

# Evolution of secondary electron emission characteristics of spacecraft surfaces: Importance to spacecraft charging

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## Introduction

Secondary electron emission (SEE) plays a key role in spacecraft charging [Garrett, 1981; Frooninckx and Sojka, 1992]. As a result, spacecraft charging codes require knowledge of the SEE characteristics of various materials in order to predict vehicle potentials in various orbital environments [Katz, *et al.*, 1986]. Because SEE is a surface phenomenon, occurring in the first few atomic layers of a material, the SEE characteristics of a given surface are extremely sensitive to changes in surface condition—*e.g.*, the addition or removal of surface contaminants, or changes in surface morphology. That spacecraft surfaces can and generally do undergo significant evolution during their operational lifetimes is a fact well established by NASA's Long Duration Exposure Facility (LDEF) [Crutcher, *et al.*, 1991a]. Deposition and removal of contaminants can occur as a result of preferential adsorption of gases on cooler surfaces, the collection of ionized gases on negatively charged surfaces, atomic-oxygen-induced oxidation, photodissociation under vacuum uv bombardment, and ion-induced desorption. Since SEE is material-dependent phenomenon, it is reasonable to assume that as a spacecraft's surfaces evolve, so too do its SEE characteristics.

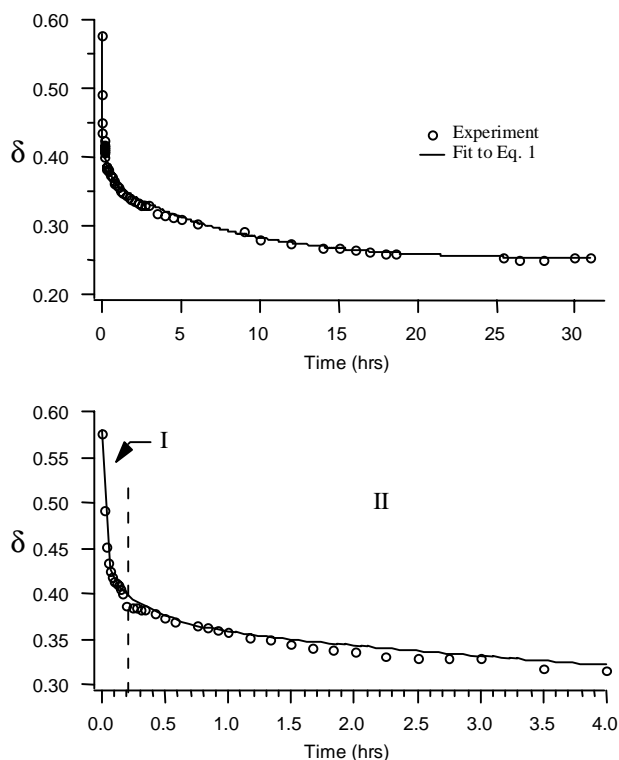
In order to determine whether or not charging models need to incorporate the effects of changing surface conditions aboard operating spacecraft, data assessing the impact of these changes on the SEE characteristics of various surfaces are required. Measurements have therefore been made investigating the dynamic evolution of secondary electron (SE) yields resulting from energetic electron bombardment of typical spacecraft materials in a rarefied atmosphere representative of the microenvironment surrounding space vehicles. A detailed report of the experiment and results has been given elsewhere [Davies, 1996; Davies and Dennison, 1997]; what follows here is a brief summary.

## Experiment and Instrument

A sample of oxidized aluminum was placed inside an ultra-high vacuum (UHV) chamber alongside a piece of PTFE (Teflon®) coated wire and continuously bombarded with 1–3 keV electrons for ~30 hours. The SE yield of the surface was monitored as a function of time throughout the electron bombardment. Oxidized aluminum was chosen as a typical material comprising spacecraft surfaces, while outgassing of the Teflon wire contaminated the UHV environment, simulating the microenvironment surrounding an operating spacecraft. Continuous electron bombardment resulted in two effects—(i) the removal of the oxide layer, and (ii) the deposition of a thin (~1 nm-thick) layer of carbon contamination—duplicating the surface effects of other processes known to occur in Earth orbit.

## Results

Total SE yield of the surface,  $\delta$ , as a function of time is depicted in Fig. 1. Detailed analysis of the data reveal the following: (i) an approximately 30% decrease in  $\delta$  due to removal of the oxide layer (region I), and (ii) an approximately 57% drop in  $\delta$  due to the deposition of an ~1 nm-thick carbon layer (region II) [Davies and Dennison, 1997]. The combined effect was a reduction in  $\delta$  from ~0.58 to ~0.25—a decrease of more than a factor of two over ~30 hrs.



**Fig. 1 Secondary yield vs. time for 2.0-keV electrons continuously incident on contaminated aluminum surface.**

## Discussion

Rates of contaminant deposition and removal observed in this investigation are representative of those recorded aboard LDEF [Crutcher, *et al.*, 1991b], and the vacuum and contaminant levels employed are typical of operating spacecraft in low-Earth orbit.

Thus it is reasonable to assume that the SE reduction observed in our laboratory is representative of that which can be expected for an oxidized aluminum surface aboard an operating spacecraft. Furthermore, because the most troublesome spacecraft potentials are negative, the reduction of a surface's SE yield translates to increased spacecraft-to-plasma charging levels for a given set of environmental conditions. It is noted that the mechanisms responsible for the sample surface modifications in our laboratory—namely, the electron-beam-induced desorption of the oxide layer and deposition of carbon—are not likely to be important in the space environment, as the beam current densities used in the laboratory ( $\sim 10^{-3}$  A cm<sup>-2</sup>) were seven orders of magnitude greater than those found in space ( $\sim 10^{-10}$  A cm<sup>-2</sup>) [Davies and Dennison, 1997; Hardy, *et.al.*, 1985].

## Conclusion

The work presented here serves to demonstrate the degree to which SEE yields can be expected to vary as a result of surface evolution. In this regard, the data make it clear that in order to properly assess electrical potentials to which spacecraft may be subject over their entire operational lifetimes, charging codes must incorporate knowledge of how the vehicle's SEE characteristics can be expected to change as its surface evolves. As an operational matter, the data are as yet insufficient for inclusion into spacecraft charging codes. In order for modelers to include the effects of surface evolution, SE yield-versus-energy curves will be required for a variety of spacecraft materials subject to varying degrees and kinds of contamination. Investigations of this type are presently underway at Utah State University under the sponsorship of NASA's Space Environment and Effects program.

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## References

- Crutcher, E.R., L. Nishimura, K. Warner, and w. Wascher, Quantification of contaminants associated with LDEF, *LDEF-69 Months in Space, First Post-Retrieval Symposium, NASA Conf. Pub. 3134, pt. 1*, 141-147, 1991a
- Crutcher, E.R., L. Nishimura, K. Warner, and w. Wascher, Migration and generation of contaminants from launch through recovery: LDEF case history, *LDEF-69 Months in Space, First Post-Retrieval Symposium, NASA Conf. Pub. 3134, pt. 1*, 121-140, 1991b
- Davies, R.E., An instrument for experimental secondary electron emission investigations, with application to the spacecraft charging problem, *M.S. Thesis, Dept. of Physics, Utah State Univ., Logan, UT*, 1996
- Davies, R.E., and J.R. Dennison, Evolution of secondary electron emission characteristics of spacecraft surfaces, *J. Spacecraft and Rockets*, 34, 4, 571-574, 1997
- Frooninckx, T.B., and J.J. Sojka, Solar cycle dependence of spacecraft charging in low Earth orbit, *J. Geophys. Res.*, 97, A3, 2985-2996, 1992
- Garrett, H.B., The charging of spacecraft surfaces, *Rev. of Geophys. and Space Phys.*, 19, 4, 577-616, 1981
- Hardy, D.A., M.S. Gussenhoven, and E. Holeman, A statistical model of auroal electron precipitation, *J. Geophys. Res.*, 90, A5, 4229-4248, 1985
- Katz, I., M. Mandell, G. Jongeward, and M.S. Gussenhoven, The importance of accurate secondary electron yields in modeling spacecraft charging, *J. Geophys. Res.*, 91, A12, 13,739-13,744, 1986