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COMMON-SOURCE TLD AND RADFET CHARACTERIZATION OF Co-60, Cs-137, AND X-RAY IRRADIATION SOURCES

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Abstract

Dose enhancement and dose rate were measured in more than a dozen gamma sources using pMOS RADFETs and TLDs from two independent sources. ARACOR X-ray dose rates were calibrated using single- and dual-dielectric RADFETs.

This work was supported by the Defense Special Weapons Agency

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DISCLAIMER

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Dose enhancement and dose rate were measured in more than a dozen gamma sources using pMOS RADFETs and TLDs from two independent sources. ARACOR X-ray dose rates were calibrated using single- and dual-dielectric RADFETs.

For Review Purposes Only

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I. INTRODUCTION

A considerable amount of total ionizing dose testing is being conducted at low dose rates (< 1 mrad/s to 1 rad/s) in the study of recently-discovered low dose rate phenomena in bipolar linear microcircuits [1-5]. A number of different test facilities and test configurations are being used in such testing. For example, some commercial sources, such as J. L. Shepherd Co-60 and Cs-137 irradiators, employ a tunnel-like irradiation chamber with the source at one end. Dose rate is changed by a) varying the distance to the test object, b) placing an attenuator (typically lead) in the chamber between source and experiment and/or c) selecting a different source strength (depending on the particular source). In large room-type facilities, the additional space allows more flexibility in constructing attenuators and increasing the distances between source and experiments. The Atomic Energy of Canada Ltd. (AECL) Gammacell 220, on the other hand, has a relatively small, cylindrical test chamber that is surrounded by Co-60 rods; here dose rate can only be reduced by introducing a cylindrical attenuator around the test chamber.

A variety of methods are used by experimenters to determine the dose rate of a test. These include the use of thermoluminescent dosimeters (TLDs) and/or ionization chambers at or near the experimental location; initial/periodic source calibration (via TLD, ionization chamber, etc.) followed by estimation of dose rate at other distances from $1/r^2$ and source decay curves; and the use of calibration data/curves provided by the source manufacturer. Complicating the determination of actual dose rate within semiconductor test samples is the presence of dose enhancement, which varies widely among different test sources and test configurations [6-10]. Dose enhancement is attributed directly to the lower energy gamma photons that are scattered from room and chamber walls as well as from intervening material, fixtures, etc. Dose enhancement can be even more significant when testing at low dose rates where the lower energy, scattered gamma spectral component tends to become a larger fraction of the total gamma flux. This occurs as the intensity of direct (MeV) gamma components are reduced (via attenuators and/or by increased exposure distance) in comparison with the more constant intensity of the scattered background radiation [11].

A major concern whenever one compares test data obtained by different experimenters using different total dose sources is ensuring that the total dose scales are the same. Obviously, any errors in determining the dose rate of a test will result in corresponding errors in total dose. This can lead to serious misinterpretations of test data; for example, differences in the response of devices irradiated at different rates presumably to the same total dose might be incorrectly attributed to a dose rate effect if, in fact, the total doses are not the same.

The purpose of this study was to perform common-source TLD and RADFET dosimetry on various total dose irradiators being used in the study of low dose rate phenomena in bipolar linear devices under the DSWA enhanced low dose rate sensitivity (ELDRS) program. The overall objective of the work is to facilitate the accurate comparison of total dose data being obtained on common devices at different dose rates and in different sources.

During this work thirteen different gamma irradiation facilities that are being used in the low dose rate testing of bipolar technologies were characterized. In addition, calibration runs were made at a "pure" Co-60 source at the National Institute of Standards and Technology (NIST). The NIST B034 teletheraputic source has minimal associated low energy or scattered gamma radiation. An ARACOR X-ray source located at SNL was also evaluated. Some additional measurements are planned at other facilities.

II. DOSIMETRY

Two types of dosimeters were used in the study: standard CaF_2 TLD chips and p-channel MOSFETs or RADFETs. TLDs packaged in aluminum to ensure electron equilibrium were provided and read by both Sandia National Laboratories (SNL) and the Naval Surface Warfare Center (NSWC) -- Crane. The TLDs were calibrated against NIST standard sources and were used in determining gamma cell dose rates. Two types of RADFETs were also employed. Dual-dielectric RADFETs obtained from SNL [12] consisted of a 370 nm thermal oxide/310 nm nitride gate dielectric, a 500 nm p^+ poly Si gate electrode and a 950 nm low temperature thermal oxide (LTO) cap; these devices had a sensitivity of –2.5 mV/rad when irradiated with –20V gate bias. Single dielectric RADFETs, obtained from Radiation Experiments and Monitors (REM), consisted of an 850 nm SiO_2 gate dielectric and 500 nm of aluminum gate metal without any dielectric overlayer; the REM devices had a sensitivity of –10 mV/rad when irradiated with +20V on the gate (and other pins grounded) [13]. The SNL devices, packaged in conventional 16-pin, dual-in-line packages (DIPs) with removable lids, were used to obtain a measure of dose enhancement (DE). DE factors were determined by comparing threshold voltage shifts in samples with gold-flashed kovar lids to the shifts produced in the same samples with ceramic lids. ARACOR X-ray source dose rates were measured using both REM and SNL RADFETs in lidless packages. To ensure linearity with dose over the measurement range, RADFETs were typically exposed in 50 to 100 rad increments and replaced after their cumulative doses had reached the 500 rad to 1 krad regime. RADFET threshold voltages were measured to the nearest millivolt at drain currents of 90 and 160 μA using a REM p MOSFET dosimeter reader.

Gamma cell measurements were made with TLDs and biased RADFETs mounted on a fiberglass circuit board. Typically, two runs were made at each measurement point. The first run with 3 SNL TLDs, 3 NSWC TLDs and 4 RADFETs -- two with kovar lids and two with ceramic lids. A second run was made without TLDs and with the RADFETs in the same positions but with the lids reversed.

In the ARACOR X-ray dosimetry, the SNL and REM RADFETs were exposed in separate runs. However, when irradiating the REM devices, data were obtained simultaneously on two FETs per chip.

III. RESULTS AND DISCUSSION

Gamma source measurement results are summarized in Table 1, where the first column lists all of the sources characterized to date. Dose rate and dose enhancement data are provided for the various measurement configurations at the distance (source to test board) indicated in the second column. Measurements were made using the Pb/Al boxes commonly used at the facility being evaluated. Comparative measurements were sometimes made without the box in order to assess box effectiveness. No box was used at the NIST B034 source since no significant scattered gamma component was present. The three dose rate values listed in the table correspond to 1) that determined from NSWC TLDs, 2) that determined from SNL TLDs and 3) the target value determined independently by the source operator using locally standard methodology (i.e. calibration curves, ionization chamber measurement, etc.).

The highest DE factors of 2.3 - 2.4 were measured without the box at the RTI Room Co-60 source's lowest dose rate of 0.8 mrads/s; at this position (223 cm with 2-inch lead attenuator) there was a relatively high intensity of scattered background radiation as indicated by the effectiveness of the box in reducing both the DE factor as well as the dose rate. Other sources seen to be characterized by relatively large DE factors are the Shepherd Cs-137 irradiators (particularly at low rates when using attenuators) and the Gammacell 220 without attenuator. The dose rates determined at the various sources from NSWC and SNL TLD readings were generally reasonably consistent with the target values.

ARACOR X-ray dosimetry data are shown in Table 2. Here the rates determined from SNL and REM RADFET exposures are compared with the rates set by the machine operator using the manufacturer-supplied silicon photodiode. No corrections for interface dose enhancement or electron-hole recombination [6,10] have been made to these data.

Table 1: Gamma Source Measurement Summary

Source	Distance (cm)	Attenuator	NSWC/SNL/Target D.R. (mr/s)		RADFET D.E.	
			No Box	Pb/Al Box	No Box	Pb/Al Box
RTI Co-60	223	2" Pb	2.24/2.30/--	0.78/0.88/0.8	2.3-2.4	1.5-1.8
(Room)	223	None	10.5/12/--	7.9/9.2/9.0	1.6-1.8	1.09
	71	None	96.2/105/--	74.8/85.3/82	1.17-1.31	1.04-1.07
NIST Co-60[1]	100	None	96.6/99.6/92.2[2]		1.015	
(B034)						
PL Co-60	260	None		93.3/95.8/91.1		1.05
(Room)	80	None		850/950/922		1.04
PL Cs-137	29.6	× 8		1.12/1.06/1.01		1.3-1.4
(Shepherd)	24.3	None		12.1/11.2/9.44		1.17
NSWC Co-60	0.37 Ci @ 8.5	None		10.6/9.94/10		0.99
(Shepherd 81-22 w	3.7 Ci @ 8.5	None	91.1/--/--	79.0/68.1/100	1.04	0.98
484 tunnel)	1.5K Ci @ 64	2" Pb		103/105/100		1.18
	1.5K Ci @ 64	None		1100/992/1000		1.08
	3K Ci @ 6.6	None		~80E3/74E3/100E3		1.01
NSWC Co-60		1.5" Pb	~4.1E3/4.0E3/--		1.18	
(AECL 220 #1)		None	42E3/38E3/--	~28E3[3]	1.48	1.24
NSWC Co-60		None		~375E3[4]		1.22
(AECL 220 #2)						
SNL Co-60	33.5	None		91.6/84.1/100		0.99
(Shepherd 81-22)	106	None		457/418/440		1.04
SNL Cs-137	47	None		95.3/87.2/92		1.20
(Shepherd 89)	47	× 10		10.1/8.98/9.2		1.17
	47	× 100		0.810/0.743/0.92		1.29
SNL Co-60		None		88.9E3/74.4E3/74.6E3	1.50	1.26
(AECL 220)						
JPL Co-60 1	280	None		1.11/1.09/1		1.03[5]
(Shep 81-18 Room)						
[30 Ci 12/95]	87	None		11/10.4/10		1.07[5]
JPL Co-60 2	650	None	1.36 ×[3]	108/105/100	1.40	1.13[5]
(Shep 81-24 Room)						(1.20 upper,
[20 kCi 12/95]						1.06 lower)[5]
						1.01[6]
	195	None		1160/1130/1000		1.03[5]
	30.5	None		45.4E3/39.5E3/40E3		.99[5]
Hughes Co-60	78.6	2" -4" Pb		73.4/68.0/50		1.08
(Shepherd 81-22						
w 484 tunnel)	76-88	2" -4" Pb				1.21[7]
[8000 Ci 6/87]						
	92.9	None		790/768/900		1.02

1 Teletheraputic or "pure" Co-60 source with minimal scattered or low energy spectral component used for calibration.
2. 92.2 mrads/s ± 5% with 95% confidence.
3. Based on relative RADFET response.
4. Approximate -- short exposure + SNL TLD only.
5. Open-top box.
6. Box with top.
7. Board exposed edge-on.

IV. CONCLUSIONS

More than a dozen different gamma and X-ray sources being used in the study of low dose rate phenomena have been characterized in terms of dose enhancement factors and/or dose rates present within standard test configurations. Measured worst-case DE factors for gold-flashed kovar lids ranged from 1.0 (no enhancement) up to between 1.5 and 1.8 (50 to 80% dose enhancement) when using the recommended Pb/Al test enclosure. Dose enhancement tended to increase as dose rate was reduced by increasing the exposure distance and/or by using attenuators. The Pb/Al enclosure was found to be highly effective in reducing dose enhancement, as was the AECL Gammacell 220 Pb attenuator which completely surrounds the test object. As a result of the study, several recommendations/changes were made in the dosimetry and test practices of individual laboratories; these will be discussed in the paper. It is concluded from the study that valid comparisons of data obtained at different gamma and X-ray test facilities are possible provided that 1) proper allowances are made for dose enhancement, 2) recommended test configurations are employed and 3) careful dosimetric practices are followed.

Table 2: X-Ray Source Measurement Summary

Source	Energy (kV)	Set Rate* [rads(SiO_2)/min]	SNL RADFET [rads(SiO_2)/min]	SNL RADFET Δ(%)	REM RADFET [rads(SiO_2)/min]	REM RADFET Δ(%)
(SNL	20	16.7	14.5	(–13.0%)	14.9	(–10.6%)
ARACOR	20	278	234	(–15.8%)	253	(–9.0%)
4100)	30	278	200	(–28.0%)	232	(–16.5%)

* Assumes equilibrium dose (SiO_2) = dose (Si)/1.8.

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