RADIATION MEASUREMENT AND RESEARCH FOR SPACE APPLICATIONS AT THE NATIONAL PHYSICAL LABORATORY

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Abstract

The electron linear accelerator at the National Physical Laboratory can be used to simulate the space environment for radiation testing of electronic components. This paper describes the accelerator facility and gives examples of the work carried out in this field in recent years.

I. Introduction

Over recent years there has been increased interest in accurate dosimetry for space applications. It is important to know, when a multi-million dollar satellite is launched, that it will not fail during its projected lifetime. Earth orbit is a harsh environment with a variety of radiation fields (photon, electron, heavy charged particles) and electronic components must be able to survive this bombardment for many years. It is therefore important to be able to simulate this environment on the ground so that components can be tested prior to launch.

The electron linear accelerator (LINAC) at the National Physical Laboratory can be used to simulate the typical electron spectrum found in satellite orbits. This paper describes the accelerator in detail and describes work carried out in radiation testing for space applications.

II. The NPL LINAC Facility

This LINAC is a versatile research accelerator designed to operate in electron or photon modes over a wide range of energies and dose-rates, although electrons are generally used for radiation testing. There are two irradiation rooms where measurements can be carried out (see Figure 1). Using a bending magnet the electron beam can be steered through an angle of 270˚ from the accelerator room into the main irradiation room. This room has good temperature control and allows entry with the accelerator in standby mode. By varying energy, dose-rate, pulse width, pulse repetition frequency it is possible to produce the required radiation field.

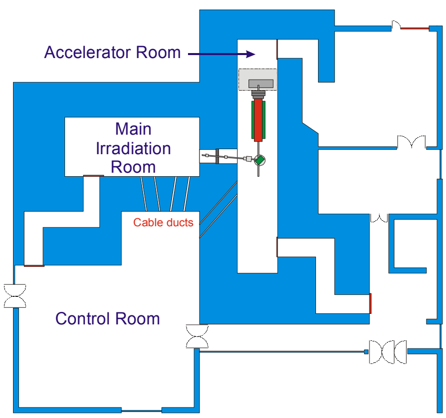

Figure 1: Plan of accelerator facility

Electron energies in the range 3 to 19 MeV are available. Lower electron energies can be achieved by introducing material at the exit window to degrade the beam. The electron beam has a low x-ray contamination although it is possible to increase the contamination by way of high-Z foils. The spectral width (FWHM) of the electron spectrum can be as low as 1.5% of the mean energy, although this increases at lower electron energies to around 4% at 4 MeV. However, by "detuning" the accelerator one can generate a much broader spectrum, with a width of up to 11% of the mean. This is shown in Figure 2 compared to a narrow electron energy spectrum.

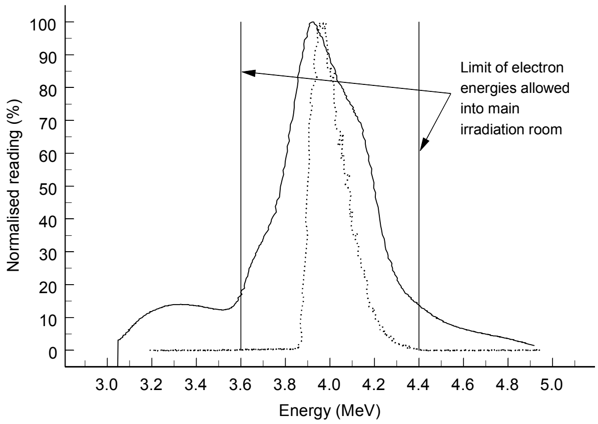

Figure 2: Typical wide and narrow energy spectra from LINAC

The electron dose-rate can be varied over a very wide range, from radiation protection levels up to industrial processing levels (that is mean dose rates of less than 0.1 Gy/min to greater than 40 kGy/min, equivalent to 10 rad/min to 4 Mrad/min, with instantaneous dose-rates from ~2×10^0 to 6×10^7 Gy/s). The range of dose-rates is achieved by varying the beam pulse repetition frequency (from 10 to 360 Hz), the electron pulse width (from 50 ns to 3 μs), and the electron pulse current (up to ~400 mA). The accelerator can also be operated in single-shot mode in, for example, testing semiconductor devices for aerospace applications. Beam uniformity can also be varied, depending on the field size and dose-rate required, by use of different scattering foils. An example of the measured beam uniformity for 10 MeV electrons at a source-to-surface distance of 1 m for a double scattering foil arrangement is shown in Figure 3, along with the measured beam uniformity for a single scattering foil arrangement. These were measured by scanning an ionization chamber horizontally across the electron beam and simultaneously recording the chamber's position and output current. The use of the double scattering foil allows the maximum mean dose-rate to be increased to around 50 kGy/min.

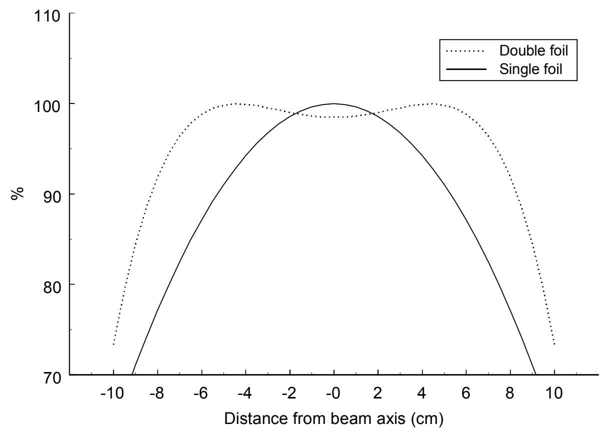

Figure 3: Beam uniformity for different types of scattering foil

The main irradiation room is 5 m x 3 m x 3 m giving scope for very large field sizes. For high dose applications, field sizes are limited to 20 cm x 20 cm. The field size can also be adjusted by the use of lead and graphite collimators (for instance, to protect sensitive equipment). The equipment to be irradiated is placed on a remotely controlled table which can be moved in three dimensions. All irradiations are carried out in-air making it simple to set up experiments and resulting in small down-times between irradiations. Direct cable access to the irradiation room (via 3 m long ducts through the accelerator's shielding) allows the possibility of on-line measurements and/or the powering of devices during irradiation.

III. Dosimetry

Accurate dosimetry (traceable to national standards) is provided by a combination of calorimeters, ionisation chambers and dose diodes. This work is supported by a theoretical service making extensive use of Monte Carlo techniques (EGS4 and MCNP4B) to model radiation fields and detector responses precisely. For example, Figure 4 shows a

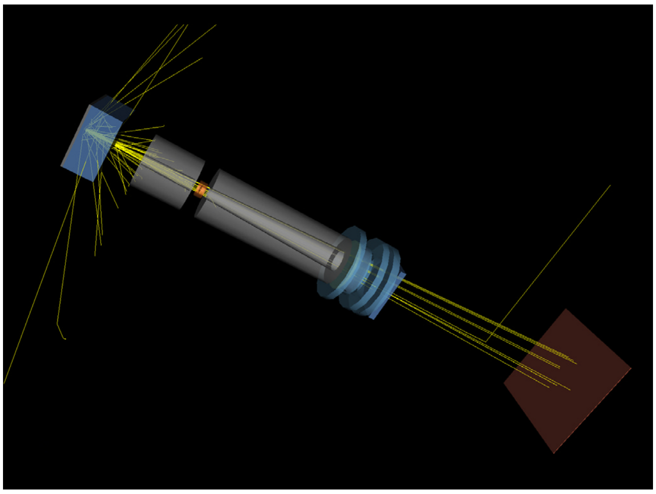

Figure 4: Monte Carlo model of a section of the NPL linear accelerator

simulation of part of the NPL linear accelerator. A schematic representation of the geometry is shown, including the target, collimators, beam flattening and additional filters. Electrons are shown in green, photons in yellow and positrons in red.

The primary standard for high energy electrons (3 to 19 MeV) is a graphite calorimeter. This has been described in detail by Burns et al [1,2] and is shown schematically in Figure 5. It consists of a graphite core and surround encapsulated in

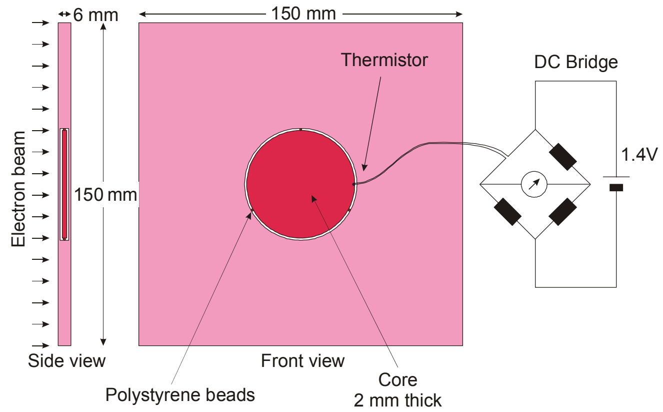

Figure 5: Schematic diagram of the primary standard electron beam calorimeter

expanded polystyrene for environmental isolation. The temperature sensing element is a thermistor in a DC Wheatstone bridge, with a resolution of 10 μK. Dose-rates down to ~5 Gy/min and doses down to 0.7 Gy can be measured with an estimated uncertainty of ±0.5% at the 95% confidence level.

A typical calorimeter run is shown in Figure 6. Conversion from graphite to some other material (e.g. water, silicon) is by way of calculated stopping power ratios. This introduces an added uncertainty of around 1.5% although work is in progress to reduce this uncertainty.

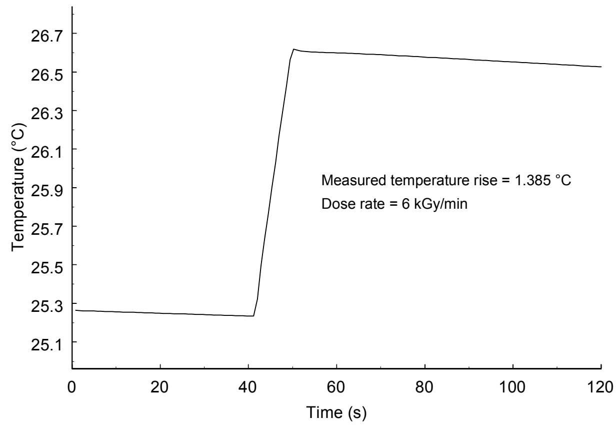

Figure 6: Typical high dose calorimeter run

Dose diodes can be calibrated against the primary standard. These are used in single-shot experiments and where the devices to be irradiated are small compared to the calorimeter. Diodes can also be used to produce dose maps of large experimental jigs, where dose variation with position in the jig can be significant. For example, the dose profile of the jig shown in Figure 7 was mapped by diode dosimetry. The results (see Figure 8) show a marked variation in dose across the front of the jig. It is important therefore when designing a test jig to take into account the radiation scattering properties as well as its electrical characteristics.

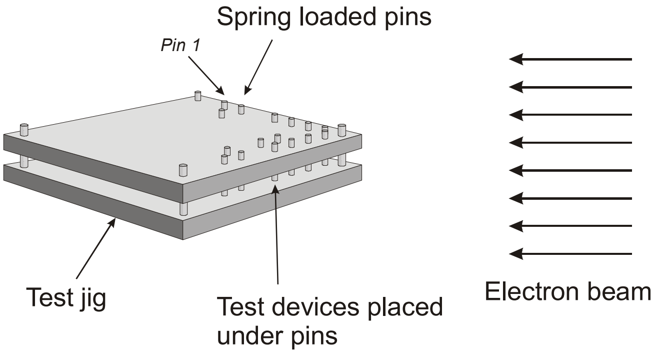

Figure 7: Dose mapping of test jig

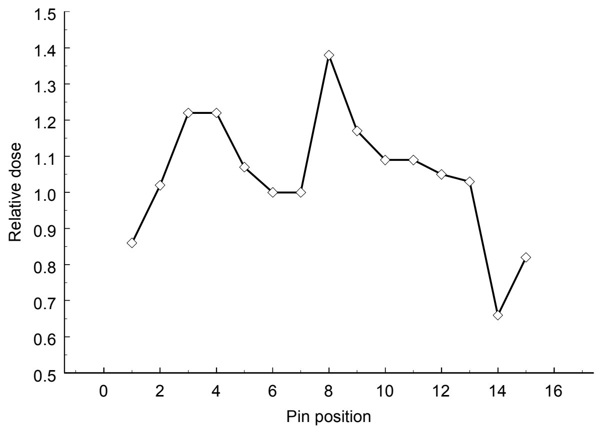

Figure 8 Dose mapping results

For calibration of diodes at low dose-rates (less than 10^4 Gy/s), an ionization chamber, previously calibrated against the calorimeter, is used. This two stage process does not add any significant uncertainty to the calibration.

Monitoring of the electron beam during irradiations is by way of a toroidal current transformer (Williams et al [3]) or transmission ion chamber, depending on the dose-rate. The toroidal monitor system also allows the measurement of individual pulses. Although the accelerator is generally very stable, variations in beam current of the order of 10% are possible over a whole day. Calibration of the monitor system is therefore carried out before and after the irradiations.

IV. Irradiations

Recent testing work for space applications includes:

1) Quality assurance testing for semiconductor device manufacturers. The irradiations were tailored to the particular test jigs used and dose diodes were used to provide accurate dosimetry. Diodes are ideally suited to the dosimetry of discrete components since they are of a similar size and can be used to plot dose distributions within the test jigs. This type of testing allowed the manufacturer to be accredited by ESA (European Space Agency) for the supply of electronic components.

2) In 1995, the NPL LINAC was used for evaluating the Space Electronics Inc. RADPAK™ radiation protection device in electron beams. RADFET dosimeters were used as test vehicles in conventional and RADPAK™ packages to allow a direct comparison of absorbed dose with different shielding [4]. Figure 9 and Figure 10 show the results of the electron beam tests.

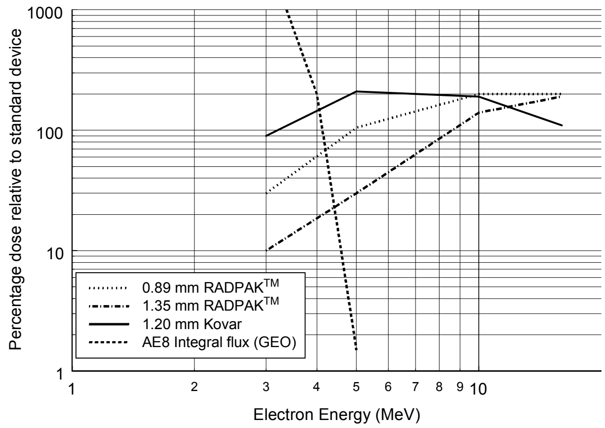

Figure 9: Relative shielding properties of RADPAK™ and standard packaged devices

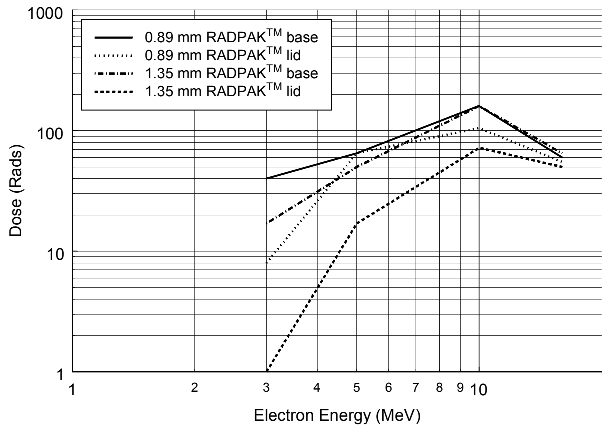

Figure 10: Variation in shielding properties of lid and base of RADPAK™ packaged devices

3) In 1996, the accelerator was used to confirm shielding calculations made using the NOVICE code for electronic devices. A variety of devices with various levels of shielding (single and multilayer) were irradiated and tested [5].

V. Conclusion

Accurate measurement plays a vital role in ensuring the successful operation of spacecraft and supporting instrumentation. In addition to the linear accelerator facility described in this paper, there are a number of other radiation facilities operated at the National Physical Laboratory suitable for radiation testing: X-ray sets, Co-60 sources, neutron field generators - together with material characterisation facilities covering the EM spectrum (microwave, infrared, UV).

VI. Acknowledgements

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VII. References

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