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A DOSIMETRIC EVALUATION OF THE RADPAK™ USING MONO-ENERGETIC ELECTRONS AND PROTONS

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Abstract - **This paper presents the results of an evaluation of the Space Electronics Inc. RADPAK™ using electron and proton accelerators. 'RADFET' dosimeters were used as test vehicles in conventional and RADPAK™ packages to allow a direct comparison of absorbed dose with different shielding. Electron results are compared with the AE-8 space spectrum and proton results verified by transport calculations.**

I. INTRODUCTION.

The RAD-PAK™ is a specially fabricated package manufactured by Space Electronics Inc. and intended to provide radiation protection to semiconductor devices in the space environment [1].

So far, ground testing has been somewhat limited and confined to the functional performance of data sheet devices. Although this gives a good estimate regarding 'survivability', it does not provide quantitative data for comparison with modelling and prediction. In this programme we have used PMOS dosimetric transistors (RADFETs) over a wide range of electron and proton energies in order to properly characterize the RAD-PAK™ and relate its properties to the physics of radiation shielding.

II. TEST SAMPLES AND RADIATION SOURCES.

The RADFETs were prepared by NMRC, Cork, using the standard 400 nm oxide, unimplanted technology, developed under ESA contract. All the RADFETs used in this programme emanated from a single wafer (Wafer 3 Run 172) which had been extensively characterised for sensitivity, fading and temperature dependence as part of ongoing ESA/NMRC research. The zero-bias sensitivity of this batch is 50 mV/krad. Die were provided to Space Electronics Inc. for packaging in 28 pin Dual-in-line with a lid thickness of 53 mils or 1.35 mm (53 mil RP) and 16 pin Flatpack with a lid thickness of 35 mils or 0.89 mm (35-mil RP) using the RAD-PAK™ technology. Reference samples for comparison with the RAD-PAK™ were packaged in 14 pin CERDIP by Rood Technology, UK, and fitted with 28 mils or 0.7 mm silicon lids by NMRC. In order to test the effect of conventional 'add-on' shielding one of the NMRC packages was fitted with an additional 4 gold plated Kovar lids to provide an extra 48 mils or 1.2 mm shielding.

Proton irradiations were performed using the ESA sponsored Proton Irradiation Facility (PIF) at the Paul Scherrer Institute, Switzerland [2]. This comprises a dedicated beam line and user interface specifically designed for space proton simulation. Energies in the range 20-300 MeV may be achieved using local degraders under computer control. Dosimetry is by ionization chambers, scintillators and diodes. Proton exposures were performed at 22, 30, 52, 100 and 150 MeV.

Electron irradiations were performed using the LINAC at the National Physical Laboratory, Teddington, UK. This is a pulsed 3-20 MeV machine capable of delivering a wide range of dose rates. Dosimetry is by Faraday cup, reference standard calorimeter and diodes. Electron exposures were performed at 3, 5, 10 and 16 MeV.

The electron exposure board was arranged to carry three reference devices, three 53-mil RP and three 35-mil RP. One each of the 53-mil RP and 35-mil RP were arranged to have the bottom of the package facing the beam and one reference device was fitted with the extra Kovar lids. The proton exposure board was arranged to carry two reference devices, two 53-mil RP and two 35-mil RP. The leads of all devices were grounded during exposure.

Radiation exposures were performed using incremental doses, the same test samples being used throughout the programme. Exposure doses were :

Electrons.
3.01 kr at 3 MeV
2.44 kr at 5 MeV
3.01 kr at 10 MeV
46.0 kr at 16 MeV
43.1 kr at 150 MeV

Protons.
0.5 kr at 22.3 MeV
4.3 kr at 30.9 MeV
4.0 kr at 52.1 MeV
10.0 kr at 100 MeV

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The dosimetric parameter of a RADFET is the threshold voltage at a given drain current and the shift of threshold voltage under radiation is a measure of the absorbed dose. All threshold voltage measurements were made using a SILTECH RDR-100 instrument specifically designed for RADFET operations. The RDR-100 provides threshold voltage measurement at 40 and 90 micro-amps. The RADFETs used in this programme were calibrated in the ESTEC 'Gammabeam 150C', 1000 curie Co-60 facility with ion chamber dosimetry.

III. EXPERIMENTAL RESULTS.

The results are shown graphically in Fig 1 for proton exposures and Fig 2 for electron exposures. Both figures show the normalized dose received by the RAD-PAK™ RADFET expressed as a percentage of the dose received by the reference RADFET.

The proton response shows the shielding effectiveness of the RAD-PAK™ at low energies - then an increase in dose compared to the reference which we ascribe to the energy loss in the RAD-PAK™ lid producing transmitted protons of higher stopping power. This effect is reduced at 100 MeV and 150 MeV which may be expected as proton stopping power does not vary as greatly at these energies.

The electron response shows the shielding effect of the RAD-PAK™ with the expected difference between 35-mil and 53-mil RAD-PAK™. The additional Kovar lids on one of the reference devices would appear to be effective only below 3 MeV. All metal lids (the two RAD-PAK™ configurations and the Kovar spot-shielded package) show an increase in absorbed dose compared with the reference device over a certain range of electron energies, probably due to generation of bremsstrahlung in the higher-Z materials. Fig 3 shows the difference in electron response between the bases and the lids of the RADPAK™ , the bases being significantly thinner than the lids.

IV. ANALYSIS.

Unfortunately this programme did not allow detailed analysis of the RADPAK™ construction. Consequently it is not possible to analyze the data in the form of g/cm^2 shielding which would have allowed a more direct comparison of results. Some indication can be gained however from the fact that a standard 28-pin Dual-in-Line package with a Kovar lid weighs 4.8 g. whereas the equivalent RADPAK™ weighs 13.5 g.

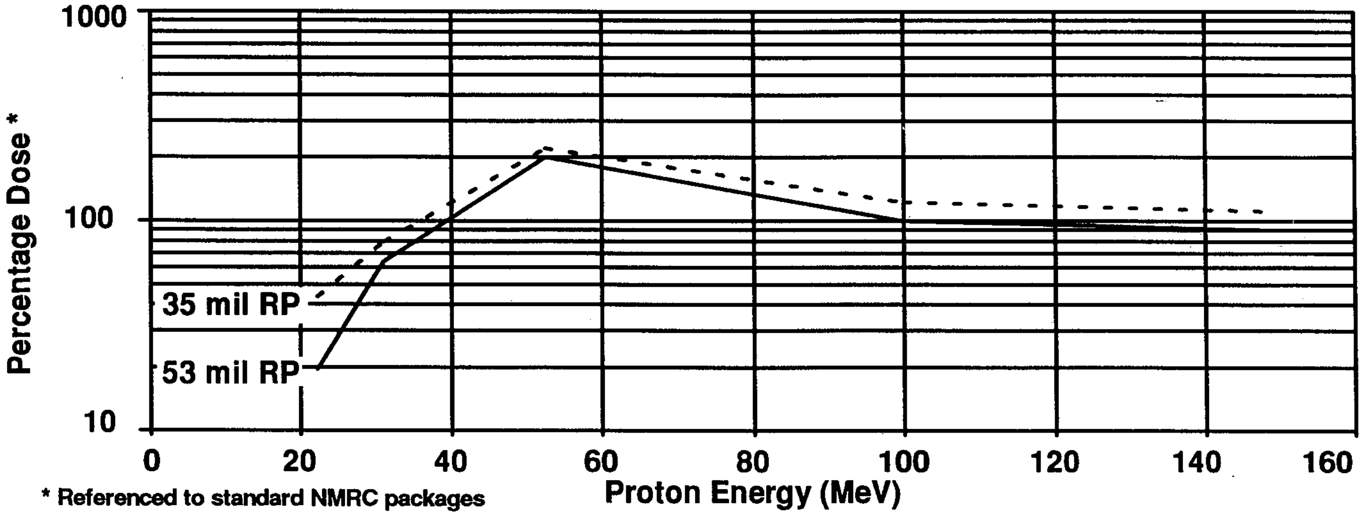
In order to understand and verify the experimental observations described above, limited radiation transport analysis was performed on the packages used in this study. This analysis demonstrated that the qualitative explanations given in the previous section were essentially correct, but also showed that experimental data taken at monoenergetic energies and normal incidence must be interpreted with care, since these results may not be indicative of the effectiveness of the packages in actual space applications where a spectrum of electrons and protons are encountered and the radiation impinging on the satellite is, in general, isotropic.

Proton analyses were performed as a function of incident proton energy, package material and thickness. Figures 4 and 5 show the result of these analyses. Fig 4 shows the calculated dose in the 400-nm RADFET oxide as a function of incident proton energy and package material. In this figure it can be seen that no dose is deposited in the oxide following transit of the Si reference package lids until proton energies of approximately 10 MeV are reached. Below this energy the protons stop in the package lid. Above this threshold energy the dose rises very rapidly, reaches a peak and then falls as the energy increases. The same general curve shape occurs for the RAD-PAK™, the threshold energy being 25 and 35 MeV for the 35-mil and 53-mil RPs respectively. Fig 5 shows the relative dose in the oxide for the two RAD-PAK™ configurations normalized to the dose seen in the reference package (28 mils silicon). The relative dose, as a function of incident proton energy, is defined as Dose(RP)/Dose(Ref), where Dose(RP) is the oxide dose following transport through the RAD-PAK™ lid and Dose(Ref) is the oxide dose after transport through the silicon lid of the reference package. It can be seen that an enhancement of the relative dose is seen for energies above approximately 25 MeV, then falling to near unity for higher proton energies. This agrees qualitatively with the experimental data shown in Fig 1. These data can be clearly understood by examining mechanisms that produce this enhancement and the 'spiking' seen in both figures.

Three cases occur that explain the experimental observations and the analyses. These are (1) the protons stop in the lids of both packages, thereby producing no dose in the chip, (2) the protons stop in the RAD-PAK™ but penetrate the reference, therefore producing a dose ratio of zero and (3) the protons traverse both packages, producing a dose ratio dependent on the incident proton energy. For the cases where the protons traverse the package lid, they lose energy during transport through the lid material and reach the chip with lower energy than the initial energy. From Fig 4, these three cases correspond to the following energy ranges :

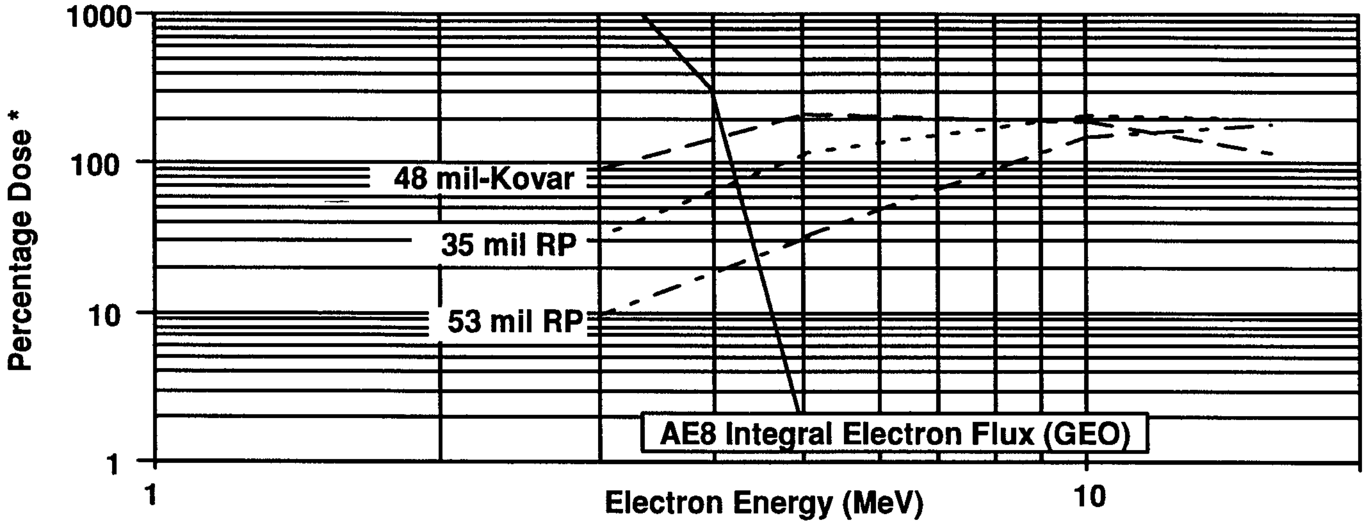
Case 1	$E_p < 10$ MeV
Case 2	10 MeV $< E_p <$ 25-35 MeV
Case 3	$E_p >$ 25-35 MeV

In case 3, since the stopping power increases with decreasing energy, higher dose is deposited in the chip oxide layer than would be seen for the incident proton energy. At some energy and package thickness, the proton energy is degraded to an energy corresponding to maximum stopping power (dE/dx). For this case the proton just gets through the package and deposits a high dose in the chip. This effect produces the 'spikes' seen in Figs 4 and 5. This also produces the relatively high dose ratio near 25-35 MeV for the RAD-PAK™. In this case, a 25 MeV proton loses approximately 2-3 MeV in the silicon reference package, interacting with the chip with 22.5 MeV, whereas the protons lose almost all their energy in the RAD-PAK™, and interact with the chip with only a few MeV (such that the dE/dx value is near the peak of the dE/dx vs Energy curve). This accounts for the 'spiking' seen in Fig 5, and the factor of 2 enhancement in the dose ratio seen in Fig 1. It should be mentioned that the transport calculations simply integrate over the proton stopping power curves, and do



* Referenced to standard NMRC packages

Fig. 1. Proton Irradiation



* Referenced to standard NMRC packages

Fig.2. Electron Irradiation

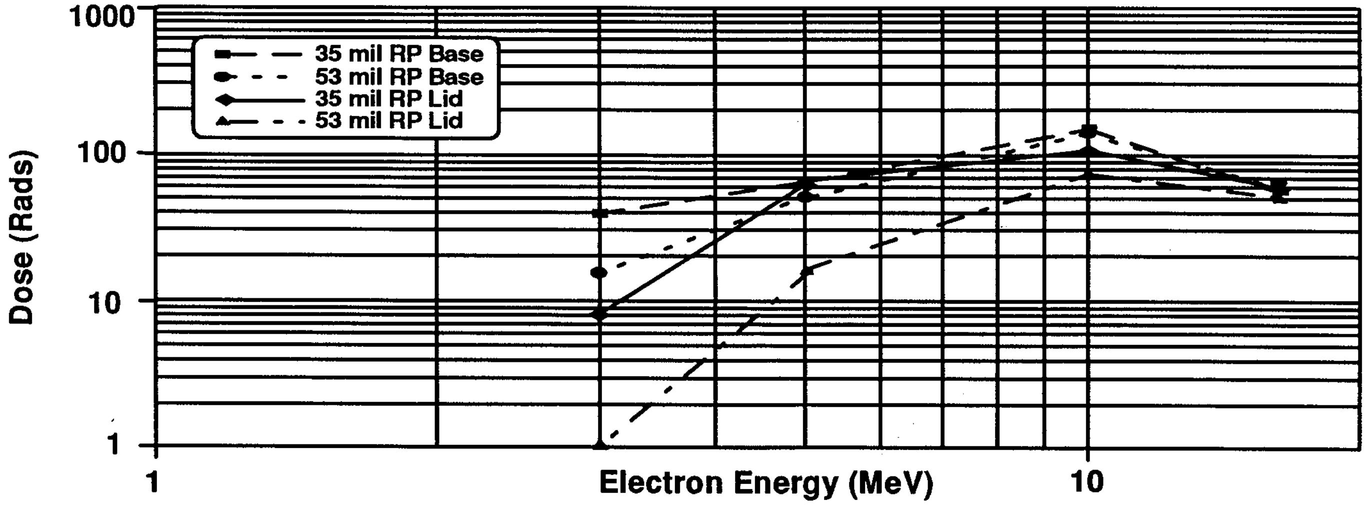


Fig.3. Electron Irradiation of Radpak™ Lids & Bases

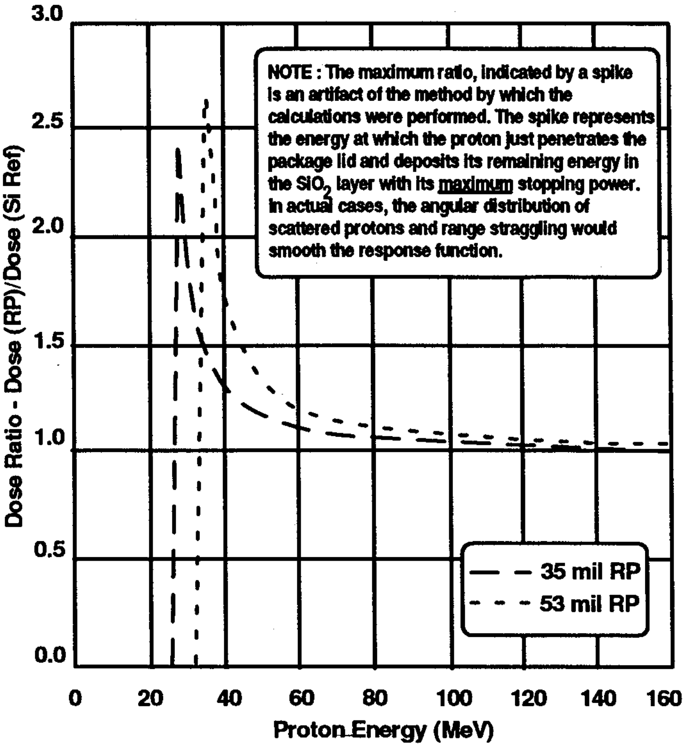


Fig.4. Relative Dose in RadPak versus Silicon Reference Package

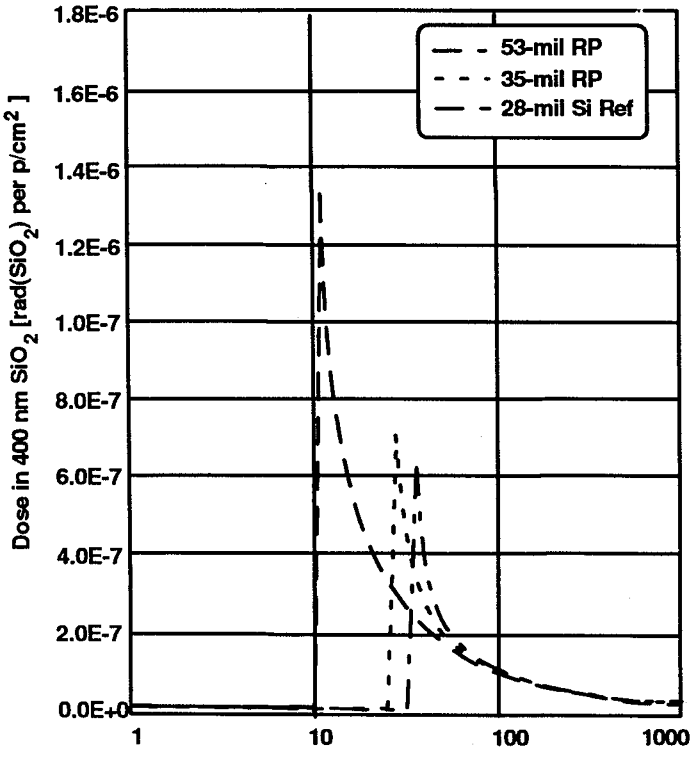


Fig.5. Dose in SiO$_2$ Layer (400 nm) After Traversing Package Lid

not consider either multiple scattering or range straggling. If these effects are incorporated into the analysis, the 'spikes' shown in the figure would be broadened and the peak values would better match the experimental data.

No specific simulations were carried out for electron exposures since this requires detailed knowledge of the multilayer composition and construction. In any case, such simulations are outside the scope of this paper. However, qualitative inspection of Fig 2 and comparing the RAD-PAK™ response with the AE-8 integral electron flux shows that the RAD-PAK™ should be highly effective in this environment.

V. CONCLUSIONS.

This paper has presented mono-energetic electron and proton data using both Space Electronics Inc RAD-PAK™, standard packages and standard packages with spot shielding. The proton data have been validated by analysis and agreement is relatively good over the range of energies and package configurations used. The RADPAK™ would appear to be highly effective in an electron dominated environment, without extensive simulations the potential advantages in a proton dominated environment are not so clear (as might be expected). The data were obtained using mono-energetic and normally incident radiation and allows a comparison of shielding effectiveness under those specific conditions.

The RADPAK™ is a complex multi-layer structure and the space environment is omni-directional and covers a wide spectrum of energies, hence the results of these experiments cannot be used to perform orbital predictions. It should be noted that the shielding from the lid and the base is different and this needs to be taken into account when performing sector analysis. A delicate balance must be maintained between the confidentiality of a commercial product such as the RADPAK™ and the needs of an end user such as a space equipment contractor. The manufacturer wishes to protect his investment in developing the product but the user needs to know a significant amount of detail in order to perform orbital simulations. A useful output of this program has been the recognition of the importance of adequate shielding data for the user and, to this end, discussions are now under way for the incorporation of the shielding characteristics of the RADPAK™ into 'SPACE RADIATION' (Severn Communications Corporation) without revealing too much proprietary data.

VI. ACKNOWLEDGEMENTS.

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VII. REFERENCES.

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