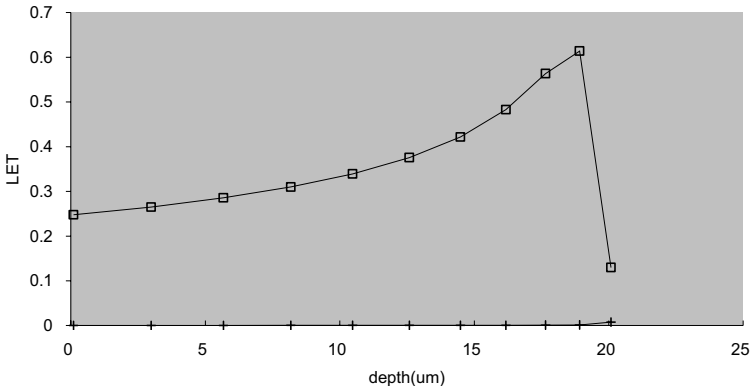


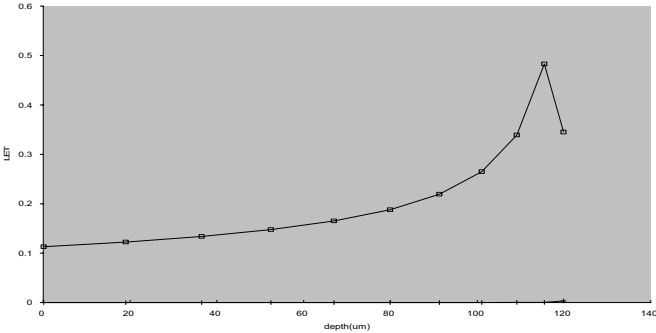
Radiation Tolerance and Shielding

Properties of Liquid Crystal Polymers (LCP)

Linear Energy Transfer (LET) of High Energy Protons in LCP

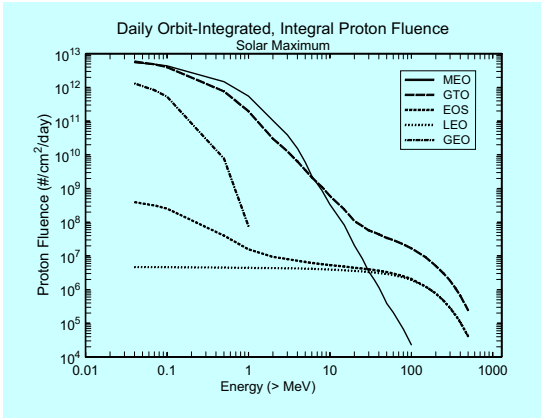


LET as a function of depth for 1 MeV protons in Vectra LCP.



LET as a function of depth for 3 MeV protons in Vectra LCP.

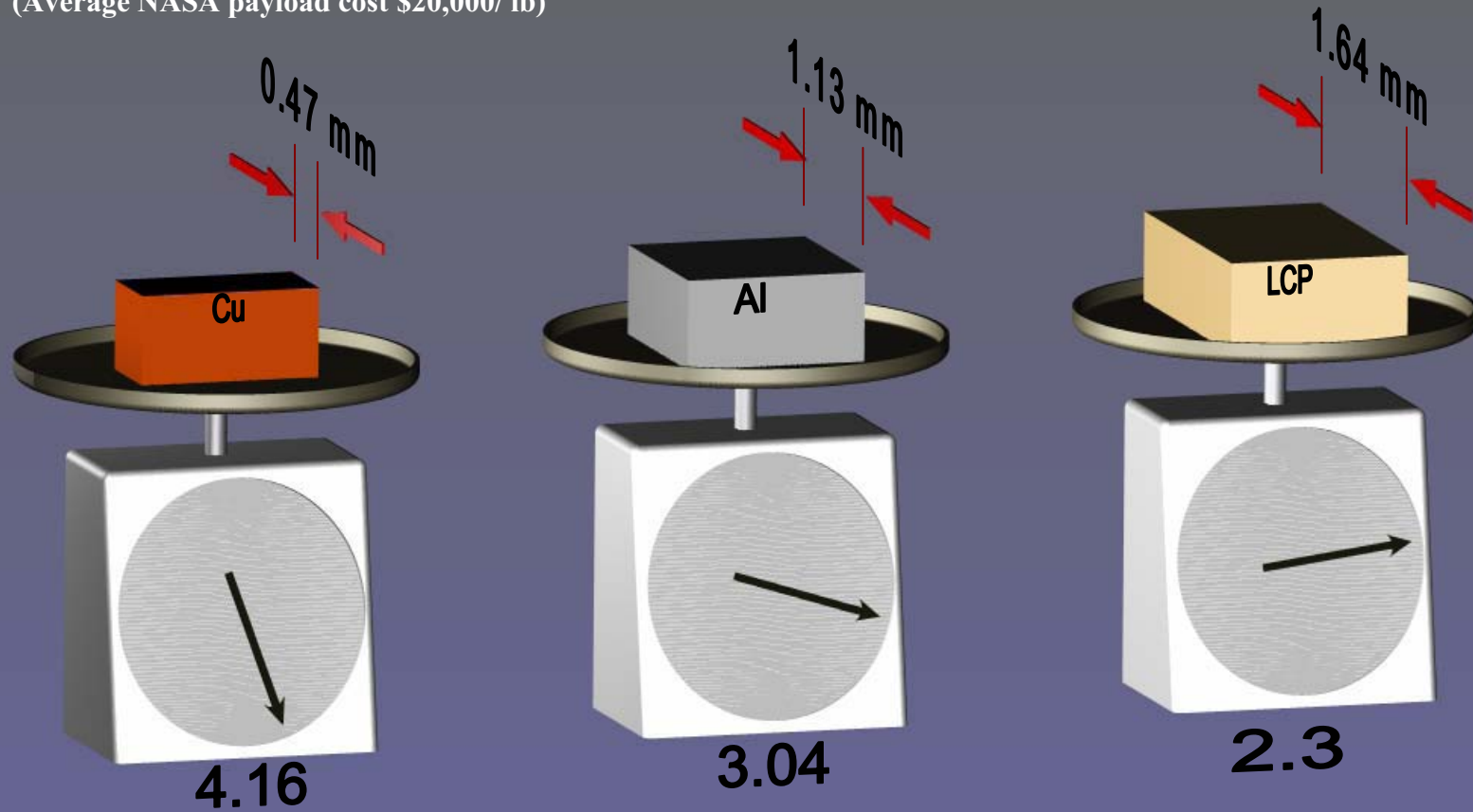
| Proton Energy, MeV | Fluence in MEO (#/cm ² /day, Barth, 1997) | Range in Vectra LCP (μm) | Range in Copper (μm) | Range in Aluminum (μm) | Range in PET (μm) |
|--------------------|--|--------------------------|----------------------|------------------------|-------------------|
| 10 | 10 ⁹ | 1640 | 468 | 1127 | 1574 |
| 5 | 10 ¹⁰ | 468 | | | |
| 1 | 10 ¹² | 29 | | | |
| 0.1 | 10 ¹³ | 1 | | | |



Source: Linden Photonics calculations using models developed by Dr. Barney Doyle, Sandia Laboratory.

Range of 10 MeV Protons in Copper, Aluminum and LCP and relative weights for equivalent shielding power

(Average NASA payload cost \$20,000/lb)



Source: Linden calculations using models developed by Dr. Barney Doyle, Sandia Laboratory

**Tensile modulus and strength
of LCP before and after exposure
to 1 Mrad proton radiation**

| Non-irradiated Sample | Young's modulus (psi) | Yield Stress (psi) | Area (sq in) |
|-----------------------|-----------------------|--------------------|--------------|
| 1 | 1006953 | 34651 | 0.00241 |
| 2 | 1059685 | 26121 | 0.001612 |
| 3 | 1146953 | 27002 | 0.00137 |
| 4 | 959259 | 39352 | 0.001512 |
| 5 | 1247600 | 47291 | 0.001827 |
| AVG | 1084090 | 34883 | |
| Irradiated Sample | Young's modulus (psi) | Yield Stress (psi) | Area (sq in) |
| 1 | 1351201 | 34123 | 0.001108 |
| 2 | 1376967 | 25358 | 0.001727 |
| 3 | 1614286 | 31718 | 0.001176 |
| 4 | 1642940 | 42163 | 0.001008 |
| AVG | 1496348 | 33340 | |

**Table 4.4.1 Cobalt 60 radiation
Vectra A950 (% retention of properties)**

| Radiation Dose | 250 Mrads | 1,000 Mrads | 2,500 Mrads | 5,000 Mrads |
|----------------------|-----------------------------|---------------|-------------|-------------|
| Tensile strength(1) | 97 | 95 | 95 | 95 |
| Tensile modulus(1) | 100 | 100 | 106 | 106 |
| Break elongation(1) | | 81 | 81 | 79 |
| Flexural strength(2) | 101 | 102 | 102 | 102 |
| Flexural modulus(2) | | 108 | 108 | 116 |
| HDT @ 1.82 MPa(3) | 100 | 100 | 100 | 94 |
| | (1) ASTM D638 (2) ASTM D790 | (3) ASTM D648 | | |

**Table 4.4.1: Artificial weathering, 2000 hrs.(ASTM D2565 –
xenon arc lamp, air temp. 125° C, water spray for 18 mins.
Every 200 min.(% retention of properties)**

| | Vectra A950 | Vectra A130 |
|----------------------|-------------|-------------|
| Tensile strength(1) | 95 | 95 |
| Tensile modulus(1) | 90 | 98 |
| Flexural strength(2) | 95 | 95 |
| Flexural modulus(2) | 95 | 95 |
| HDT @ 1.82 MPa(3) | 90 | 92 |
| Notched Izod(4) | 90 | 95 |

Source: Linden Photonics experiments at Sandia Laboratory as part of the Phase 1 effort