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Dose Deposition and Electrostatic Charging of Kapton Films Irradiated with Electrons

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Abstract

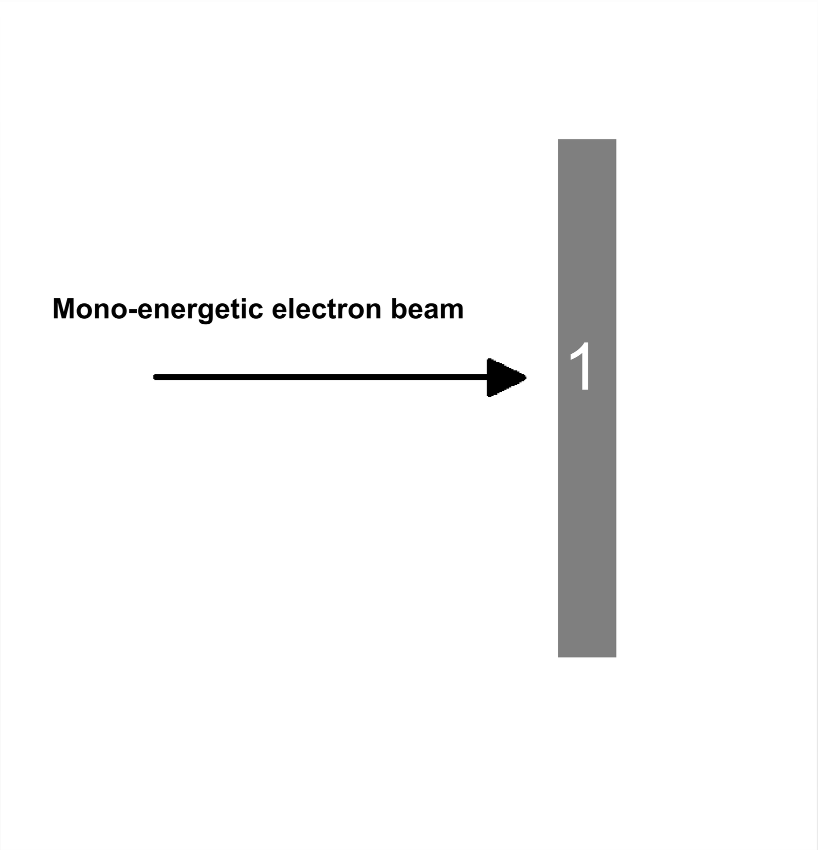
Kapton films are widely utilized in harsh radiation environments where radiation resistant insulating materials are required. For space applications, Kapton polymers are used on satellites as substrates for solar arrays and outer layers of thermal systems. Kapton is also used in nuclear power plants as wire insulation. Kapton materials can be exposed in nuclear reactors to a reactive chemical environment in addition to severe radiation. It is of utmost important to understand how Kapton materials behave under high irradiation conditions and mitigate radiation damage effects. High-energy electrons can deposit ionizing dose and electric charge deeply inside Kapton materials. The charge accumulation grows over time and may exceed the dielectric strength of Kapton resulting in the electrostatic discharge that may cause extensive material damage. The dose deposition and electrostatic charging of Kapton irradiated with electrons has been studied using the Monte Carlo stepping model implemented in the Geant4 software toolkit. The secondary radiation emission (photo-, Auger-, Compton-electrons, and fluorescence photons) generated by primary electrons is taken into account in the redistribution of dose and charge deposition within a Kapton film. The results of this study are the profiles of dose and charge deposited by primary and generated secondary electrons and photons within a thin film of Kapton as a function of its depth. The results also provide insights into distributions of dose and charge in Kapton films under various incidence angles and energies of electrons.

Background and Motivation

- **radiation interacting with the Insulation materials :** electrons, gammas and protons
- **energetic electrons:** the ones with energy below 1 MeV
- **source of electrons:** a nuclear explosion above the earth atmosphere in a vacuum
- **high energy electrons:** deposit charge in the insulation materials which accumulates to produce deep electrostatic discharge
- **energy of electrons:** 100 keV, 300 keV and 500 keV
- **recombination factor:** should be considered because electrons recombine with holes inside the material which neutralize the charge

Computational Model

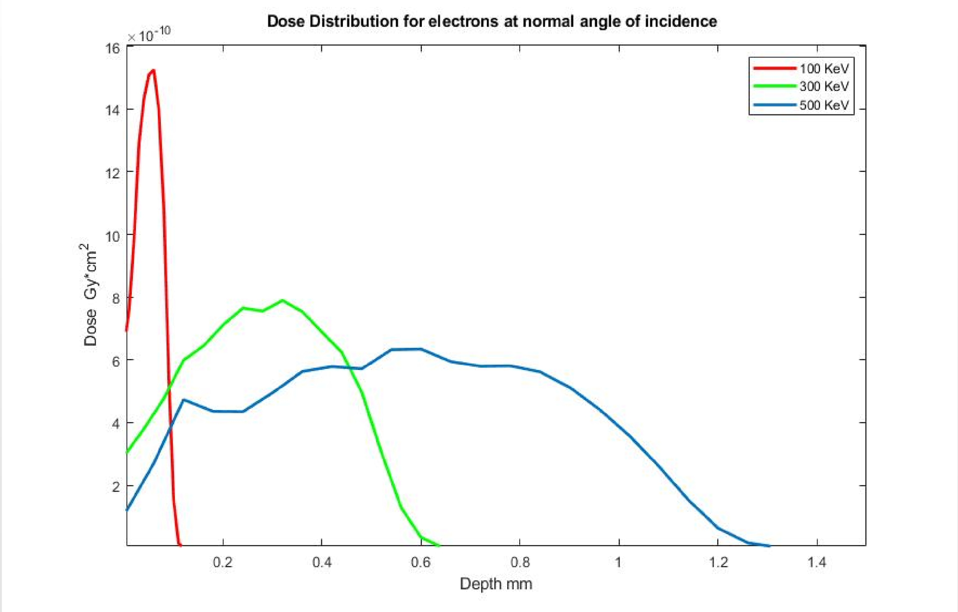
- **Thin-slab system:** considered in the Monte Carlo simulations
- **GEANT4**: software toolkit developed in the context of the CERN RD44 R&D project by Geant4 Collaboration for the simulation of the passage of particles through matter.
  - GEANT4 provides a complete set of tools for all areas of radiation transport simulation, geometry tracking, and material response
  - Monte Carlo simulations were used to predict particle interactions within the thin-slab
  - The low energy Livermore model is used to describe the electromagnetic physics processes for photons and electrons
  - The thin-slab is a representation of kapton insulation layer on the surface of a space-craft
  - Mono-energetic electrons of 100 keV , 300 keV and 500 keV were used
  - Monte Carlo modeling of photoabsorbtion, Compton scattering, Rayleigh scattering, gamma conversion, impact Ionization, Auger effect as well as generation of secondary particles



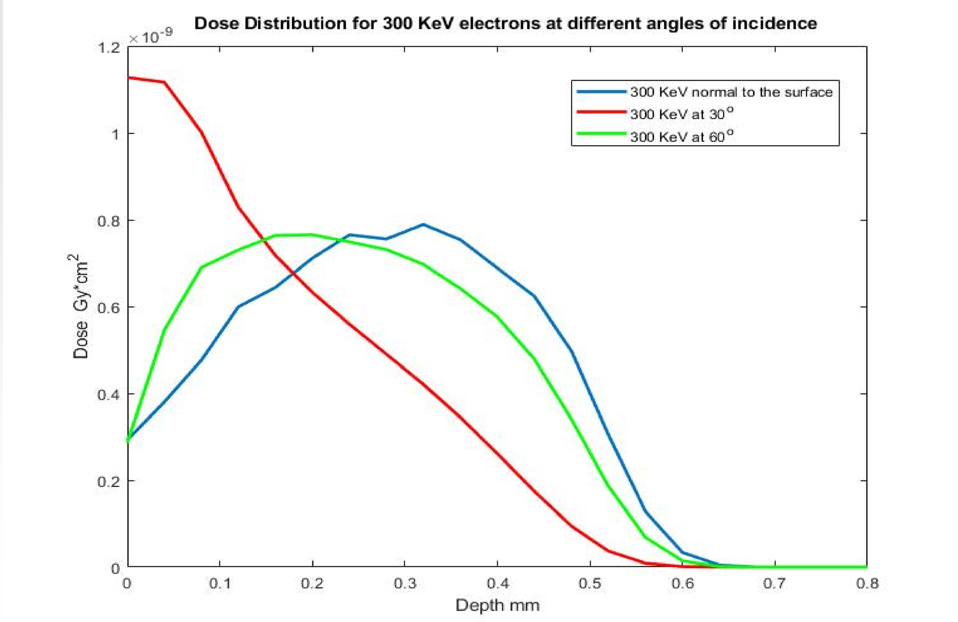
- **set up of the simulation:**
- High energy electrons incident on a slab assembly that mimics an insulation layer
- 1-Kapton FN (1-1.5 millimeters) (Mass Density: 1.42 g/cm^3)
- Vacuum environment (Density: $1 * 10^{-25}$g/cm^3)

Distribution

Dose deposition profile in thin-slab by mono-energetic electrons

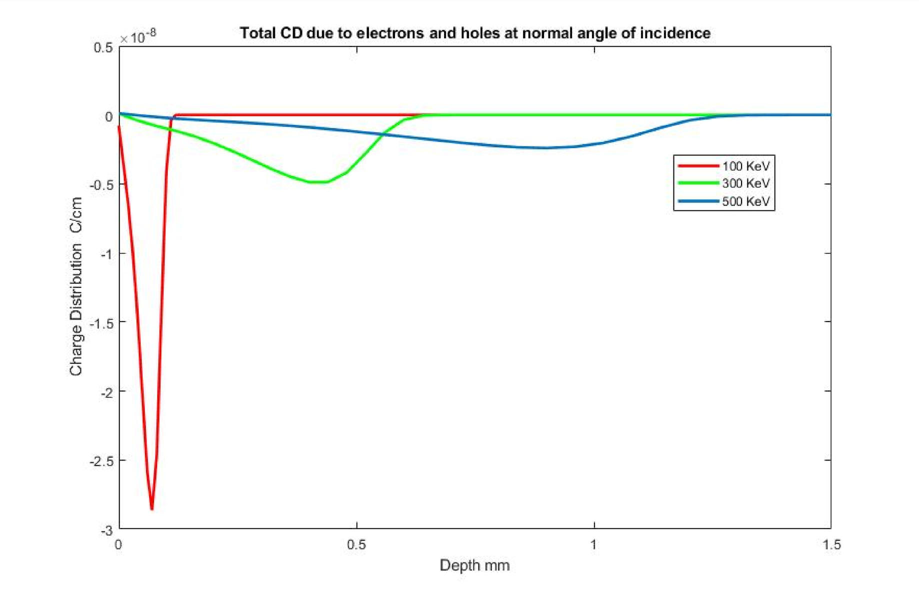


- **Dose deposition profiles: generated by mono-energetic electrons with 100 keV, 300 keV and 500 keV**

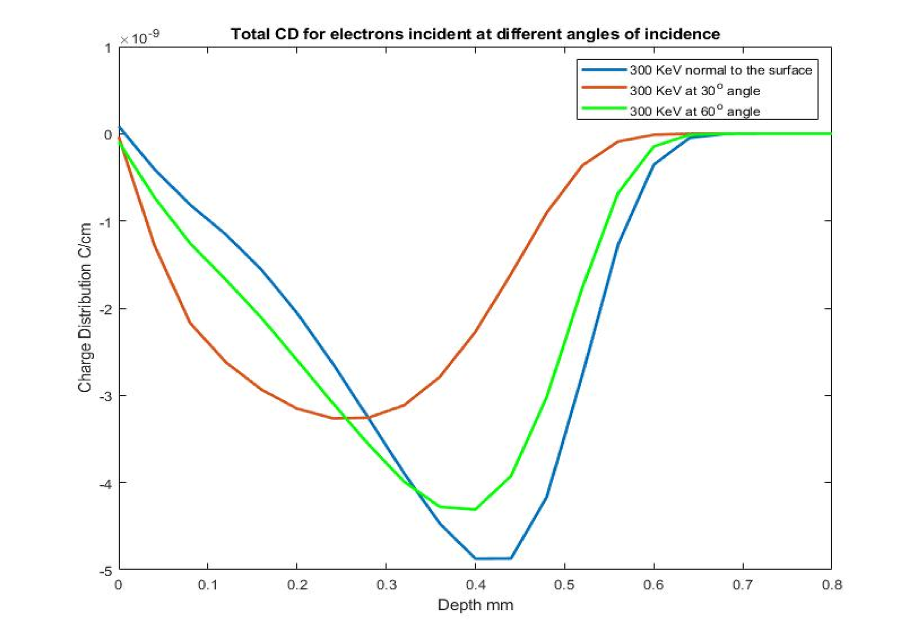


- **Dose deposition profiles: generated by 300 keV electrons at angles of 30, 60 and 90 degrees with respect to the surface of kapton slab**

Accumulated charge deposition in thin-slab by mono-energetic electrons



- **Charge distribution profile: produced by mono-energetic electrons with 100 keV, 300 KeV and 500 keV**



- **Charge distribution profile: produced by 300 keV electrons incident at angles of 30, 60 and 90 degrees with respect to the surface of kapton slab**

Conclusions

- **Dose deposition and charge distribution are produced by mono-energetic electrons in a thin-slab representing Kapton surface insulation of a space-craft**
- **Backscattered electrons escape from the front surface of the slab and leave uncompensated positive charges but as the depth increases , charge accumulates more because backscattered electrons can't escape anymore and accumulate at the peak region**
- **Charge accumulation's peak and dose's peak are higher near the surface for low energy electrons (100 keV) as they can't penetrate deeper into the material**
- **While for higher energy electrons (300 keV and 500 keV), as they penetrate deeper, both charge and dose deposition tend to be distributed more along the depth not just near the surface**
- **As the angle of incidence decreases the electrons can't penetrate deeper into the slab thus the peak for both charge and dose deposition shifts towards the surface**

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