities of TLDs.

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[3] Murray, K. M., "An Absolute Silicon-Dose Calorimeter," Nuc. Inst. Meth., 107, 109, 1973.

APPENDIX

Checklist of Questions asked in this Survey

A Name of test facility; mailing address.

- 1. Personnel contacted, phone number, their area of responsibility.

B. Radiation facility: characteristics.

- 1. Photons: γ-ray sources, make and model, if commercially made.
  - a. Physical surrounding of source during use (in lead or tungsten pig, open air, water).
  - b. Total activity of source.
  - c. Specific activity of source.
  - d. Geometry of source during use.
  - e. How are irradiations timed (including transit times).
  - f. Spectrum of source, if known.
- 2. Photons: x rays (bremsstrahlung) from linac, flash machine, other accelerator. Make and model of machine.
  - a. Energy of incident electron beam.
  - b. Spectrum of incident electron beam.
  - c. Material and thickness of x-ray converter target.
  - d. Spectrum of incident photon beam.
  - e. Pulse rate of beam.
  - f. Pulse width of beam.
  - g. Beam current (average, peak).
- 3. Electrons: linac, flash, other. Give make and model.
  - a. Energy of incident beam.
  - b. Spectrum of incident beam.
  - c. Pulse rate of beam.
  - d. Pulse width of beam.
  - e. If scattering foil is used, give material and thickness.
  - f. Beam current (average, peak).

C. Electronic devices or system being tested; give general description.

- 1. Location in radiation field.
- 2. General composition; high- or low-Z materials and their general location in box.
- 3. General dimensions of system.

D. Dosimetry employed.

1. Calibration of the radiation source.
    a. Person or organization that performed the calibration.
    b. Date of this calibration; the frequency with which the calibration is performed.
    c. Type of dosimeter(s) used; manufacturer.
    d. If calibration of dosimeter is required, describe how this is done.
    e. General description of geometry of dosimeter and source; any material around dosimeter.
    f. Description of environmental conditions during calibration.
    g. Give the specified dose (rate) or exposure (rate); quantity and units of specified dose; how obtained.
    h. Give material in which the dose (rate) was specified.
    i. Give specified accuracy of the calibration.
2. Routine dosimetry
    a. Personnel that perform day-to-day dosimetry measurements.
    b. Give type of dosimeter(s) used.
    c. If commercial equipment is used, give make and model.
    d. For pulse-type radiation, are dosimeters or detectors used to monitor all irradiations.
    e. If dosimeters are used in equilibrium material, specify material, thickness and geometry.
    f. If calibration of dosimeters is required, describe how this is done.
    g. Give units or quantitites of the dose specified and in which material.
    h. Observations on typical irradiation of the dosimeters: handling, environmental conditions, exposure to UV light, directional effects.
    i. Describe location of dosimeters in the radiation field and in relation to the devices being tested.

    - j. Observations on typical readings of the dosimeters; handling, TLD reader settings and behavior, length of time between exposure and readout.
    - k. Give reproducibility and accuracy of these routine measurements.
    - l. If TLDs are used, are they annealed and used repeatedly; anneal cycle; total number of times they are reused; total accumulated dose.

E. General Comments from Facility Personnel

1. What do they feel are problem areas in their dosimetry measurements?
2. What type of dosimetry standard would they like to see developed? What dosimetry system would be most useful to them?

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As part of a program to develop better quality assurance in the measurement of total dose in the field of radiation-hardness testing of electronic devices, a survey was conducted at twelve radiation test facilities. The survey was carried out through personal visits at which time various characteristics of the test facilities and dosimetry procedures were noted. This report summarizes the results of the survey. Particular attention is given to the types of dosimetry problems perceived by the dosimetry personnel at the facilities as well as to general observations by the surveyor.

The observations and information obtained through this survey led to some conclusions on where problems in total-dose measurements may occur. Some specific recommendations result and give direction to the program plan for developing more consistent measurement procedures within the radiation-hardness testing community.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Dosimeter calibration; electronic devices; ionizing radiation; radiation dosimetry; radiation hardness testing; radiation sources; thermoluminescence dosimeters; total dose.

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