warranted oversimplification, however, since in the case of an optically thin plume, all particles within the control volume can "see" the surroundings, and energy is emitted from each particle in all directions without subsequent attenuation. When the plume is optically thick, radiation from particles in the interior of the plume is absorbed by the surrounding particles. In this case, only those particles located within a layer one "optical depth" from the boundary of the plume radiate to the surroundings. However, since this layer is essentially optically thin, radiation is again in all directions rather than only through the lateral surface of the control volume. In both cases, then, the energy balance is incorrect. When the plume is optically thin, the radiation term in the energy balance should be expressed as the summation of contributions from all particles within the control volume using, of course, the emissivity appropriate to the individual particles. In the radiation controlled, optically thick case, a solution to the equation of radiative transfer is required which accounts for the radial temperature gradient that is established by cooling of the outer layer of the plume.

To determine the plume emissivity, Fontenot assumed that, within the temperature and wavelength intervals of interest the absorption coefficient α_λ of an aluminum oxide particle cloud could be expressed as $\alpha_\lambda = 0.57/\lambda$,[3,4] where λ is the wavelength in microns. (Refs. 3 and 4 were originally Refs. 5 and 6 in Fontenot's paper.) Although the functional relationship is valid, examination of Refs. 3 and 4 (as well as of the text of Ref. 1) revealed that the coefficient 0.57 was obtained from observations of soot-laden flames. Since solid carbon is a much more efficient emitter than aluminum oxide, the aforementioned expression cannot be applied to plumes comprised of alumina particles. The optical properties of alumina particles, however, can be found from Mie theory[5] using the refractive index data obtained by several investigators.[6–8] On the basis of the individual particle properties, Bartky and Bauer[9] have determined the emittance of homogeneous alumina containing plumes and discussed application of their results to inhomogenous media.

In spite of repeated statements by Fontenot that his assumptions are justified by the agreement between his theoretical results and experimental data, the information presented here clearly demonstrates that the assumptions are not realistic. Several methods for calculating radiation from optically thick plumes which correctly take into account the appropriate spectral optical properties of the alumina particles have been developed.[10–12]

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Comment on "Effect of Simulated Micrometeoroid Exposure on Performance of *N/P* Silicon Solar Cells"

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In a paper[1] examining the effects of simulated micrometeoroid exposure on shielded and unshielded *N/P* silicon solar cells, the authors arrived at the conclusion that an unprotected *N/P* silicon solar cell will degrade to 50% of its initial short-circuit current in about 34 space days. This result was based on the flux model of Ref. 2, from which the authors arrived at a value of 0.225 joule/year incident on a 1- × 2-cm surface in space. An even larger change was arrived at (50% in 4 space days), using the data from Ref. 3 (4.95 joule/year). Because the degree of damage incurred for relative short periods in space was so extensive, the authors suggest that integral covers, or very thin coatings that protect against radiation (elementary charged particle), may not be adequate to protect the cell against micrometeoroids.

The micrometeoroid flux models that the authors used are inconsistent with recently published data.[4–6] Specifically, it can be determined from Ref. 4 that only 0.0029 joule/year will be incident on a 1- × 2-cm surface in space. It is therefore appropriate that the authors re-evaluate their studies and present the updated damage predictions. It is expected that both the problem area that they alluded to in Ref. 1 and the previously published problems on the effects of simulated micrometeoroid exposure of thermal control surfaces[7] will be significantly affected.

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Reply by Authors to R. A. Breuch

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IN his comment[1] on our paper,[2] Breuch credited us with a conclusion that nowhere appeared in that paper. In the authors' enumerated conclusions it was explicitly stated that the "rate of reduction . . . (of cell performance) . . . depends heavily on the micrometeoroid flux distribution chosen as representative of the micrometeoroid environment." We also stated "this rate is not yet definitive." Even if this had not been explicitly stated, it should have been clear that there remained great doubt as to the exact micrometeoroid flux in space since two flux models giving extremely differing results were included in the paper. This was done in an attempt to cover the possible extremes indicated by actual micrometeoroid flux data available at present.

Breuch also says that the micrometeoroid flux models used in Ref. 2 are "inconsistent with recently published data."[3–5] Contrary to his statement, two of these references[3,4] (all of which are well-known to the authors) contain no micrometeoroid data whatsoever. The third[5] contains no data relevant to the micrometeoroid particle size used in Ref. 2. Although his comment suggests that these references present a new and better flux model that negates the data and hence the models presented in Refs. 6 and 7, this is really not the case at all. And it is interesting to note that in his own paper,[8] published in the *AIAA Journal*, September 1967, Breuch cannot refer to this "recently published data" when discussing the micrometeoroid environment, but uses instead Ref. 9, published in 1962, even predating the references used by the authors.

In Ref. 3, Shapiro et al. attempted to find an explanation for the earth's dust belt as recorded by the many American and Russian satellite micrometeoroid sensors. In spite of a very complete computer study of orbiting particle trajectories, they were unable to clarify the situation, and very cleverly indicate the remaining doubt on the subject with the title of their paper: "The Earth's Dust Belt: Fact or Fiction?" Again, there is no new micrometeoroid flux model presented in this reference. In Ref. 4, Nilsson only points out the possibility of thermal noise as an explanation for the data obtained by the microphone sensors on the various American satellites if these should prove, eventually, to be high. He also notes that scientists have known about this noise problem previous to his work and that those making these satellite measurements had already made sensor noise studies. He also notes that no noise was observed on Explorer I while temperatures were changing and that this appears to contradict his explanation. Again, Nilsson does not present a new flux model in his paper. Naumann, in Ref. 5, essentially using the penetration measurements of Explorer XVI, Explorer XXIII, and Pegasus satellites along with the interpretation of photometric measurements of F-corona and zodiacal light by Van de Hulst, presents a model for "penetrating particles in heliocentric orbits." From the type of data he uses, the model derived applies to meteoroid masses much larger than those considered by the authors of Ref. 2. Consequently, it must be realized that Naumann's model cannot be simply extrapolated into the mass range considered by the authors of Ref. 2 without conclusive proof that such an extrapolation is valid, and without showing conclusively that all of the microphone, photomultiplier, and collection measurement data are invalid. Naumann specifically states that he has not done this and that "it is clear that there are still many unanswered questions that must be resolved before all of the above measurements can be properly interpreted." The authors, as well as others in this field, are fully aware of the controversy existing over the near-earth dust belt, and again it must be repeated that it was for this very reason that two different flux models[6,7] (in the mass range of interest) giving drastically differing results were presented in Ref. 2.

Breuch also feels that "the previously published problems on the effects of simulated micrometeoroid exposure on thermal control surfaces will be significantly affected" and refers to Ref. 10. This statement is irrelevant when referring to Ref. 10. That paper describes a totally consistent ground study of laboratory degradation of the surface thermal properties of polished metal surfaces, and nowhere in the paper is a flux model assumed to relate damage with real space time. On the contrary, it is explicitly stated in this paper that "meteoroid flux uncertainties are still a major factor preventing good quantitative estimates of surface life in space to be made." The purpose of this work was, in fact, to provide information regarding a possible new sensor for studying micrometeoroid effects in the lower mass size range, and eventually clarifying the controversy that exists. This point, which was specifically made in the introduction as well as elsewhere in that paper, was apparently overlooked by Breuch.

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