Response to the proposed new requirements for radiation testing

V. Horvat

New government regulations may soon be put in place, requiring that all silicon-based devices to be used in long space-flight missions pass radiation tests at the linear energy transfer (LET) of 75 MeV·cm^2/mg, according to the recommendations from the Aerospace corporation [1]. The Cyclotron Institute's Radiation Testing Facility (also referred to as SEE-line) offers several beams that can meet this requirement. However, only a few of them can be used at normal incidence. Measurements at incidence angles θ other than zero degrees are optional for these beams, but for the other beam candidates they are necessary in order to qualify.

Since LET values change as the beam penetrates the substrate, the quantity of interest here is the depth interval Δz over which the effective LET value (L_e) is greater than or equal to 75 (in the standard units specified above). Another relevant quantity may be L_e^{max}, the maximum value of L_e reached within the depth interval Δz.

The results presented here are obtained under the assumption that the beam passes through a 1 mil thick aramica window and 3 cm of air before hitting a bare silicon substrate. If under these conditions the value of L_e at the surface of the substrate at normal incidence is less than 75, it is assumed that aluminum degraders (and/or some other layers of material) are set so that the value of L_e at the surface of the substrate is exactly 75.

For each beam and for each incidence angle the effective LET as a function of depth must be calculated in order to determine the corresponding value of Δz. Results of these calculations, obtained using our SEUSS software [2], are shown in Fig. 1 for the case of 15 MeV/u ^{165}Ho beam at normal

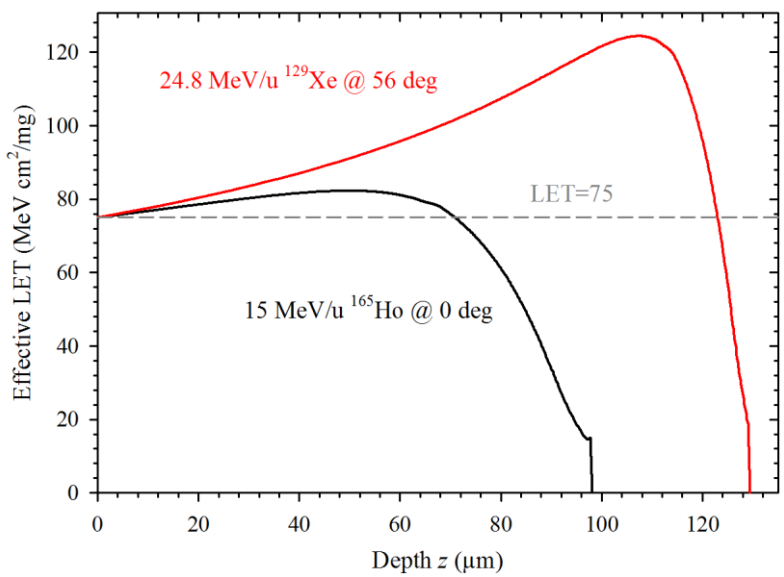

Fig. 1. Effective LET in silicon plotted against the penetration depth, for two of the standard beams used in radiation effects testing at the Cyclotron Institute. The effective LET values are expressed in the standard units of MeV·cm^2/mg. For the holmium beam it was assumed that the beam energy is slightly reduced so that the effective LET value at the surface of the substrate equals 75.

incidence and for the case of 24.8 MeV/u ^{129}Xe beam at $\theta = 56^o$. From these results we find that for the holmium beam $\Delta z = 71$ µm and $L_e^{max} = 82$, while for the xenon beam $\Delta z = 120$ µm and $L_e^{max} = 124$.

Table I shows the values of Δz and L_e^{max} for the standard SEE-line beams that can be used at normal incidence. Note that L_e of the gold beam at the surface of the substrate is greater than 75 and that it can be lowered only by increasing the beam energy, which is not a viable option. Therefore, any additional dead layers present above the surface of the substrate and any increased air gap would reduce the listed value of Δz.

Table I. Depth interval (Δz) in which the LET values stay at or above 75 and the maximum LET value within that interval (L_e^{max}), for the standard SEE-line beams at normal incidence. Note that for the ^{197}Au beam the LET value at the surface of the substrate is 83, exceeding the value of 75.

Beam	Δz (µm)	L_e^{max} (MeV·cm^2/mg)
15 MeV/u ^{165}Ho	71	82
15 MeV/u ^{181}Ta	94	88
15 MeV/u ^{197}Au	98	94

Table II shows the corresponding results for these and other beams used at angles θ such that the value of Δz is maximized. In the general case, provided that L_e at the surface of the substrate at normal incidence (L_o) is less than 75, $\theta = \cos^{-1}(L_o/75)$. Otherwise, the best solution corresponds to $\theta = 0$. The listed value of Δz is reduced if any additional dead layers are present above the surface of the substrate and/or the air gap is increased. Consequently, if L_B is the value of L_e at the Bragg peak, then $L_e^{max} = L_B / \cos\theta = 75\, L_B / L_o$.

Table II. Depth interval (Δz) in which the effective LET values stay at or above 75 and the maximum effective LET value within that interval (L_e^{max}), for the standard SEE-line beams at the angle of incidence θ that maximizes Δz, provided that θ does not exceed 60°.

Beam	θ (deg)	Δz (µm)	L_e^{max} (MeV·cm^2/mg)
15 MeV/u ^{109}Ag	53	56	99
15 MeV/u ^{129}Xe	41	67	93
15 MeV/u ^{141}Pr	35	70	87
15 MeV/u ^{165}Ho	15	85	85
15 MeV/u ^{181}Ta	4	95	88
15 MeV/u ^{197}Au	0	98	94
25 MeV/u ^{129}Xe	56	120	124

[1] G. Johnson-Roth, Aerospace Report No. TOR-2011(8591)-21, pp. 14; https://s3vi.ndc.nasa.gov .
[2] https://cyclotron.tamu.edu/vladimir/SeussW-Download.htm .