Many contemporary spacecraft materials exhibit cathodoluminescence when exposed to electron flux from the space plasma environment. A quantitative, physics-based model has been developed to predict the intensity of the glow as a function of incident electron current density and energy, temperature, and intrinsic material properties. We present a comparative study of the absolute spectral radiance for several types of dielectric and composite materials based on this model which spans three orders of magnitude. Variations in intensity are contrasted for different electron environments, different sizes of samples and sample sets, different testing and analysis methods, and data acquired at different test facilities. Together, these results allow us to estimate the accuracy and precision to which laboratory studies may be able to determine the response of spacecraft materials in the actual space environment. It also provides guidance as to the distribution of emissions that may be expected for sets of similar flight hardware under similar environmental conditions.

**Model of Cathodoluminescent Intensity**

The model developed for the observed electron-induced luminescence phenomenon is based on band theory of highly disordered insulating materials [3,10]. The observed luminescence occurs when an incident high energy, charged particle undergoes a series of inelastic collisions exciting valence electrons into the conduction band. The excited electrons rapidly decay to localized (shallow trapped) states, with a mean binding energy $E_b$, below the mobility edge. A final emission transition, from the short-lived shallow trap states to longer-lived deep trap states is the origin of the emitted photon.

The model predicts that the overall luminescence intensity:

$$I_{out}(E_{in}, T, x) \propto \frac{D(E_{in})}{D_{e}} (e^{-\frac{E_b}{kT}} - 1)$$

The range of variations of the 36 sample data set is indicated by the ~±5% Variations with Energy and Penetration Depth

The energy dependence of cathodoluminescence is more complicated due to the energy-dependent penetration depth or range, $R(E_{in})$, in Eq. (2). For nonpenetrating radiation—where the energy-dependent penetration depth or range, $R(E_{in})$, is less than the film thickness—$L$, all incident power is absorbed in the material. At low incident power, both $D$ and $I$ are linearly proportional to the incident energy and power density, $D(E_{in}) = k E_{in}$ and $I(E_{in}) = f(E_{in}) D(E_{in})$. At higher incident power, both $D$ and $I$ exhibit saturation effects for increasing energy and fixed power density. For penetrating radiation—where $R(E_{in}) > L$ the absorbed power is reduced by a factor of $L/R(E_{in})$, leading to a similar dependence for $D$ and $I$. This range shows a dose and range dependence for selected materials as functions of incident energy. An energy-dependent correction to the incident flux, $I_{corr} = I_{out} / I_{in}$, is also included in Eq. (2) to account for the effects of backscattered electrons that do not deposit substantial energy; $I_{corr} = I_{out} / I_{in}$ is the backscattered electron yield [11]. For the most part, this correction is small and weakly dependent on energy. For biased samples, when excess charge is stored in the trap states, a surface voltage $V$, results and $E_b$ is replaced everywhere in Eqs. (1) and (2) by the landing energy, $(E_{b} - q V)$.

**Variations with Materials**

Absolute cathodoluminescent spectral radiance versus incident electron energy of four materials, scaled to 10 mA/cm² electron current density.

![Image of cathodoluminescent spectral radiance versus incident electron energy for four materials, scaled to 10 mA/cm² electron current density.](https://ntrs.nasa.gov/search.jsp?R=20150000269)

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**References**

- T. Barfels, A. von Czarnowski, and A. N. Trukhin, "Comparison of the Effective Dielectric Permittivity of Ceramic and Graphite Coated Mirror Mounted in the Top Left, Limiting Cathodoluminescence to This Quadrant."

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**Conclusions**

Cathodoluminescence is an important space environment-induced phenomenon to understand, especially in applications where extremely sensitive space-based optical detection is necessary.

- Measurements of the absolute spectral intensities per incident electron power are presented with a quality, physics-based model to predict the intensity of the glow as a function of incident electron current density and energy, temperature, and sample thicknesses and compositions.
- Comparisons for these materials show three orders of magnitude variation.
- For bulk nonpenetrating materials, spectral radiance increases with increasing incident electron power and flux. In thin films where electron penetration is possible, a linear relation is seen for all energies, but once penetration occurs intensity decreases with increasing energy.
- Composite materials, where both penetrating and nonpenetrating electron effects are present, required a combination of these two effects in the model. Saturation effects at higher doses were observed and accurately modeled, for both penetrating and nonpenetrating electrons.
- Statistical analysis of the observed statistical fluctuations of cathodoluminescence for a large set of similar epoxy samples exposed simultaneously to similar space-like monochromatic electron flux conditions provides a measure of both the instrumentation precision and the stochastic variations inherent to the material.

The statistical analysis of the results of studies of numerous similar samples led to higher precision and accuracy results that allow for quantification of additional more subtle effects.

Together, these results allow us to estimate the accuracy and precision to which laboratory studies may be able to determine the response of spacecraft materials in the actual space environment. It also provides guidance as to the distribution of emissions that may be expected for sets of similar flight hardware under similar environmental conditions.