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Technical Memorandum 33-737

The Relocation of Particulate Contamination During Spaceflight

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PREFACE

The work described in this report was performed by the Project Engineering Division of the Jet Propulsion Laboratory.

FOREWORD

The objective of this research was the development of an analytical technique to evaluate the probability that particles would relocate from nonsterile to sterile areas on a spacecraft. This recontamination process is important for all multiple missions with separate microbiological burden allocations for various major spacecraft systems, and critical for life detection experiments that risk contamination from nonsterile components.

The approach has been to study the effects of typical mission environments on the redistribution of particles on spacecraft surfaces both analytically and experimentally. This study consisted of three logical components, which have been reflected in the effort: (1) particle adhesion, (2) dynamic release mechanisms, and (3) particle transport. The effort in particle adhesion has been principally a particle release experimental program, together with analytical work and attempts to correlate other data found in the literature and elsewhere. Under dynamic release mechanisms, meteoroid impact and pyrotechnic firing have been modeled. The particle transport activity was an analytical effort which included the development of computer codes for spacecraft geometry and orientation, forces acting on released particles, and trajectory.

An analysis of the particle adhesion experimental data was consistent with a dominant contribution by Van der Waals (molecular) forces in vacuum. These forces have the same linear dependence on particle size as the major adhesive force in air with a relative humidity in excess of 65% (capillary or water surface tension force). Surprisingly, our numerical results for vacuum adhesion are commensurate with published data for experiments conducted in air.

Meteoroid impact has been modeled by the elastic response of a large plate to a Gaussian spatial distribution of pressure. The analytical solution for the Green's function is known. The relationship between meteoroid and target physical parameters and the time dependence and magnitude of the pressure function was developed by an adaptation of an existing analysis. Predictions of particulate release due to meteoroid impact were calculated and compared with the results of experimental simulations.

The particle transport analysis was to solve the equation of motion of the released particle in the vicinity of the spacecraft. Of the important forces, the electrostatic force on the particle due to the electric field of the spacecraft is most difficult to predict. Results for the charging rate and equilibrium potential of particulates in interplanetary space and an approximate electric field were obtained.

Finally all of these components were assembled into an operational, integrated computer code. For a demonstration calculation with this computer code, a geometrical model of a dual purpose spacecraft and the spaceflight phase between Earth orbit and Mars encounter were chosen. The results indicate that particulate recontamination is a likely process for this mission model. Other predictions, such as the distribution of escapes and particulates which relocate on the relatively contaminated regions of the spacecraft were also obtained.

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ABSTRACT

A computer simulation program to model the redistribution of particulate contaminants on a spacecraft after launch has been developed. The component models for particulate adhesion, meteoroid impact, and electrostatic forces are described and intermediate results are presented. The results of a sample calculation have shown that the recontamination process is important.

I. INTRODUCTION

Planetary quarantine is an international cooperative program concerned with the prevention of the contamination of another planet by terrestrial organisms. Such a contamination by an automated spacecraft could yield false positive results from its own life detection instruments and, if the terrestrial microbes grew and spread on the planet, would confuse all subsequent studies (Ref. 1).

In the implementation of a planetary quarantine program for a particular spaceflight mission, a distinction is made between spacecraft which are intended to probe or to land on another planet and those which are designed to flyby or orbit outside its atmosphere (Ref. 2). Thus for a multiple purpose mission to another planet, the allowed (and actual) microbial contamination of the non-incursive spacecraft components would be significantly larger than that of the others. The recontamination process is the redistribution of particulates, presumably associated with microbes,[1] from a region on a spacecraft with a relatively large burden to a region that has been decontaminated. The objective of the study discussed in this paper is the development of the techniques to evaluate the probability of this process.

The approach has been to study the effects of typical mission environments on the redistribution of particles on spacecraft surfaces, both analytically and experimentally. This study consists of three logical components, which have been reflected in the effort: 1) particle adhesion, 2) dynamic release mechanisms, and 3) particle transport. The effort in particle adhesion has been principally a particle release experiment, together with analytical work and attempts to correlate other data found in the literature and elsewhere. Under dynamic release mechanisms, meteoroid impact and pyrotechnic firing have been modeled. The particle transport activity was an analytical effort which included the development of codes for spacecraft geometry and orientation, forces acting on released particles, and trajectory analysis.

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[1] This study does not treat directly the transfer of viable microbes because the relationship is unknown and because of the lethality of natural space environments for microbes.

Finally, all of these components were assembled into an operational, integrated computer code. For a demonstration calculation with this computer code, a geometrical model was based on a hypothetical spacecraft and the spaceflight phase between Earth orbit and Mars encounter was chosen.

II. MODELS

A. PARTICLE ADHESION

The four types of adhesion forces which may play an important role in particulate adhesion to a surface are: Van der Waals, contact potential, Coulomb, and capillary. The Van der Waals or molecular force is proportional to the particle dimension, depends critically on surface roughness, and is fairly unaffected by material conditions. Although the other forces may be much larger under certain circumstances, the molecular force is the major source of adhesion for inert contaminants seeded in air onto a surface and then evacuated. Contact potential differences due to the surface effects of dissimilar materials cause an electrostatic binding proportional to the particle dimension to the two-thirds power. Coulomb forces arise from actual charges on the particles due to external ambient electric fields. Since these forces are inversely proportional to the particle dimension, they are quite important for small particles. The electric charges involved, however, in both contact potential and Coulomb forces will neutralize in the presence of ambient water. More importantly, for particles seeded in air (or even in dry nitrogen) onto a surface which is then evacuated, the Paschen limit places an upper limit on the residual charge. During evacuation, a region of corona breakdown, where the field in the small gap between particles and the surface causes the air to ionize, is passed. Finally, the capillary or water surface tension force, which is also proportional to particle size, is potentially largest. It is, however, negligible in a reasonable vacuum. At ambient air pressures, the capillary force exhibits a definite hysteresis effect with respect to relative humidity. That is, the force depends on the history as well as the relative humidity at a given time.

Some conclusions relevant to the recontamination task may be drawn from the preceding discussion. The Van der Waals force, proportional to particle size, is the best model for the vacuum problem in space. During the ascent, the adhesion force changes in a very complicated fashion, but it approaches the Van der Waals as a lower limit. Conversely, a particle adhesion experiment in vacuum should reliably measure the Van der Waals force. One may compare vacuum results with results obtained under ambient pressures only with caution.

Previous models used in this study have related the applied force (given by the product of the applied acceleration and the particle mass) to the removal fraction. In each case a characteristic acceleration or force corresponding to a fixed removal fraction was defined. In Ref. 3, the characteristic acceleration a_o for a removal fraction of 0.63 was given as:

$$a_o = \frac{2 \times 10^{-4}(0.4 + 0.006\ \mathrm{RH})}{\pi d^2 \rho G} \qquad (1)$$

where a_o is in units of kilo-gee[2] (kG), ρ is the particle density (g μm^{-3}), d is the particle diameter (μm), G is the acceleration due to gravity (980 cm s^{-2}), and RH is the relative humidity (percent) during release. The numerical constants in Eq. 1 were determined empirically from data in the literature.

Subsequently, an experimental program was conducted to obtain data on particulate adhesion under vacuum conditions. The data to be modeled (Figs. 1-5) were obtained by an impulse method for glass beads on stainless steel. The details of the apparatus and the test procedures have been previously reported (Refs. 3 and 4). It should be noted that in these tests the glass beads were seeded in air, and then the removal occurred in vacuum.

As discussed above, for this experiment and for the recontamination analysis, one expects a characteristic force, F_o, corresponding to a removal fraction of 0.5 given by:

$$F_o = kd \qquad (2)$$

or the characteristic acceleration a_o given by:

$$a_o = \frac{6k}{\pi d^2 \rho} \qquad (3)$$

[2] One gee equals 9.8 m/s^2, the acceleration due to gravity at the surface of the earth.

where d is the diameter and ρ is the density of the particle. Note that Eqs. 1 and 3 are of the same form for zero relative humidity.

The next component of the model must relate the applied force or acceleration and the characteristic force or acceleration to predict the removal fraction. Since a distribution of adhesion forces is expected even for a collection of identical particles because of the variation in microscopic surface conditions, a probabilistic model is indicated. In the present model, the constant k of Eq. 2 is assumed to be log-normally distributed with a mean value of log k equal to m and a standard deviation σ_r. Then the removal fraction for a specific d is given by the probability that the applied force F^* exceeds the characteristic force F_o. This probability may be written:

$$P(F^* > F_o) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{(\log k^* - m)/\sigma_r} dt \exp(-t^2/2) \tag{4}$$

where

$$k^* = F^*/d = \frac{\pi d^2 \rho a^*}{6} \tag{5}$$

and a^* is the applied acceleration.

By inverting Eq. 4 for a given data point and an assumed value of σ_r, one can calculate an estimate for m. Such a collection of estimates for m may be averaged to provide a best-estimate m_o for the selected σ_r. There is also a standard deviation of this collection, σ_m, which should be minimized. The program for search over σ_r, treating the data, and minimizing σ_m has been incorporated into a computer code. The best fit to the data was obtained for $\sigma_r = 0.4$, $m_o = -0.882$, and $\sigma_m = 0.52$. These values are consistent with MKS metric units, e.g., k^* and 10^{m_o} have units of newton meter^{-1}.

Up to this point the theoretical development is due to B. Nelson (Ref. 5). Nelson, however, uses Eq. 4 with σ_m substituted for σ_r and $m = m_o$ for the most probable removal fraction. The correct procedure appears to be the use of σ_r and m_o for the most probable calculation. Further, the meaning of σ_m is such that if one calculates the removal fraction with $m = m_o - \sigma_m$ substituted into Eq. 4 and with $m = m_o + \sigma_m$, there is the usual 68% probability that a test result will fall between the two answers. If one is concerned only with an upper limit on the removal fraction, there is an 84% (50 + 34) probability that the prediction with $m = m_o - \sigma_m$ will not be exceeded. These comments may be extended in the usual way.

The results of this analysis are shown in Figs. 1-5. Each figure corresponds to a particular size of glass bead. The data and the predictions of Eq. 4 are given as removal fractions in percent vs. surface acceleration in kG. The most probable and the "conservative" ($m = m_o - \sigma_m$) predictions are shown and, in the case of 110-μm beads, the "non-conservative" ($m = m_o + \sigma_m$) prediction is also given.

It is interesting to compare our new results for the adhesion force with the previous model and with results published in the literature. The present prediction of the mean adhesion force (N) is given by Eq. 2 with the diameter d expressed in meters and a value of k = 0.13 N/m. Corn (Ref. 6) used the same formula and obtained the following values (converted to MKS units): 0.17 N/m for the adhesion of Pyrex particles to optical glass, 0.12 N/m for the adhesion of quartz particles to optical glass, and 0.075 N/m for the adhesion of quartz particles to Pyrex glass. Since these data were obtained in air at 95% relative humidity, the agreement with the present results must be considered somewhat fortuitous.

A comparison with the characteristic acceleration of the previous model, Eq. 1, requires some algebra. One may express the prediction of that model in terms of the force required to cause a 63% removal in air (RH = 0%):

$$F(0.63) = 0.13d \tag{6}$$

where F is expressed in newtons and the particle diameter d is expressed in meters. The prediction of the present model has a coefficient of 0.18 for this removal fraction (compare to 0.13). This fair agreement may also be coincidental. The previous model was based on data for many materials in air with a relative humidity of 50 - 60%.

From a comparison of the data in the literature and a consideration of the Van der Waals and capillary adhesion forces only, one may predict the trend of total adhesion between ambient pressure with 100% relative humidity and vacuum. As the relative humidity is decreased, the capillary force decreases in a linear fashion (Ref. 6). As long as water is present, the Van der Waals force is reduced to a negligible factor by the molecular interaction with the interface water (Ref. 7). For small relative humidity (<50%), there is a minimum adhesion. Finally, as the test system is evacuated, the capillary force becomes negligible and the Van der Waals force attains its maximum value. On the basis of the data, the adhesion force in vacuum is commensurate with that in air at 100% relative humidity and certainly exceeds values for low (but non-zero) relative humidity.

This particle adhesion model has been developed into a computer code called RELEAS. A version modified for its integration into the complete recontamination code appears in Appendix C. An independent version which accepts surface response data in punched card form is also available.

B. METEOROID IMPACTED SURFACE RESPONSE

The meteoroid impact model is intended to provide surface response characteristics as a function of meteoroid and surface physical parameters.

The connection between the meteoroid impact parameters and plate response is the loading function. The loading function model predicts a pressure P, in general a function of time t, and r, position on the surface relative to the center of impact, for a given meteoroid event. For simplicity, the positional dependence has been assumed to be Gaussian and factorable:

$$P(r, t) = P_o e^{-r^2/s^2} f(t) \tag{7}$$

This choice was motivated by the existence of a closed-form solution for the velocity response of a thin plate subjected to a loading of this form with the impulse time function (Ref. 4). This response function is related to the response due to a general loading time history f(t) by convolution integrals.

In the preliminary considerations, it was found that for reasonable forms of the time dependence $f(t)$, only a characteristic time T_o of the impact was important for the peak acceleration, our primary interest. The detailed behavior of $f(t)$ certainly determines the detailed time history of the surface acceleration.

The function $f(t)$ has been chosen:

$$f(t) = \left(1 + \frac{t}{T_o}\right)^{-2} \tag{8}$$

This form has been derived along the lines of an analysis due to Ludloff (Ref. 8). This treatment takes into account the transport of molten target material in the crater region. The result depends on Ludloff's form for the crater radius; the crater is assumed to be hemispherical. The expression for the crater radius R in terms of the target material strength S, the projectile diameter d, density ρ_P and velocity v_o is:

$$\frac{R}{d} = \frac{1}{2}\left(\frac{\rho_P v_o^2}{S}\right)^{1/3} \tag{9}$$

This formula agrees reasonably well with the data in the literature.

In this analysis, the time history of Eq. 8 is valid only for the boundary of the crater being formed. This restriction appears to pose no problem in calculating the post-impact elastic wave far from the crater. The solution of the equation of motion leads to Eq. 8. The characteristic time T_o may be immediately identified as:

$$T_o = \frac{4}{3} \frac{d\, S^{1/6}}{v_o^{4/3}\, \rho_P^{1/6}} \left(1 + \frac{4\rho_T\, v_o^2}{S}\right) \tag{10}$$

One may also identify $P_o = 2S$. In the formula for T_o, ρ_T is the target density and all other symbols have been previously defined. Ludloff, in keeping with his treatment of the molten target material, takes as the target material strength S:

$$S = \lambda_F \rho_T \tag{11}$$

In this formula λ_F is the latent heat of fusion. For aluminum, for example, $S = 8.7 \times 10^8 \ N/m^2$.

Finally, we have chosen for the parameter s in the loading function (Eq. 7), a value of (1/3)R, where R is the crater radius given in Eq. 9. At this point the loading function is completely expressed in terms of known parameters of a meteoroid impact.

As stated previously, classical plate theory provides the velocity response WDOT of a thin plate to an impulsive loading with a Gaussian shape factor. A computer code written by J. Yang yielded the surface velocity $\dot{w}$ and surface acceleration $\ddot{w}$ by a convolution with f(t):

$$\dot{w}(r,t) = \int_o^t d\tau \ \mathrm{WDOT}(r,\tau) \ f(t-\tau) \tag{12}$$

$$\ddot{w}(r,t) = \int_o^t d\tau \ \mathrm{WDOT}(r,\tau) \ \dot{f}(t-\tau) \tag{13}$$

In the process of inserting f(t) into this thin-plate code THINPL and testing it, a close inspection of the code was made to find a way of shortening it. By an analysis of the convolution integral and the shapes of WDOT and f(t), we have succeeded in predicting the time t for a given lateral distance r at which peak acceleration occurs. Since the calculation of the surface velocity and acceleration for a given position requires two integrations for each value of time, a great savings is realized by limiting the values of time to near the time of peak acceleration. In addition, the convolution integration can be optimized for these values. As a result, the present code yields peak acceleration and the simultaneous velocity as a function of position by a limited search over t. An entire curve of peak acceleration versus position is computed in about the time the previous code required for the time history of the acceleration at one position.

The analysis of the impact of a small meteoroid and/or the analysis for positions close to, but not in, the impact area entails a consideration of the semi-infinite half-space problem. This analysis, which treats the plate as though it were infinitely thick, has been published in the literature (Ref. 9). The computer code based on this analysis yields peak accelerations inversely proportional to the position r beyond the impact locus. Because our problem is limited to finite plate thicknesses, the absolute values of the peak accelerations predicted are suspect.

In the past we have taken the transition between the "thick" and "thin" regions to be the value of r equal to three plate thicknesses and have matched the peak acceleration at that point. In fact, however, this transition region beyond which shear waves dominate the compressional waves depends on the other plate properties and the impacting projectile properties. Fortunately, the prediction of the classical thin-plate program levels off and then actually decreases with decreasing values of r. One may interpret this odd behavior of the peak acceleration as due to destructive interference between the various contributions to it from the different parts of the finite region of disturbance. Since the thin-plate analysis treats shear waves only, the leveling off of its prediction identifies the transition region uniquely.

The meteoroid impact program developed for this task, YANG1/THINPL, uses this identification by searching for the maximum peak acceleration predicted by the classical thin-plate program for decreasing values of r. For all smaller values of r than the specified value found, the peak acceleration is taken as inversely proportional to r. The infinitely thick-plate analysis code, a cumbersome long-running code, is not used at all for production runs. For very large values of r, the prediction of the program drops off finally below a cut-off in acceleration, and calculations cease. In addition to the version of the meteoroid impact code YANG1/THINPL used in the complete recontamination computer program (Appendix C), an independent version which produces the surface response summary in printed, plotted, and punched card form is available. This form of YANG1/THINPL may be used in conjunction with the independent particle adhesion code RELEAS to provide predictions of particle removal due to meteoroid impact. Such predictions, shown in Figs. 6-9, compare favorably with the experimental results of a group at Langley Research Center (LRC) (Refs. 10 and 11). A more complete discussion is available in Ref. 3.

C. ELECTROSTATICS

The particle transport analysis addresses the problem of following the motion of the released particles. Formally stated, given the particle parameters, the initial conditions, and the forces acting on the particle, the analysis is to solve the equation of motion. Of the important forces, the electrostatic force on the particle due to the electric field of the spacecraft is most difficult to predict. A major effort within this task has been in the electrostatic area. The basic approach has been to analyze particle charging so that the particle charge as a function of time is known and to analyze the potential solution for the spacecraft-solar plasma system (Ref. 12) to develop an approximate electric field.

The particle-charging model deals with spherical particles for simplicity and consists of three special cases: illuminated particle, shaded (by the spacecraft) particle in the wake, and shaded particle outside the wake. The wake region of the spacecraft is a complicated analysis that is discussed under the electric field heading. Given the geometry of the particle and the potential-dependent currents flowing into it, one may express the charging rate in an implicit form.

For the illuminated particle, the charging rate $d\phi/dt$ is given by:

$$\frac{d\phi}{dt} = \frac{2.9 \times 10^{-9}}{R^2} \pi d \left[A_p + (1 - \alpha) A_e + A_\nu \right] \tag{14}$$

where

$$A_p = n_p v_o/4 \qquad \text{for } |\phi| \ll M v_o^2/2e$$

$$A_e = -n_e \overline{v}_e/4 \times \begin{cases} \exp\left(e\phi/kT_e\right) & \text{for } \phi \le 0 \\ \left[1 + 2e\phi/kT_e\right]^{1/2} & \text{for } \phi > 0 \end{cases}$$

A_ν = photoelectron flux, dependent on ϕ

α = secondary emission yield, dependent on ϕ

In this equation, the proton flux A_p depends on the number density $n_p(m^{-3})$ and the directed velocity $v_o(ms^{-1})$, and the electron flux A_e depends on the number density $n_e(m^{-3})$, the mean thermal speed $\bar{v}_e(ms^{-1})$ and the temperature $kT_e(eV)$. The photoelectron flux is calculated from photoelectric yield data (Ref. 13) for the solar spectrum, material of the particle, and surface potential ϕ (V). With A_p, A_e, and A_ν in units of $m^{-2}\,s^{-1}$, the particle diameter d in m and the heliocentric distance R in AU, one obtains $d\phi/dt$ in Vs^{-1}.

A model for the secondary emission coefficient has been devised based on an empirical formula for the secondary yield of a given material as function of the primary electron energy (see Ref. 14). This yield function was formally integrated with an assumed Maxwellian solar-wind electron energy distribution with a specified temperature. The resulting coefficient is the ratio of the secondary electron flux to the primary (incident solar wind) electron flux. Parameter values for the empirical formula were also taken from Ref. 14. The dependence of the coefficient on the particle potential is of the form:

$$\alpha = (A - Be\phi)/(kT_e - e\phi) \qquad \text{for } \phi < 0 \tag{15}$$

For the shaded particle, the photoelectron flux A_ν is zero. The electron flux A_e and the secondary emission yield are essentially unchanged. The crux of the problem is the proton flux A_p. The proton accretion may be expected to depend only on the thermal motion of the protons, since there is no line of sight in the shade. It follows then that for this case:

$$A_p = \frac{\bar{n}_p \bar{v}_p}{4} \times \begin{cases} \exp(-e\phi/kT_p) & \text{for } \phi \geq 0 \\ \left[1 - 2e\phi/kT_p\right]^{1/2} & \text{for } \phi < 0 \end{cases} \tag{16}$$

where $\bar{v}_p$ is the proton mean thermal speed and kT_p is the proton temperature. This equation, an analog to the electron flux equation, is only approximate. The quality of the approximation depends largely on the value taken for $\bar{n}_p$, an effective proton number density in the shade.

The effective proton density $\bar{n}_p$ in the shade depends on the complete solution to the potential problem of the spacecraft itself. Poisson's equation relates the potential everywhere to the charge distribution everywhere. The boundary condition (surface potential of the spacecraft), the potential, and the charge distribution form a self-consistent set. For an equivalent spherical spacecraft, a conical wake region is assumed where $\bar{n}_p = 0$. The base of this cone contains the center of the sphere and is a cross-section of the sphere. The altitude of the cone lies in the anti-Sun direction. The half-angle of the cone is given by (Ref. 15):

$$\tan \theta = \frac{2}{\sqrt{\pi}} \frac{\bar{v}_p}{v_o} \tag{17}$$

Outside this cone $\bar{n}_p$ is taken to be n_p, the undisturbed proton number density.

The particulate charging rate for the three conditions (sunlight, shade, and wake) is calculated in a computer code PARPOT (Appendix C), as well as the necessary terms like the photoelectric current and the secondary emission coefficient. An independent version of this code, which provides values for these quantities, and also the equilibrium potential of a particle in the sun is available. Sample results are shown in Figs. 10 and 11.

The analysis of the spacecraft electric field or potential problem requires many of the same considerations as the particle charging model. However, the spacecraft surface potential is merely a boundary condition rather than the answer. Fortunately the spacecraft/plasma system equilibrates rapidly (time proportional to the inverse of a size dimension) so that a time-independent equilibrium analysis is adequate. The problem of the potential distribution of an object in a plasma, the plasma sheath problem, is known mathematically as a Poisson-Boltzmann or, in the case of a non-interacting plasma, a Poisson-Vlasov system.

The three-dimensional potential solution for an object moving relative to a plasma is very difficult even in the simplest geometry, a uniform conducting sphere. This situation, which has been solved implicitly by others, requires that the directed relative velocities (as opposed to the thermal, random velocities) of all components of the plasma be equal. These conditions are satisfied when all of the directed relative velocity is due to the object's motion. In the case of interplanetary spaceflight in the solar-wind plasma, however, the proton component has a directed velocity which dominates its thermal velocity, while the electron component by comparison is essentially at rest. Finally, the photoelectric effect produces yet another plasma component exactly at rest with respect to the spacecraft. Thus the potential problem is a much more difficult one than a mere complicated geometry to be approximated by known solutions for simple geometries.

The general approach taken was to artificially sector the region of space about the spacecraft into the near-field, wake, and far-field subregions (Fig. 12). The electric field in the near-field case was approximated by a one-dimensional solution for a plate of material nearest the given position. The near-field boundary was taken as the characteristic e-folding distance (effective Debye length) for that material. The electric field model in the wake regions was adapted from an analysis by Al'pert et al. (Ref. 16). The wake boundary was taken to be a cone with a half-angle given by Eq. 17 (see previous discussion on particle charging) and a base radius (XYWAKE) calculated on the basis of a circle with an area equivalent to the spacecraft shade projection. The far-field electric field model was an equivalent sphere with a uniform potential equal to the area-averaged value PHIAVE and with an effective e-folding parameter equal to an area-averaged value ALAMAV.

The solution to the one-dimensional Poisson-Vlasov problem of a plate exposed to solar illumination, electrons, and protons has been found in the literature (Refs. 17 and 18). In this solution, the positional dependence of the electric potential in equilibrium was expressed implicitly in terms of the surface potential and the plasma parameters. An approximate explicit form for the potential based on this work has been developed which provides an approximate formula for the electric field as well (Ref. 19):

$$E = 4c_2\left\{-c_1 + \left[\left(\sqrt{\phi_0 - \phi_m} + c_1\right)^{1/2} - c_2 x\right]^2\right\} \times \left[\left(\sqrt{\phi_0 - \phi_m} + c_1\right)^{1/2} - c_2 x\right] \qquad (18)$$

for the region

$$x < \frac{\left(\sqrt{\phi_Q - \phi_m} + c_1\right)^{1/2}}{c_2} \tag{19}$$

where c_1 and c_2 are known constants, which are calculated.

In order to obtain numerical values for the electric field, the plasma parameters and the equilibrium surface potential are required. The pertinent parameters of the solar-wind plasma are available (Ref. 20). For the photo-electron plasma, the typical experimental values obtained for ultra-clean surfaces are expected to differ drastically from values corresponding to realistic spacecraft surfaces. However, a detailed experiment for realistic surfaces of several spacecraft materials has been reported (Ref. 13). Finally, the equilibrium surface potential for these materials has been determined with the use of the parameters above and the requirement that the net current becomes zero at equilibrium. The values of these parameters are given in Table 1.

Following the authors of Refs. 17 and 18, two classes of solutions to the problem were found and noted as monotonic and non-monotonic. The quantity of interest in the electric field in the vicinity of the plate is, however, virtually the same for the two solutions. Some results for aluminum and silica are shown in Fig. 13. The most striking feature of these results is a falloff of the field with distance at a far faster rate than the field for the case with no photo-electric effect. The latter problem has an exact solution, a decreasing exponential, with an e-folding distance equal to the Debye length. For the solar-wind plasma parameters, the Debye length is about 12 m. In contrast, the e-folding distance, as determined by an exponential fit to the results given in Fig. 13, is about 0.8 m for aluminum and 2 m for silica in our analysis. Thus, the effect of the photoelectrons is to dramatically reduce the effective range of the electric field and to render the effective range of the electric field material-dependent.

The one-dimensional problem in the shade was modeled by a surface potential equal to minus three times the electron temperature (in eV) with an exponential spatial dependence. The Debye length in the absence of photo-electrons was employed.

The electric field for the wake is approximate and basically depends on a potential model of the form:

$$\phi = \phi_o \left[J_o\left(2.4 \frac{r}{\bar{a}}\right) \exp\left(-2.4 \frac{|z|}{\bar{a}}\right) \right] \tag{20}$$

where (r, z) is the position in cylindrical coordinates, $\bar{a}$ is the cone radius at height z, ϕ_o is the shaded surface equilibrium potential, and J_o is the zeroth order Bessel function. Corrections were made to approximately satisfy the boundary conditions of a conical geometry.

The electric field in the far-field region is based on the usual potential solution for a uniform sphere in a plasma (at rest) with a known Debye length:

$$\phi = \bar{\phi}_o \left(\frac{a}{r}\right) \exp\left[-\frac{(r - a)}{\bar{\lambda}}\right] \tag{21}$$

In the present application, the surface potential $\bar{\phi}_o$ is identified as PHIAVE, the sphere's radius a is identified as XYWAKE, the Debye length $\bar{\lambda}$ is identified as ALAMAV, and r is the spherical coordinate distance. The electric field may be obtained by a formal differentiation of Eq. 21.

The calculations of the various surface parameters and averaged quantities occur in the computer code ESURF (Appendix C). The determination of the appropriate model for a given spatial position and the electric field evaluation are accomplished in EFIELD (Appendix C).

Table 1. Potential parameters

Material	n_e, cm^{-3}	kT_e, eV	n_ν, cm^{-3}	kT_ν, eV	n_i, cm^{-3}	ϕ_0, V	ϕ_m, V
Al (monotonic)	5	20	1000	3	8.9	13.0	0
Al (non-monotonic)	5	20	1000	3	7.1	12.6	-0.5
SiO_2 (monotonic)	5	20	100	2	10.4	3.7	0
SiO_2 (non-monotonic)	5	20	100	2	7.9	3.3	-0.4

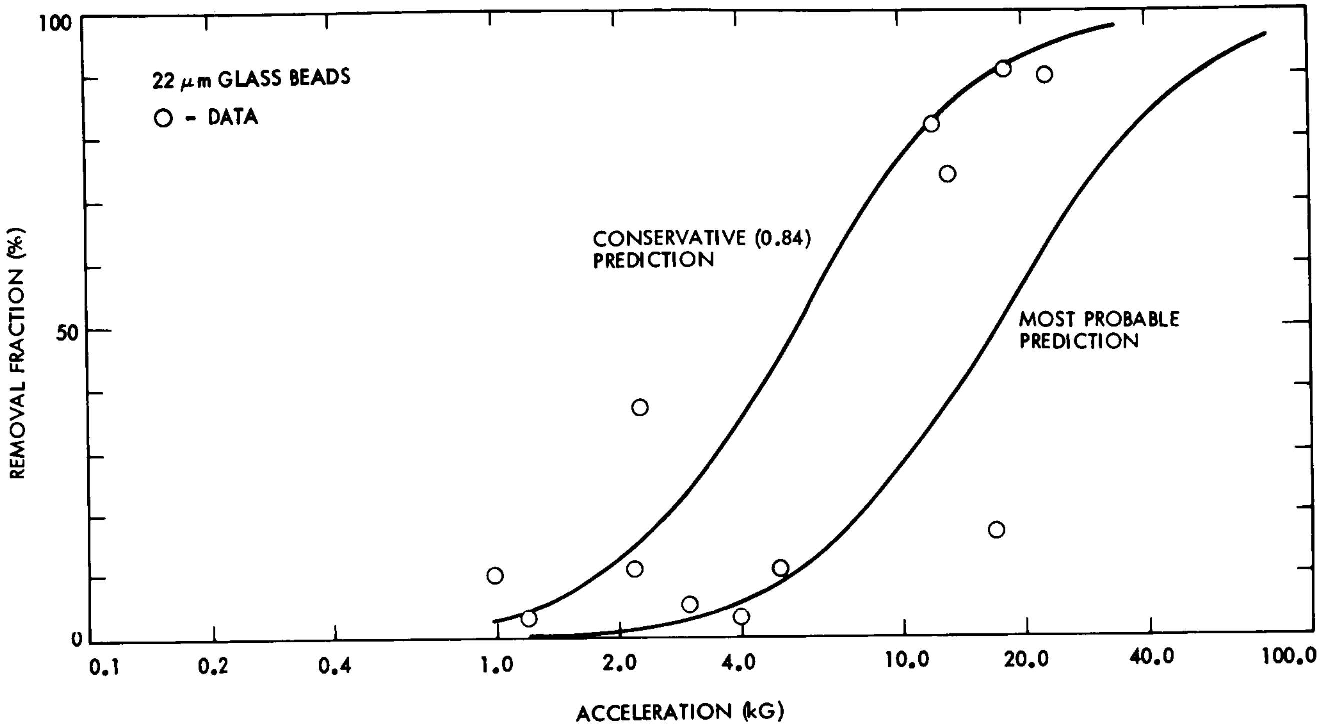

Fig. 1. Comparison of particle adhesion data with predictions of model, 22-μm glass beads

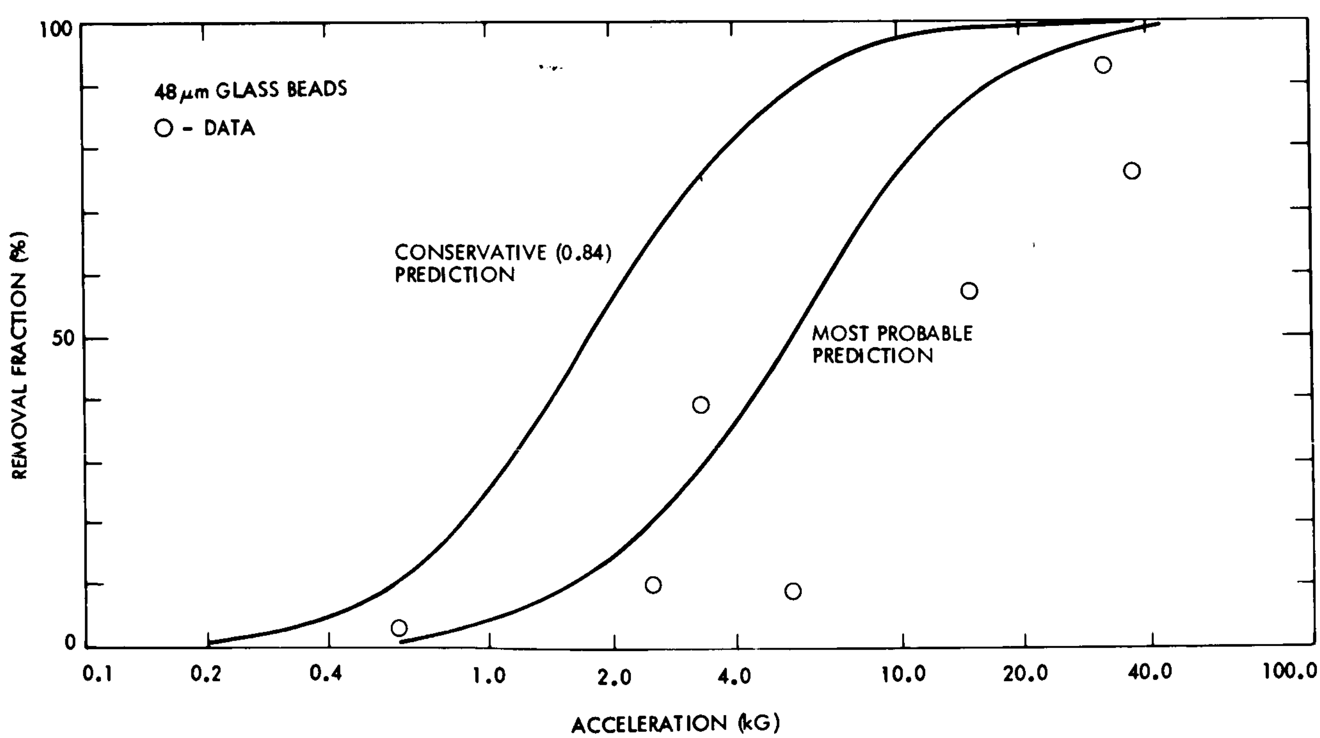

Fig. 2. Comparison of particle adhesion data with predictions of model, 48-μm glass beads

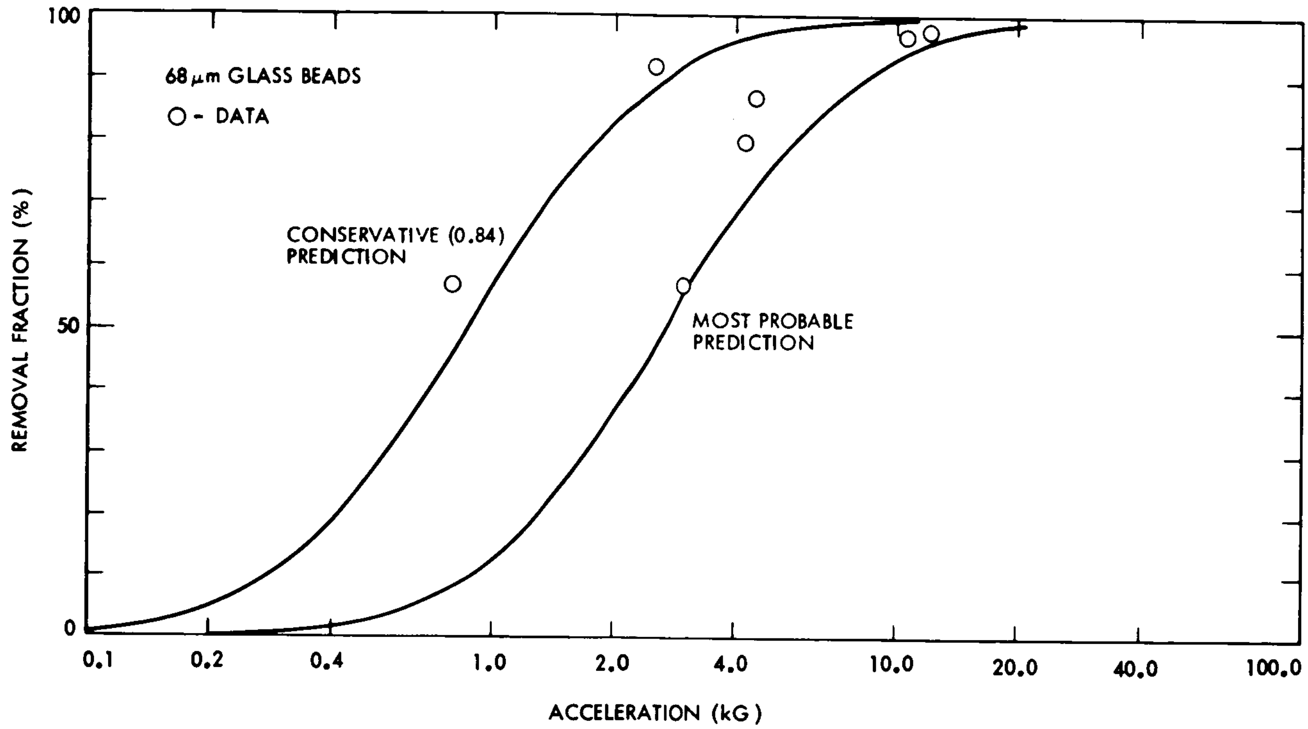

Fig. 3. Comparison of particle adhesion data with predictions of model, 68-μm glass beads

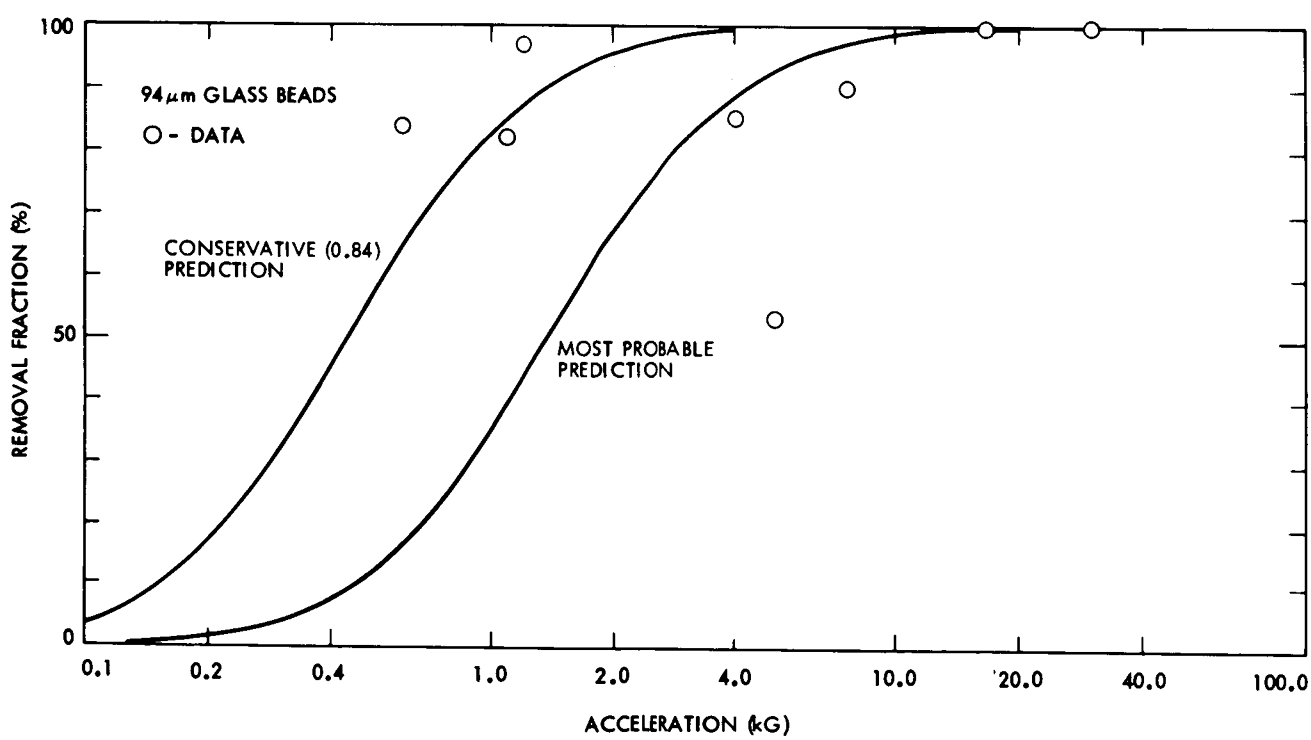

Fig. 4. Comparison of particle adhesion data with predictions of model, 94-μm glass beads

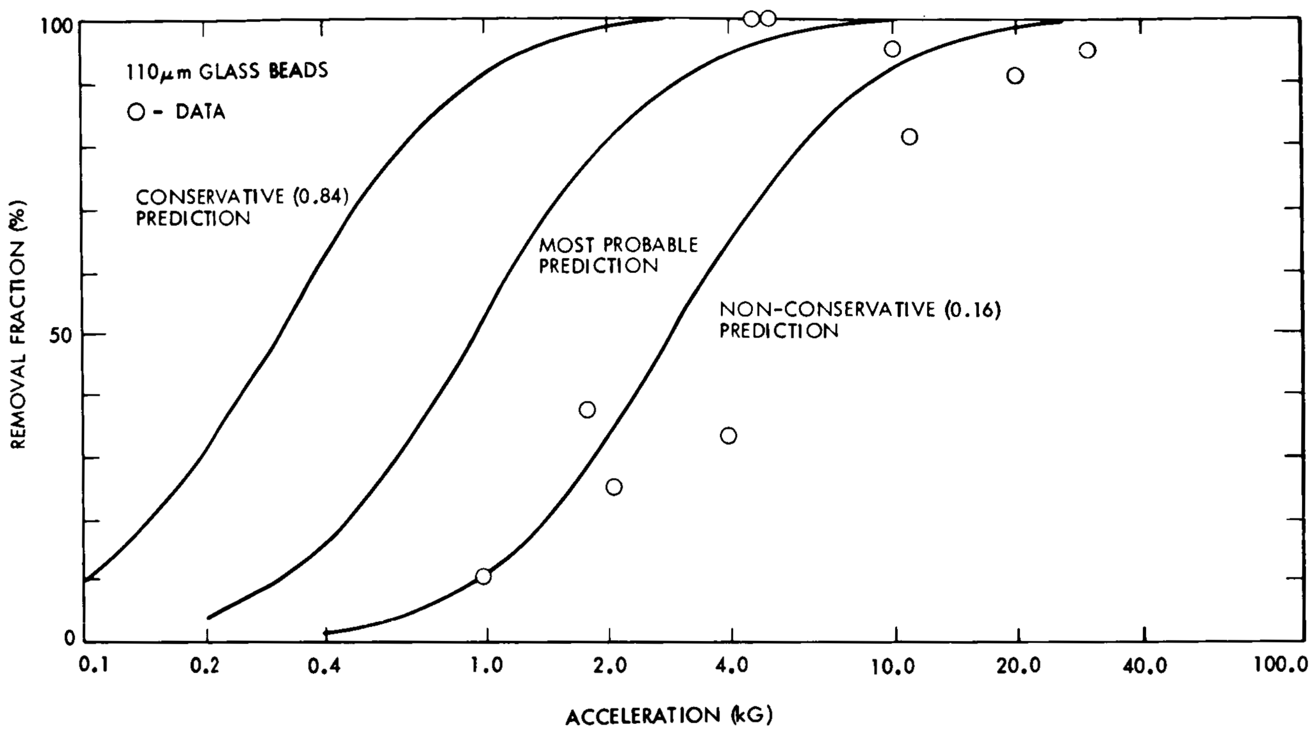

Fig. 5. Comparison of particle adhesion data with predictions of model, 110-μm glass beads

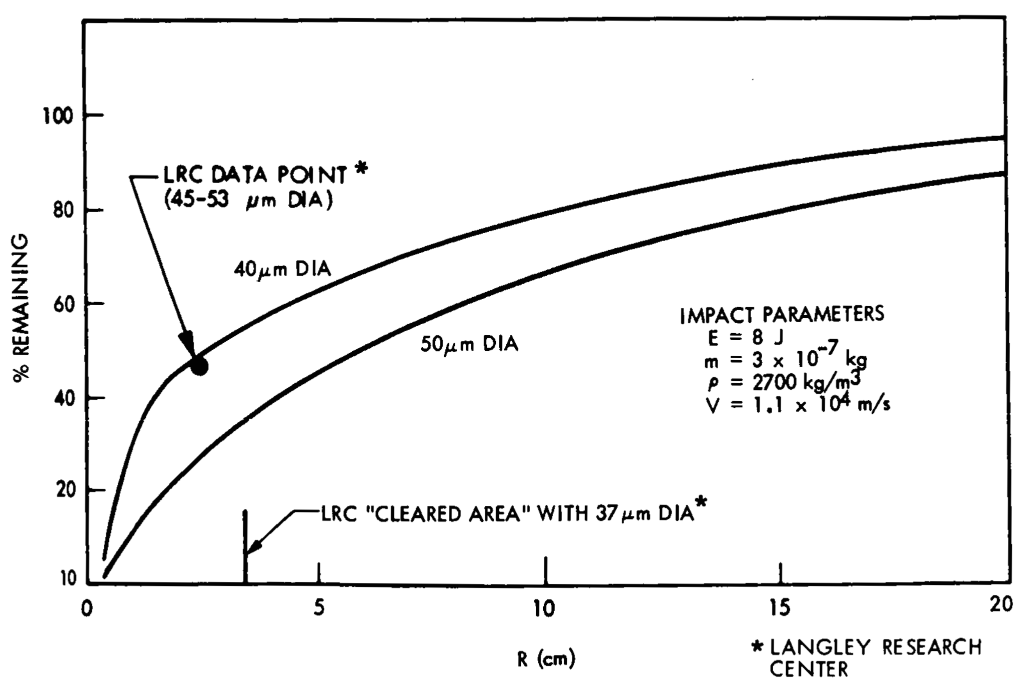

Fig. 6. Glass bead profile predicted post impact for simulation of LRC experiment, Case 1

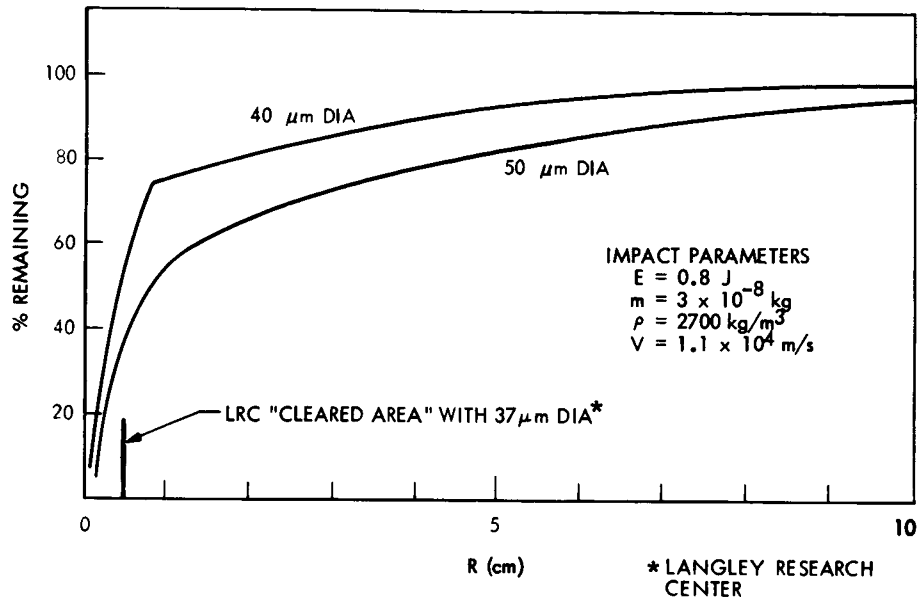

Fig. 7. Glass bead profile predicted post impact for simulation of LRC experiment, Case 2

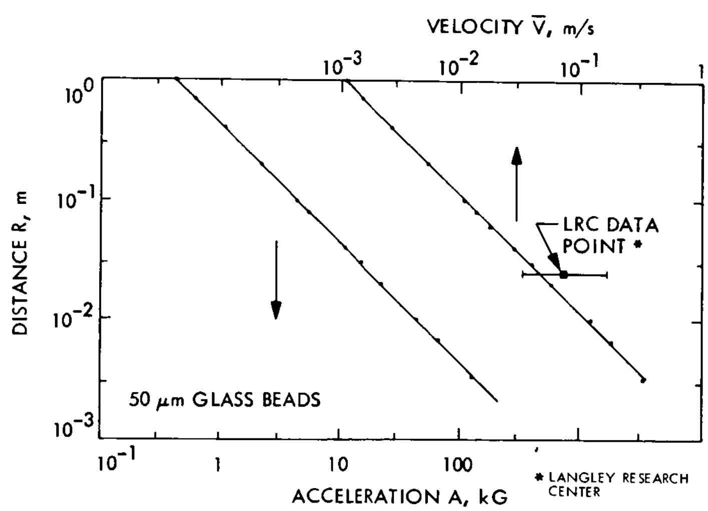

Fig. 8. Particulate removal simulation of LRC Run #6 (NASA TN-7494)

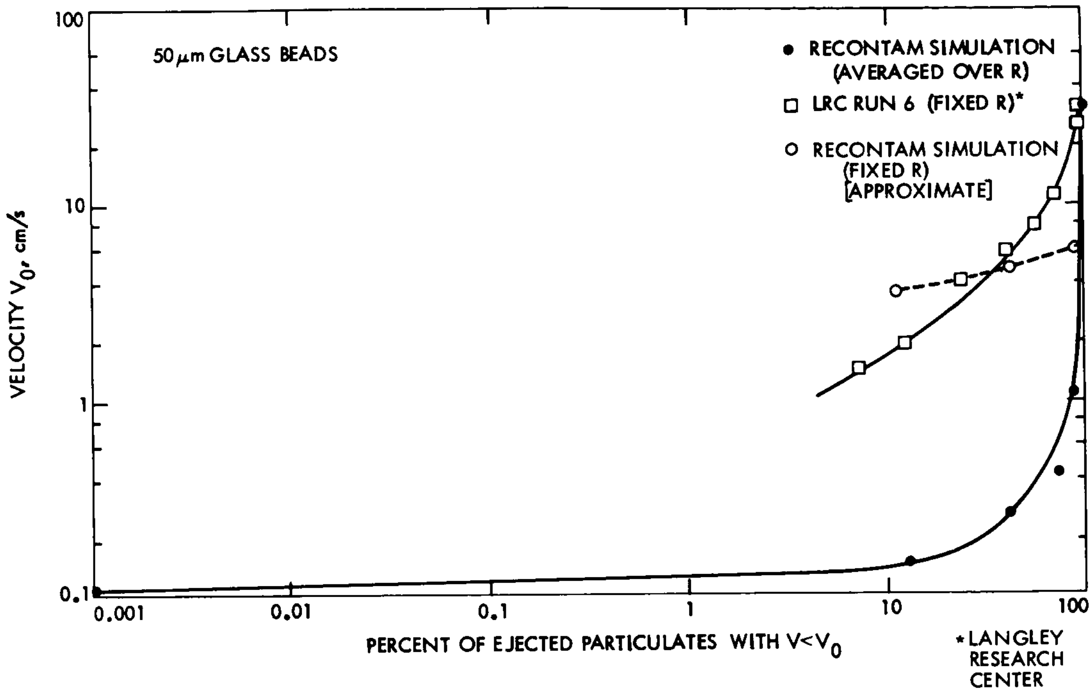

Fig. 9. Release velocity distribution simulation of LRC Run #6 (NASA TN-7494)

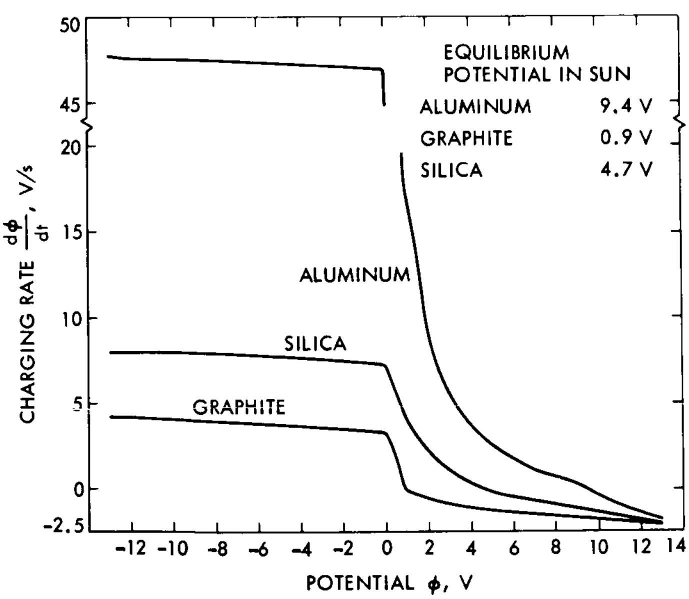

Fig. 10. Grain charging in Sun

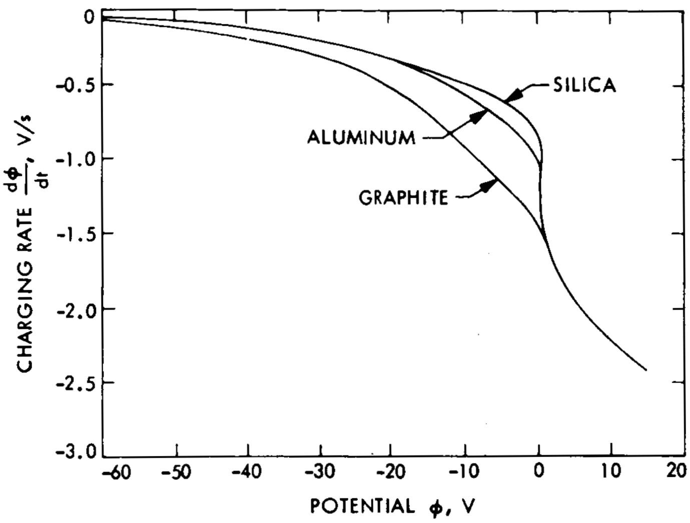

Fig. 11. Grain charging in shade

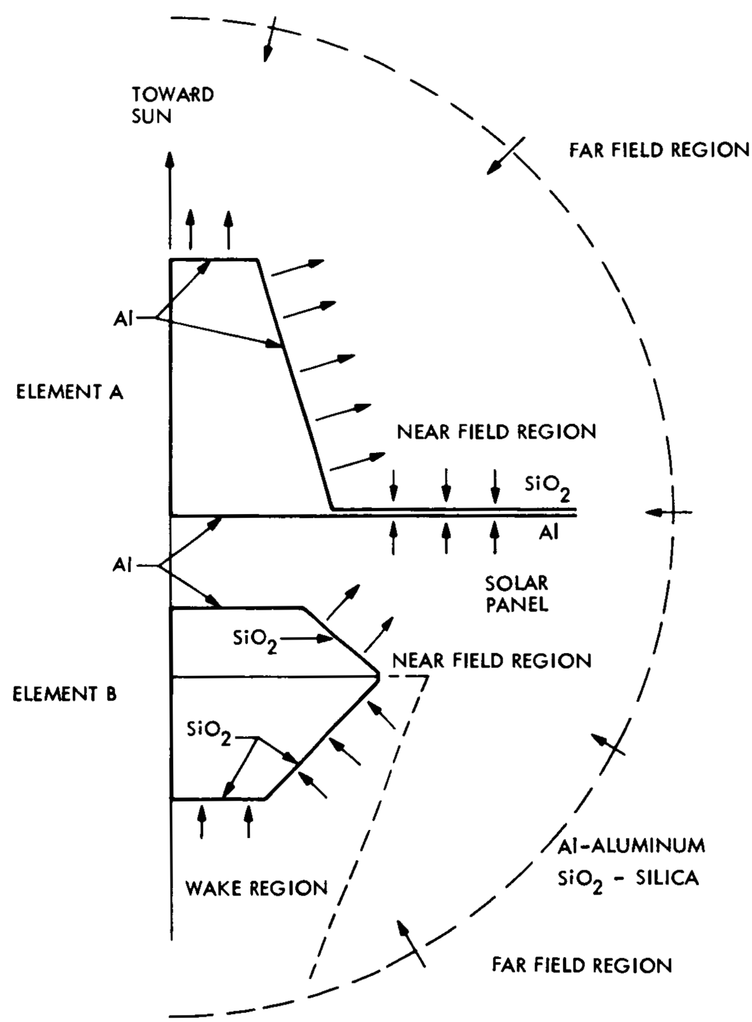

Fig. 12. General indication of the spacecraft electric field with component material designations

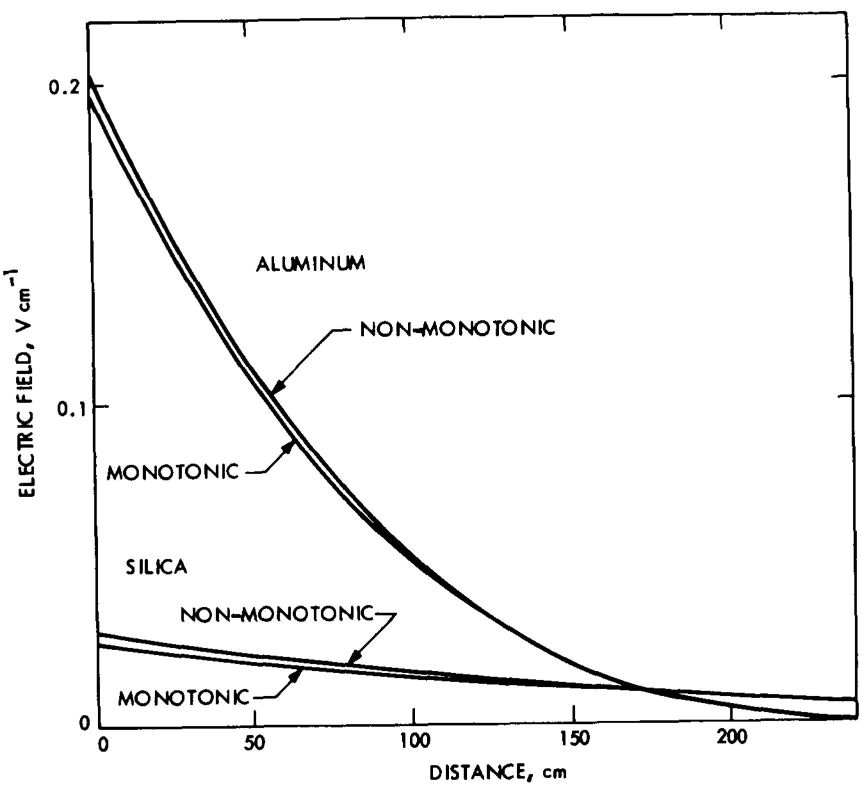

Fig. 13. One-dimensional electric field

III. COMPUTER SIMULATION PHILOSOPHY

A. BLOCK DIAGRAM OVERVIEW

The integration of the specific models for the spacecraft surface-impact response from micrometeoroids, the particle release prediction, and the pyrotechnic device firing is displayed conceptually in Fig. 14. These major computer-coding subgroups indicate the general relationship among the constituent modeling efforts.

The Meteoroid Model block represents the establishment of a ten by three matrix containing ten mass groupings which span 10^{-6} to 10^{-13} kilograms and three velocity groupings of 1.6×10^4, 2.4×10^4 and 3.2×10^4 m/s. These parameter ranges will later be seen to encompass meteoroids of realistic concern as discussed in Ref. 21. The output matrix contains the cometary meteoroid total mission fluence for each mass-velocity (M-V) matrix location and the cometary meteoroid M-V group flux.

Once the flux and fluence calculations have been made, the data for each M-V group are transferred to the Surface Impact Model code. At this point, the effect of a single meteoroid impact upon a thin plate of specified thickness is determined with the output formulated into three arrays of data, corresponding to each M-V sample. These data arrays contain the peak acceleration of the surface and the velocity of the surface at the time when peak acceleration occurs, each as a function of the range from the impact (third array).

The simulation has chosen sample meteoroids that span the range of physical interest in the case of particulate redistribution. Other meteoroid models could also be introduced that yield output in a suitable form: acceleration and velocity of the surface vs. range from impact and a representative fluence evaluation. This is essentially what the PYRO EVENT Model grouping produces for the relevant pyrotechnic devices of known response and location (Appendix B).

The next group of computer coding represents the prediction of particle (on the impacted surface) release probabilities that depend upon the surface environments described above. The internal probabilities are functions of the particulate diameter (10 size groups) and the range from impact. The properties of symmetry and reciprocity allowed all impact ranges to be tested at any one position.

The number of trial ejecta histories required for full simulation has been increasing during each step in the discussion. For each of the thirty M-V groups, ten ejecta sizes were analyzed along with, typically, six to nine ejecta velocities (see Appendix C). This totals approximately to 2500 trial histories necessary to fully cover the variable ranges developed to this point in the program flow.

The next consideration concerns the location of impact on the geometrically specified spacecraft. Reference 21, upon which the cometary meteoroid information has been based, describes an isotropic directional distribution; thus, all portions of the exposed spacecraft are assumed equally likely to have micrometeoroid impact. The particle transport code, therefore, begins with a Monte Carlo selection of the surface position, limited to the unsterile surfaces (Fig. 15), to be considered as the initial trajectory location. The Monte Carlo method has the advantage of producing an unbiased set of random impact points. A disadvantage of Monte Carlo is that a large number of selections must be made to obtain statistically representative data. For this reason, Monte Carlo was applied only to this one parameter, the position. An analytically deterministic approach using the discrete group distributions generated above for all other relevant parameters was applied for statistical and economic optimization.

The program is arranged such that the descending order of selection within the coding follows: M-V groups; number of positions to be considered; ejecta size; and velocity groups, respectively. The arrangement allows the testing of all ejecta size and velocity groups (60-80 total) at every position for each M-V set (2500 times number of positions).

The final computer code group keeps account of statistical information as the model courses its way through the execution. During each kinematical grain trajectory, positional track is kept on the ejected particle to monitor for spacecraft recontact and recontact location. The categories of interest are whether the ejecta recontacts a nonsterile surface, a sterile surface, or escapes.

B. REQUIRED INPUT DATA

The spacecraft being modeled is required to be of the basic configuration displayed earlier in Fig. 12. The truncated cone dimensions are arbitrary, in that the inclination angles and base dimensions are adjusted to describe a specific mission. Figure 15 identifies the spacecraft model components. The spacecraft surface must be specified for density, thickness, particulate load, and physical dimensions. Solar generated plasma parameters, solar energy spectrum, material photo-electron yield, physical constants, mission-dependent information. etc., need characterization. Appendix A lists each specific data entry requirement within the coding for element DATAIN.

C. OUTPUT DATA FORMULATION

Upon completion of the mission data entry and the compilation of an executable element (Appendices A and D, respectively), the execution commences. The following extended list, Table 2a-i, represents samples of a typical computer run printout. Initially, the mission-dependent internally-calculated constants are listed as in Table 2a; the tangents of the cone section defining angles are listed; the areas of the various sections (i.e., ASP is the solar panel area, etc.); the Z axis cone truncation intercepts are listed, with Z1 defining the dark side Debye length; the radius and depth of the plasma wake (XYWAKE, ZWAKE, respectively); the Z axis coordinates of the cone verticies (AL); the electrical characteristics of the spacecraft, where ALAMB is sunlit side Debye length for aluminum and silica, EFEL is the sunlit side electric field magnitude, EFED is the shaded side electric field magnitude, PHIEL and PHIED are the illuminated and shaded surface potentials for aluminum and silica, DEB is the shaded side Debye length, ALAMAV and PHIAVE are area averaged Debye length and surface potential (for far-field considerations), respectively; and finally, the AMAT array describes the spacecraft material beginning with the element A top plate and ending with the element B bottom plate (see Appendix A).

The next page in the printout shows the data card image for the case to be studied (Table 2b). We have listed the image for a typical meteoroid mass-velocity group case study and the image for a pyrotechnic event simulation (see Appendix E). The two parameters designated as pyrotechnic localizers limit the random pyrotechnic position selection to a particular section of the space vehicle (see Appendix B). The next page (Table 2c) lists the group identifiers, meteoroid mass, meteoroid velocity, and M-V group flux and fluence values. Immediately thereafter, the table of range, peak acceleration vs. range, and velocity vs. range for the impacted surface is printed. (Table 2c data correspond to points A and B on Fig. 14.) In the pyrotechnic event phase, the corresponding page output is shown in Table 2d. This likewise corresponds to point B on Fig. 14.

Preliminary summaries in the form of "Box Scores" are then output during execution for each position selected (part D on Fig. 14). Tables 2e and 2f depict this information for one position of a meteoroid M-V group and a pyrotechnic event, respectively. The position coordinates are for the initial ejecta location (Z axis origin is one Debye length in the anti-Sun direction). The Box Score indicates the number of ejected grains that recontacted a safe area, recontacted a "sterile specified" zone, passed near but missed the spacecraft, and escaped at this position. The average velocity of escape in m/s is also indicated.

Table 2g shows the altered form of the output when a recontamination event occurs (part C on Fig. 14). This output indicates the ejecta size and velocity, as well as several constants relating to the particular characteristics of this grain, followed by a step-by-step account of the trajectory from meteoroid impact triggered grain ejection to the sterile zone recontact. This accounting includes the integrated path length, the positional coordinates, the particle charge, the visually helpful shade-solar panel-sector indicies, the electric field vector, and the incremental time-of-flight from previous position. Upon recontamination, a recap is printed with a Box Score list for this position. When all of the positions have been tested for one meteoroid M-V group, another Box Score is printed, as shown in Table 2h, that reflects the total mission results due to this particular meteoroid group.

The general software is configured to study many M-V groups in sequence, after which the grand ensemble values for all the groups studied are listed. Table 2i concludes the printout showing the total mission fluence due to these M-V groups, the grand ensemble, the standard deviation for the recontamination prediction, an angular distribution listing for the grains that escape, and a probability value (assuming Poisson statistics) for the event that one or more grains recontaminate the sterile zone.

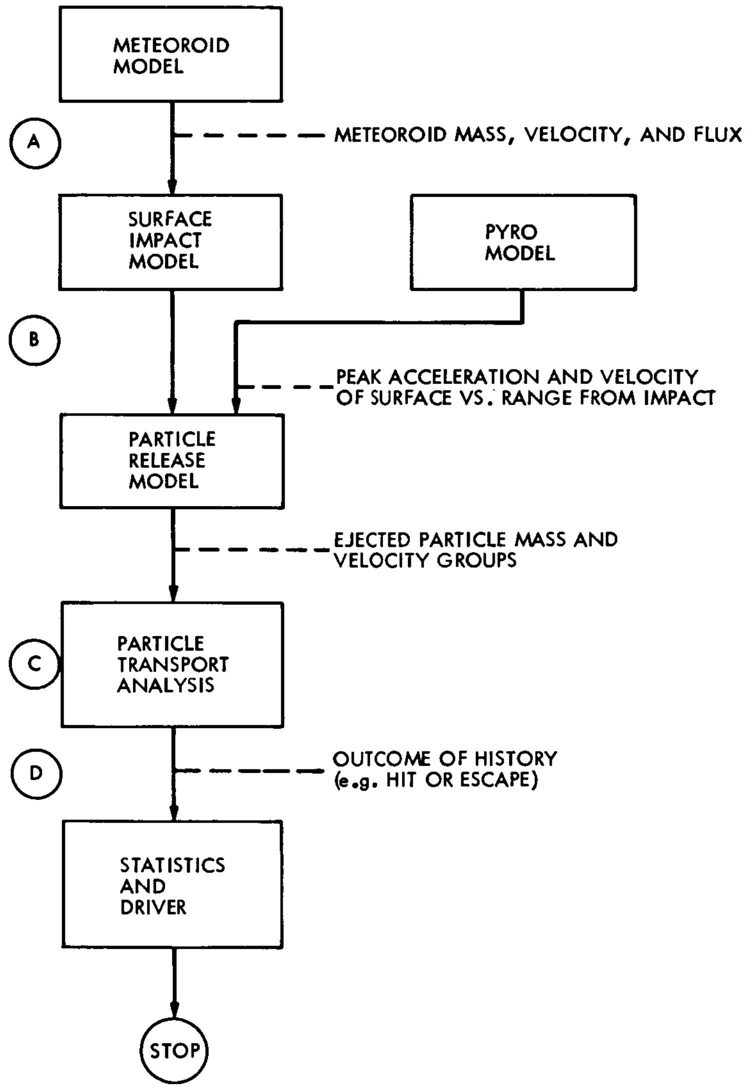

Fig. 14. Major software component block diagram

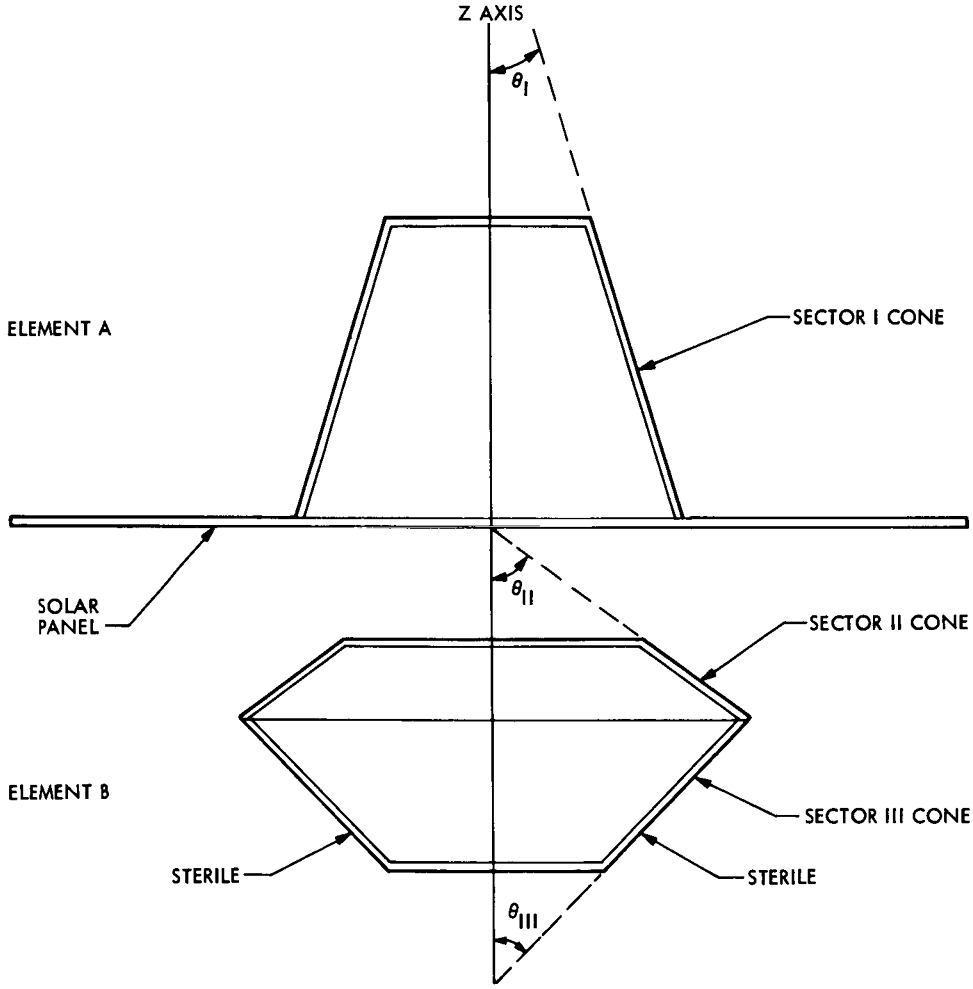

Fig. 15. Cone spacecraft model cross-sectional geometry

TABLE 2a. Initial constants for hypothetical mission (sample computer printout)

```
THE FOLLOWING ARE GENERAL SPACECRAFT MODEL DATA

THE TANGENTS FOR CONE ANGLES ARE .7585    -.6437    -4.199    7.196

ASP=20.8    ATP=1.82    ATS=14.0    AI=36.6    AII=7.83    ATOT=44.4    PRI=.176    ABP=.398    ABCS=12.7

Z1= 18.22    Z2= 19.34    Z3= 19.79    Z4= 20.68    Z5= 22.81

XYWAKE=  2.1179    ZWAKE=  5.4403

THE AL ARRAY CONTAINS 17.95    20.51    26.01    5.440
  . . ALAMB . .          . . EFEL . .          . . EFED . .        DEB
 .783       1.74      19.1      2.31      -3.29      -3.29      18.2

  . . PHIEL . .          . . PHIED . .         . ALAMAV . . PHIAVE .
 13.0       3.69      -60.0     -60.0      9.56      -25.2

  . . AMAT ARRAY . .                       . . AMAT ARRAY . .
AL      AL      SI02    AL      AL      AL      SI02    SI02    SI02

. . EL ARRAY  . .
AL      SI02
```

TABLE 2b. Typical initialization data printout (sample computer printout)

THE INPUT METEOROID CASE DATA CARD FOR MASS GROUP 4 AND VELOC. GROUP 2

DUMMY VARIABLE	IMPACT DATA DIMENSION	EJECTA SIZE INCLUSIVE (10-100 μm)	GROUP METEOROID VELOCITY (m/s)	GROUP METEOROID MASS (Kg)	VELOCITY GROUP	MASS GROUP	SM1 (RELATED TO FLUX)
1	22	1 10	.21686+05	.10000-10	2	4	.5295-09

THE INPUT PYRO CASE DATA CARD FOR PYRO NUMBER 1

DUMMY VARIABLE	IMPACT DATA DIMENSION	EJECTA SIZE INCLUSIVE (10-100 μm)	PYRO NUMBER	NUMBER OF PYROS	PYRO LOCALIZING PARAMETERS	SECTOR IDENTIFICATION
2	6	1 10	1	4	.22000+30	.54000+00SECTOR ONE CONE

TABLE 2c. Meteoroid model identifiers and surface response model data (sample computer printout)

```
MASS GROUP=  4  VELOC. GROUP=  2

THE METEOROID MASS IS 1.0000-11  THE METEOROID VELOC. IS 2.1686+04

WITH A GROUP FLUX OF 9.4786-07   AND THE TOTAL METEOROID IMPACTS OF THIS TYPE EXPECTED ARE  1092.
```

I	R(I)	PKACC(I)	VAP(I)
1	2.00902-04	2.17186+01	-4.86386-01
2	9.05040-04	4.82112+00	-1.07969-01
3	1.60918-03	2.71151+00	-6.07242-02
4	2.31332-03	1.88617+00	-4.22407-02
5	3.01746-03	1.44602+00	-3.23836-02
6	3.72159-03	1.17243+00	-2.62565-02
7	4.42573-03	9.85896-01	-2.20791-02
8	5.12987-03	8.50569-01	-1.90484-02
9	5.83401-03	7.47909-01	-1.67494-02
10	6.53815-03	6.67362-01	-1.49455-02
11	7.24228-03	6.02477-01	-1.34924-02
12	7.47030-03	5.82957-01	-1.30647-02
13	8.43658-03	5.05988-01	-1.13248-02
14	1.00000-02	4.47197-01	-1.00579-02
15	2.00000-02	3.05795-01	-7.39327-03
16	3.00000-02	2.10800-01	-5.32661-03
17	4.00000-02	1.49413-01	-3.98310-03
18	6.00000-02	1.06780-01	-2.53372-03
19	8.00000-02	8.07691-02	-2.12841-03
20	1.00000-01	5.94890-02	-1.72649-03
21	2.00000-01	3.33092-02	-8.06471-04
22	4.00000-01	1.67776-02	-4.19887-04

TABLE 2d. Typical pyrotechnic device response data (sample computer printout)

```
PYRO NO.   1  LOCATED IN FIRST X-Y QUADRANT AT
                    SECTOR ONE CONE
   TOTAL NO. AT EQUIVALENT POSITIONS ON S/C IS   4
```

I	R(I)	PKACC(I)	VAP(I)
1	5.20000-04	1.00000+02	-1.65000+01
2	8.00000-02	2.80000+01	-4.60000+00
3	2.50000-01	3.00000+00	-2.70000-01
4	5.00000-01	8.00000-01	-6.80000-02
5	7.50000-01	4.00000-01	-3.90000-02
6	1.00000+00	1.00000-01	-2.70000-02

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OF POOR QUALITY

TABLE 2e. Typical meteoroid M-V case positional box score (sample computer printout)

```
MASS GROUP  7     VELOC. GROUP  1     POSITION NO.   91

PR= .1097

THE RANDOM POSITION VECTOR IS .9409      1.086       19.59

ISHADE= 0  IPANEL= 0  NPNL= 0  ISECTR= 2

THE NORMAL VECTOR FOR THIS CASE IS    .3547       .5088       .8409



 OX SCORE FOR RANDOM POSITION    9.41-01  1.08+00  1.96+01

NO. SAFEHITS  22.906
NO. RECONTAM HITS  .00000
NO. NEAR MISSES  12.440
NO. ESCAPES  435.92
AVE. ESCAPE VEL.  .27973
```

TABLE 2f. Typical pyrotechnic device event positional box score (sample computer printout)

```
PYRO NO.  1     POSITION NO.    4

PR= .5116

THE RANDOM POSITION VECTOR IS .4031      .7598       22.40

ISHADE= 0  IPANEL= 0  NPNL= 0  ISECTR= 1

THE NORMAL VECTOR FOR THIS CASE IS    .5559       .8594       .2317



BOX SCORE FOR RANDOM POSITION    4.03-01  7.60-01  2.24+01

NO. SAFEHITS  .26879-01
NO. RECONTAM HITS  .00000
NO. NEAR MISSES  10.604
NO. ESCAPES  6962.8
AVE. ESCAPE VEL.  1.9215
```

TABLE 2g. Typical recontamination event summary and trajectory (sample computer printout)

```
MASS GROUP  4      VELOC. GROUP  2      POSITION NO.   17

PR= .1327

THE RANDOM POSITION VECTOR IS 1.080      1.197      19.48

ISHADE= 0  IPANEL= 0  NPNL= 0  ISECTR= 2

THE NORMAL VECTOR FOR THIS CASE IS    .3626      .5018      .8409


POSITION    17    GRAIN SIZE GROUP     4    GRAIN VELOC. GROUP     6


DIM= .4000-04  COEFRP=-.5864-14  CONSTA= .2224-14  PRTCHG= .8205-14  GMASS= .8042-10  PRBDIA= .4671-01
VELMAG= .4963-02  PBVELC= .4058-02  WEIGHT= .3389-02  VELVEC= .1800-02   .2491-02   .4174-02
```

STEP	PATH LENGTH	X-POSITION	Y-POSITION	Z-POSITION	PART. CHG.	SH-P-SE	E(X)	E(Y)	E(Z)	DT
0	0.00000	1.0800	1.1970	19.476	8.20497-15	0 0 2	.8365	.9271	1.940	7.72
1	4.52335-02	1.0964	1.2190	19.512	9.42882-15	0 0 2	.8135	.9045	1.890	6.11
2	8.90538-02	1.1132	1.2407	19.546	9.15129-15	0 0 2	.7922	.8829	1.843	5.13
3	.13156	1.1300	1.2618	19.579	9.10908-15	0 0 2	.7722	.8623	1.798	4.56
4	.17347	1.1469	1.2828	19.611	9.07890-15	0 0 2	.7531	.8424	1.755	4.16
5	.21501	1.1638	1.3037	19.642	9.05613-15	0 0 2	.7347	.8230	1.714	3.84
6	.25629	1.1809	1.3246	19.674	9.03834-15	0 0 2	.7170	.8042	1.674	3.63
7	.29738	1.1980	1.3455	19.705	9.02408-15	0 0 2	.6998	.7859	1.635	3.44
8	.33833	1.2152	1.3663	19.735	9.01243-15	0 0 2	.6832	.7681	1.597	3.28
9	.37916	1.2325	1.3872	19.766	9.00277-15	0 0 2	.6670	.7507	1.560	3.15
10	.41991	1.2499	1.4081	19.796	8.99466-15	0 0 2	0.0000	0.0000	0.0000	3.04
11	.45965	1.2670	1.4286	19.826	8.98778-15	0 0 2	0.0000	0.0000	0.0000	3.08
12	.49940	1.2843	1.4494	19.855	8.99007-15	0 0 2	0.0000	0.0000	0.0000	3.12
13	.53914	1.3018	1.4705	19.884	8.98356-15	0 0 2	0.0000	0.0000	0.0000	3.16
14	.57887	1.3196	1.4918	19.912	8.98641-15	0 0 2	0.0000	0.0000	0.0000	3.20
15	.61861	1.3375	1.5134	19.940	8.98896-15	0 0 2	0.0000	0.0000	0.0000	3.24
16	.65833	1.3558	1.5354	19.968	8.98233-15	0 0 2	0.0000	0.0000	0.0000	3.28
17	.69806	1.3742	1.5576	19.995	8.98545-15	0 0 2	0.0000	0.0000	0.0000	3.33
18	.73778	1.3930	1.5801	20.022	8.98823-15	0 0 2	0.0000	0.0000	0.0000	3.38
19	.77750	1.4119	1.6029	20.048	8.99068-15	0 0 2	0.0000	0.0000	0.0000	3.42
20	.81722	1.4312	1.6260	20.074	8.98345-15	0 0 2	0.0000	0.0000	0.0000	3.47
21	.85693	1.4507	1.6495	20.100	8.98660-15	0 0 2	0.0000	0.0000	0.0000	3.52
22	.89664	1.4705	1.6733	20.124	8.98938-15	0 0 2	0.0000	0.0000	0.0000	3.57
23	.93635	1.4906	1.6975	20.149	8.98201-15	0 0 2	0.0000	0.0000	0.0000	3.62
24	.97606	1.5110	1.7219	20.172	8.98551-15	0 0 2	0.0000	0.0000	0.0000	3.67
25	1.0158	1.5316	1.7468	20.195	8.98856-15	0 0 2	0.0000	0.0000	0.0000	3.73
26	1.0555	1.5526	1.7720	20.218	8.98098-15	0 0 2	0.0000	0.0000	0.0000	3.78
27	1.0952	1.5739	1.7976	20.240	8.98478-15	0 0 2	0.0000	0.0000	0.0000	3.84
28	1.1349	1.5955	1.8235	20.260	8.98807-15	0 0 2	0.0000	0.0000	0.0000	3.89
29	1.1746	1.6174	1.8498	20.281	8.99092-15	0 0 2	0.0000	0.0000	0.0000	3.95
30	1.2143	1.6396	1.8765	20.300	8.98256-15	0 0 2	0.0000	0.0000	0.0000	4.00
31	1.2541	1.6621	1.9036	20.318	8.98633-15	0 0 2	0.0000	0.0000	0.0000	4.06
32	1.2938	1.6849	1.9310	20.336	8.98957-15	0 0 2	0.0000	0.0000	0.0000	4.11
33	1.3335	1.7080	1.9588	20.352	8.98106-15	0 0 2	0.0000	0.0000	0.0000	4.16
34	1.3733	1.7314	1.9870	20.368	8.98522-15	0 0 2	0.0000	0.0000	0.0000	4.22
35	1.4130	1.7552	2.0155	20.382	8.98877-15	0 0 2	0.0000	0.0000	0.0000	4.27
36	1.4528	1.7791	2.0443	20.395	8.98007-15	0 0 2	0.0000	0.0000	0.0000	4.31
37	1.4926	1.8034	2.0735	20.407	8.98455-15	0 0 2	0.0000	0.0000	0.0000	4.36
38	1.5324	1.8279	2.1030	20.418	8.98833-15	0 0 2	0.0000	0.0000	0.0000	4.40
39	1.5722	1.8527	2.1327	20.427	8.99151-15	0 0 2	0.0000	0.0000	0.0000	4.44
40	1.6120	1.8776	2.1627	20.435	8.98200-15	0 0 2	0.0000	0.0000	0.0000	4.47
41	1.6519	1.9028	2.1929	20.442	8.98631-15	0 0 2	0.0000	0.0000	0.0000	4.50
42	1.6918	1.9280	2.2233	20.447	8.98990-15	0 0 2	0.0000	0.0000	0.0000	4.52
43	1.7317	1.9535	2.2539	20.451	8.98049-15	0 0 2	0.0000	0.0000	0.0000	4.53
44	1.7717	1.9790	2.2845	20.453	8.98513-15	0 0 2	0.0000	0.0000	0.0000	4.54
45	1.8116	2.0045	2.3153	20.454	8.98897-15	0 0 2	0.0000	0.0000	0.0000	4.55
46	1.8516	2.0301	2.3460	20.454	8.97966-15	0 0 2	0.0000	0.0000	0.0000	4.54
47	1.8917	2.0556	2.3767	20.451	8.98445-15	0 0 2	0.0000	0.0000	0.0000	4.54
48	1.9317	2.0812	2.4074	20.448	8.98840-15	0 0 2	0.0000	0.0000	0.0000	4.52
49	1.9718	2.1066	2.4380	20.443	8.99165-15	0 0 2	0.0000	0.0000	0.0000	4.50
50	2.0119	2.1319	2.4684	20.436	8.98198-15	0 0 2	0.0000	0.0000	0.0000	4.47
51	2.0521	2.1570	2.4986	20.428	8.98630-15	0 0 2	0.0000	0.0000	0.0000	4.44
52	2.0922	2.1820	2.5286	20.418	8.98985-15	0 0 2	0.0000	0.0000	0.0000	4.40
53	2.1324	2.2067	2.5584	20.408	8.98069-15	0 0 2	0.0000	0.0000	0.0000	4.36
54	2.1726	2.2313	2.5878	20.396	8.98512-15	0 0 2	-3.499	-4.072	.4483	4.31
55	2.2074	2.2519	2.6128	20.383	8.98876-15	0 0 2	-3.427	-3.991	.4596	8.79
56	2.2391	2.2683	2.6331	20.365	8.97695-15	0 0 2	-3.368	-3.926	.4701	9.48
57	2.2699	2.2677	2.6344	20.334	8.98792-15	0 0 2	-3.357	-3.919	.5142	9.34
58	2.3293	2.2341	2.5972	20.302	8.99481-15	0 0 2	-3.447	-4.031	.5852	4.56
59	2.3750	2.2058	2.5651	20.286	8.98497-15	0 0 2	0.0000	0.0000	0.0000	3.53
60	2.4161	2.1807	2.5366	20.273	8.98755-15	0 0 2	0.0000	0.0000	0.0000	3.51
61	2.4553	2.1658	2.5082	20.259	8.99019-15	0 0 2	0.0000	0.0000	0.0000	3.48
62	2.4954	2.1311	2.4801	20.245	8.98290-15	0 0 2	0.0000	0.0000	0.0000	3.45
63	2.5354	2.1065	2.4522	20.230	8.98611-15	0 0 2	0.0000	0.0000	0.0000	3.43
64	2.5758	2.0822	2.4245	20.214	8.98888-15	0 0 2	0.0000	0.0000	0.0000	3.40

TABLE 2g. Typical recontamination event summary and trajectory (sample computer printout) (contd)

STEP	PATH LENGTH	X-POSITION	Y-POSITION	Z-POSITION	PART. CHG.	SH-P-SE	E(X)	E(Y)	E(Z)	DT
65	2.6159	2.0581	2.3971	20.197	8.98194-15	0 0 2	0.0000	0.0000	0.0000	3.37
66	2.6561	2.0342	2.3699	20.180	8.98519-16	0 0 2	0.0000	0.0000	0.0000	3.34
67	2.6963	2.0105	2.3429	20.162	8.98800-15	0 0 2	0.0000	0.0000	0.0000	3.31
68	2.7365	1.9870	2.3162	20.143	8.99044-15	0 0 2	0.0000	0.0000	0.0000	3.28
69	2.7767	1.9638	2.2897	20.124	8.98354-15	0 0 2	0.0000	0.0000	0.0000	3.25
70	2.8168	1.9407	2.2635	20.104	8.98648-15	0 0 2	0.0000	0.0000	0.0000	3.22
71	2.8570	1.9179	2.2375	20.083	8.98903-15	0 0 2	0.0000	0.0000	0.0000	3.18
72	2.8972	1.8953	2.2118	20.062	8.98251-15	0 0 2	0.0000	0.0000	0.0000	3.15
73	2.9374	1.8729	2.1863	20.041	8.98549-15	0 0 2	0.0000	0.0000	0.0000	3.12
74	2.9776	1.8507	2.1610	20.019	8.98808-15	0 0 2	0.0000	0.0000	0.0000	3.09
75	3.0174	1.8287	2.1360	19.996	8.99035-15	0 0 2	0.0000	0.0000	0.0000	3.06
76	3.0580	1.8070	2.1113	19.973	8.98392-15	0 0 2	0.0000	0.0000	0.0000	3.03
77	3.0982	1.7854	2.0868	19.950	8.98662-15	0 0 2	0.0000	0.0000	0.0000	3.00
78	3.1384	1.7641	2.0625	19.926	8.98899-15	0 0 2	0.0000	0.0000	0.0000	2.98
79	3.1786	1.7429	2.0385	19.901	8.98289-15	0 0 2	0.0000	0.0000	0.0000	2.95
80	3.2187	1.7220	2.0146	19.877	8.98564-15	0 0 2	0.0000	0.0000	0.0000	2.92
81	3.2589	1.7013	1.9911	19.852	8.98805-15	0 0 2	0.0000	0.0000	0.0000	2.89
82	3.2991	1.6808	1.9677	19.826	8.99017-15	0 0 2	0.0000	0.0000	0.0000	2.86
83	3.3393	1.6604	1.9446	19.800	8.98418-15	0 0 2	0.0000	0.0000	0.0000	2.84
84	3.3795	1.6403	1.9217	19.774	8.98667-15	0 0 2	.5260	.6162	1.259	2.81
85	3.4191	1.6206	1.8992	19.748	8.98888-15	0 0 2	.5376	.6300	1.287	2.87
86	3.4580	1.6009	1.8769	19.722	8.98301-15	0 0 2	.5494	.6442	1.315	2.94
87	3.4980	1.5813	1.8546	19.696	8.98574-15	0 0 2	.5615	.6586	1.345	3.02
88	3.5375	1.5617	1.8323	19.670	8.98822-15	0 0 2	.5739	.6733	1.375	3.11
89	3.5769	1.5421	1.8102	19.644	8.99048-15	0 0 2	.5865	.6884	1.405	3.21
90	3.6162	1.5226	1.7880	19.618	8.98373-15	0 0 2	.5993	.7038	1.436	3.32
91	3.6554	1.5031	1.7660	19.592	8.98671-15	0 0 2	.6124	.7195	1.468	3.45
92	3.6946	1.4836	1.7440	19.566	8.98942-15	0 0 2	.6258	.7356	1.500	3.60
93	3.7337	1.4642	1.7221	19.541	8.98199-15	0 0 2	.6394	.7520	1.533	3.77
94	3.7720	1.4448	1.7003	19.515	8.98563-15	0 0 2	.6532	.7687	1.567	3.98
95	3.8114	1.4254	1.6786	19.489	8.98892-15	0 0 2	.6672	.7857	1.601	4.24
96	3.8500	1.4061	1.6571	19.464	8.98025-15	0 0 2	.6815	.8031	1.636	4.56
97	3.8883	1.3869	1.6356	19.438	8.98495-15	0 0 2	.6959	.8207	1.672	4.98
98	3.9263	1.3677	1.6144	19.413	8.98919-15	0 0 2	.7104	.8385	1.707	5.54
99	3.9636	1.3486	1.5934	19.389	8.97779-15	0 0 2	.7248	.8565	1.743	6.38
100	4.0001	1.3297	1.5729	19.366	8.98497-15	0 0 2	.7391	.8744	1.779	7.75
101	4.0347	1.3112	1.5533	19.344	8.99156-15	0 0 2	.7527	.8917	1.813	10.0
102	4.0634	1.2947	1.5368	19.327	8.97010-15	0 0 3	-2.093	-2.484	.4513	10.0
103	4.1001	1.2768	1.5114	19.316	8.98428-15	0 0 3	-2.094	-2.491	.4522	7.35
104	4.1498	1.2383	1.4750	19.306	8.99073-15	0 0 3	-2.098	-2.499	.4533	4.94
105	4.1943	1.2094	1.4421	19.299	8.98028-15	0 0 3	-2.101	-2.506	.4544	4.09
106	4.2372	1.1814	1.4101	19.292	8.98444-15	0 0 3	-2.105	-2.512	.4554	3.52
107	4.2795	1.1540	1.3785	19.287	8.98751-15	-1 0 3	-1.276	-1.625	2.621	.934
108	4.2914	1.1462	1.3696	19.285	6.76327-15	-1 0 3	-1.276	-1.525	2.622	.969
109	4.3039	1.1381	1.3602	19.284	4.53902-15	-1 0 3	-1.277	-1.526	2.623	1.01
110	4.3170	1.1295	1.3503	19.283	2.31477-15	-1 0 3	-1.277	-1.527	2.624	1.05

RECONTAMINATION HIT ON THIS TRIAL

FINAL STEP	FINAL PATH LENGTH	FINAL (X,Y,Z)	FINAL CHARGE	FINAL-SHADE-PANEL-SECTOR
111	4.33078	(1.121 , 1.340 , 19.28)	9.05289-17	-1 0 3

BOX SCORE FOR RANDOM POSITION 1.08+00 1.20+00 1.95+01

NO. SAFEHITS .31396
NO. RECONTAM HITS .33891-02
NO. NEAR MISSES .34359
NO. ESCAPES .51094
AVE. ESCAPE VEL. .12476

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TABLE 2h. Box score example for all positions of the test meteoroid M-V group (sample computer printout)

```
BOX SCORE FOR ONE METEOROID OF MASS GROUP  7  AND VELOC. GROUP
SUMMED OVER   100  POSITIONS


NO. SAFEHITS  4032.0
NO. RECONTAM HITS  .51930
NO. NEAR MISSES  35.847
NO. ESCAPES  41850.
AVE. ESCAPE VEL.  .26571
```

TABLE 2i. Typical final box score and angular escape distribution (sample computer printout includes 4 M-V groups)

```
BOX SCORE FOR OVERALL ENSEMBLE OF METEOROID MASS AND VELOCITY GROUPS
TOTAL NO. OF METEOROIDS IN ENSEMBLE DURING MISSION  8942.

NO. SAFEHITS  593.02
NO. RECONTAM HITS  3.0256
NO. NEAR MISSES  103.98
NO. ESCAPES  568.88


STANDARD DEVIATION FOR NO. OF RECONTAMINATION HITS IS  1.7394

 THE AVERAGE ESCAPE VELOCITY IS   .2050     M/SEC

THE ANGULAR DISTRIBUTION FOR THE ESCAPED VELOCITY VECTOR RELATIVE TO THE +Z DIRECTION

DEG.     NO. ESCAPES

 10.         31.1
 20.         1.70
 30.         1.16
 40.         35.1
 50.         1.17
 60.         .608
 70.         1.47
 80.         41.3
 90.         6.27
100.         6.99
110.         6.99
120.         8.50
130.         30.4
140.         62.3
150.         81.4
160.         88.1
170.         74.7
180.         89.6


RECONTAMINATION PROBABILITY IS   .95147
```

IV. MODEL EXECUTION

A. DISCUSSION OF THE INHERENT ASSUMPTIONS

The total integration of the diverse internal modeling efforts naturally requires basic and limiting assumptions. We shall separate these categorically into those the model unalterably depends upon and those the user may arbitrarily define to correspond to a specific mission.

1. Fixed Characteristics

The deterministic meteoroid environment applied to the simulation follows precisely the analytical expressions for the fluence reported in Ref. 21, a standard and reasonable description. The model used covers the interplanetary region of from 1 to 30 A. U. for cometary meteoroids. The distribution on the fluence was divided into 10 discrete mass groups for this simulation so that a deterministic evaluation would cover the entire range of possibilities in 10 passes. This approach avoids the larger number of trial meteoroid impacts, necessary for statistical confidence, required during a Monte Carlo sequence on this distributed variable. The meteoroid mass range is fixed to cover 10^{-6} to 10^{-13} kilograms because the fluence for larger meteoroids fell to below the 1% likelihood range and the smaller meteoroids would not disturb the surface enough to eject any dust grains into a trajectory.

The next assumption in this category concerns the spacecraft configuration. As seen earlier, the spacecraft consists of an element with four panels and a separate element. The Z axis is fixed along the Sun vector (for maximum photoelectric solar cell usage) allowing computational ease in defining shaded areas on the spacecraft. The solar panels are infinitely thin-plane sections. The region of the spacecraft considered "sterile" is the shaded cone surface and bottom plate of the separate element B (Fig. 15). This may be changed in CHKHIT (Appendix C). Any grain, ejected from a nonsterile surface, contacting or penetrating these surfaces, is labeled as a recontaminating contact. The nonsterile areas, i. e. potential grain ejection positions, can be modified in RNDPOS (Appendix C).

The interconnecting superstructure of the multiple element body has been ignored, for lack of a simplified characterization.

The spacecraft surface has a residue of particulate contamination that is termed individually in space as ejecta. Studies (Ref. 3) have shown that the physical dimensions of the dust grains that are typically dislodged are distributed predominantly between 10 and 100 μm, a fixed size range.

Whenever possible within the coding, proposed trial trajectories would first be tested to see if the magnitude of the ejection velocity was greater than five times the escape velocity established by the radiation pressure force in the direction of the Sun (+ Z axis). Those ejecta having sufficient velocity to escape were labeled as such and their trajectory calculation was bypassed.

The grains were considered to be launched along the surface normal vector. In the case of the solar panels, an additional 10% of the velocity magnitude was randomly added to either the x or y velocity component as compensation for the fact that the panels are, in reality, not flat, but structured to allow real grain releases along other than normal angles.

The last fixed characteristic of this model requiring elucidation is the particular method applied for calculating the electric field. Surface material on this general style of space vehicle consists of predominantly aluminum (Al) and silica (SiO_2). The thermal blanket covering the element A section was consequently presumed Al; the solar panel illuminated portion was considered SiO_2, with Al used for the dark side, and SiO_2 used to simulate the insulating paint coated on the element B exposed surface. Figure 12 shows the cross-sectional view of the spacecraft with the assumed component materials designated. Other arrangements are possible, but the present model can only employ Al and SiO_2.

The electric field in the region of space near any particular surface was obtained from the flat-plate solution (Ref. 19) previously discussed with the appropriate shaded or illuminated Debye length and surface value from the description above. Figure 12 shows, by arrows, the general nature of the electric field near the surfaces and in the far field. Three exceptions exist: (1) for positions near (compared to the appropriate Debye length) the solar panel, the algebraic sum of the surface potential of the illuminated and dark sides is formed and then the field is calculated analogously; (2) for positions in the wake of the spacecraft the field is approximated following the analysis by Al'pert et al. (Ref. 17); and (3) the far-field case is treated as an equivalent sphere.

The discontinuous boundaries unavoidably present in this hybrid approximation in a strict mathematical sense are unacceptable. This problem comprises the major limitation on the overall validity for the field value. Essentially, we consider the grain to be influenced by the characteristics of the nearest spacecraft surface component. This assumption proved usable upon scrutiny of the initial trial particle trajectories in which the inertial characteristics more heavily dominated the movement from step to step, whereas the radiation pressure and electrostatic force effects were manifest over several intervals of the trajectory.

2. Mission Peculiar Specifications

The specific geometric dimensions utilized follow the configuration of the multi-element spacecraft and are detailed in Appendix A within the symbolic computer code element named DATAIN. This element forms the user entry point wherein the actual material and physical parameters needed by the entire model are defined. The major limitation considered for the surface impact submodel is that all the impacted surfaces were treated as 1/8-inch aluminum plate material. The option exists to specify thicker or thinner plates of different materials (for instance, the thermal blankets or the solar panel silica) via DATAIN, although the choice of the aluminum yielded conservative ejection environments (i.e., more surface activity).

The ejecta were considered as silica dust grains with an original surface load areal or density for grains larger or equal to 5μm of $5.4 \times 10^5/m^2$ (Ref. 22). The integral distribution of areal density has been assumed to have an inverse dependence on the square of the particulate size. This dependence is set by a DEFINE procedure in RELEAS (Appendix C). Any other decreasing function may be substituted, and the normalization is automatic.

B. OUTPUT DATA PRESENTATION

As the simulation progressed, evaluations were made, at each meteoroid mass and velocity group level, of the number of impinging meteoroids (denoted as F(I, J) for the (I, J)th mass, velocity group), the number of safe hits (S(I, J)) per impacting meteoroid, the number of recontamination contacts (R, (I, J)) per meteoroid, the number of ejected grains that escaped (E(I, J)) per meteoroid. The mass ranges and velocity ranges corresponding to the meteoroid group indices (I, J) are shown in Table 3.

$$\underline{\text{Fluence}} = \underset{\substack{\text{(mass}\\\text{distribution)}}}{\sum_{I=1}^{9}} \quad \underset{\substack{\text{(velocity}\\\text{distribution)}}}{\sum_{J=1}^{3}} F(I, J) \tag{22}$$

$$\underline{\text{Safe hits}} = \sum_{I=1}^{9} \sum_{J=1}^{3} F(I, J) \times S(I, J) \tag{23}$$

where S(I, J) is the number of dust grains safely recontacting the spacecraft per meteoroid of type IJ as accumulated during simulation.

$$\underline{\text{Recontamination hits}} = \sum_{I=1}^{9} \sum_{J=1}^{3} F(I, J) \times R(I, J) \tag{24}$$

where R(I, J) is the number of dust grains that recontaminate the spacecraft per meteoroid of type IJ.

$$\underline{\text{Escapes}} = \sum_{I=1}^{9} \sum_{J=1}^{3} F(I, J) \times E(I, J) \tag{25}$$

where E(I, J) is the number of dust grains that escape the spacecraft vicinity per meteoroid of type IJ. The overall average velocity of the escaping grains is given by:

$$\underline{\text{Overall average velocity}} = \frac{\sum_{I=1}^{9} \sum_{J=1}^{3} A(I, J) \times F(I, J) \times E(I, J)}{\sum_{I=1}^{9} \sum_{J=1}^{3} F(I, J) \times E(I, J)} \tag{26}$$

where A(I, J) is the IJ group average escape velocity magnitude.

We note that mass-group 10 meteoroids had a fluence of less than 0.01 events per mission, and hence, were considered insignificant.

The summary of the hypothetical full simulation results is shown in Table 4. This table has been separated by velocity groups; each group is followed by a mission subtotal. The complete enumeration of the model predictions is referred to by ensemble grand total on this chart.

A less conservative interpretation may be extracted from this data by assuming only a single nominal velocity for the meteoroid impacts, for instance, velocity group 1 with the range $1.2 - 2.0 \times 10^{-4}$ m/s, and linearly interpolating (multiply by 3 to simulate the number of total trials) the results. Also considered here was a pyrotechnic event simulation (see Appendix B). Comparison of these three approaches appears in Table 5.

The data from Table 4 have been graphically plotted in a perspective 3-dimensional manner as seen in Figs. 16-20. The most immediately noticeable characteristic is the strong inherent velocity dependence. These plots all have linear Z-axes and the peak value indicated. The anomalous hump at the low end of the fluence surface exists because the first mass range increment is larger than the remaining intervals (see Table 3). It is apparent that the small meteoroids (10^{-15} -3×10^{-10} kg) heavily dominate this distribution. The next figure represents the distribution of grains that were recaptured safely by the nonsterile portion of the spacecraft. It is interesting to note that the three surfaces for safe hits, recontaminating hits, and escapes, respectively, contain peaks within their range of validity. This means the competing aspects throughout the complete simulation apparently did span the range of actual physical interaction within the limits of the assumptions.

The recontamination data are shown in Fig. 18. The nature of the double hump is elusive at present. The spacecraft may have areas that could be considered as "hot spots." The random selection of the meteóroid impact position considered 100 choices for each mass-velocity group. The bulk of the recontaminating events were from either the top of the solar panels or the element A thermal blanket material. (This is an area that would most likely yield lower predictions for the recontamination, should the element A surface be assigned a more accurate thickness and other mechanical property values.) Perhaps the solar panel and element A surfaces have different "pass bands" for the recontamination events. The surface positions allowed for meteoroid impact were on the illuminated region of element A, both sides of the solar panels, and the illuminated cone of element B. Several surfaces were positively charged, requiring the ejecta to initially have a positive charge. The sterile zone is always shaded and therefore has about -60 eV in electric potential. When the ejecta were forced toward element B by the solar radiation pressure, there were perhaps a few ideal possible trajectories allowing each of these areas to bring the positive ejecta close enough to element B to be attracted.

Figure 20, for the average escape velocity, indicates that meteoroids of up to 3×10^{-8} kg and for all velocity ranges cause grains to escape with about the same average velocity, and not until the large meteoroids impact (groups 8 and 9) does the typical value of about 0.2 m/s drastically change. The relative importance of these escape velocities was studied by weighting the average velocity of any particular M-V group by the number of grains escaping, and then normalizing by the total number of escapes. That is

$$\underline{\text{Weighted velocity magnitude (I, J)}} = \frac{A(I, J) * F(I, J) * E(I, J)}{\sum_{I=1}^{9} \sum_{J=1}^{3} F(I, J) * E(I, J)} \qquad (27)$$

Figure 21 indicates this functional surface with the high mass-velocity groups dominating the spectrum of escaping grains velocities.

During the execution, as mentioned in Section III. C, the particles escaping were classified and summed into 18 angular bins corresponding to 0-180 degrees in 10-degree increments. Figure 22 contains the polar plot of the resultant angular distribution obtained during the simulation. The spikes in the Sun direction may be explained by the predominant number of grains that exceeded the initial escape velocity criteria from: 1) the top plate and upper solar panels, 2) the illuminated portion of element B, and 3) the element A cone surface. The bulk of the grains were forced outward from the Sun by the solar radiation pressure. This polar plot lends further confidence to the overall model and indicates that the electric field approximation was realistically bounded by the momentum properties (the spikes 1, 2, and 3 on Fig. 22) and the solar radiation pressure force (area 4 on Fig. 22).

C. OPERATIONAL ECONOMICS

This model was executed on a UNIVAC 1108 computer system in a sequence of runs. The compiled processor occupies approximately 16K of core and the Monte Carlo/deterministic structure is inherently CPU bound.

Each of the M-V groups and 4 pyrotechnic firings were evaluated totaling 18.5 hours of CPU time. The present computer rates at JPL amounted to approximately \$4.7K for a grand total of 2.5×10^5 histories (some runs were made during Prime Time at increased expense). This gives a rough factor of about 2¢/history.

Table 3. Discrete mass and velocity group index-magnitude correspondence

Mass group I	Mass range, kg	Velocity group J	Velocity range, m/s
1	$10^{-15} - 3 \times 10^{-14}$	1	$1.2 - 2.0 \times 10^{4}$
2	$3 \times 10^{-14} - 3 \times 10^{-13}$	2	$2.0 - 2.8 \times 10^{4}$
3	$3 \times 10^{-13} - 3 \times 10^{-12}$	3	$2.8 - 3.6 \times 10^{4}$
4	$3 \times 10^{-12} - 3 \times 10^{-11}$		
5	$3 \times 10^{-11} - 3 \times 10^{-10}$		
6	$3 \times 10^{-10} - 3 \times 10^{-9}$		
7	$3 \times 10^{-9} - 3 \times 10^{-8}$		
8	$3 \times 10^{-8} - 3 \times 10^{-7}$		
9	$3 \times 10^{-7} - 3 \times 10^{-6}$		

Table 4. Output data distribution from the simulation of the hypothetical spacecraft mission

Meteoroid			Safe hits	Recontamination hits	Escapes	Escape velocity, m/s
Mass group I	Velocity group J	Impacts F(I, J)				
1	1	.2656+04	.4515+01	.1000-01	.1594+01	.2310+00
2	1	.1068+04	.2884+01	.1068+00	.1068+01	.1830+00
3	1	.1510+04	.4968+02	.4530+00	.2356+02	.9900-01
4	1	.7278+03	.1319+03	.7278+00	.1610+03	.1890+00
5	1	.2483+03	.4355+03	.5214+00	.5368+03	.2390+00
6	1	.6120+02	.1048+04	.1371+01	.1840+04	.1210+00
7	1	.1190+02	.4798+03	.6188-01	.4980+04	.2260+00
8	1	.7500+00	.1939+03	.1000-01	.1950+04	.9130+00
9	1	.4600-01	.8142+02	.1000-01	.1955+04	.2347+01
Velocity group 1 subtotal		.6284+04	.2427+04	.3242+01	.1145+05	.6881+00
1	2	.3984+04	.7570+01	.1000-01	.2789+01	.2290+00
2	2	.1602+04	.3156+02	.8010+00	.1009+02	.2050+00
3	2	.2265+04	.1316+03	.1585+01	.7474+02	.1580+00
4	2	.1092+04	.4224+03	.5460+00	.4815+03	.2160+00
5	2	.3724+03	.1528+04	.3575+01	.2007+04	.1940+00
6	2	.9190+02	.2502+04	.2435+01	.7029+04	.1280+00
7	2	.1790+02	.8755+03	.1969-01	.1584+05	.3950+00
8	2	.1120+01	.5197+03	.1000-01	.5254+04	.1672+01
9	2	.6000-01	.1983+03	.1000-01	.4760+04	.3723+01
Velocity group 2 subtotal		.9426+04	.6215+04	.9963+01	.3546+05	.9636+00
1	3	.5312+04	.5843+02	.1062+01	.2284+02	.2460+00
2	3	.2136+04	.4956+02	.1922+01	.1944+02	.1850+00
3	3	.3020+04	.3663+03	.1027+02	.1921+03	.1390+00
4	3	.1456+04	.1003+04	.1310+01	.1158+04	.2270+00
5	3	.4965+04	.3460+04	.4369+01	.5332+04	.1750+00
6	3	.1226+03	.4678+04	.1373+01	.1779+05	.1560+00
7	3	.2380+02	.1469+04	.6188-01	.3396+05	.5420+00
8	3	.1500+01	.1031+04	.1000-01	.1042+05	.2541+01
9	3	.9000-01	.4567+03	.1000-01	.1097+05	.4940+01
Velocity group 3 subtotal		.1257+05	.1257+05	.2037+02	.7987+05	.1291+01
Ensemble Grand Totals		.2828+05	.2121+05	.3257+02	.1268+06	.1145+01

Table 5. Summary of results of recontamination analysis for a hypothetical spaceflight

Model	Recontamination hits	Safe hits	Escapes	Average escape velocity, m/s	Meteoroid impacts -- pyrotechnic events
Conservative meteoroid velocity	33	21,215	126,778	1.15	28,279
Nominal meteoroid velocity	10	7,281	34,349	0.69	18,842
Pyrotechnic device	1	849	35,000	1.94	4

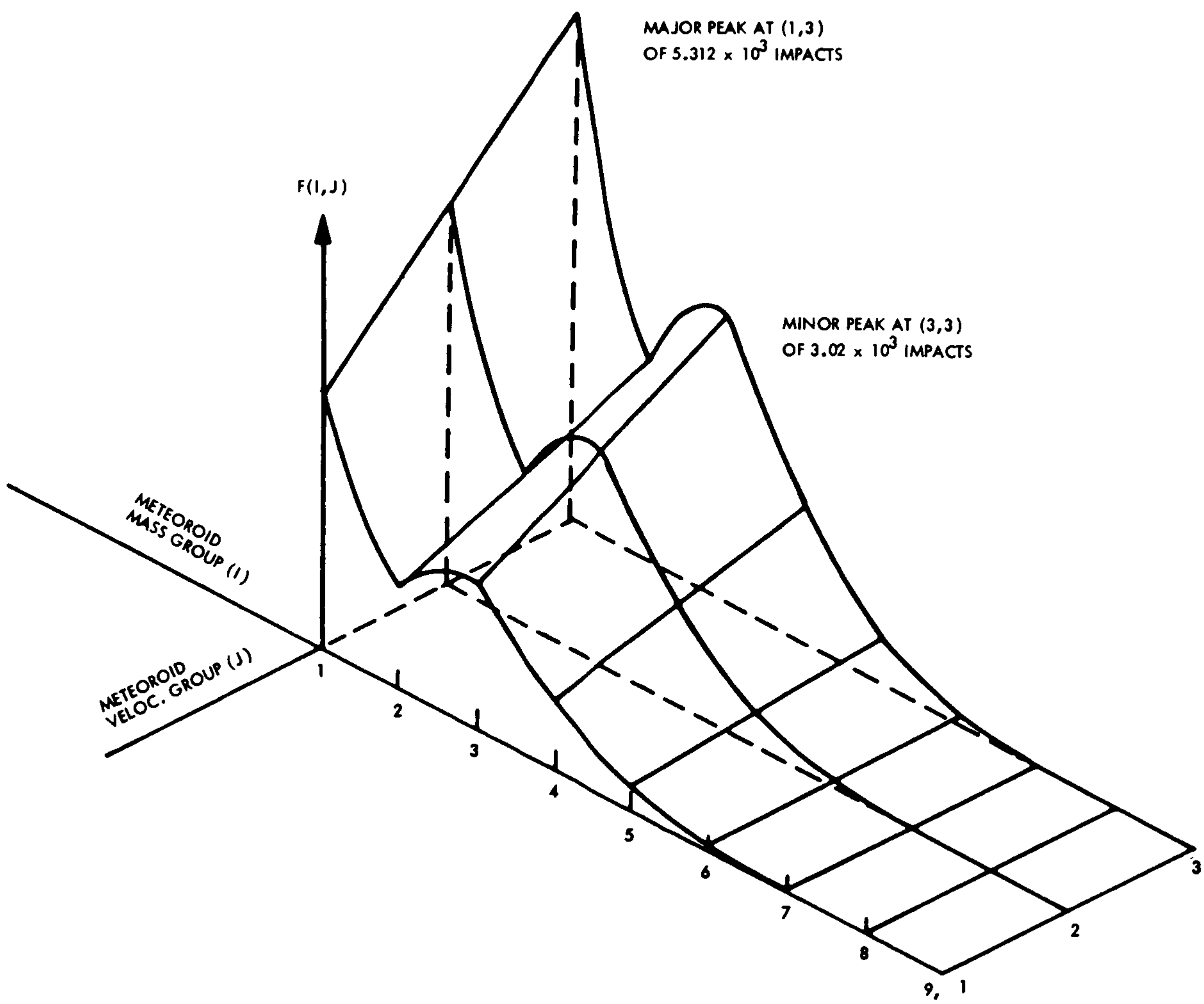

Fig. 16. Mission micrometeoroid fluence distribution over meteoroid mass and velocity groups (after NASA Ref. 19)

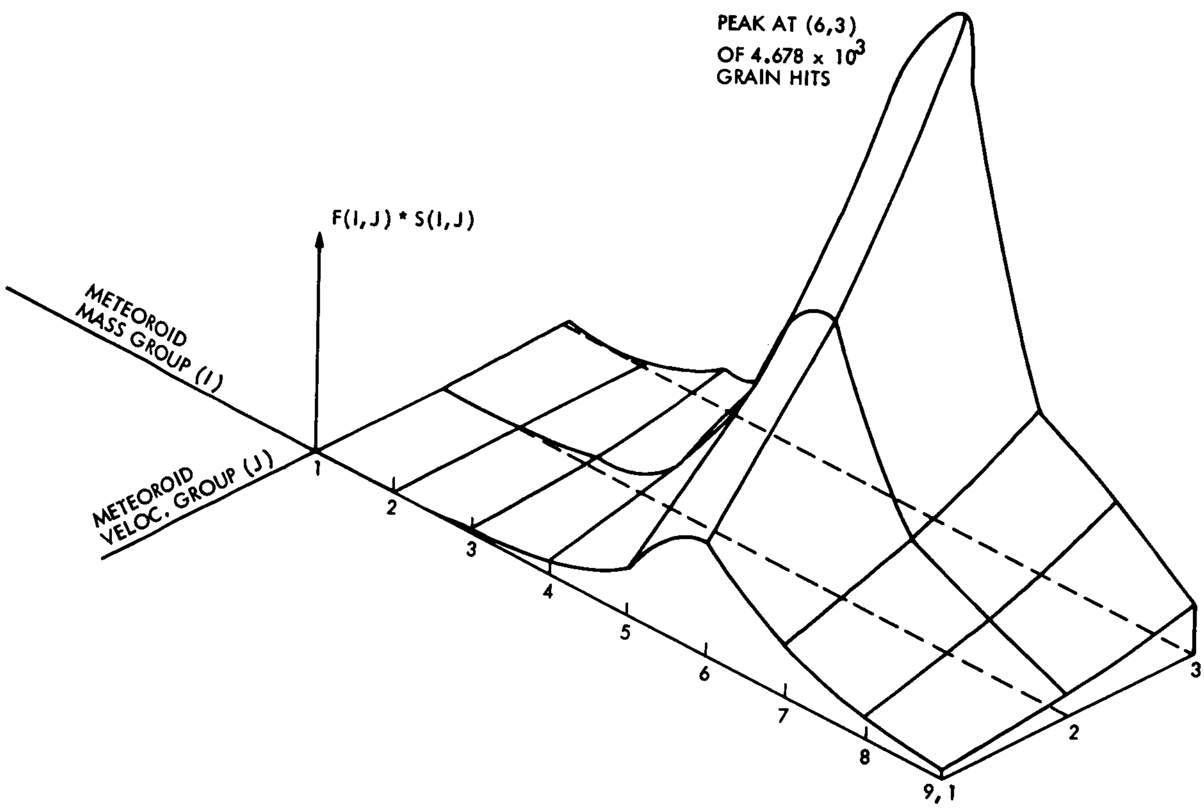

Fig. 17. Mission safe-hit distribution over meteoroid mass and velocity groups

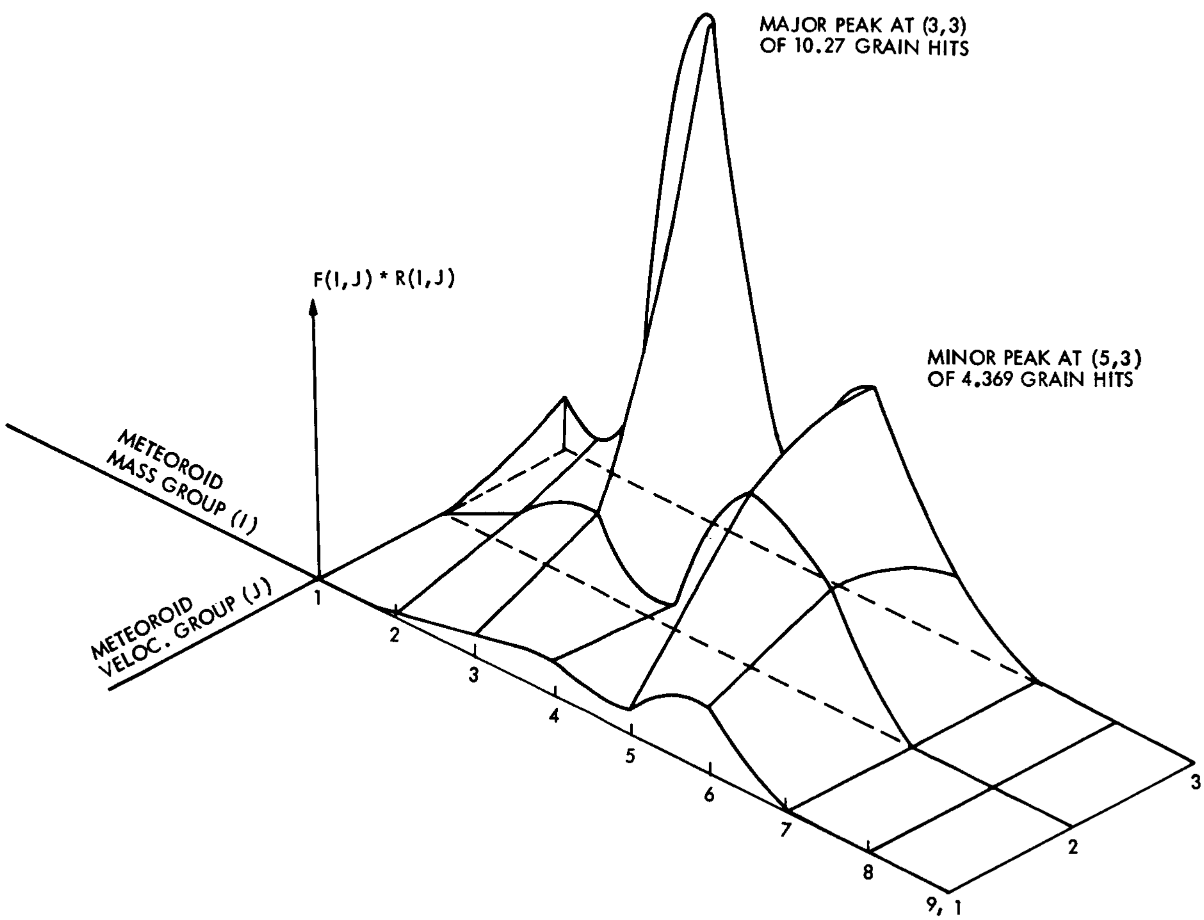

Fig. 18. Mission grain recontamination distribution over meteoroid mass and velocity groups

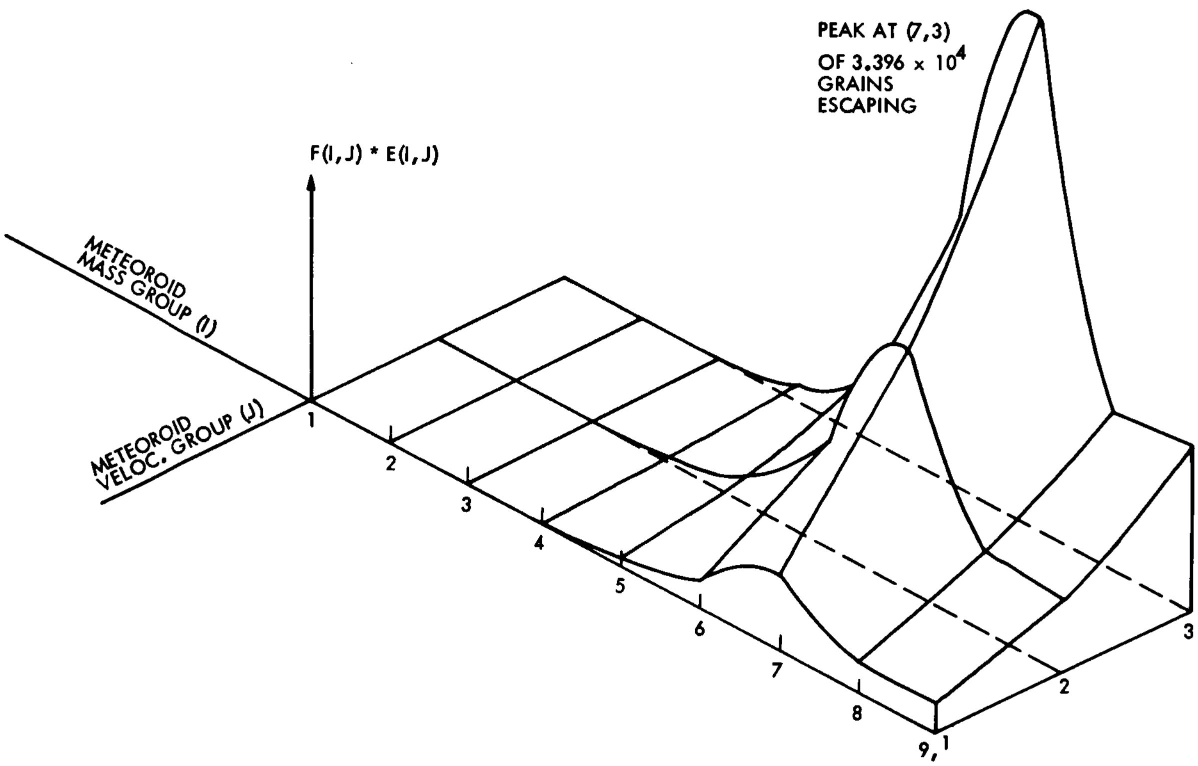

Fig. 19. Mission grain escape distribution over meteoroid mass and velocity groups

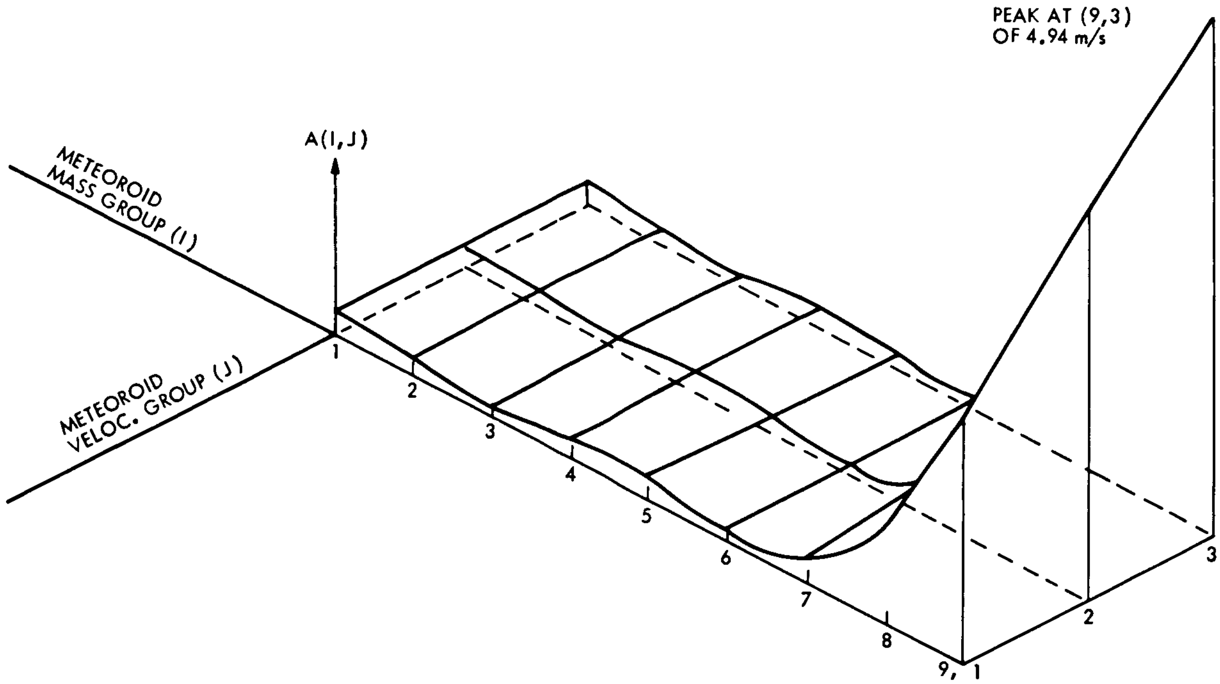

Fig. 20. Mission average escape velocity distribution over meteoroid mass and velocity groups

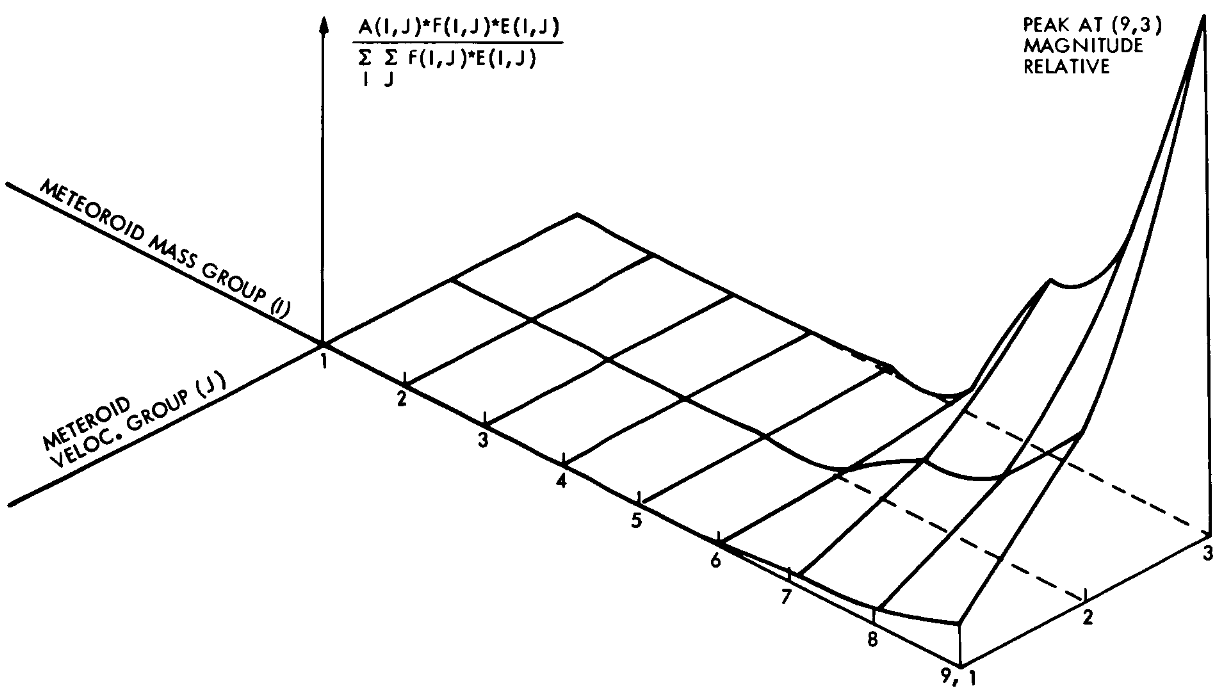

Fig. 21. Weighted average escape velocity distribution over meteoroid mass and velocity groups

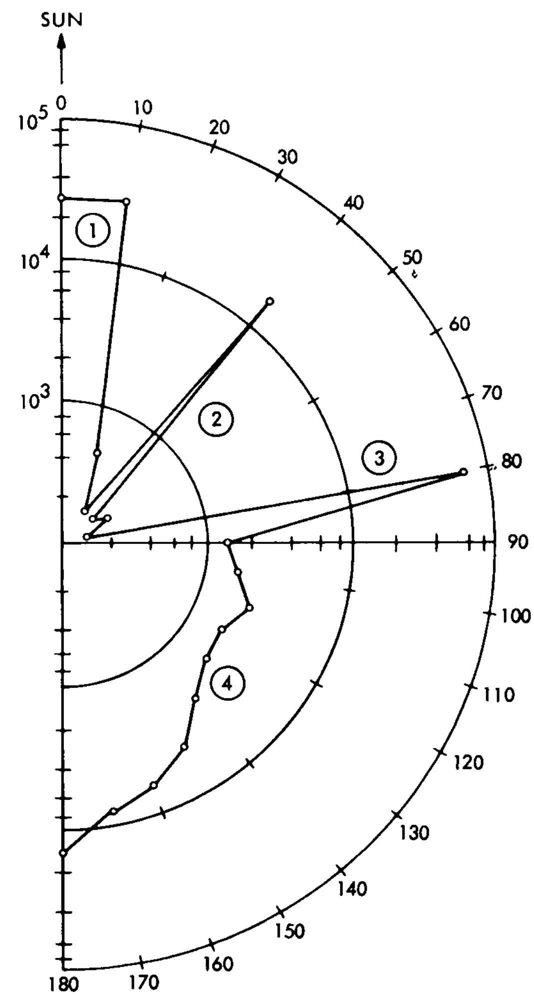

Fig. 22. Escaped grain angular distribution

V. CONCLUSIONS

The major objective of this research was to study the effects of typical mission environments on the distribution of particles on spacecraft surfaces. Specifically, the various migration mechanisms that result in particulate redistribution were investigated and quantified. The ultimate goal was to develop a methodology and quantitative analytical tool for the evaluation of the recontamination hazard for various planetary missions and mission strategies.

The results obtained for a simulated hypothetical mission of 300 days are given in Table 5. These indicate that within the limits of the stated assumptions, a total of 28, 279 meteoroids impacted the craft causing 148, 026 grains to be ejected (less than 1% of the total load) with 126, 778 escaping, 21, 215 recontacting the spacecraft on safe areas, and 33 recontaminating element B sterile zone. The pyrotechnic events added another 35, 000 escapes, 849 safe hits, and 1 recontaminating grain. Assuming a Poisson distribution for the statistics, we see that the expected number of particulate recontamination events is 33 with a standard deviation $\sigma(33) = \mathrm{SQRT}(33) = 5.7$ and that the probability of one or more recontaminating events occurring is

$$\text{Prob (recont.)} = 1. - \exp(-33) = .9999\ldots \qquad (28)$$

The numbers predicted scale directly with mission elapsed time and particulate areal density.

The general structure of the computer software (see Appendix C) allows the ready application (with few modifications) to studies of varying natures. For instance, the sterile zone may be redefined easily to be the cylindrical area of space observed by the Canopus sensor in the near field to count the predicted number and velocities of the grains traversing its view; particular meteoroid classes may be studied; various impact locations may be designated; spacecraft geometries that may be interpreted as degenerate cones are applicable; the ejected particles captured by planetary bodies during flyby may be studied; etc.

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APPENDIX A

INPUT ELEMENT DATAIN DESCRIPTION

Each particular spaceflight mission simulation requires specific parameter definition in order to identify material constituents, interplanetary setting, etc. The following computer listing, Table A-1, shows the symbolic code used for the hypothetical mission discussed earlier.

The common block section provides the interconnection map which transfers data throughout the general computer program. The parameters have been arranged into groups corresponding to their general use. The first grouping is for the meteoroid impact model and grain release routines. The variable ACCMIN is the threshold level for surface acceleration below which dust grains are not released. Array ADRHO contains the material density of the ejected particle for aluminum, graphite, and silica. AKM and SIG are parameters that were obtained from a best fit of the particle adhesion model to an experiment (Eq. 4). APVEL is the array that holds the three meteoroid velocity group magnitudes. E is Young's modulus for aluminum. H is the presupposed thickness of the target surface. MAT is the variable that designates the material assumed for the ejected dust grain. PO is the loading function (detailed analysis appears in Ref. 3). Finally, RHO specifies the target density (aluminum).

The next grouping concerns the parameters necessary for electric field and potential determination. The AMAT array determines the material (either aluminum (Al) or silica (SiO_2)) for the spacecraft sections as indicated. The arrays A and B contain material dependent coefficients obtained from an empirical equation for the secondary-emission coefficient of the form:

$$\alpha = \frac{A_{(I)} - B_{(I)} e\phi_o}{kT_e - e\phi_o} \tag{A1}$$

where I = 1, 2, 3 for aluminum, carbon, and silica respectively, kT_e is the Boltzmann constant times electron temperature and $e\phi_o$ is the current potential (both in eV). (Note: Actually A and B also depend weakly on kT_e, so values are valid only for kT_e near 20eV.) Array EL is the Hollerith dictionary reference for the AMAT array. The other electrical parameters are self-explanatory.

The next grouping covers the basic spacecraft parameter identification scheme. The origin is one Debye length from the bottom plate of the model. The parameters SP1-SP4 and SP01-SP03 are measures of distances in the X axis direction, whereas D1-D4 indicate the Z axis dimensions of the cone altitudes and inter-element spacing. Following the geometric inputs are arrays that contain solar spectrum energies and yield values as noted.

Finally, the miscellaneous variables appear and are mostly self-explanatory. K1 must be fixed at 10. The entries for N1 and N2 end up being default values because they are read in again via input case card. SRMIN and SRMAX specify the heliocentric limits for the mission, whereupon the fluence evaluations are computed using the geometric mean of these end points.

TABLE A-1. ELEMENT DATAIN SYMBOLIC LISTING

```
      BLOCK DATA              @ INPUT DATA FOR THE SUBROUTINES.
C
C     COMMON BLOKC1 CONNECTS DATAIN, MAIN AND RELEAS.
      COMMON /BLOKC1/ AKM,DRHO,K1,PRBVEL(35,10),CR(10),SIG,DDIA(10)
     1,ANPART,ANNORM,PRBDIA(10)
C     COMMON BLOKC5 CONNECTS DATAIN, MAIN, RELEAS AND YANG1
      COMMON /BLOKC5/ KO,PMASS,PRHC,RS(35),FVAP(35),FPKACC(35),RHO
C     COMMON BLOKC6 CONNECTS DATAIN, MAIN AND YANG1.
      COMMON /BLOKC6/ E,H,NU,PO,ISKIP
C     COMMON BLOKC8 CONNECTS CONTAM, DATAIN, MAIN AND PARPOT.
      COMMON /BLOKC8/ DIM,PATHMX,SR,VELMAG
C     COMMON BLOK17 CONNECTS DATAIN, MAIN AND YANG1.
      COMMON /BLOK17/ PVEL,ACCMIN
C     COMMON BLOK18 IN DATAIN,EFIELD,ESURF,MAIN,RNDPOS,SCPLOT,SHADE, AND CONTAM
      COMMON /BLOK18/ SP1,SP2,SP3,SP4
C     COMMON BLOK19 CONNECTS DATAIN, EFIELD, ESURF,MAIN, RNDPOS AND SCPLOT.
      COMMON /BLOK19/ SPC1,SPC2,SPC3
C     COMMON BLOK24 CONNECTS EFIELD, ESURF MAIN AND DATAIN.
      COMMON /BLOK24/ALAMB(2),ANPHOT(2),AKPHOT(2),EFEL(2),EFED(2),DEB,
     1AMAT(9),EL(2),PHIEL(2),PHIED(2),ALAMAV,PHIAVE
C     COMMON BLOK26 CONNECTS DATAIN, MAIN AND PARPOT.
      COMMON /BLOK26/ MAT,AVP
C     COMMON BLOK28 CONNECTS DATAIN AND PARPOT.
      COMMON /BLOK28/ A(3),B(3),MATPOS(3),SOLSPC(135,2),YIELD(15,3),YIEL
     1DP(16,2)
C     COMMON BLOK29 CONNECTS DATAIN,EFIELD,ESURF,MAIN AND PARPOT.
      COMMON /BLOK29/ AKTE,AKTP,ANE
C     COMMON BLOK30 CONNECTS DATAIN AND MAIN.
      COMMON /BLOK30/ADRHO(3),D1,D2,D3,D4,N1,N2,SRMAX,SRMIN
     1,EPSILN,ELECT,APVEL(3),THISS , KPLOT
C
C     INPUT DATA FOR METEOROID IMPACT AND GRAIN RELEASE ROUTINES.
C
      DATA ACCMIN/0.031/  @ MINIMUM ACCELERATION OF INTEREST.
      DATA  ADRHO/2700.,2250.,2400./  @ ALUM., GRAPHITE AND SILICA.
      DATA AKM/-.882/ SIG/.400/   @ STATISTICAL QUANTITIES NEEDED FOR RELEAS.
      DATA  APVEL/1.6E4,2.4E4,3.2E4/     @ METEOROID VELOCITY VALUES.
      DATA  E/6.897E10/   @ YOUNG'S MODULUS.
      DATA  H/3.175E-3/   @ TARGET THICKNESS (METERS.)
C     MAT -- NUMBER DEFINING MATERIAL OF PARTICLE.   1 = ALUMINUM,
C          2 = GRAPHITE,   3 = SILICA
      DATA MAT/3/  @ CHOSEN FOR SILICA.
      DATA  NU/.25/   @ POISSON'S RATIO.
      DATA PO/1.74E9/     @ LOADING FUNCTION (N/M*M.)
      DATA  RHO/2.683E3/     @ TARGET DENSITY. (ALUMINUM.)
C
C     GENERAL INPUT DATA FOR THE ELECTRIC FIELD AND SURFACE POTENTIAL
C     AND PARTICLE POTENTIAL ROUTINES.
C
C     AMAT SPECIFIES THE MATERIAL OF THE SPACECRAFT SECTIONS.
      DATA  AMAT/'AL','AL','SIO2','AL','AL','AL','SIO2','SIO2','SIO2'/
      DATA A/7.67,2.76,10.17 /      @ WEAK DEPENDENCE ON AKTE.
      DATA B/.430,.122,.389/        @ WEAK DEPENDENCE ON AKTE.
      DATA EL/'AL','SIO2'/    @ FOR ALUMINUM AND SILICA.
      DATA AKTE/20./    @ BOLTZMAN CONSTANT TIMES THERMAL ELECTRON TEMP.
      DATA AKTP/10.7/  @ BOLTZMAN CONSTANT TIMES THERMAL PROTON TEMP.
      DATA AVP/4.25E5/  @ THE PROTON DIRECTED VELOCITY.
      DATA  ANE/5.E6/  @ PROTON NUMBER DENSITY.
      DATA AKPHOT/3.,2./      @ PHOTOELECTRON TEMP (EV)
      DATA ANPHOT/1.E9,1.E8/  @ PHOTON NUMBER DENSITY. (MKS)
C     ANPHOT/ANE .GT. AKTE/AKPHOT .GT. 1.0 MUST OBTAIN
C
C     SPACECRAFT DIMENSIONS
C
```

ORIGINAL PAGE IS OF POOR QUALITY

TABLE A-1. ELEMENT DATAIN SYMBOLIC LISTING

```
C          1                                SPACE-CRAFT MODEL
C          1                                  SIDE VIEW
C          1                                    (X,Y CYLINDRICAL SYMMETRY)
C          1             SP01
C          1             /
C          1 AMAT(1)    /
C     Z5->1********
C          1        *
C          1         *
C          1           *    AMAT(2)
C          1            *
C          1             *
C          1              *
C          1               *
C          1                 *                      SOLAR PANEL
C          1     SP1          *     SP2             /
C          1     /             *   /               /        SP3
C          1    /               * /      AMAT(3) /        /
C     Z4->1SP-SP*****************SP-SP-SP-SP-SP-SP-SP-SP
C          1       AMAT(5)                     AMAT(4)
C          1                        SPC2
C  Z       1       AMAT(6)         /          AMAT(7)
C     Z3->1*.*.*.*.*.*.*.*.*.*.*.*.
C  A       1                        *.              SP4
C  X       1                           *           /                WITH:
C  I       1                              *.      /                  Z1=DEBYE(CALCULATED
C  S  Z2->1*  *  *  *  *  *  *  *  *  *  *                          Z2=Z1+D1          WITHIN)
C          1                               .*                        Z3=Z2+D2
C          1 N-B                          .*                         Z4=Z3+D3
C          1 A--J                       .*                           Z5=Z4+D4
C          1 S---P                    .*           AMAT(8)
C          1 A----L                 .*                               D1-4
C     Z1->1*.*.*.*.*.*.*.*.*.*.*.*                                   SP1-4,SP01-3 ARE
C          1       AMAT(9)                                           USER SPECIFIED
C          1
C          1                      SP03
C          1
C   ------0--------------------------------X-AXIS---
C
C     THE ARRAY MATPCS POINTS TO THE FIRST NON-ZERO YIELD FOR EACH MAT.
C
      DATA  MATPOS / 1, 3, 6 /
C
C  THE ARRAY SOLSPC CONTAINS VALUES OF ENERGY IN ELECTRON VOLTS (TRANS-
C     LATED FROM WAVELENGTH OF THE SOLAR SPECTRUM) AND THE SOLAR
C     IRRADIANCE AS AN INTEGRAL FRCM WAVELENETH=C.C CR E=INFINITY.
C
      DATA  (SOLSPC(I,1), I=1, 62)  /
     1              .00124, .01240, .01550, .02067, .02480, .03100,
     2      .03543, .04133, .04960, .06200, .06526, .06889, .07294,
     3      .07750, .08267, .08857, .09538, .10333, .11273, .12400,
     4      .13778, .15500, .17714, .20667, .24800, .25306, .25833,
     5      .26383, .26957, .27556, .28182, .28837, .29524, .30244,
     6      .31000, .31795, .32632, .33514, .34444, .35429, .36471,
     7      .37575, .38750, .40000, .41333, .42759, .44286, .45926,
     8      .47692, .49600, .51667, .53913, .56364, .59048, .62000,
     9      .65263, .68889, .72941, .77500, .82667, .88571, .95385 /
      DATA  (SOLSPC(I,1), I=63, 116)   /
     5      1.03333, 1.12727, 1.24000, 1.30526, 1.37778, 1.45882,
     1      1.55000, 1.65333, 1.67568, 1.69863, 1.72222, 1.74648,
     2      1.77143, 1.79710, 1.82353, 1.85075, 1.87879, 1.90769,
     3      1.93750, 1.96825, 2.00000, 2.03279, 2.04959, 2.06667,
     4      2.08403, 2.10170, 2.11966, 2.13793, 2.15652, 2.17544,
```

TABLE A-1. ELEMENT DATA IN SYMBOLIC LISTING

```
     5     2.19469, 2.21429, 2.23423, 2.25455, 2.27523, 2.29630,
     6     2.31776, 2.33962, 2.36190, 2.38462, 2.40777, 2.43137,
     7     2.45545, 2.48000, 2.50505, 2.53061, 2.55670, 2.58333,
     8     2.61053, 2.63830, 2.66667, 2.69565, 2.72527, 2.75556 /
      DATA  (SOLSPC(I,1), I=117, 170)  /
     9     2.78652, 2.81818, 2.85057, 2.88372, 2.91765, 2.95238,
     5     2.98795, 3.02439, 3.06173, 3.10000, 3.13924, 3.17949,
     1     3.22078, 3.26316, 3.30667, 3.35135, 3.39726, 3.44444,
     2     3.49296, 3.54286, 3.59420, 3.64706, 3.70149, 3.75758,
     3     3.81538, 3.87500, 3.93651, 4.00000, 4.06557, 4.13333,
     4     4.20339, 4.27586, 4.35088, 4.42857, 4.50909, 4.59259,
     5     4.67925, 4.76923, 4.86275, 4.96000, 5.06122, 5.16667,
     6     5.27660, 5.39130, 5.51111, 5.63636, 5.90476, 6.20000,
     7     6.52632, 6.88889, 7.29412, 7.75000, 8.26667, 8.85714 /
      DATA  (SOLSPC(I,1), I=171, 185)  /
     8     10.33333, 10.78261, 11.27273, 11.80952, 12.40000, 13.05263,
     9     13.77778, 14.58824, 15.50000, 16.53333, 17.71429, 19.07692,
     5     20.66667, 22.54545, 24.80000 /
      DATA  (SOLSPC(I,2), I=1, 36)  /   135.30, 135.29865, 135.29855,
     1     135.29829, 135.29801, 135.29735, 135.29671, 135.29556,
     2     135.29328, 135.28776, 135.28596, 135.28376, 135.28101,
     3     135.27756, 135.27321, 135.26801, 135.26091, 135.25056,
     4     135.23606, 135.21506, 135.18356, 135.13456, 135.05506,
     5     134.91806, 134.63905, 134.599, 134.556, 134.510, 134.459,
     6     134.403, 134.341, 134.273, 134.199, 134.116, 134.025, 133.926/
      DATA  (SOLSPC(I,2), I=37, 90)  /
     7     133.819, 133.702, 133.573, 133.433, 133.277, 133.098,
     8     132.889, 132.646, 132.361, 132.031, 131.661, 131.251,
     9     130.796, 130.286, 129.696, 129.036, 128.301, 127.456,
     5     126.491, 125.346, 123.921, 122.116, 119.886, 117.231,
     1     114.116, 110.456, 106.056, 100.676, 93.9859, 90.0334,
     2     85.7234, 81.0309, 75.7934, 69.9384, 68.6909, 67.4159,
     3     66.1139, 64.7849, 63.4284, 62.0429, 60.6284, 59.1869,
     4     57.7159, 56.2174, 54.6893, 53.1329, 51.5469, 49.9284,
     5     49.1079, 48.2797, 47.4427, 46.5972, 45.7442, 44.8874 /
      DATA  (SOLSPC(I,2), I=91, 144)  /
     6     44.0289, 43.1712, 42.3169, 41.4669, 40.6132, 39.7519,
     7     38.8822, 37.9979, 37.0977, 36.1827, 35.2592, 34.3379,
     8     33.4214, 32.4927, 31.5422, 30.5767, 29.6012, 28.6237,
     9     27.6422, 26.6297, 25.6002, 24.5809, 23.5607, 22.5322,
     5     21.5014, 20.4857, 19.5037, 18.5707, 17.7024, 16.8769,
     1     16.0439, 15.1939, 14.3037, 13.4224, 12.5737, 11.8054,
     2     11.1509, 10.5792, 10.0302, 9.47566, 8.90641, 8.32191,
     3     7.74366, 7.19366, 6.65591, 6.11191, 5.57141, 5.03566,
     4     4.49691, 3.96191, 3.45341, 3.00216, 2.60366, 2.24041 /
      DATA  (SOLSPC(I,2), I=145, 185)  /
     5     1.91741, 1.63816, 1.36366, 1.09716, .897910, .763660,
     6     .657190, .548160, .443910, .365160, .306660, .263060,
     7     .227385, .193560, .162985, .131485, .096585, .067985,
     8     .027785, .010985, .004280, .002300, .0013500, .000930,
     9     .00078, .00073, .00059993, .00057200, .00056570, .0005526,
     5     .0005372, .0005292, .0005215, .0005121, .0005059, .0005027,
     1     .0005010, .0004984, .0004929, .0004896, .0004863 /
C
C  THE ARRAY YIELD CONTAINS THE VALUES FOR THE YIELD IN EACH ENERGY
C     RANGE FOR THREE MATERIALS.
C
      DATA  YIELD       /1.0E-7, 3.1E-6, 8.6E-6, 3.1E-5, 1.6E-4, 8.6E-4,
     2     6.3E-3, 3.2E-2, 7.4E-2, .15, .2, .23, .25, .27, .12, 0., 0.,
     3     2.7E-7, 1.1E-5, 3.2E-5, 9.0E-5, 3.1E-4, 7.4E-4, 1.3E-3,
     4     4.7E-3, 1.8E-2, 2.5E-2, 2.5E-2, 2.5E-2, 2.5E-2, 0.0, 0., 0.,
     5     0., 0., 1.0E-4, 1.9E-3, 1.0E-2, 2.3E-2, 4.0E-2, 6.8E-2,
     6     8.5E-2, .1, .1, .063 /
```

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TABLE A-1. ELEMENT DATA IN SYMBOLIC LISTING

```
C  THE ARRAY YIELDP CONTAINS:  FIRST, SEVERAL VALUES OF ENERGIES
C     (ELECTRON-VOLTS) DIVIDING THE YIELD (ELECTRONS/PHOTON) DATA INTO
C     RANGES, AND SECOND THE AVERAGE ENERGY VALUE FOR EACH RANGE.
C
      DATA  YIELDP      / 4.0, 4.25, 4.75, 5.5, 6.5, 7.5, 8.5, 9.5,
     2     10.5, 11.5, 12.5, 13.5, 14.5, 15.5, 22.5, 27.5, 4.12, 4.5,
     3     5., 6., 7., 8., 9., 10., 11., 12., 13., 14., 15., 19.,
     4     25., 0. /
C
C     MISC. INPUT FOR THE MAIN DRIVER.
C
      DATA ANPART/5.4E05/  @ CONTAM AREAL DENSITY.GT.5 MICRONS(M**-2)
      DATA  ELECT/1.6E-19/  @ ELECTRONIC CHARGE (MKS.)
      DATA EPSILN/8.85E-12/  @ FREE SPACE PERMITTIVITY.
      DATA  KPLOT/0/  @ 0-NO PLOT, 1-PLOT THE SPACECRAFT.
      DATA  K1/10/  @ NUMBER OF EJECTA DIAMETER BINS.
      DATA N1/2/N2/4/  @ OUTER AND INNER LOOP INDICIES RESP.
      DATA  PATHMX/20./  @ TWENTY METERS FOR WANT OF A VALUE.
      DATA  PRHO/500./   @ METEOROID DENSITY.  (MKS)
      DATA SRMAX/1.5/SRMIN/1./  @ HELIOCENTRIC RADII LIMITS.
      DATA  TMISS/300./                 @ MISSION DURATION - DAYS.
      END
```

APPENDIX B

PYROTECHNIC EVENT MODEL

The pyrotechnic model used for the simulation is comprised simply of two parts: a plausible value for the surface acceleration related to the particular pyrotechnic device of interest (that decreases exponentially with range - see example in Table 2), and a means of localizing the pyrotechnic device on the geometric model. The choice of the surface acceleration, of course, depends on the pyrotechnic device and will not be discussed further. The means of localizing the device is accomplished by using the standard random position selection subroutines (RNDPOS) modified as follows. In Fig. 15, the names of the areas of the model that are considered contaminated are: ATP, the area of the element A top plate; ATS, the area of the element A cone surface; ASP, the solar panel area (both top and bottom); and AII, the nonsterile cone surface area of element B. A linear mapping relates scalar values (normalized by the total ATP + ATS + ASP + AII) to geometric areas on the spacecraft. The input of two limiting scalar quantities (e.g., the pyrotechnic data card on Table 2) establishes the definition of a specific subarea of spacecraft for the pyrotechnic event grain ejection study.

APPENDIX C

MODEL SYMBOLIC LISTINGS

The FORTRAN symbolic codes describing the main driver and the subroutines are now listed. The brief general nature of each element is shown in Table C-1.

Table C-1. Brief functional description of the driver programs and the subroutines

Program Names	Functional Description
CHKHIT	Cone region surface recontact determination.
CONTAM	Particle transport control coding (no printout).
CONTM2	Same as CONTAM with the trajectory, etc. printed.
EFIELD	Electric field of the model spacecraft.
ESURF	Spacecraft surface potential calculation.
FULBPS	Driver used when surface effect and meteoroid model data input on cards.
FULDET	Driver that contains the meteoroid model/impact model.
PARPOT	Potential of the ejected particle.
PYROM	Pyro event driver.
RANDNO	Random number generator.
RELEAS	Particle release effect model.
RNDPOS	Random ejection location code.
SCPLOT	Plot profile of spacecraft.
SHADE	Determine whether ejecta are shaded.
SPHIT	Determine if a solar panel was hit.
THINPL	Thin-plate meteoroid impact model.
TRAJEC	Incremental particle trajectory code.
TRANSL	X-Y Symmetry maintenance code.
VNORML	Calculate initial normal vector for ejecta launch.
YANG1	Driver for thin-plate impact code.

SUBROUTINE CHKHIT

```
      SUBROUTINE CHKHIT
C     ****  NASA  JPL               ****  9/12/74 **** D.EDGARS, BIONETICS ****
C     ****
C     THIS ROUTINE CHECKS WHETHER A PREVIOUSLY FREE PARTICLE(POSVEC) COMES
C     IN CONTACT(NEWPOS) WITH THE CONICAL SPACECRAFT AREAS. THE SC MODEL
C     DATA REQUIRED ARE ACCESSED VIA COMMON BLOCK AND ARE DEFINED AS
C     ENCOUNTERED.
C     A SEPERATE SUBROUTINE MONITORS THE SOLAR PANEL ZONE AND IS CALLED
C     WHEN THE PARTICLE APPROACHES THEIR PROXIMITY.
C     DEFINITIONS:
C     (1) XYZ(3) IS THE NEW(PRESENT) POSITION OF THE PARTICLE.
C     (2) IS IS THE INDEX DENOTING SPACECRAFT SECTOR OF INTEREST.
C     (3) IH1 IS THE SAFE SURFACE HIT INDEX.  (OUTPUT)
C                                  (A) 0-DID NOT CONTACT SAFE SURFACE
C                                  (B) 1-DID CONTACT SAFE SURFACE
C     (4) IH2   IS THE INDEX DENOTING
C                                  (A)  0 - DID NOT CONTACT STERILE SURFACE
C                                  (B)  1 - DID CONTACT STERILE SURFACE.
C     ****
      REAL NEWPOS
C     COMMON BLOK02 CONNECTS CHKHIT, MAIN, RNDPOS AND SHADE.
      COMMON /BLOK02/ AL(4)
C     COMMON BLOK09 IN CHKHIT,CONTAM,MAIN,SHADE,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK09/ NEWPOS(3)
C     COMMON BLOK13 CONNECTS CHKHIT, CONTAM, MAIN AND SPHIT.
      COMMON /BLOK13/ IHIT(2)
C     COMMON BLOK15 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,VNORML.
      COMMON /BLOK15/ ISECTR
C     COMMON BLOK20 IN CHKHIT, EFIELD, MAIN, RNDPOS, SHADE AND VNORML.
      COMMON /BLOK20/ TANTH1,TANTH2,TANTH3,TANTH4
C     COMMON BLOK21 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,SPHIT,SCPL
      COMMON /BLOK21/ Z1,Z2,Z3,Z4,Z5
      EQUIVALENCE (XYZ(1),NEWPOS(1)),(ISECTR,IS),(IHIT(1),IH1),(IHIT(2),
     1IH2)
      DIMENSION XYZ(3)
      GO TO(100,200,300), IS
  100 IF(XYZ(3).GT.Z5) GO TO 150        @ IN SECTOR 1
      ZSC= SQRT(XYZ(1)*XYZ(1)+XYZ(2)*XYZ(2))*TANTH3    +   AL(3)
      IF(ZSC.LT.XYZ(3)) GO TO 150
  125 IH1=1
      IH2=0
      RETURN   @ HIT SAFE SURFACE.
  150 IH1=0
      IH2=0
      RETURN   @ NO HITS REGISTERED.
  200 IF(XYZ(3).GT.Z3) GO TO 150        @ IN SECTOR 2
      ZSC= SQRT(XYZ(1)*XYZ(1)+XYZ(2)*XYZ(2))*TANTH2       +AL(2)
      IF(ZSC.LT.XYZ(3)) GO TO 150
      GO TO 125
  300 IF(XYZ(3).LT.Z1) GO TO 150        @ IN SECTOR 3
      ZSC= SQRT(XYZ(1)*XYZ(1)+XYZ(2)*XYZ(2))*TANTH1       +AL(1)
      IF(ZSC.GT.XYZ(3)) GO TO 150
      IH1=0
      IH2=1
      RETURN                            @ HIT STERILE SURFACE.
      END
```

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SUBROUTINE CONTAM

```
      SUBROUTINE CONTAM
C     *****                    *****                    *****
C     ****  NASA  JPL              ****  9/12/74 **** D.EDGARS, BIONETICS ****
C     *****                    *****                    *****
C     THIS SUBROUTINE COORDINATES THE TRAJECTORY ANALYSIS FOR THE EJECTED
C     GRAIN UNTIL THE GRAIN ACHIEVES ONE OF THE FOLLOWING CONDITIONS:
C
C        1-THE GRAIN RECONTACTS AN ACCEPTABLE PORTION OF THE SPACECRAFT
C          WHEREUPON THE VARIABLE IHIT(1) IS SET TO  1  -  SAFE HIT.
C
C        2-THE GRAIN TRAJECTORY SURPASSES THE PRESCRIBED MAXIMUM PATHLENGTH
C          OF PATHMX (20 METERS)  -  ESCAPED.
C
C        3-THE NUMBER OF TRAJECTORY INCREMENTS EXCEEDS 500 STEPS - ESCAPE.
C
C        4-THE GRAIN HAS RECONTACTED AN AREA OF THE SPACECRAFT CONSIDERED
C          STERILE WHEREUPON  IHIT(2) IS SET TO 1  -  RECONTAM HIT.
C
C     DURING THE EXECUTION THE PARTICLE IS KINEMATICALLY PROJECTED FROM
C     AN INITIAL POSITION THRU INCREMENTED POSITIONS USING THE PARTICLE
C     CHARGE, THE ELECTRIC AND INERTIAL FORCES EXPERIENCED BY THE
C     PARTICLE AT THE INITIAL LOCATION OF EACH INCREMENT.  THE NEW POSI-
C     TION IS SYMMETRICALLY MAINTAINED IN THE FIRST OCTANT AND MONITORED
C     FOR THE HIT CONDITIONS MENTIONED.
C
C     THE PARAMETERS ARE
C     POSOLD(3)  -  POSITION VECTOR (INITIAL CONDITIONS).        INPUT
C     VELOLD(3)  -  VELOCITY VECTOR (INITIAL CONDITIONS).        INPUT
C     GMAS       -  THE PARTICLE (EJECTED MASS)                  INPUT
C     VMAG       -  THE VELOCITY MAGNITUDE                       INPUT
C     ISE        -  DEFINES THE SECTOR OF CONCERN.               INPUT
C     IP         -  DEFINES CONDITION WHERE:                     INTERNAL/OUT
C                                   1 = PARTICLE UNDER A SOLAR PANEL.
C                                   0 = PARTICLE NOT UNDER A SOLAR PANEL.
C     ISH        -  DEFINES CONDITION WHERE:                     INTERNAL/OUT
C                                   1 = PARTICLE SHADED FROM SUN(OUTSIDE WAKE)
C                                   0 = PARTICLE NOT SHADED FROM SUN.
C                                  -1 = PARTICLE SHADED FROM SUN (INSIDE WAKE)
C     ****                       ****         ****                    ****
      REAL  NEWPOS,NEWVEL
      DIMENSION  POSOLD(3), POSNEW(3), VELOLD(3), VELNEW(3)
C     COMMON BLOK04 CONNECTS CONTAM, MAIN, PARPOT, SPHIT AND TRAJEC.
      COMMON /BLOK04/ COEFRP,CONSTA,PRTCHG,PHIO
C     COMMON BLOK08 CONNECTS CONTAM, DATAIN, MAIN AND PARPOT.
      COMMON /BLOK08/ DIM,PATHMX,SR,VELMAC
C     COMMON BLOK09 IN CHKHIT,CONTAM,MAIN,SHADE,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK09/ NEWPOS(3)
C     COMMON BLOK10 CONNECTS CONTAM,MAIN,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK10/ NEWVEL(3), DELTAT
C     COMMON BLOK11 IN CONTAM,EFIELD,MAIN,RNDPOS,SPHIT,TRAJEC,VNORML.
      COMMON /BLOK11/ POSVEC(3)
C     COMMON BLOK12 CONNECTS CONTAM, MAIN AND TRAJEC.
      COMMON /BLOK12/ GMASS ,VELVEC(3) ,ILOST
C     COMMON BLOK13 CONNECTS CHKHIT, CONTAM, MAIN AND SPHIT.
      COMMON /BLOK13/ IHIT(2)
C     COMMON BLOK14 CONNECTS CONTAM, EFIELD, MAIN, SHADE AND TRAJEC.
      COMMON /BLOK14/ IPANEL,ISHADE
C     COMMON BLOK15 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,VNORML.
      COMMON /BLOK15/ ISECTP
C     COMMON BLOK18 IN DATAIN,EFIELD,ESURF,MAIN,RNDPOS,SCPLOT,SHADE, AND CONTAI
      COMMON /BLOK18/ SP1,SP2,SP3,SP4
C     COMMON BLOK21 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,SPHIT,SCPL
      COMMON /BLOK21/ Z1,Z2,Z3,Z4,Z5
C     COMMON BLOK25 CONNECTS CONTAM, EFIELD, MAIN AND TRAJEC.
```

SUBROUTINE CONTAM

```
      COMMON /BLOK25/ EVEC(3)
C     COMMON BLOK31    CONNECTS CONTAM, EFIELD AND MAIN.
      COMMON /BLOK31/ NRMISS
      EQUIVALENCE  (ISECTR,ISE   )              ,(IPANEL,IP),(ILOST,IL)
      EQUIVALENCE  (NEWPOS(1),POSNEW(1)),(NEWVEL(1),VELNEW(1))
      EQUIVALENCE  (VELVEC(1),VELOLD(1)),(POSVEC(1),POSOLD(1))
      EQUIVALENCE  (VELMAG,VMAG),(GMASS,GMAS), (ISHADE,ISH)
      KCOUNT=0
      PATHLG = 0.          @ INITIALIZE CONTAM PATH LENGTH ACCUMULATOR.
      IL=0      @ INITIALIZE ILOST REGISTER FOR NEW TRIAL.
      IHIT(1)=0
      IHIT(2)=0
      NRMISS=0
      DELTAT=0.
    5 Z=POSOLD(3)
      CHGOLD=PRTCHG
      GO TO (200,220,220,10),ISE
  250 IF(VELOLD(3).GT.0.) GO TO 1999         @ PARTICLE LOST
      GO TO 220
   10 IF(VELOLD(3).LE.0.0)                GO TO 1999
      GO TO 220
  200 CONTINUE
      IF(Z.GT.Z1+Z5)    GO TO 250                      @ 1 DEBYE LENGTH ABOVE
  220 CALL TRAJEC        @  INCREMENT PARTICLE POSITION.
      ISHOLD=ISHADE
      IPOLD=IP
      ISEOLD=ISE
      KOLD=KCOUNT
      PTHOLD=PATHLG
  305 CALL SHADE         @ SEE IF PARTICLE IS SHADED AT THE NEW POSITION.
      SUM=0.
      DO 1001 KK=1,3
 1001 SUM=SUM+(POSOLD(KK)-POSNEW(KK))**2
      PATHLG=PATHLG+SQRT(SUM) @ THE ACCUMULATED PATH LENGTH.
      KCOUNT=KCOUNT+1.        @ INCREMENT STEP COUNTER.
      IF(PATHLG.GE.PATHMX) GO TO 1999
      IF(KCOUNT.EQ.500)  GO TO 1999
      DO 230 J=1,2       @ DETERMINE IF COORDINATES NEED TRANSL.
  230 IF(POSNEW(J).LT.0.0) GO TO 235
      GO TO 236
  235 CALL TRANSL        @ TRANSLATE PARTICLE BACK TO FIRST XY QUADRANT.
  236 CONTINUE
  240 IF(ISE.EQ.4)  GO TO 1000
      IF(IP.EQ.1.AND.ISE.LE.2.AND.POSNEW(3).GT.Z3) GO TO 241
C
C     SUBROUTINE CHKHIT DETERMINES WHETHER THE NEW POSITION HAS CONTACTED
C     A SPACECRAFT CONE SECTION.
C
      CALL CHKHIT
C
C     WHEN THE PARTICLE TRAVERSES THE CONE REGION AT THE TIP LOCATION
C     (Z2,SP4) - THE FALSE VALUE OF A RECONTAM HIT IS REVERSED TO A SAFE
C     HIT.
C
      IF(ISE.NE.3.OR.ISEOLD.NE.2.OR.IHIT(2).NE.1) GO TO 242
      IHIT(1)=1
      IHIT(2)=0
      GO TO 2001
C
C     THE PARTICLE IS IN THE REGION OF A SOLAR PANEL AND IS MONITORED BY
C     SUBROUTINE SPHIT FOR SURFACE CONTACT - SAFE HIT IF OCCURS.
C
  241 CALL SPHIT
C
```

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C     WHEN THE PARTICLE LEAVES THE TOP OF THE SOLAR PANEL AND BECAUSE OF
C     THE CHARGE-ELECTRIC FIELD CONDITION   IS SUCH THAT THE PARTICLE IS,
C     SUCKED BACK THROUGH THE PANEL AND MOVING DOWNWARD A SAFE HIT IS
C     REGISTERED.
C
      IF(KCOUNT.EQ.1.AND.IP.EQ.1.AND.IPOLD.EQ.1.AND.((NEWPOS(3).LT.
     1Z4.AND.VELVEC(3).GT.0.0).OR.(NEWPOS(3).GT.Z4.AND.
     2VELVEC(3).LT.0.0)))   IHIT(1)=1
  242 IF(IHIT(1).EQ.0.AND.IHIT(2).EQ.0) GO TO 1000  @ TO NEXT ITERATION.
C     ON TO STATISTICS EVALUATION
      GO TO 2001                        @ STATISTICAL EVALUATION
C
C     INCREMENT THE VELOCITY AND POSITION VECTOR COMPONENTS.
C
 1000 CONTINUE
 1010 DO 1011 LJ=1,3
      VELOLD(LJ)=NEWVEL(LJ)
 1011 POSOLD(LJ)=POSNEW(LJ)
      GO TO 5
 1999 IL=1      @ THE EJECTA WAS LOST ON THIS TRIAL.
C     ONE MONTE CARLO PASS COMPLETED.
 2001 RETURN
      END       @ CONTAM
```

SUBROUTINE CONTM2

```
      SUBROUTINE CONTM2
C     ****  NASA  JPL            ****  9/12/74 **** D.EDGARS, BIONETICS ****
C     *****                 *****                  *****
C
C     CONTM2 IS THE VERSION OF CONTAM THAT PRINTS THE TRAJECTORY INFOR-
C     MATION FROM THE INITIAL GRAIN REMOVAL FROM THE RANDOMLY SELECTED
C     MODEL SURFACE LOCATION TO THE RECONTAMINATION CONTACT.  THE CHARGE
C     AND THE ELECTRIC FIELD WRITTEN ON EACH LINE TELEOLOGICALLY CORRESPOND
C     TO THE PARTICLES EXPERIENCE AT THE POSITION COORDINATES PRINTED.
C     THE PATH LENGTH IS ACCUMULATED FOR ESCAPE CRITERIA EVALUATION AND
C     THE TIME OF FLIGHT INCREMENT FROM THE PREVIOUS POSITION IS INDICATED.
C     THIS VALUE APPRECIABLY CHANGES WHEN THE GRAIN TRAVERSES A SHADE/SUN
C     BOUNDRY, AN INDICATION OF THE THREEFOLD BALANCING MECHANISM INHERANT
C     WITHIN THE SUBROUTINE TRAJEC CALLED HEREIN.  THE VISUALLY INFORM-
C     ATIVE COLUMN  SH-P-SE  REPRESENTS THE SHADE, PANEL AND SECTOR
C     INDICIES YIELDING QUICK IDENTIFICATION OF THE PARTICLE ENVIRONMENT.
C
C     THIS SUBROUTINE COORDINATES THE TRAJECTORY ANALYSIS FOR THE EJECTED
C     GRAIN UNTIL THE GRAIN ACHIEVES ONE OF THE FOLLOWING CONDITIONS:
C
C       1-THE GRAIN RECONTACTS AN ACCEPTABLE PORTION OF THE SPACECRAFT
C         WHEREUPON THE VARIABLE IHIT(1) IS SET TO  1  -  SAFE HIT.
C
C       2-THE GRAIN TRAJECTORY SURPASSES THE PRESCRIBED MAXIMUM PATHLENGTH
C         OF PATHMX (20 METERS)  -  ESCAPED.
C
C       3-THE NUMBER OF TRAJECTORY INCREMENTS EXCEEDS 500 STEPS - ESCAPE.
C
C       4-THE GRAIN HAS RECONTACTED AN AREA OF THE SPACECRAFT CONSIDERED
C         STERILE WHEREUPON  IHIT(2) IS SET TO 1  -  RECONTAM HIT.
C
C     DURING THE EXECUTION THE PARTICLE IS KINEMATICALLY PROJECTED FROM
C     AN INITIAL POSITION THRU INCREMENTED POSITIONS USING THE PARTICLE
C     CHARGE, THE ELECTRIC AND INERTIAL FORCES EXPERIENCED BY THE
C     PARTICLE AT THE INITIAL LOCATION OF EACH INCREMENT.  THE NEW POSI-
C     TION IS SYMMETRICALLY MAINTAINED IN THE FIRST OCTANT AND MONITORED
C     FOR THE HIT CONDITIONS MENTIONED.
C
C     THE INPUT PARAMETERS ARE:
C     POSOLD(3)  -  POSITION VECTOR (INITIAL CONDITIONS).        INPUT
C     VELOLD(3)  -  VELOCITY VECTOR (INITIAL CONDITIONS).        INPUT
C     CMAS       -  THE PARTICLE (EJECTED MASS)                  INPUT
C     VMAG       -  THE VELOCITY MAGNITUDE                       INPUT
C     ISC        -  DEFINES THE SECTOR OF CONCERN.               INPUT
C     IP         -  DEFINES CONDITION WHERE:                     INTERNAL/OUT
C                                 1 = PARTICLE UNDER A SOLAR PANEL.
C                                 0 = PARTICLE NOT UNDER A SOLAR PANEL.
C     ISH        -  DEFINES CONDITION WHERE:                     INTERNAL/OUT
C                                 1 = PARTICLE SHADED FROM SUN(OUTSIDE WAKE)
C                                 0 = PARTICLE NOT SHADED FROM SUN.
C                                -1 = PARTICLE SHADED FROM SUN (INSIDE WAKE)
C     ****                     ****          ****                    ****
      REAL  NEWPOS,NEWVEL
      DIMENSION  POSOLD(3), POSNEW(3), VELOLD(3), VELNEW(3)
C     COMMON BLOK04 CONNECTS CONTAM, MAIN, PARPOT, SPHIT AND TRAJEC.
      COMMON /BLOK04/ COEFF,CONSTA,PRTCHC,PHIC
C     COMMON BLOK08 CONNECTS CONTAM, DATAIN, MAIN AND PARPOT.
      COMMON /BLOK08/ DIM,PATHMX,SR,VELMAC
C     COMMON BLOK09 IN CHKHIT,CONTAM,MAIN,SHADE,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK09/ NEWPOS(3)
C     COMMON BLOK10 CONNECTS CONTAM,MAIN,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK10/ NEWVEL(3), DELTAT
C     COMMON BLOK11 IN CONTAM,EFIELD,MAIN,RNDPOS,SPHIT,TRAJEC,VNORML.
      COMMON /BLOK11/ POSVEC(3)
```

SUBROUTINE CONTM2

```
C     COMMON BLOK12 CONNECTS CONTAM, MAIN AND TRAJEC.
      COMMON /BLOK12/ GMASS ,VELVEC(3) ,ILOST
C     COMMON BLOK13 CONNECTS CHKHIT, CONTAM, MAIN AND SPHIT.
      COMMON /BLOK13/ IHIT(2)
C     COMMON BLOK14 CONNECTS CONTAM, EFIELD, MAIN, SHADE AND TRAJEC.
      COMMON /BLOK14/ IPANEL,ISHADE
C     COMMON BLOK15 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,VNORML.
      COMMON /BLOK15/ ISECTR
C     COMMON BLOK18 IN DATAIN,EFIELD,ESURF,MAIN,RNDPOS,SCPLOT,SHADE, AND CONTA
      COMMON /BLOK18/ SP1,SP2,SP3,SP4
C     COMMON BLOK21 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,SPHIT,SCPL
      COMMON /BLOK21/ Z1,Z2,Z3,Z4,Z5
C     COMMON BLOK25 CONNECTS CONTAM, EFIELD, MAIN AND TRAJEC.
      COMMON /BLOK25/ EVEC(3)
C     COMMON BLOK31    CONNECTS CONTAM, EFIELD AND MAIN.
      COMMON /BLOK31/ NRMISS
      EQUIVALENCE  (ISECTR,ISE   )          ,(IPANEL,IP),(ILOST,IL)
      EQUIVALENCE  (NEWPOS(1),POSNEW(1)),(NEWVEL(1),VELNEW(1))
      EQUIVALENCE  (VELVEC(1),VELOLD(1)),(POSVEC(1),POSOLD(1))
      EQUIVALENCE  (VELMAG,VMAG),(CMASS,GMAS), (ISHADE,ISH)
 1500 FORMAT( 1X,I6,2X,5(1PG12.5,2X) ,I2,1X,I1,1X,I1,2X,3(1PG10.4,2X),
     11PE8.3)
 1501 FORMAT( 1H0,4X,'THE PARTICLE ESCAPED')
 1502 FORMAT(1H1,2X,'STEP   PATH LENGTH    X-POSITION     Y-POSITION    Z
     1-POSITION    PART. CHG.  SH-P-SE',4X,'E(X)',8X,'E(Y)',8X,
     2'E(Z)',8X,'DT')
 1503 FORMAT( 1H0,'FINAL STEP',2X,'FINAL PATH LENGTH',15X,'FINAL (X,Y,Z)'
     1,13X,'FINAL CHARGE',2X,'FINAL-SHADE-PANEL-SECTOR',/,1X,I6,7X,
     21PG12.5,8X,'(',1PG10.4,',',1PG10.4,',',1PG10.4,')',2X,1PG12.5,
     310X,I2,5X,I1,5X,I1)
      KCOUNT=0       @ INITIALIZATION OF THE WORKING PARAMETERS.
      IL=0
      PATHLG = 0.
      IHIT(1)=0
      IHIT(2)=0
      NRMISS=0
      DELTAT=0.
      TIME=0.
    5 Z=POSOLD(3)
      CHGOLD=PRTCHG
      GO TO (200,220,220,10),ISE
  200 IF(VELOLD(3).GT.0.) GO TO 1999          @ PARTICLE LOST
      GO TO 220
   10 IF(VELOLD(3).LE.0.0)                GO TO 1999
      GO TO 220
  200 CONTINUE
      IF(Z.GT.Z1+Z5)   GO TO 250                     @ 1 DEBYE LENGTH ABOVE
  220 CALL TRAJEC          @  INCREMENT PARTICLE POSITION.
      TIME=TIME+DELTAT
      ISHOLD=ISHADE
      IPOLD=IP
      ISEOLD=ISE
      KOLD=KCOUNT
      PTHOLD=PATHLG
  305 CALL SHADE         @ SEE IF PARTICLE IS SHADED AT THE NEW POSITION.
      SUM=0.
      DO 1001 KK=1,3
 1001 SUM=SUM+(POSOLD(KK)-POSNEW(KK))**2
      PATHLG=PATHLG+SQRT(SUM) @ THE ACCUMULATED PATH LENGTH.
      KMOD=MOD(KCOUNT,47)
      IF(KMOD.EQ.0)  WRITE(6,1502)
      KCOUNT=KCOUNT+1.         @ INCREMENT STEP COUNTER.
      IF(PATHLG.GE.PATHMX) GO TO 1399
```

SUBROUTINE CONTM2

```
      IF(KCOUNT.EQ.500)  GO TO 1999
      DO 230 J=1,2          @ DETERMINE IF COORDINATES NEED TRANSL.
  230 IF(POSNEW(J).LT.0.0) GO TO 235
      GO TO 236
  235 CALL TRANSL         @ TRANSLATE PARTICLE BACK TO FIRST XY QUADRANT.
  236 WRITE(6,1500) KOLD,PTHOLD,POSVEC,CHGOLD,ISHOLD,IPOLD,ISEOLD,EVEC,
     1DELTAT
  240 IF(ISE.EQ.4)  GO TO 1000
      IF(IP.EQ.1.AND.ISE.LE.2.AND.POSNEW(3).GT.Z3) GO TO 241
C
C     SUBROUTINE CHKHIT DETERMINES WHETHER THE NEW POSITION HAS CONTACTED
C     A SPACECRAFT CONE SECTION.
C
      CALL CHKHIT
C
C     WHEN THE PARTICLE TRAVERSES THE CONE REGION AT THE TIP LOCATION
C     (Z2,SF4) - THE FALSE VALUE OF A RECONTAM HIT IS REVERSED TO A SAFE
C     HIT.
C
      IF(ISE.NE.3.OR.ISEOLD.NE.2)  GO TO 242
      ROLD=SQRT(POSOLD(1)*POSOLD(1)+POSOLD(2)*POSOLD(2))
      RNEW=SQRT(POSNEW(1)*POSNEW(1)+POSNEW(2)*POSNEW(2))
      IF(RNEW.LT.SF4.AND.ROLD.LT.SF4)  GO TO 2410
      GO TO 242
 2410 IHIT(1)=0
      IHIT(2)=1
      GO TO 242
C
C     THE PARTICLE IS IN THE REGION OF A SOLAR PANEL AND IS MONITORED BY
C     SUBROUTINE SPHIT FOR SURFACE CONTACT - SAFE HIT IF OCCURS.
C
  241 CALL SPHIT
C
C     WHEN THE PARTICLE LEAVES THE TOP OF THE SOLAR PANEL AND BECAUSE OF
C     THE CHARGE-ELECTRIC FIELD CONDITIONS IS SUCH THAT THE PARTICLE IS
C     SUCKED BACK THROUGH THE PANEL AND MOVING DOWNWARD A SAFE HIT IS
C     REGISTERED.
C
      IF(KCOUNT.EQ.1.AND.IP.EQ.1.AND.IPOLD.EQ.1.AND.((NEWPOS(3).LT.
     1Z4.AND.VELVEC(3).GT.0.0).OR.(NEWPOS(3).GT.Z4.AND.
     2VELVEC(3).LT.0.0)))   IHIT(1)=1
  242 IF(IHIT(1).EQ.0.AND.IHIT(2).EQ.0) GO TO 1000  @ TO NEXT ITERATION.
C     ON TO STATISTICS EVALUATION
      GO TO 2001                        @ STATISTICAL EVALUATION
C
C     INCREMENT THE VELOCITY AND POSITION VECTOR COMPONENTS.
C
 1000 CONTINUE
 1010 DO 1011 LJ=1,3
      VELOLD(LJ)=NEWVEL(LJ)
 1011 POSOLD(LJ)=POSNEW(LJ)
      GO TO 5
 1999 IL=1       @ THE EJECTA WAS LOST ON THIS TRIAL.
      WRITE(6,1500) KOLD,PTHOLD,POSVEC,CHGOLD,ISHOLD,IPOLD,ISEOLD,EVEC,
     1DELTAT
      WRITE(6,1501)
      WRITE(6,1503) KCOUNT,PATHLG,NEWPOS,PRTCHG,ISHADE,IPANEL,ISECTR
C     ONE MONTE CARLO PASS COMPLETED.
      GO TO 2003
 2001 CONTINUE
      IF(IHIT(2).EQ.1)  WRITE(6,2004)
      WRITE(6,1503) KCOUNT,PATHLG,NEWPOS,PRTCHG,ISHADE,IPANEL,ISECTR
      WRITE(6,1504) TIME
```

SUBROUTINE CONTM2

```
1504 FORMAT(1H0,'THE PARTICLE TRAJECTORY ELAPSED TIME WAS',G12.3,2X,
    1'SECONDS')
2004 FORMAT(1H0,'RECONTAMINATION HIT ON THIS TRIAL')
2002 RETURN
     END
```

SUBROUTINE EFIELD

```
      SUBROUTINE EFIELD        @ J. BARENGOLTZ, JPL **10/7/74**
C
C     * EFIELD *
C     CALCULATES THE VECTOR ELECTRIC FIELD AT A POSITION NEAR THE S/C
C     USING THE SURFACE CONDITIONS ESTABLISHED BY ESURF.   IN GENERAL,
C     THE POSITION IS TESTED FOR BEING NEAR A SURFACE IN WHICH CASE THE
C     USUAL FLAT PLATE SOLUTION IS EMPLOYED WITH AN APPROPRIATE DEBYE
C     LENGTH AND SURFACE VALUE PER LENGTH AND SURFACE VALUE PER ESURF.
C     THESE FACTORS DEPEND ON THE SUN/SHADE INDEX (ISHADE) ALSO.   TWO
C     EXCEPTIONS EXIST: (1) FOR POSITIONS NEAR (COMPARED TO APPROPRIATE
C     DEBYE LENGTH) THE SOLAR PANEL, THE ALGEBRAIC SUM OF THE SURFACE
C     POTENTIAL OF THE ILLUMINATED AND DARK SIDES IS FORMED AND THEN
C     THE FIELD IS CALCULATED ANALOGOUSLY.  (2) FOR POSITIONS IN THE
C     WAKE OF THE SPACECRAFT THE NEAR CASE AND FAR CASE ARE APPROXIMATED
C     FOLLOWING AN ANALYSIS BY ALPERT, ET AL., SPACE SCIENCE REVIEWS,
C     VOL. 2 (1963.)
C     THE FAR FIELD CASE IS CALCULATED BY AN EQUIVALENT SPHERE OF AREA-
C     AVERAGED POTENTIAL AND THE DEBYE LENGTH BELOW THE SPACECRAFT OR
C     AN AVERAGED EFFECTIVE DEBYE LENGTH (SEE ESURF) ABOVE OR ALONGSIDE
C     THE SPACECRAFT.
C
      DOUBLE PRECISION W, B0(2),B1(2)
      DIMENSION  COSJ(4), SINJ(4), TANJ(4)
C     COMMON BLOK11 IN CONTAM,EFIELD,MAIN,RNDPOS,SPHIT,TRAJEC,VNORML.
      COMMON /BLOK11/ POSVEC(3)
C     COMMON BLOK14 CONNECTS CONTAM, EFIELD, MAIN, SHADE AND TRAJEC.
      COMMON /BLOK14/ IPANEL,ISHADE
C     COMMON BLOK15 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,VNORML.
      COMMON /BLOK15/ ISECTR
C     COMMON BLOK18 IN DATAIN,EFIELD,ESURF,MAIN,RNDPOS,SCPLOT,SHADE.
      COMMON /BLOK18/ SP1,SP2,SP3,SP4
C     COMMON BLOK19 CONNECTS DATAIN, EFIELD, ESURF,MAIN, RNDPOS AND SCPLOT.
      COMMON /BLOK19/ SPO1,SPO2,SPO3
C     COMMON BLOK20 IN CHKHIT, EFIELD, MAIN, RNDPOS, SHADE AND VNORML.
      COMMON /BLOK20/ TANTH1,TANTH2,TANTH3,TANTH4
C     COMMON BLOK21 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,SPHIT,SCPL
      COMMON /BLOK21/ Z1,Z2,Z3,Z4,Z5
C     COMMON BLOK23 CONNECTS EFIELD, MAIN AND SHADE.
      COMMON /BLOK23/ XYWAKE,ZWAKE , JPOT
C     COMMON BLOK24 CONNECTS EFIELD, ESURF MAIN AND DATAIN.
      COMMON /BLOK24/ALAMB(2),ANPHOT(2),AKPHOT(2),EFEL(2),EFED(2),DEB,
     1AMAT(9),EL(2),PHIEL(2),PHIED(2),ALAMAV,PHIAVE
C     COMMON BLOK25 CONNECTS CONTAM, EFIELD, MAIN AND TRAJEC.
      COMMON /BLOK25/ EVEC(3)
C     COMMON BLOK29 CONNECTS DATAIN,EFIELD,ESURF,MAIN AND PARPOT.
      COMMON /BLOK29/ AKTE,AKTP,ANE
C     COMMON BLOK31    CONNECTS CONTAM, EFIELD AND MAIN.
      COMMON /BLOK31/ NRMISS
      EQUIVALENCE (X,POSVEC(1)),(Y,POSVEC(2)),(Z,POSVEC(3))
      EQUIVALENCE (EX,EVEC(1)), (EY,EVEC(2)), (EZ,EVEC(3))
      EQUIVALENCE (KSECTR,ISECTR)
      EQUIVALENCE  (J,JPOT)
      TANJ(1)=TANTH3
      TANJ(2)=TANTH2
      TANJ(3)=TANTH1
      TANJ(4)=TANTH4
      DO 50  I=1,4
      COSJ(I)=1./SQRT(1.+TANJ(I)*TANJ(I))
   50 SINJ(I)=ABS(TANJ(I))*COSJ(I)
      R=SQRT(X*X+Y*Y)
      J=1
      EX=0.0
      EY=0.0
      EZ=0.0
```

SUBROUTINE EFIELD

```
      PI=3.14159
      IF(ISECTR-2) 100,200,300
C     SECTOR I IN CLOSE
  100 IF(IPANEL.NE.1) GO TO 110
      IF(AMAT(3).EQ.EL(2)) J=2       @ ABOVE SOLAR PANEL.
      DIST=ABS(Z-Z4)
      IF(DIST.GE.ALAMB(J)) GO TO 110
      EZ=(EFEL(J)+EFED(1)*DEB/ALAMB(J))*EXP(-DIST/ALAMB(J))
      RETURN
  110 IF(Z.LE.Z5) GO TO 120
      IF(R.GE.SPCI) GO TO 120
C     ABOVE TOP CIRCLE
      IF(AMAT(1).EQ.EL(2)) J=2
      DIST=ABS(Z-Z5)
      IF(DIST.GE.ALAMB(J)) GO TO 120
      EZ=EFEL(J)*EXP(-DIST/ALAMB(J))
      RETURN
  120 IF(Z.GE.Z5) GO TO 400
C     ALONGSIDE CONICAL SECTION
      IF(AMAT(2).EQ.EL(2)) J=2
      DIST=((R-SP2)* ABS(TANJ(1))+Z-Z4)*COSJ(1) +
      IF(DIST.GE.ALAMB(J)) GO TO 400
      EMAG=EFEL(J)*EXP(-DIST/ALAMB(J))
      EX=EMAG*SINJ(1)*X/R
      EY=EMAG*SINJ(1)*Y/R
      EZ=EMAG*COSJ(1)
      RETURN
  200 CONTINUE
      IF(R.GT.SP3) GO TO 400
      IF(IPANEL.NE.1) GO TO 210
      DIST=ABS(Z-Z4)
      IF(DIST.GE.(Z4-Z3)) GO TO 210
      IF(AMAT(3).EQ.EL(2)) J=2
C     SECTOR II IN CLOSE
      EZ=-(EFED(1)+EFEL(J)*ALAMB(J)/DEB)*EXP(-DIST/DEB) @ BELOW SOLAR PANEL.
      RETURN
  210 IF(Z.LE.Z3) GO TO 220
C     NOT UNDER SOLAR PANEL BUT Z.GT.Z3.AND.LE.SP3, CRUDE FIX WITH E=0.
      RETURN
  220 CONTINUE       @ NOT NECESSARILY  UNDER PANEL. Z.LE.Z3
      IF(AMAT(7).EQ.EL(2)) J=2
      DIST=((R-SP4)* ABS(TANJ(2))+Z-Z2)*COSJ(2)
      IF(DIST.GE.ALAMB(J)) GO TO 400
C     ALONGSIDE CONICAL SECTION
      EMAG=EFEL(J)*EXP(-DIST/ALAMB(J))
      EX=EMAG*SINJ(2)*X/R
      EY=EMAG*SINJ(2)*Y/R
      EZ=EMAG*COSJ(2)
      RETURN
  300 CONTINUE
C     SECTOR III IN CLOSE TO WAKE BUT NOT INSIDE.
      IF(Z.LE.0.) GO TO 400    @ BELOW WAKE.
      IF(ISHADE.EQ.-1) GO TO 320
      RE=SQRT(X*X+Y*Y+(Z-Z4)*(Z-Z4))
      IF(RE.GE.ALAMAV)  GO TO 401
      DIST=((R-XYWAKE)*ABS(TANJ(4))+Z4-Z)*COSJ(4)
      IF(DIST.GE.ALAMAV)  GO TO 400
      EMAG=EFED(1)*EXP(-DIST/DEB)         @ LEADING COEF. SHOULD BE WAKE SURF.
      EX=EMAG*SINJ(4)*X/R
      EY=EMAG*SINJ(4)*Y/R
      EZ=-EMAG*COSJ(4)
      RETURN
  320 CONTINUE       @ INSIDE WAKE.
      IF(Z.LE.Z1) GO TO 330
```

```
C     NEAR BOTTOM CONE, CRITICAL AREA
      DIST=((R-SP4)* ABS(TANJ(3))+Z2-Z)*COSJ(3)
      EMAG=EFED(1)*EXP(-DIST/DEB)
      EX=EMAG*SINJ(3)*X/R
      EY=EMAG*SINJ(3)*Y/R
      EZ=-EMAG*COSJ(3)
      IF(DIST.LT.0.01) NRMISS=1
      RETURN
  330 CONTINUE            @ BELOW S/C IN WAKE.
C     FIELD PER JBB 9/10/74 FOR CYLINDER.
C     VALID CLOSE TO S/C BOTTOM ONLY.
      ACYL=(Z1-Z4+ZWAKE)*XYWAKE/ZWAKE
      DIST=ABS(Z1-Z)
      W=2.4*R/ACYL
      IF(DIST.GE.ACYL) GO TO 390
      CALL BJY01(W,1,1,B0,B1)
      EMAGRO=2.4*EFED(1)*(DEB/ACYL)*EXP(-W)
      EZ=-EMAGRO*B0(1)
      IF(R.LE.0.)  RETURN
      EX=EMAGRO*X/R*B1(1)
      EY=EMAGRO*Y/R*B1(1)
      NRMISS=1
      RETURN
  390 CONTINUE            @ IN WAKE BUT FAR FROM BOTTOM.
      EMAGRO=-AKTE/DEB
      EX=EMAGRO*X/R
      EY=EMAGRO*Y/R
      EZ=(AKTE/ACYL)*ALOG(DEB/ACYL)*EXP(-W)
      RETURN
  400 CONTINUE
C     EQUIVALENT SPHERE
      RE=SQRT(X*X+Y*Y+(Z-Z4)*(Z-Z4))
  401 ALAM=ALAMAV
      EMAG=PHIAVE*(1./RE)*(1./RE+1./ALAM  )*XYWAKE
      IF(RE.LE.XYWAKE) GO TO 470
      EMAG=EMAG*EXP(-(RE-XYWAKE)/ALAM)
  470 CONTINUE
      EX=EMAG*X/RE
      EY=EMAG*Y/R
      EZ=EMAG*(Z-Z4)/RE
      RETURN
      END
```

ORIGINAL PAGE IS
OF POOR QUALITY

SUBROUTINE ESURF

```
      SUBROUTINE ESURF          @ J. BARENGOLTZ, JPL**10/7/74**
C
C     * ESURF *
C     CALCULATES SUNLIT SURFACE POTENTIAL PHIEL FOR AL AND SIO2 AND THE
C     CORRESPONDING SURFACE FIELD EFEL AND THE DISTANCE PARAMETER ALAMB
C     PER JPL QTR. VOL. 3 NO 1, APRIL 1973, AND SETS SHADED SURFACE
C     POTENTIAL (PHIED) TO -3*ELECTRON TEMPERATURE (IN VOLTS) AND
C     SURFACE FIELD (EFED) TO THE POTENTIAL DIVIDED BY THE DEBYE LENGTH
C     (DEB.)  THIS ROUTINE ALSO CALCULATES AREA-AVERAGED SURFACE POTENT-
C     IAL (PHIAVE) AND AN EFFECTIVE DEBYE LENGTH (ALAMAV.)
C
      DIMENSION  ANION(2) ,AA(9)
C     COMMON BLOK03 CONNECTS ESURF,  MAIN AND RNDPOS.
      COMMON /BLOK03/ ASP,ATP,ATS,FRI,ATOT,ABF,ABCS,ATI
C     COMMON BLOK18 IN DATAIN,EFIELD,ESURF,MAIN,RNDPOS,SCPLOT,SHADE.
      COMMON /BLOK18/ SP1,SP2,SP3,SP4
C     COMMON BLOK19 CONNECTS DATAIN, EFIELD, ESURF,MAIN, RNDPOS AND SCPLOT.
      COMMON /BLOK19/ SPC1,SPC2,SPC3
C     COMMON BLOK24 CONNECTS EFIELD, ESURF MAIN AND DATAIN.
      COMMON /BLOK24/ALAMB(2),ANPHOT(2),AKPHOT(2),EFEL(2),EFED(2),DEB,
     1AMAT(9),EL(2),PHIEL(2),PHIED(2),ALAMAV,PHIAVE
C     COMMON BLOK29 CONNECTS DATAIN,EFIELD,ESURF,MAIN AND PARPOT.
      COMMON /BLOK29/ AKTE,AKTP,ANE
      PI=3.14159
      DO 100 I=1,2
      R1=AKTE/AKPHOT(I)
      R2=ANPHOT(I)/ANE
      IF(R1.LE.1.0.OR.R2.LE.R1) GO TO 900
      PHIEL(I)=AKPHOT(I)*(ALOG(R2)-0.5*ALOG(R1))
      ANION(I)=(ANE/2.)*(SQRT(R1)+1.0)*1.E-6
      C0=(ANPHOT(I)/SQRT(AKPHOT(I))-ANE/SQRT(AKTE))*1.E-6
      C1=-1.5*SQRT(PI)*ANION(I)/C0
      C00=8./3.*SQRT(PI)*C0*1.44E-7
      C2=SQRT(C00/2.)/2.
C
C     C1 AND C2 AND FORMS OF PHI AND E TAKEN FROM BARENGOLTZ AND BAUERLE,
C     JPL QTR'LY, VOL. 3, NO 1 (1973)  EXCEPT EX100 FOR V/M.
C
      C4=SQRT(PHIEL(I))
      C5=SQRT(C4+C1)
      XMAX=C5/C2
      XDELT=XMAX/100.
      EFEL(I)=400.*C2*C4*C5
      X=XDELT
      DO 200  J=1,100
      EEX=400.*C2*(-C1+(C5-C2*X)**2.)*(C5-C2*X)
      RTEST=EEX/EFEL(I)
      IF(RTEST.LE.0.3679) GO TO 300
      X=X+XDELT
  200 CONTINUE
      WRITE(6,902)
      STOP
  300 ALAMB(I)=X/100.     @ CONVERT TO METERS.
      PHIED(I)=-3.*AKTE         @ SHADE SURFACE.
      EFED(I)=PHIED(I)/DEB     @ SHADE SURFACE.
  100 CONTINUE
      AA(1)=ATP
      AA(2)=ATS
      AA(3)=ASP/2.
      AA(4)=AA(3)
      AA(5)=PI*SP2*SP2
      AA(6)=PI*SPC2*SPC2
      AA(7)=ATI
      AA(8)=ABCS
```

```
      AA(9)=ASP
C     FAR FIELD CASE, ALL SECTORS (APPROX.)
      ALAMAV=0.0
      PHIAVE=0.0
      ASC=0.0
      DO 440   I=1,3
      J=1
      IF(AMAT(I).EQ.EL(2)) J=2
      PHIAVE=PHIAVE+AA(I)*PHIEL(J)
      ASC=ASC+AA(I)
  440 ALAMAV=ALAMAV+ALAMB(J)*AA(I)
      DO 450   I=4,6
      PHIAVE=PHIAVE+AA(I)*PHIED(1)
      ASC=ASC+AA(I)
  450 ALAMAV=ALAMAV+DEB*AA(I)
      J=1
      IF(AMAT(7).EQ.EL(2)) J=2
      PHIAVE=PHIAVE+AA(7)*PHIEL(J)
      ALAMAV=ALAMAV+AA(7)*ALAMB(J)
      ASC=ASC+AA(7)
      DO 460   I=8,9
      PHIAVE=PHIAVE+AA(I)*PHIED(1)
      ASC=ASC+AA(I)
  460 ALAMAV=ALAMAV+AA(I)*DEB
      PHIAVE=PHIAVE/ASC
      ALAMAV=ALAMAV/ASC
      WRITE(6,1000) ALAMB,EFEL,EFED,DEB,PHIEL,PHIED,ALAMAV,PHIAVE,
     1AMAT,EL
 1000 FORMAT(4X,'* * ALAMB * *',10X,'* * EFEL * *',10X,'* * EFED * *',
     119X,'DEB',/,1X,7(1PG9.3,2X),//,4X,'* * PHIEL * *',9X,'* * PHIED * *
     2'
     3,6X,'* ALAMAV * * PHIAVE *',/,1X,6(1PG9.3,2X),//,4X,'* * AMAT ARRA
     4Y * *',19X,'* * AMAT ARRAY * *',/,1X,9(A6,2X),//,1X,'* * EL ARRAY
     5 * *',/,1X,2(A6,2X))
      RETURN
  900 WRITE(6,901) EL(I)
      STOP
  901 FORMAT(1X,'PHOTOELECTRIC DATA INCONSISTENT WITH PLASMA DATA, SEE M
     1AIN FOR ',A6)
  902 FORMAT(1X,'EFFECTIVE SUNLIT DEBYE LENGTH COULD NOT BE FOUND BY ESU
     1RF')
      END
```

MAIN DRIVER (VERSION – FULBPS)

```
C     **** NASA  JPL **** D. EDGARS (BIONETICS), J. BARENGOLTZ (JPL) ****
C     *****                      *****                      *****
      REAL NU, NEWPOS, NEWVEL, IVESC
C     *****                      *****                      *****
      DIMENSION WNET(5),WNET2(5),VAP2(36),ISFUN(36),WANGDS(18),
     1 VANGDS(18)
      DIMENSION   ANGDEG(18)
      DIMENSION  POSHID(3)
      DIMENSION  VAP(35), PKACC(35)
      DIMENSION ANGDIS(18), FLUXM1(3,10)
C     *****                      *****                      *****
C
C     THIS IS THE DRIVER PROGRAM FOR THE BYPASS MODE OF THE SPACECRAFT
C     RECONTAMINATION MODEL.  THIS MODEL HAS BEEN BRIEFLY DISCUSSED IN
C     THE JET PROPULSION LABORATORY DOCUMENT  900-675, SECTION III,
C     SEPTEMBER, 1974.
C
C     THE DISTRIBUTIONS OF THE MASS AND VELOCITY FOR THE METEOROIDS IN
C     THE SPATIAL REGION BETWEEN THE EARTH AND MARS HAVE BEEN CATAGORIZED
C     INTO TEN  MASS AND THREE VELOCITY GROUPS. ,SEPERATE EXECUTION  OF
C     THE SURFACE EFFECT MODEL (YANG1/THINPL) HAS PRODUCED DATA ENSEMBLES
C     WHICH THIS PRESENT VERSION READS AS INPUT.  THE PARTICLE RELEASE
C     MODEL (RELEAS) CONTAINED HEREIN COMPUTES THE STATISTICAL QUANTITIES
C     FOR PARTICLE RELEASE PROBABILITIES.
C
C     THE METEOROID MASS AND VELOCITY GROUP UNDER CONSIDERATION THEN HAS
C     RANDOM POSITIONS FOR IMPACT DETERMINED, AT EACH OF WHICH RELEASED
C     GRAINS ARE KINEMATICALLY FOLLOWED ON THEIR TRAJECTORIES. THESE
C     TRIAL GRAIN HISTORIES LEAD TO ONE OF SEVERAL SITUATIONS. THE GRAIN
C     CAN RECONTACT THE SPACECRAFT ON A REGION WHERE THE STERILITY IS OF
C     NO CONCERN.  THIS IS REFERRED TO AS  A SAFE-HIT.  THE GRAIN MAY
C     ALSO ESCAPE THE VICINITY OF THE SPACECRAFT WHEREUPON THE NUMBER OF
C     AND DIRECTION OF THE ESCAPE IS NOTED FOR LATER TABULATION.  THE
C     IMPORTANT DATA GENERATED WITHIN INDICATING THE NUMBER OF GRAINS
C     REACHING THE PRESCRIBED STERILE AREAS ARE CALLED RECONT. HITS.
C
C     *****                      *****                      *****
C
C     THE COMMON BLOCKS LISTED INTERCOMMUNICATE ESSENTIAL DATA AMONG THE
C     SUBROUTINES
C
C     COMMON BLOK01 CONNECTS DATAIN, MAIN AND RELEAS.
      COMMON /BLOK01/ AKM,DRHO,K1,FRBVEL(35,10),CR(10),SIG,DDIA(10)
     1,ANPART,ANNORM,PRBDIA(10)
C     COMMON BLOK02 CONNECTS CHKHIT, MAIN, RNDPOS AND SHADE.
      COMMON /BLOK02/ AL(4)
C     COMMON BLOK03 CONNECTS ESURF,  MAIN AND RNDPOS.
      COMMON /BLOK03/ ASP,ATP,ATS,PRI,ATOT,ABP,ABCS,AII
C     COMMON BLOK04 CONNECTS CONTAM, MAIN, PARPOT, SPHIT AND TRAJEC.
      COMMON /BLOK04/ COEFRP,CONSTA,PRTCH3,PHIO
C     COMMON BLOK05 CONNECTS DATAIN, MAIN, RELEAS AND YANG1
      COMMON /BLOK05/ KO,PMASS,PRHO,RS(35),FVAP(35),FPKACC(35),RHO
C     COMMON BLOK06 CONNECTS DATAIN, MAIN AND YANG1.
      COMMON /BLOK06/ E,H,NU,PO,ISKIP
C     COMMON BLOK08 CONNECTS CONTAM, DATAIN, MAIN AND PARPOT.
      COMMON /BLOK08/ DIM,PATHMX,SR,VELMAG
C     COMMON BLOK09 IN CHKHIT,CONTAM,MAIN,SHADE,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK09/ NEWPOS(3)
C     COMMON BLOK10 CONNECTS CONTAM,MAIN,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK10/ NEWVEL(3), DELTAT
C     COMMON BLOK11 IN CONTAM,EFIELD,MAIN,RNDPOS,SPHIT,TRAJEC,VNORML.
      COMMON /BLOK11/ POSVEC(3)
C     COMMON BLOK12 CONNECTS CONTAM, MAIN AND TRAJEC.
      COMMON /BLOK12/ GMASS ,VELVEC(3) ,ILOST
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MAIN DRIVER (VERSION – FULBPS)

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C     COMMON BLOCK13 CONNECTS CHKHIT, CONTAM, MAIN AND SPHIT.
      COMMON /BLOK13/ IHIT(2)
C     COMMON BLOK14 CONNECTS CONTAM, EFIELD, MAIN, SHADE AND TRAJEC.
      COMMON /BLOK14/ IPANEL,ISHADE
C     COMMON BLOK15 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,VNORML.
      COMMON /BLOK15/ ISECTR
C     COMMON  BLOK16 CONNECTS        MAIN,RNDPOS,SHADE AND VNORML.
      COMMON /BLOK16/ NPNL
C     COMMON BLOK17 CONNECTS DATAIN, MAIN AND YANG1.
      COMMON /BLOK17/ PVEL,ACCMIN
C     COMMON BLOK18 IN DATAIN,EFIELD,ESURF,MAIN,RNDPOS,SCPLOT,SHADE.
      COMMON /BLOK18/ SP1,SP2,SP3,SP4
C     COMMON BLOK19 CONNECTS DATAIN, EFIELD, ESURF,MAIN, RNDPOS AND SCPLOT.
      COMMON /BLOK19/ SPO1,SPO2,SPO3
C     COMMON BLOK20 IN CHKHIT, EFIELD, MAIN, RNDPOS, SHADE AND VNORML.
      COMMON /BLOK20/ TANTH1,TANTH2,TANTH3,TANTH4
C     COMMON BLOK21 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,SPHIT,SCPL
      COMMON /BLOK21/ Z1,Z2,Z3,Z4,Z5
C     COMMON BLOK22 CONNECTS MAIN AND VNORML.
      COMMON /BLOK22/ VELNRM(3)
C     COMMON BLOK23 CONNECTS EFIELD, MAIN AND SHADE.
      COMMON /BLOK23/ XYWAKE,ZWAKE , JPOT
C     COMMON BLOK24 CONNECTS EFIELD, ESURF AND MAIN.
      COMMON /BLOK24/ALAMB(2),ANPHOT(2),AKPHOT(2),EFEL(2),EFED(2),DEB,
     1AMAT(9),EL(2),PHIEL(2),PHIED(2),ALAMAV,PHIAVE
C     COMMON BLOK25 CONNECTS CONTAM, EFIELD, MAIN AND TRAJEC.
      COMMON /BLOK25/ EVEC(3)
C     COMMON BLOK26 CONNECTS DATAIN, MAIN AND PARPOT.
      COMMON /BLOK26/ MAT,AVP
C     COMMON BLOK29 CONNECTS DATAIN,EFIELD,ESURF,MAIN AND PARPOT.
      COMMON /BLOK29/ AKTE,AKTP,ANE
C     COMMON BLOK30 CONNECTS DATAIN AND MAIN.
      COMMON /BLOK30/ADRHO(3),D1,D2,D3,D4,N1,N2,SRMAX,SRMIN
     1,EPSILN,ELECT,APVEL(3),TMISS, KPLOT
C     COMMON BLOK31    CONNECTS CONTAM, EFIELD AND MAIN.
      COMMON /BLOK31/ NRMISS
      EQUIVALENCE (FVAP(1),VAP(1)),(FPKACC(1),PKACC(1))  @ MAIN, RELEAS
      EQUIVALENCE (K1D,JSIZE),(KOD, JVEL)
      PI=3.14159
C
C     THE NEXT APPROXIMATELY FIFTY LINES OF CODE CALCULATE THE NECESSARY
C     MODEL WORKING PARAMETERS FROM THE USER SPECIFIED SPACECRAFT
C     INFORMATION ENTERED IN THE BLOCK DATA ELEMENT DATAIN.
C
      DRHO=ADRHO(MAT)
      ALPHA=ATAN(2.*1.6E4*SQRT(AKTP)/(AVP*SQRT(PI)))  @ WAKE HALF ANG.
      DRPIO6=DRHO*PI/6.
      WRITE(6,1)
    1 FORMAT(1H1,'THE FOLLOWING ARE GENERAL SPACECRAFT MODEL DATA')
      TANTH1=D1/(SP4-SPO3)
      TANTH2=-D2/(SP4-SPO2)
      TANTH3=-D4/(SP2-SPO1)
      TANTH4=TAN(PI/2.-ALPHA)
      WRITE(6,700) TANTH1,TANTH2,TANTH3,TANTH4
  700 FORMAT(1H0,'THE TANGENTS FOR CONE ANGLES ARE',4(G9.4,2X))
C
      XYWAKE=(SP4+SQRT(SP4*SP4+8.*SP1*(SP3-SP4)/PI))/2.
      ASP=16.*SP1*(SP3-SP2)
      ATP=PI*SPO1**2
      ATS=PI*(SPO1+SP2)*SQRT(D4*D4+(SP2-SPO1)*(SP2-SPO1))
      AI=ASP+ATS+ATP
      AII=PI*(SPO2+SP4)*SQRT(D2*D2+(SP4-SPO2)*(SP4-SPO2))
      ATOT=AI+AII
      PRI=AII/ATOT
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ORIGINAL PAGE IS
OF POOR QUALITY

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      ABP=PI*SPC3**2
      ABCS=PI*(SPO3+SP4)*SQRT(D1*D1+(SP4-SPO3)*(SP4-SPO3))
      WRITE(6,702)ASP,ATP,ATS,AI,AII,ATOT,PRI,ABP,ABCS
  702 FORMAT(1H0,'ASP=',G7.3,3X,'ATP=',G7.3,3X,'ATS=',G7.3,3X,'AI=',
     1G7.3,3X,'AII=',G7.3,3X,'ATOT=',G7.3,3X,'PRI=',G7.3,3X,'ABP=',G7.3
     2,3X,'ABCS=',G7.3)
      SQTARG=EPSILN*AKTE/(ANE*ELECT)
      SUMFL = 0.0
      IVESC = 0.0
      SMVESC=0.
      ACCUM1=0.
      ACCUM2=0.
      ACCUM3=0.       @ FOR NRMISS, SEE EFIELD
      DO 3  LM=1,18
    3 ANGDIS(LM)=0.     @ INITIALIZE THIS ARRAY EXPLICITLY.
   10 SR=10.**(0.5*(ALOG10(SRMIN)+ALOG10(SRMAX)))
      Z1=SQRT(SQTARG)*SR                @  DEBYE LENGTH AT RADIUS SR
      Z2=Z1+D1
      Z3=Z2+D2
      Z4=Z3+D3
      Z5=Z4+D4
      DEB=Z1
      WRITE(6,720)Z1,Z2,Z3,Z4,Z5
  720 FORMAT(1H0,'Z1=',G9.4,2X,'Z2=',G9.4,2X,'Z3=',G9.4,2X,'Z4=',G9.4,
     12X,'Z5=',G9.4)
      ZWAKE=Z4-XYWAKE*TANTH4
      WRITE(6,701) XYWAKE,ZWAKE
  701 FORMAT (1H0,'XYWAKE=',F9.4,4X,'ZWAKE=',F9.4)
C     THE AL'S ARE THE Z-AXIS INTERCEPT FOR THE APPROPRIATE CONE.
      AL(1)=Z2-SP4*TANTH1
      AL(2)=Z2-SP4*TANTH2
      AL(3)=Z4-SP2*TANTH3
      AL(4)=ZWAKE
      WRITE(6,721)AL
  721 FORMAT(1H0,'THE AL ARRAY CONTAINS',4(G9.4,2X))
      CALL ESURF
    4 READ(5,1111) N2,KPLOT
 1111 FORMAT(2I10)
    5 READ(5,1600,ERR=50,END=50) IHICUP,KO,IGML,IGMU,PVEL,PMASS,IMV,IMM,
     1SM1
      SMTEST=0.
      WRITE(6,1609) IMM,IMV
 1609 FORMAT(1H1,'THE INPUT METEOROID CASE DATA CARD FOR MASS GROUP',
     1I4,2X,'AND VELOC. GROUP',I4)
      WRITE(6,1610)IHICUP,KO,IGML,IGMU,PVEL,PMASS,IMV,IMM,SM1
 1600 FORMAT(4(I3,2X),10X,2E12.5,1X,2(I2,2X),E9.4)
 1610 FORMAT(1H0,4(I3,2X),10X,2E12.5,1X,2(I2,2X),E9.4)
      IF(KPLOT.EQ.1)  CALL SCPLOT(IGCON)  @ SPACECRAFT PLOT.
      IF(IGCON.EQ.-1) STOP
   20 FLUXM1(IMV,IMM)=.25*PVEL*SM1/3.
      FLTOT=FLUXM1(IMV,IMM)*ATOT*TMISS*8.64E4
      WRITE(6,705) IMM,IMV ,PMASS,PVEL,FLUXM1(IMV,IMM),FLTOT
  705 FORMAT(1H1,'MASS GROUP=',I3,2X,'VELOC. GROUP=',I3,//,1X,'THE METEO
     1ROID MASS IS',1PG10.4,2X,'THE METEOROID VELOC. IS',1PG10.4, /
     2/,1X,'WITH A GROUP FLUX OF',1PG10.4, 3X,'AND',1X,
     3'THE TOTAL METEOROID IMPACTS OF THIS TYPE EXPECTED ARE',1X,G9.4)
      WRITE(6,1599)
      READ(5,1601)IDUMY1,RS(I),PKACC(I),VAP(I)
      WRITE(6,1601)IDUMY1,RS(I),PKACC(I),VAP(I)
  510 CONTINUE
 1599 FORMAT(1H0,////,2X,'I',11X,'R(I)',9X,'PKACC(I)',9X,'VAP(I)')
 1601 FORMAT(I3,3X,1P3E15.5)
      IF(FLTOT.LT.0.01) GO TO 240
   27 CALL RELEAS                            @ DET.PART.RELEASE PARAM.
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MAIN DRIVER (VERSION – FULBPS)

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      DO 8001 I=1,18
 8001 VANGDS(I)= 0.0
      DO 8000 I=1,5
 8000 WNET2(I)= 0.0
C     ALGORITHM TO PACK VAP ARRAY
      VAP2(1)= ABS(VAP(1))
      IJ=2
      ISFUN(1)=1
      DO 8100  I=2,KO
      DO 8200  II=IJ,KO
      ISFUN(I)=II
      IF(ABS(VAP(II)).LE. 0.5*ABS(VAP(IJ-1))) GO TO 8300
 8200 CONTINUE
 8300 IFIX=ISFUN(I)
      VAP2(I)= 0.5*(ABS(VAP(IJ-1))+ABS(VAP(IFIX)))
      IQUIT=I
      IF(ISFUN(I).EQ. KO) GO TO 8400
      IJ=ISFUN(I)+1
 8100 CONTINUE
 8400 CONTINUE
      IQUIT=IQUIT+1
      VAP2(IQUIT)=ABS(VAP(KO))
C     EXIT WITH GROUP POINTING ARRAY IN ISFUN(I),IQUIT IS NO. OF GROUPS,
C     AND VAP2(I) IS GROUP VEL. ARRAY
      DO 955 IT=1,IHICUP
  955 DUMMY=RANDNO(1.,0.)  @ INCREMENT THE SYSTEM RANDOM NUMBER GEN.
      DO 40 J=1,N2                                  @ INNER MONTE CARLO INDEX
      WRITE(6,2)  IMM,IMV,J
    2 FORMAT(1H1,///,1X,'MASS GROUP',I3,5X,'VELOC. GROUP',I3,5X,
     1'POSITION NO.',I5  )
      DO 4000 I=1,5
 4000 WNET(I)=0.0
      DO 4001 I=1,18
 4001 WANGDS(I)=0.0
      CALL RNDPOS                                   @ DETERMINE IMPACT LOCATION
      DO 29  K=1,3
      POSHID(K)=POSVEC(K)
   29 NEWPOS(K)=POSVEC(K)
      CALL SHADE
      ISHHID=ISHADE
      IPHID=IPANEL
      ISEHID=ISECTR
      CALL VNORML                                   @ NORMAL UNIT VECTOR @POSVEC
      WRITE(6,709)      POSVEC,ISHADE,IPANEL,NPNL,ISECTR
  709 FORMAT(1H0,'THE RANDOM POSITION VECTOR IS',
     13(G9.4,2X),//,1X,'ISHADE=',I2,2X,
     2'IPANEL=',I2,2X,'NPNL=',I2,2X,'ISECTR=',I2)
      WRITE(6,710) VELNRM
  710 FORMAT(1H0,'THE NORMAL VECTOR FOR THIS CASE IS  ',3(G10.4,2X))
      IF(ISHADE.NE.0) GO TO 31
      CALL EFIELD
      PHIO=PHIEL(JPOT)
      GO TO 32
   31 PHIO=PHIED(1)
   32 CONTINUE
      PHIDE=PHIO
      DO 5000  JSIZE=IGML,IGMU  @  JSIZE.EQ.KID  GRAIN LOOP
      DIM=DDIA(KID)*1.0E-6
      COEFRP=-7.E-6*PI*.25*(DIM/SR)**2       @ RADIATION PRESSURE FORCE IN SUN
      CONSTA=2.*PI*EPSILN*DIM      @ CONVERT ΔPHI TO ΔQ
      GMASS=DRPI06*(DIM**3)
      DO 6000 JVEL=1,IQUIT @JVEL EQUIV. KOD .GRAIN VEL LOOP
C     CALCULATE RELATIVE PROBABILITY OF JSIZE,JVEL PAIR
      IF(JVEL .EQ.1) GO TO 9001
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      IF(JVEL .EQ. IQUIT)  GO TO 9003
      IFIX=ISFUN(JVEL)
      IFIX1=ISFUN(JVEL-1)
      PBVELC=PRBDIA(JSIZE)*(PRBVEL(IFIX,JSIZE)-PRBVEL(IFIX1,JSIZE))
      GO TO 9002
 9001 PBVELC=PRBDIA(JSIZE)*PRBVEL(1,JSIZE)
      GO TO 9002
 9003 PBVELC= PRBDIA(JSIZE) * (1.-PRBVEL(KC,JSIZE))
 9002 CONTINUE
      WEIGHT=PBVELC*ANNORM        @TOTAL GRAINS THIS SIZE AND VEL REMOVED
      VELMAG= VAP2(JVEL)
      DO 35  NN=1,3                               @ VELOC. VECTOR (INITIALLY)
      POSVEC(NN)=POSHID(NN)
   35 VELVEC(NN)=VELMAG*VELNRM(NN)      @ BUILD INITIAL VELOCITY VECTOR.
      PHIO=PHIDE
      PRTCHG=CONSTA*PHIO
      ISHADE=ISHHID
      IPANEL=IPHID
      ISECTR=ISEHID
      ATEST=WEIGHT*FLTOT
      SMTEST=SMTEST+ATEST
      IF(WEIGHT .LE. .001.OR.ATEST.LE.0.05) GO TO 5999
      IF(GMASS.LE.C.) GO TO 800  @ DEBUGGING
      VMAX=SQRT(-10.*COEFRP*PATHMX/GMASS)  @ 5 TIMES THE MINIMUM ESCAPE VEL.
      IF(VMAX.LT.VELMAG.AND.NPNL.NE.-1) GO TO 36
      IF(VELVEC(3).LE.0..AND.NPNL.NE.-1) GO TO 810  @ DEBUGGING
      CALL CONTAM  @ TEST CASE TRAJECTORY ANALYSIS
      IF(NRMISS.EQ.1)  WNET(3)=WNET(3)+WEIGHT
      IF(ILOST.EQ.1)  GO TO 38
      IF(IHIT(1).EQ.1) WNET(1)=WNET(1)+WEIGHT
      IF(IHIT(2).EQ.1) WNET(2)=WNET(2)+WEIGHT
      IF(IHIT(2).EQ.1)  GO TO 3000
      GO TO 6000
 3000 CONTINUE
C     THIS PRINTS THE TRAJECTORY OF THE PRECEEDING RECONTAMINATION EVENT.
      DO 3500 NN=1,3
      POSVEC(NN)=POSHID(NN)
 3500 VELVEC(NN)=VELMAG*VELNRM(NN)      @ BUILD INITIAL VELOCITY VECTOR.
      PHIO=PHIDE
      PRTCHG=CONSTA*PHIO
      ISHADE=ISHHID
      IPANEL=IPHID
      ISECTR=ISEHID
      WRITE(6,2000)J,JSIZE,JVEL
 2000 FORMAT(1H1,'POSITION',I6,4X,'GRAIN SIZE GROUP',I6,4X,
     1'GRAIN VELOC. GROUP',I6)
      WRITE(6,711)       DIM,COEFRP,CONSTA,PRTCHG,GMASS
     1,PRBDIA(JSIZE)
  711 FORMAT(1H0,///,1X,                 'DIM=',G9.4,2X,'COEFRP=',G9.4,2X,
     1'CONSTA=',G9.4,2X,'PRTCHG=',G9.4,2X,'GMASS=',G9.4,2X,'PRBDIA=',G9.
     24)
      WRITE(6,712)       VELMAG,PBVELC,WEIGHT,VELVEC
  712 FORMAT(1X,                'VELMAG=',G9.4,2X,'PBVELC=',G9.4,2X,
     1'WEIGHT=',G9.4,2X,'VELVEC=',3(G9.4,2X))
      CALL CONTM2   @ REDO THE CONTAM CALC. W/PRINTING.
      GO TO 6000
   36 CONTINUE
      DO 37 I=1,3
   37 NEWVEL(I)= VELVEC(I)
   38 WNET(4)=WNET(4)+WEIGHT
      WNET(5)=WNET(5)+SQRT(NEWVEL(1)**2+NEWVEL(2)**2+NEWVEL(3)**2)
     1*WEIGHT
      THETA=-ATAN(NEWVEL(3)/SQRT(NEWVEL(1)**2+NEWVEL(2)**2+1.E-9))+PI/2.
      IARG=THETA*17.99/PI+1.
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      WANGDS(IARG)=WANGDS(IARG)+ WEIGHT
      GO TO 6000
 5999 CONTINUE
 6000 CONTINUE  @GRAIN VEL LOOP END
 5000 CONTINUE  @GRAIN SIZE LOOP END
      IF(WNET(4).GT.0.)  WNET(5)=WNET(5)/WNET(4)
      WRITE(6,6666)
 6666 FORMAT(1X,15(/,1X))
      WRITE(6,9100)POSHID
 9100 FORMAT(1H0,'BOX SCORE FOR RANDOM POSITION',2X,1P3E9.2)
      WRITE(6,9101) (WNET(I),I=1,4)
 9101 FORMAT(1H0,'NO. SAFEHITS',2X,G9.5,/,1X,'NO. RECONTAM HITS',2X,G9.5
     1,/,1X,'NO. NEAR MISSES',2X,G9.5,/,1X,'NO. ESCAPES',2X,G9.5)
      IF(WNET(4).GT.0.)  WRITE(6,9102) WNET(5)
 9102 FORMAT(1X,'AVE. ESCAPE VEL.  ',G9.5)
      DO 9200 I=1,4
 9200 WNET2(I)=WNET2(I)+WNET(I)
      WNET2(5)=WNET2(5)+WNET(5)*WNET(4)
      DO 9201  I=1,18
 9201 VANGDS(I)= VANGDS(I)+WANGDS(I)/N2
      IF(SMTEST.LE.0.5) GO TO 9470
   40 CONTINUE  @ POSITION LOOP END
      GO TO 9475
 9470 WRITE(6,9474) IMM,IMV,SMTEST
 9474 FORMAT(1H0,'THE METEOROID CLASS OF MASS GROUP',I6,2X,'AND  VELOC.
     1GROUP',I6,/,1X,'YIELDED ONLY',G12.4,2X,'RELEASED GRAINS.'
     2,/,1X,'GO ON TO THE NEXT METEOROID CASE')
 9475 IF(WNET2(4).GT.0.) WNET2(5)=WNET2(5)/WNET2(4)
      WRITE(6,9300)  IMM,IMV,N2
      WRITE(6,6666)
 9300 FORMAT(1H1,'BOX SCORE FOR ONE METEOROID OF MASS GROUP',I3,2X,'AND
     1VELOC. GROUP',I3,/,1X,'SUMMED OVER',I6,2X,'POSITIONS')
      WRITE(6,9101) (WNET2(I),I=1,4)
      IF(WNET2(4).GT.0.) WRITE(6,9102) WNET2(5)
      ACCUM1=ACCUM1+WNET2(1)*FLTOT
      ACCUM2=ACCUM2+WNET2(2)*FLTOT
      ACCUM3=ACCUM3+WNET2(3)*FLTOT
      IVESC=IVESC+WNET2(4)*FLTOT
      SUMFL=SUMFL+FLTOT
      SMVESC=SMVESC+WNET2(5)*FLTOT*WNET2(4)
      DO 9400 J=1,18
 9400 ANGDIS(J)=ANGDIS(J) +VANGDS(J)*FLTOT
      WRITE(6,9500)
 9500 FORMAT(1H1)
      GO TO 5
  240 WRITE(6,241)
  241 FORMAT(1H0,'FLUENCE TOO SMALL,  SKIP THIS METEOROID')
      GO TO   5
   50 CONTINUE
C     *    *    *
      SAVESC=SAVESC/N2
      SAFENO=ACCUM1/N2
      HITNO =ACCUM2/N2
      ANRMIS=ACCUM3/N2
      IVESC= IVESC/N2
      SIGTOT=SQRT(HITNO)
      WRITE(6,100)
  100 FORMAT(1H1,'BOX SCORE FOR OVERALL ENSEMBLE OF METEOROID MASS AND V
     1ELOCITY GROUPS')
      WRITE(6,9469) SUMFL
 9469 FORMAT(1X,'TOTAL NO. OF METEOROIDS IN ENSEMBLE DURING MISSION',
     1G10.4)
      WRITE(6,9101) SAFENO,HITNO,ANRMIS,IVESC
      WRITE(6,6665)
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      WRITE(6,9103) SIGTOT
 9103 FORMAT(1H0,'STANDARD DEVIATION FOR NO. OF RECONTAMINATION HITS IS'
     1,2X,G9.5)
      RPROB=1.-EXP(-HITNO)
      VAVESC=SMVESC/IVESC
      WRITE(6,760)  VAVESC
  760 FORMAT(1H0,1X,'THE AVERAGE ESCAPE VELOCITY IS',2X,1PG9.4,
     12X,'M/SEC')
      DO 320 K=1,18
  320 ANGDEG(K)=10.*K
      WRITE(6,765) (ANGDEG(I),ANGDIS(I),I=1,18)
  765 FORMAT(1H0,'THE ANGULAR DISTRIBUTION FOR THE ESCAPED VELOCITY VECT
     1OR RELATIVE TO THE +Z DIRECTION',//,1X,'DEG.',4X,'NO. ESCAPES',//,
     218(1X,0PF4.0,4X,1PG10.3,/))
      WRITE(6,335) RPROB
  335 FORMAT(1H0,4(1X,/),1X,'RECONTAMINATION PROBABILITY IS',G12.5)
C     *    *    *
      STOP
  800 WRITE(6,801)
  801 FORMAT(1X,'THE MASS VALUE GMASS IS INCORRECT')
  802 STOP
  810 WRITE(6,811)
  811 FORMAT(1X,'THE VELOCITY VECTOR IS INCORRECT')
  812 STOP
      END
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FULDET DRIVER

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C     **** NASA JPL **** D. EDGARS (BIONETICS), J. BARENGOLTZ (JPL) ****
      REAL NU, NEWPOS, NEWVEL, IVESC
      DIMENSION WNET(5),WNET2(5),VAP2(36),ICFUN(36),WANGDS(19),
     1 VANGDS(19)
      DIMENSION   ANGDEG(19)
      DIMENSION  POTHIC(3)
      DIMENSION  VAP(35), PKACC(35)
      DIMENSION ANCDIS(18), FLUXM1(7,10)
C     COMMON BLOK01 CONNECTS DATAIN, MAIN AND RELEAS.
      COMMON /BLOK01/ AKM,DRHO,K1,FRBVEL(35,10),CR(10),SIG,DDIA(10)
     1,ANPART,ANNORM,PRBDIA(10)
C     COMMON BLOK02 CONNECTS CHKHIT, MAIN, RNDPOS AND SHADE.
      COMMON /BLOK02/ AL(4)
C     COMMON BLOK03 CONNECTS ESURF,  MAIN AND RNDPOS.
      COMMON /BLOK03/ ASP,ATP,ATS,PRI,ATOT,ABP,ABCS,AII
C     COMMON BLOK04 CONNECTS CONTAM, MAIN, PARPOT, SPHIT AND TRAJEC.
      COMMON /BLOK04/ COEFRP,CONSTA,PRTCH3,PHIO
C     COMMON BLOK05 CONNECTS DATAIN, MAIN, RELEAS AND YANG1
      COMMON /BLOK05/ KC,PMASS,PRHO,RS(35),FVAP(35),FPKACC(35),RHO
C     COMMON BLOK06 CONNECTS DATAIN, MAIN AND YANG1.
      COMMON /BLOK06/ E,H,NU,PC,ISKIP
C     COMMON BLOK08 CONNECTS CONTAM, DATAIN, MAIN AND PARPOT.
      COMMON /BLOK08/ DIM,PATHMX,SR,VELMAG
C     COMMON BLOK09 IN CHKHIT,CONTAM,MAIN,SHADE,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK09/ NEWPOS(3)
C     COMMON BLOK10 CONNECTS CONTAM,MAIN,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK10/ NEWVEL(3), DELTAT
C     COMMON BLOK11 IN CONTAM,EFIELD,MAIN,RNDPOS,SPHIT,TRAJEC,VNORML.
      COMMON /BLOK11/ POSVEC(3)
C     COMMON BLOK12 CONNECTS CONTAM, MAIN AND TRAJEC.
      COMMON /BLOK12/ GMASS ,VELVEC(3) ,ILOST
C     COMMON BLOK13 CONNECTS CHKHIT, CONTAM, MAIN AND SPHIT.
      COMMON /BLOK13/ IHIT(2)
C     COMMON BLOK14 CONNECTS CONTAM, EFIELD, MAIN, SHADE AND TRAJEC.
      COMMON /BLOK14/ IPANEL,ISHADE
C     COMMON BLOK15 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,VNORML.
      COMMON /BLOK15/ ISECTR
C     COMMON  BLOK16 CONNECTS         MAIN,RNDPOS,SHADE AND VNORML.
      COMMON /BLOK16/ NPNL
C     COMMON BLOK17 CONNECTS DATAIN, MAIN AND YANG1.
      COMMON /BLOK17/ PVEL,ACCMIN
C     COMMON BLOK18 IN DATAIN,EFIELD,ESURF,MAIN,RNDPOS,SCPLOT,SHADE.
      COMMON /BLOK18/ SP1,SP2,SP3,SP4
C     COMMON BLOK19 CONNECTS DATAIN, EFIELD, ESURF,MAIN, RNDPOS AND SCPLOT.
      COMMON /BLOK19/ SP01,SP02,SP03
C     COMMON BLOK20 IN CHKHIT, EFIELD, MAIN, RNDPOS, SHADE AND VNORML.
      COMMON /BLOK20/ TANTH1,TANTH2,TANTH3,TANTH4
C     COMMON BLOK21 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,SPHIT,SCPL
      COMMON /BLOK21/ Z1,Z2,Z3,Z4,Z5
C     COMMON BLOK22 CONNECTS MAIN AND VNORML.
      COMMON /BLOK22/ VELNRM(3)
C     COMMON BLOK23 CONNECTS EFIELD, MAIN AND SHADE.
      COMMON /BLOK23/ XYWAKE,ZWAKE , JPOT
C     COMMON BLOK24 CONNECTS EFIELD, ESURF AND MAIN.
      COMMON /BLOK24/ALAM3(2),ANPHOT(2),AKPHOT(2),EFEL(2),EFED(2),DEB,
     1AMAT(9),EL(2),PHIEL(2),PHIED(2),ALAMAV,PHIAVE
C     COMMON BLOK25 CONNECTS CONTAM, EFIELD, MAIN AND TRAJEC.
      COMMON /BLOK25/ EVEC(3)
C     COMMON BLOK26 CONNECTS DATAIN, MAIN AND PARPOT.
      COMMON /BLOK26/ MAT,AVP
C     COMMON BLOK29 CONNECTS DATAIN,EFIELD,ESURF,MAIN AND PARPOT.
      COMMON /BLOK29/ AKTE,AKTP,ANE
C     COMMON BLOK30 CONNECTS DATAIN AND MAIN.
      COMMON /BLOK30/ADRHO(3),D1,D2,D3,D4,N1,N2,SRMAX,SRMIN
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     1,EPSILN,ELECT,APVEL(3),TMISS, KPLOT
C     COMMON BLOK21    CONNECTS CONTAM, EFIELD AND MAIN.
      COMMON /BLOK31/ NRMISS
      EQUIVALENCE (FVAP(1),VAP(1)),(FPKACC(1),PKACC(1))  @ MAIN, RELEAS
      EQUIVALENCE (K1D,JSIZE),(KOD,JVEL)
    2 FORMAT(1H1,///,1X,'MASS GROUP',I3,5X,'VELOC. GROUP',I3,5X,
     1'HISTORY NO.',I5  )
      READ(5,1000) MML,MMU,MVL,MVU,IGML,IGMU,N2,IHICUP
      WRITE(6,1000)MML,MMU,MVL,MVU,IGML,IGMU,N2,IHICUP
 1000 FORMAT(8(I3,3X))
      DO 955 IT=1,IHICUP
  955 DUMMY=RANDNO(1.,0.)   @ INCREMENT THE SYSTEM RANDOM NUMBER GEN.
      PI=3.14159
      DRHO=ADRHO(MAT)
      ALPHA=ATAN(2.*1.6E4*SQRT(AKTP)/(AVP*SQRT(PI)))   @ WAKE HALF ANG.
      DRPI06=DRHO*PI/6.
      TANTH1=D1/(SP4-SP03)
      TANTH2=-D2/(SP4-SP02)
      TANTH3=-D4/(SP2-SP01)
      TANTH4=TAN(PI/2.-ALPHA)
  700 FORMAT(1X,'THE TANGENTS FOR CONE ANGLES ARE',4(G9.4,2X))
      WRITE(6,700) TANTH1,TANTH2,TANTH3,TANTH4
C
      XYWAKE=(SP4+SQRT(SP4*SP4+8.*SP1*(SP3-SP4)/PI))/2.
      ASP=16.*SP1*(SP3-SP2)
      ATP=PI*SP01**2
      ATS=PI*(SP01+SP2)*SQRT(D4*D4+(SP2-SP01)*(SP2-SP01))
      AI=ASP+ATS+ATP
      AII=PI*(SP02+SP4)*SQRT(D2*D2+(SP4-SP02)*(SP4-SP02))
      ATOT=AI+AII
      PRI=AII/ATOT
      ABP=PI*SP03**2
      ABCS=PI*(SP03+SP4)*SQRT(D1*D1+(SP4-SP03)*(SP4-SP03))
      WRITE(6,702) ASP,ATP,ATS,AI,AII,ATOT,PRI,ABP,ABCS
  702 FORMAT( 1X,'ASP=',G7.3,3X,'ATP =',G7.3,3X,'ATS=',G7.3,3X,'AI=',
     1G7.3,3X,'AII=',G7.3,3X,'ATOT=',G7.3,3X,'PRI=',G7.3,3X,'ABP=',G7.3
     2,3X,'ABCS=',G7.3)
      SQTARG=EPSILN*AKTE/(ANE*ELECT)
      SUMFL = 0.0
      IVESC = 0.0
      SMVESC=0.
      ACCUM1=0.
      ACCUM2=0.
      ACCUM3=0.      @ FOR NRMISS, SEE EFIELD
      DO 3  LM=1,18
    3 ANGDIS(LM)=0.     @ INITIALIZE THIS ARRAY EXPLICITLY.
   10 SR=10.**(0.5*(ALOG10(SRMIN)+ALOG10(SRMAX)))
      Z1=SQRT(SQTARG)*SR                  @  DEBYE LENGTH AT RADIUS SR
      Z2=Z1+D1
      Z3=Z2+D2
      Z4=Z3+D3
      Z5=Z4+D4
      DEB=Z1
      CALL ESURF
      WRITE(6,720)Z1,Z2,Z3,Z4,Z5
  720 FORMAT(1X,'Z1=',G9.4,2X,'Z2=',G9.4,2X,'Z3=',G9.4,2X,'Z4=',G9.4,
     12X,'Z5=',G9.4)
      ZWAKE=Z4-XYWAKE*TANTH4
      WRITE(6,701) XYWAKE,ZWAKE
  701 FORMAT  (1X,'XYWAKE=',F9.4,4X,'ZWAKE=',F9.4)
C     THE AL'S ARE THE Z-AXIS INTERCEPT FOR THE APPROPRIATE CONE.
      AL(1)=Z2-SP4*TANTH1
      AL(2)=Z2-SP4*TANTH2
      AL(3)=Z4-SP2*TANTH3
      AL(4)=ZWAKE
```

```
      WRITE(6,721)AL
  721 FORMAT(1X,'THE AL ARRAY CONTAINS',4(G9.4,2X))
      IF(KPLOT.EQ.1)  CALL SCFLOT(IGOON)  @ SPACECRAFT PLOT.
      IF(IGOON.EQ.-1) STOP
      SMOLD1=10.**(-18.142+9.93 - 1.5*ALOG10(SR))
      DO 200 IMV=MVL,MVU      @ MVU.LE.3
      PVEL=APVEL(IMV)/SQRT(SR)
      DO 250 IMM=MML,MMU      @ MMU.LE.10
      PMASSE=IMM-12
      PMOSSE=PMASSE-1.
      IF(IMM.EQ.1) PMASSE=-10.52
      IF(IMM.EQ.10) PMASSE=-2.52
C     CALCULATION OF COMETARY METEOROID FLUX PER NASA SP 8083.
      IF(PMASSE.LE.-6.0) GO TO 11
      SLOG10=-18.173-1.213*PMASSE-1.5*ALOG10(SR)
      GO TO 12
   11 SLOG10=-18.142-1.584*PMASSE-.063*PMASSE*PMASSE-1.5*ALOG10(SR)
   12 PMASS=10.**(PMASSE-3.)                          @ IN KILOGRAMS.
      SMNEW1=10.**(SLOG10)
      IF(IMM.EQ.1)  GO TO 25
      IF(IMM.EQ.10) GO TO 25
      IF(IMM.EQ.2) PMOSSE=-10.52
      IF(PMOSSE.LE.-6.)  GO TO 13
      SLAG10=-18.173-1.213*PMOSSE-1.5*ALOG10(SR)
      SMOLD1=10.**(SLAG10)
      GO TO 25
   13 SLAG10=-18.142-1.584*PMOSSE-.063*PMOSSE*PMOSSE-1.5*ALOG10(SR)
      SMOLD1=10.**(SLAG10)
   25 SM1=SMNEW1
      IF(IMM.LE.9) SM1=SMOLD1-SMNEW1   @ GROUP NO. DENSITY
   26 FLUXM1(IMV,IMM)=.25*PVEL*SM1/3.
      FLTOT=FLUXM1(IMV,IMM)*ATOT*TMISS*8.64E4
      WRITE(6,705) IMM,IMV ,PMASS,PVEL,FLUXM1(IMV,IMM),FLTOT
  705 FORMAT(1X,'MASS GROUP=',I3, 2X,'VELOC. GROUP=',I3,/,1X,'THE METEOR
     1OID MASS IS',1PG10.4,2X,'THE METEOROID VELOC. IS',1PG10.4,
     2/,1X,'WITH A GROUP FLUX OF',1PG10.4, 3X,'AND
     3THE TOTAL METEOROID IMPACTS OF THIS TYPE EXPECTED ARE',G9.4)
      IF(FLTOT.LT.0.01) GO TO 240
      CALL YANG1                          @ DESCRIBES SURFACE MV'MT
      IF(ISKIP.EQ.1) GO TO 750
   27 CALL RELEAS                         @ DET.PART.RELEASE PARAM.
      DO 8001 I=1,18
 8001 VANGDS(I)= 0.0
      DO 8000 I=1,5
 8000 WNET2(I)= 0.0
C     ALGORITHM TO PACK VAP ARRAY
      VAP2(1)= ABS(VAP(1))
      IJ=2
      ISFUN(1)=1
      DO 8100  I=2,KO
      DO 8200  II=IJ,KO
      ISFUN(I)=II
      IF(ABS(VAP(II)).LE. 0.5*ABS(VAP(IJ-1))) GO TO 8300
 8200 CONTINUE
 8300 IFIX=ISFUN(I)
      VAP2(I)= 0.5*(ABS(VAP(IJ-1))+ABS(VAP(IFIX)))
      IQUIT=I
      IF(ISFUN(I).EQ. KO) GO TO 8400
      IJ=ISFUN(I)+1
 8100 CONTINUE
 8400 CONTINUE
      IQUIT=IQUIT+1
      VAP2(IQUIT)=ABS(VAP(KO))
      WRITE(6,3501) IQUIT
```


C-2

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      DO 3500 ITEMP=1,IQUIT
      WRITE(6,3502) ISFUN(ITEMP),VAP2(ITEMP)
 3500 CONTINUE
 3501 FORMAT(1H0,'IQUIT=',I2,//,3X,'ISFUN',10X,'VAP2',//)
 3502 FORMAT(6X,I2,10X, 1PG9.4)
C     EXIT WITH GROUP POINTING ARRAY IN ISFUN(I),IQUIT IS NO. OF GROUPS,
C     AND VAP2(I) IS GROUP VEL. ARRAY
      DO 40 J=1,N2                              @ INNER MONTE CARLO INDEX
      DO 4000 I=1,5
 4000 WNET(I)=0.0
      DO 4001 I=1,18
 4001 WANGDS(I)=0.0
      WRITE(6,2)  IMM,IMV,J
      CALL RNDPOS                               @ DETERMINE IMPACT LOCATION
      DO 29  K=1,3
      POSHID(K)=POSVEC(K)
   29 NEWPOS(K)=POSVEC(K)
      CALL SHADE
      ISHHID=ISHADE
      IPHID=IPANEL
      ISEHID=ISECTR
      WRITE(6,709)      POSVEC,ISHADE,IPANEL,NPNL,ISECTR
  709 FORMAT(1X,'THE RANDOM POSITION VECTOR IS',
     1                          3(G9.4,2X),/,'ISHADE=',I2,2X,
     2'IPANEL=',I2,2X,'NPNL=',I2,2X,'ISECTR=',I2)
      CALL VNORML                               @ NORMAL UNIT VECTOR @POSVEC
      WRITE(6,710) VELNRM
  710 FORMAT(1X,'THE NORMAL VECTOR FOR THIS CASE IS  ',3(G9.4,2X))
      IF(ISHADE.NE.0) GO TO 31
      CALL EFIELD
      PHIC=PHIEL(JPOT)
      GO TO 32
   31 PHIC=PHIED(1)
   32 CONTINUE
      PHIDE=PHIC
      DO 5000  JSIZE=IGML,IGMU  @  JSIZE.EQ.K1D  GRAIN LOOP
      DIM=DDIA(K1D)*1.0E-6
      COEFRP=-7.E-6*PI*.25*(DIM/SR)**2        @ RADIATION PRESSURE FORCE IN SUN
      CONSTA=2.*PI*EPSILN*DIM        @ CONVERT ¬PHI TO ¬Q
      GMASS=DRPI06*(DIM**3)
      DO 6000 JVEL=1,IQUIT @JVEL EGUIV. KCC .GRAIN VEL LOOP
C     CALCULATE RELATIVE PROBABILITY OF JSIZE,JVEL PAIR
      IF(JVEL .EQ.1) GO TO 9001
      IF(JVEL .EQ. IQUIT)  GO TO 9003
      IFIX=ISFUN(JVEL)
      IFIX1=ISFUN(JVEL-1)
      PBVELC=PRBDIA(JSIZE)*(PRBVEL(IFIX,JSIZE)-PRBVEL(IFIX1,JSIZE))
      GO TO 9002
 9001 PBVELC=PRBDIA(JSIZE)*PRBVEL(1,JSIZE)
      GO TO 9002
 9003 PBVELC= PRBDIA(JSIZE) * (1.-PRBVEL(KC,JSIZE))
 9002 CONTINUE
      WEIGHT=PBVELC*ANNORM @TOTAL GRAINS THIS SIZE AND VEL REMOVED BY MT
      VELMAG= VAP2(JVEL)
      DO 35  NN=1,3                             @ VELOC. VECTOR (INITIALLY)
      POSVEC(NN)=POSHID(NN)
   35 VELVEC(NN)=VELMAG*VELNRM(NN)      @ BUILD INITIAL VELOCITY VECTOR.
      PHIO=PHIDE
      PRTCHG=CONSTA*PHIO
      ISHADE=ISHHID
      IPANEL=IPHID
      ISECTR=ISEHID
      WRITE(6,711)JSIZE,DIM,COEFRP,CONSTA,PRTCHG,GMASS
     1,PRBDIA(JSIZE)
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FULDET DRIVER

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711 FORMAT(1H0,///,1X,'JSIZE=',I3,2X,'DIM=',G9.4,2X,'COEFRP=',G9.4,2X,
   1'CONSTA=',G9.4,2X,'PRTCHG=',G9.4,2X,'GMASS=',G9.4,2X,'PRBDIA=',G9.
   24)
    WRITE(6,712) JVEL,VELMAG,PBVELC,WEIGHT,VELVEC
712 FORMAT(1X,'JVEL=',I3,2X,'VELMAG=',G9.4,2X,'PBVELC=',G9.4,2X,
   1'WEIGHT=',G9.4,2X,'VELVEC=',3(G9.4,2X))
    IF(WEIGHT .LE. .001) GO TO 5999
    IF(GMASS.LE.0.) GO TO 900  @ DEBUGGING
    VMAX=SQRT(-10.*COEFRP*PATHMX/GMASS)  @ 5 TIMES THE MINIMUM ESCAPE VEL.
    IF(VMAX.LT.VELMAG.AND.NPNL.NE.-1) GO TO 36
    IF(VELVEC(3).LE.0..AND.NPNL.NE.-1) GO TO 910  @ DEBUGGING
    CALL CONTAM  @ TEST CASE TRAJECTORY ANALYSIS
    IF(ILOST.EQ.1)  GO TO 38
    IF(IHIT(1).EQ.1) WNET(1)=WNET(1)+WEIGHT
    IF(IHIT(2).EQ.1) WNET(2)=WNET(2)+WEIGHT
    IF(NRMISS.EQ.1)  WNET(3)=WNET(3)+WEIGHT
    GO TO 6000
 36 CONTINUE
    WRITE(6,736) VMAX
736 FORMAT(1H0,'GRAIN VELOCITY',1X,                 'EXCEEDED ESCAPE
   1CRITERIA,  VEL=',2X,1PG9.4)
    DO 37 I=1,3
 37 NEWVEL(I)= VELVEC(I)
 38 WNET(4)=WNET(4)+WEIGHT
    WNET(5)=WNET(5)+SQRT(NEWVEL(1)**2+NEWVEL(2)**2+NEWVEL(3)**2)
   1*WEIGHT
    THETA=-ATAN(NEWVEL(3)/SQRT(NEWVEL(1)**2+NEWVEL(2)**2))+PI/2.
    IARG=THETA*17.99/PI+1.
    WANGDS(IARG)=WANGDS(IARG)+ WEIGHT
    GO TO 6000
5999 WRITE(6,5998) WEIGHT
5998 FORMAT(1X,'WEIGHT TOO SMALL(',G9.5,'),LOOP SKIPPED')
6000 CONTINUE  @GRAIN VEL LOOP END
5000 CONTINUE  @GRAIN SIZE LOOP END
    IF(WNET(4).GT.0.)  WNET(5)=WNET(5)/WNET(4)
    WRITE(6,9100)POSHID,IMM,IMV
9100 FORMAT(1H1,'BOX SCORE FOR RANDOM POSITION',2X,1P3E9.2,2X,'AND METE
   1OROID MASS GROUP',I3,2X,'METEOROID VELOC. GROUP',I3)
    WRITE(6,9101) (WNET(I),I=1,4)
9101 FORMAT(1H0,'NO. SAFEHITS',2X,G9.5,/,1X,'NO. RECONTAM HITS',2X,G9.5
   1,/,1X,'NO. NEAR MISSES',2X,G9.5,/,1X,'NO. ESCAPES',2X,G9.5)
    IF(WNET(4).GT.0.)  WRITE(6,9102) WNET(5)
9102 FORMAT(1X,'AVE. ESCAPE VEL.  ',G9.5)
    DO 9200 I=1,5
9200 WNET2(I)=WNET2(I)+WNET(I)
    DO 9201  I=1,18
9201 VANGDS(I)= VANGDS(I)+WANGDS(I)/N2
 40 CONTINUE  @ POSITION LOOP END
    WNET2(5)=WNET2(5)/N2
    WRITE(6,9300)  IMM,IMV,N2
9300 FORMAT(1H1,'BOX SCORE FOR METEOROID MASS GROUP',I3,2X,'AND VELOC.
   1GROUP',I3,/,1X,'SUMMED OVER',I6,2X,'POSITIONS')
    WRITE(6,9101) (WNET2(I),I=1,4)
    WRITE(6,9102) WNET2(5)
    ACCUM1=ACCUM1+WNET2(1)*FLTOT
    ACCUM2=ACCUM2+WNET2(2)*FLTOT
    ACCUM3=ACCUM3+WNET2(3)*FLTOT
    IVESC=IVESC+WNET2(4)*FLTOT
    SUMFL=SUMFL+FLTOT
    SMVESC=SMVESC+WNET2(5)*FLTOT
    DO 9400 J=1,18
9400 ANGDIS(J)=ANGDIS(J) +VANGDS(J)*FLTOT
    GO TO 250
750 WRITE(6,751)
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FULDET DRIVER

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  751 FORMAT(1H0,'ZERO IN ACCELERATION ARRAY, THEREFORE SKIP TO THE NEXT
     2 OUTER LOOP')
      GO TO 250
  240 WRITE(6,241)
  241 FORMAT(1H0,'FLUENCE TOO SMALL, SKIP THIS LOOP')
  250 CONTINUE @METEOROID MASS LOOP END
  200 CONTINUE @METEOROID VEL  LOOP END
   50 CONTINUE
C     *    *    *
      SAFENO=ACCUM1/N2
      HITNO =ACCUM2/N2
      ANRMIS=ACCUM3/N2
      IVESC= IVESC/N2
      WRITE(6,100)
  100 FORMAT(1H1,'BOX SCORE FOR OVERALL ENSEMBLE OF METEOROID MASS AND V
     1ELOCITY GROUPS')
      WRITE(6,9101) SAFENO,HITNO,ANRMIS,IVESC
      VAVESC = SMVESC/ SUMFL
      WRITE(6,700)  VAVESC
  760 FORMAT(1H0,1X,'THE AVERAGE ESCAPE VELOCITY IS',2X,1PG9.4)
      DO 320 K=1,18
  320 ANGDEG(K)=10.*K
      WRITE(6,765)  (ANGDEG(I),ANGDIS(I),I=1,18)
  765 FORMAT(1H0,'THE ANGULAR DISTRIBUTION FOR THE ESCAPED VELOCITY VECT
     1OR RELATIVE TO THE +Z DIRECTION',//,1X,'DEG.',4X,'NO. ESCAPES',//,
     218(1X,F4.0,4X,1PG10.3,/))
      ANGTOT=0.
      DO 333 J=1,18
  333 ANGTOT=ANGDIS(J)+ANGTOT
      WRITE(6,335)  ANGTOT,IVESC   @ DIAGNOSTIC  PULL LATER
  335 FORMAT(1H0,'ANGTOT=',G10.2,4X,'IVESC=',G10.2)
C     *    *    *
      STOP
  800 WRITE(6,801)
  801 FORMAT(1X,'THE MASS VALUE GMASS IS INCORRECT')
  802 STOP
  810 WRITE(6,811)
  811 FORMAT(1X,'THE VELOCITY VECTOR IS INCORRECT')
  812 STOP
      END
```

SUBROUTINE PARPOT

```
      SUBROUTINE PARPOT
C
C     CALCULATION OF THE TIME DEPENDENT CHANGE IN POTENTIAL (PHICNG)
C     AT A GIVEN POTENTIAL  (PHIO)
C
C     COMMON BLOK04 CONNECTS CONTAM, MAIN, PARPOT, SPHIT AND TRAJEC.
      COMMON /BLOK04/ COEFRP,CONSTA,PRTCHG,PHIO
C     COMMON BLOK08 CONNECTS CONTAM, DATAIN, MAIN AND PARPOT.
      COMMON /BLOK08/ DIM,PATHMX,SR,VELMAG
C     COMMON BLOK14 CONNECTS CONTAM, EFIELD, MAIN, SHADE AND TRAJEC.
      COMMON /BLOK14/ IPANEL,ISHADE
C     COMMON BLOK26 CONNECTS DATAIN, MAIN AND PARPOT.
      COMMON /BLOK26/ MAT,AVP
C     COMMON BLOK27 CONNECTS PARPOT AND TRAJEC
      COMMON /BLOK27/ PHICNG
C     COMMON BLOK28 CONNECTS DATAIN AND PARPOT.
      COMMON /BLOK28/ A(3),B(3),MATPOS(3),SOLSPC(185,2),YIELD(15,3),YIEL
     1DP(16,2)
C     COMMON BLOK29 CONNECTS DATAIN,EFIELD,ESURF,MAIN AND PARPOT.
      COMMON /BLOK29/ AKTE,AKTP,ANE
      EQUIVALENCE(DIAM,DIM),(RDIST,SR)
    4 FORMAT(1H0,'ERROR IN PARPOT, PHIO EXCEEDS RANGE AND EQUALS',3X,E10
     1.4)
    5 FORMAT(1H0,'ERROR IN PARPOT, YIELDP ARRAY.  CHECK YIELD DATA')
C

C     THE MODIFICATION NECESSARY TO INCLUDE THE SECONDARY ELECTRON CONTRIBUTION
C     TO THE PARTICLE TRANSPORT ANALYSIS.  REF.'74 SEMI-ANNUAL REPORT (JBB)
C
C
      PHIMIN=-3.*AKTE
      IF(ISHADE.GE.0.OR.PHIO.GT.PHIMIN)  GO TO 15
      PHICNG=0.
      RETURN
   15 ONEALP=1.0
      IF(PHIO.GT.0.0)  GO TO 20
      ALPHA=(A(MAT)-B(MAT)*PHIO)/(AKTE-PHIO)
      ONEALP=1.-ALPHA
   20 CONTINUE
      C1=(ANE/4.)*SQRT(AKTE)*6.7E5
      C2=(ANE/4.)*AVP
      C3=(ANE/16.)*SQRT(AKTP)*1.6E4
      IF(ISHADE)  1500,10,1100
10    CONTINUE
      IFRONT = 0
      TOTYLD = 0.0
      MATP = MATPOS(MAT)
      PHIUSE = 0.0
      IF   (PHIO .GT. 0.0)   PHIUSE = PHIO
C
C   PHIBAS IS THE WORK FUNCTION
C
      PHIBAS = YIELDP(MATP,1)
      ENGBAS = PHIBAS + PHIUSE
C
C  PHIBAS IS THE PHOTON ENERGY AT THE BOTTOM OF THE FIRST NON-ZERO

C        YIELD RANGE, I.E. WORK FUNCTION (APPROX.)
C   ENGBAS IS THE MINIMUM PHOTON ENERGY THAT MAY CAUSE
C       PHOTOEMISSION (APPROX.)
C
      IF  (ENGBAS .LT. .001241)  GO TO 300
      IF  (ENGBAS .LT. 23.6)   GO TO 150
      GO TO 2000
```

```
C
C  THE ENERGY IN SOLSPC CLOSEST TO ENGBAS IS FOUND AND THE RELATED
C     INTEGRAL OF IRRADIANCE STORED IN SPEC1.  IF A HIGHER RANGE OF
C     YIELDP WAS NEEDED, THE YIELD FROM THE PREVIOUS PARTIAL RANGE IS
C     STORED IN TOTYLD.
C
150   DO 200   J=1, 185, 1
         IF  (SOLSPC(J,1) .LT. ENGBAS)   GO TO 200
         JS = J
         IF  ((SOLSPC(J,1) - ENGBAS) .GT. (ENGBAS - SOLSPC(J-1,1)) )
     2         JS = J-1
         SPEC1 = SOLSPC(JS,2)
         JT = JS + 1
         MATP = MATP + 1
         IF  (IFRONT .EQ. 0)   GO TO 500
         TOTYLD = TOTYLD + ((SOLSPC(1,2) - SPEC1) * YIELD(MATP-2,
     2          MAT)) / (YIELDP(MATP-2,2) * 1.6E-16)
         GO TO 500
200      CONTINUE

C  NEW VALUES OF ENGBAS ARE CALCULATED BY STEPPING UP THE YIELDP RANGES
C     UNTIL A LARGE ENOUGH ENERGY IS FOUND TO FIT IN THE SOLAR SPECTRUM
C     RANGE.
C
300   II = MATP + 1
      DO 400   I= II, 15, 1
         ENGBAS = YIELDP(I,1)+ PHIUSE
         IF  (ENGBAS .LT. .001241)   GO TO 400
         MATP = I
         IFRONT = 1
         GO TO 150
400      CONTINUE
      GO TO 2100
C
C  THE YIELDS FOR EACH ENERGY RANGE OF YIELD ARE ADDED USING THE
C     IRRADIANCE VALUES OF THE SOLAR SPECTRUM UNTIL THOSE ENERGIES
C     EXCEED THE SOLAR SPECTRUM RANGE.
C
500   DO 800   I= MATP, 16, 1
         ENGBAS = PHIUSE+YIELDP(I,1)
         DO 600   J= JT, 185, 1
            IF  (SOLSPC(J,1) .LT. ENGBAS)   GO TO 600
            JS = J
            IF  ((SOLSPC(J,1) - ENGBAS)  .GT.  (ENGBAS -
     2             SOLSPC(J-1,1)))   JS = J-1
            SPEC2 = SOLSPC(JS,2)
            JT = JS + 1
            GO TO 700
600         CONTINUE
        GO TO 850
700      TOTYLD = TOTYLD + (SPEC1 - SPEC2) * YIELD(I-1, MAT) /
     2         (1.6E-16 * YIELDP(I-1, 2))
         SPEC1 = SPEC2
800      CONTINUE
      ENGTOP = 24.8 - PHIUSE
C
C  HERE A FINAL YIELD IS ADDED FOR THE HIGHEST ENERGIES OF THE SOLAR
C     SPECTRUM.
C
      TOTYLD = TOTYLD + ((SPEC1 - SOLSPC(185,2)) * 2.0 * YIELD(15, MAT))
     2      / ((27.5 + ENGTOP) * 1.6E-16)
      GO TO 900
850   TOTYLD = TOTYLD + ((SPEC1 - SOLSPC(185,2)) * YIELD(I-1,MAT)) /
     2      (YIELDP(I-1,2) * 1.6E-16)
```

SUBROUTINE PARPOT

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900   TOTYLD = TOTYLD * 10000.0 / 2.0
C
C  THE VALUE OF PHICNG IS CACULATED USING THE VALUE FOR THE TOTAL PHOTO-
C     ELECTRIC YIELD OBTAINED -- TOTYLD.
C
      IF   (PHIO .GT. 0.0)   GO TO 925
C     PHIO.LE.0.
      PHICNG=2.88E-9*3.14159*DIAM*( -C1*EXP(PHIO/AKTE)*ONEALP+C2 +
     1TOTYLD)/(RDIST*RDIST)
      RETURN
C     PHIO.GT.0.
925   PHICNG = 2.88E-9 * 3.14159 * DIAM * (-C1     * SQRT(1.0 + (2.0 *
     2     PHIO/AKTE))*ONEALP+C2 +TOTYLD)/(RDIST*RDIST)
      RETURN
C
C  PHICNG IS CALCULATED WITHOUT ANY PHOTOELECTRIC OR PROTON EFFECT
C    BECAUSE THE PARTICLE IS IN THE SHADE AND IN THE WAKE.
C
1500  IF   (PHIO .GT. 0.0)   GO TO 1600
C     PHIO.LE.0.
      PHICNG=2.88E-9*3.14159*DIAM*(-C1)*EXP(PHIO/AKTE)*ONEALP/
     2(RDIST*RDIST)
           RETURN
C     PHIO.GT.0.
 1600 PHICNG=2.88E-9*3.14159*DIAM*(-C1)*SQRT(1.+(2.*PHIO/AKTE))
     2*ONEALP/(RDIST*RDIST)
      RETURN
C
C     PHICNG CALCULATED FOR SHADE BUT OUTSIDE THE WAKE.
C     REF. '74 SEMI-ANNUAL REPORT (JBB)
C
 1100 IF(PHIO.GT.0.) GO TO 1200
      PHICNG=2.88E-9*3.14159*DIAM*(-C1 *EXP(PHIO/AKTE)*ONEALP+C3*SQRT(
     11.-(2.*PHIO/AKTP)))/(RDIST*RDIST)    @ PHIO.LE.0.
      IF(PHICNG.LT.0.0.AND.PHIO.LE.PHIMIN)  PHICNG=0.
      RETURN
 1200 PHICNG=2.88E-9*3.14159*DIAM*(-C1 *SQRT(1.+(2.*PHIO/AKTE))*ONEALP+
     1C3*EXP(-PHIO/AKTP))/(RDIST*RDIST)     @ PHIO.GT.0.
      RETURN
 2000 WRITE(6,4) PHIO
      GO TO 900
 2100 WRITE(6,5)
      STOP
      END
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PYRO EVENT DRIVER

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C     **** NASA  JPL **** D. EDGARS (BIONETICS), J. BARENGOLTZ (JPL) ****
C     VERSION OF MAIN FOR PYRO CALCULATION IN RECONTAMINATION
      REAL NU, NEWPOS, NEWVEL, IVESC
      DIMENSION WNET(5),WNET2(5),VAP2(36),ISFUN(36),WANGDS(18),
     1 VANGDS(18)
      DIMENSION   ANGDEG(18), ANAME(3)
      DIMENSION  POSHID(3)
      DIMENSION  VAP(35), PKACC(35)
      DIMENSION ANGDIS(18)
C     COMMON BLOK01 CONNECTS DATAIN, MAIN AND RELEAS.
      COMMON /BLOK01/ AKM,DRHC,K1,FRBVEL(35,10),CR(10),SIG,DDIA(10)
     1,ANPART,ANNORM,PRBDIA(10)
C     COMMON BLOK02 CONNECTS CHKHIT, MAIN, RNDPOS AND SHADE.
      COMMON /BLOK02/ AL(4)
C     COMMON BLOK03 CONNECTS ESURF,  MAIN AND RNDPOS.
      COMMON /BLOK03/ ASP,ATP,ATS,PRI,ATOT,ABP,ABCS,AII
C     COMMON BLOK04 CONNECTS CONTAM, MAIN, PARPOT, SPHIT AND TRAJEC.
      COMMON /BLOK04/ COEFRP,CONSTA,PRTCH3,PHIO
C     COMMON BLOK05 CONNECTS DATAIN, MAIN, RELEAS AND YANG1
      COMMON /BLOK05/ KO,PMASS,PRHO,RS(35),FVAP(35),FPKACC(35),RHO
C     COMMON BLOK06 CONNECTS DATAIN, MAIN AND YANG1.
      COMMON /BLOK06/ E,H,NU,PO,ISKIP
C     COMMON BLOK08 CONNECTS CONTAM, DATAIN, MAIN AND PARPOT.
      COMMON /BLOK08/ DIM,PATHMX,SR,VELMAG
C     COMMON BLOK09 IN CHKHIT,CONTAM,MAIN,SHADE,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK09/ NEWPOS(3)
C     COMMON BLOK10 CONNECTS CONTAM,MAIN,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK10/ NEWVEL(3), DELTAT
C     COMMON BLOK11 IN CONTAM,EFIELD,MAIN,RNDPOS,SPHIT,TRAJEC,VNORML.
      COMMON /BLOK11/ POSVEC(3)
C     COMMON BLOK12 CONNECTS CONTAM, MAIN AND TRAJEC.
      COMMON /BLOK12/ GMASS ,VELVEC(3) ,ILOST
C     COMMON BLOK13 CONNECTS CHKHIT, CONTAM, MAIN AND SPHIT.
      COMMON /BLOK13/ IHIT(2)
C     COMMON BLOK14 CONNECTS CONTAM, EFIELD, MAIN, SHADE AND TRAJEC.
      COMMON /BLOK14/ IPANEL,ISHADE
C     COMMON BLOK15 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,VNORML.
      COMMON /BLOK15/ ISECTR
C     COMMON  BLOK16 CONNECTS         MAIN,RNDPOS,SHADE AND VNORML.
      COMMON /BLOK16/ NPNL
C     COMMON BLOK17 CONNECTS DATAIN, MAIN AND YANG1.
      COMMON /BLOK17/ PVEL,ACCMIN
C     COMMON BLOK18 IN DATAIN,EFIELD,ESURF,MAIN,RNDPOS,SCPLOT,SHADE.
      COMMON /BLOK18/ SP1,SP2,SP3,SP4
C     COMMON BLOK19 CONNECTS DATAIN, EFIELD, ESURF,MAIN, RNDPOS AND SCPLOT.
      COMMON /BLOK19/ SPO1,SPO2,SPO3
C     COMMON BLOK20 IN CHKHIT, EFIELD, MAIN, RNDPOS, SHADE AND VNORML.
      COMMON /BLOK20/ TANTH1,TANTH2,TANTH3,TANTH4
C     COMMON BLOK21 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,SPHIT,SCPL
      COMMON /BLOK21/ Z1,Z2,Z3,Z4,Z5
C     COMMON BLOK22 CONNECTS MAIN AND VNORML.
      COMMON /BLOK22/ VELNRM(3)
C     COMMON BLOK23 CONNECTS EFIELD, MAIN AND SHADE.
      COMMON /BLOK23/ XYWAKE,ZWAKE , JPOT
C     COMMON BLOK24 CONNECTS EFIELD, ESURF AND MAIN.
      COMMON /BLOK24/ALAMB(2),ANPHOT(2),AKPHOT(2),EFEL(2),EFED(2),DEB,
     1AMAT(9),EL(2),PHIEL(2),PHIED(2),ALAMAV,PHIAVE
C     COMMON BLOK25 CONNECTS CONTAM, EFIELD, MAIN AND TRAJEC.
      COMMON /BLOK25/ EVEC(3)
C     COMMON BLOK26 CONNECTS DATAIN, MAIN AND PARPOT.
      COMMON /BLOK26/ MAT,AVP
C     COMMON BLOK29 CONNECTS DATAIN,EFIELD,ESURF,MAIN AND PARPOT.
      COMMON /BLOK29/ AKTE,AKTP,ANE
C     COMMON BLOK30 CONNECTS DATAIN AND MAIN.
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      COMMON /BLOK30/ADRHO(3),D1,D2,D3,D4,N1,N2,SRMAX,SRMIN
     1,EPSILN,ELECT,APVEL(3),TMISS, KPLOT
C     COMMON BLOK31    CONNECTS CONTAM, EFIELD AND MAIN.
      COMMON /BLOK31/ NRMISS
C     COMMON BLOK32 CONNECTS PYROM AND RNDPOS.
      COMMON/BLOK32/ PRMIN,PRMAX
      EQUIVALENCE (FVAP(1),VAP(1)),(FPKACC(1),PKACC(1))  @ MAIN, RELEAS
      EQUIVALENCE (K10,JSIZE),(KOD,JVEL)
      PI=3.14159
      DRHO=ADRHO(MAT)
      ALPHA=ATAN(2.*1.6E4*SQRT(AKTF)/(AVP*SQRT(PI)))  @ WAKE HALF ANG.
      DRPI06=DRHO*PI/6.
      WRITE(6,1)
    1 FORMAT(1H1,'THE FOLLOWING ARE GENERAL SPACECRAFT MODEL DATA')
      TANTH1=D1/(SP4-SPD3)
      TANTH2=-D2/(SP4-SPD2)
      TANTH3=-D4/(SP2-SPD1)
      TANTH4=TAN(PI/2.-ALPHA)
      WRITE(6,700) TANTH1,TANTH2,TANTH3,TANTH4
  700 FORMAT(1H0,'THE TANGENTS FOR CONE ANGLES ARE',4(G9.4,2X))
C
      XYWAKE=(SP4+SQRT(SP4*SP4+8.*SP1*(SP3-SP4)/PI))/2.
      ASP=16.*SP1*(SP3-SP2)
      ATP=PI*SPD1**2
      ATS=PI*(SPD1+SP2)*SQRT(D4*D4+(SP2-SPD1)*(SP2-SPD1))
      AI=ASP+ATS+ATP
      AII=PI*(SPD2+SP4)*SQRT(D2*D2+(SP4-SPD2)*(SP4-SPD2))
      ATOT=AI+AII
      PRI=AII/ATOT
      ABP=PI*SPD3**2
      ABCS=PI*(SPD3+SP4)*SQRT(D1*D1+(SP4-SPD3)*(SP4-SPD3))
      WRITE(6,702)ASP,ATP,ATS,AI,AII,ATOT,PRI,ABP,ABCS
  702 FORMAT(1H0,'ASP=',G7.3,3X,'ATP=',G7.3,3X,'ATS=',G7.3,3X,'AI=',
     1G7.3,3X,'AII=',G7.3,3X,'ATOT=',G7.3,3X,'PRI=',G7.3,3X,'ABP=',G7.3
     2,3X,'ABCS=',G7.3)
      SQTARG=EPSILN*AKTE/(ANE*ELECT)
      SUMFL = 0.0
      IVESC = 0.0
      SMVESC=0.
      ACCUM1=0.
      ACCUM2=0.
      ACCUM3=0.       @ FOR NRMISS, SEE EFIELD
      DO 3  LM=1,18
    3 ANGDIS(LM)=0.     @ INITIALIZE THIS ARRAY EXPLICITLY.
   10 SR=10.**(0.5*(ALOG10(SRMIN)+ALOG10(SRMAX)))
      Z1=SQRT(SQTARG)*SR                @  DEBYE LENGTH AT RADIUS SR
      Z2=Z1+D1
      Z3=Z2+D2
      Z4=Z3+D3
      Z5=Z4+D4
      DEB=Z1
      WRITE(6,720)Z1,Z2,Z3,Z4,Z5
  720 FORMAT(1H0,'Z1=',G9.4,2X,'Z2=',G9.4,2X,'Z3=',G9.4,2X,'Z4=',G9.4,
     12X,'Z5=',G9.4)
      ZWAKE=Z4-XYWAKE*TANTH4
      WRITE(6,701) XYWAKE,ZWAKE
  701 FORMAT (1H0,'XYWAKE=',F9.4,4X,'ZWAKE=',F9.4)
C     THE AL'S ARE THE Z-AXIS INTERCEPT FOR THE APPROPRIATE CONE.
      AL(1)=Z2-SP4*TANTH1
      AL(2)=Z2-SP4*TANTH2
      AL(3)=Z4-SP2*TANTH3
      AL(4)=ZWAKE
      WRITE(6,721)AL
  721 FORMAT(1H0,'THE AL ARRAY CONTAINS',4(G9.4,2X))
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      CALL ESURF
    4 READ(5,1111) N2,KPLOT
 1111 FORMAT(2I10)
    5 READ(5,1600,ERR=50,END=50) IHICUP,KO,IGML,IGMU,IPYRO,NPYRO,
     1PRMIN,PRMAX,ANAME
      SMTEST=0.
      WRITE(6,1609) IPYRO
 1609 FORMAT(1H1,'THE INPUT PYRO CASE DATA CARD FOR PYRO NUMBER',I4)
      WRITE(6,1610)IHICUP,KO,IGML,IGMU,IPYRO,NPYRO,PRMIN,PRMAX,ANAME
 1600 FORMAT(6(I3,2X),2E12.5,3A6)
 1610 FORMAT(1H0,6(I3,2X),2E12.5,3A6)
      IF(KPLOT.EQ.1)  CALL SCPLOT(IGOON)   @ SPACECRAFT PLOT.
      IF(IGOON.EQ.-1) STOP
      FLTOT=NPYRO
      WRITE(6,705) IPYRO,ANAME,NPYRO
  705 FORMAT(1H1,'PYRO NO.',1X,I3,2X,'LOCATED IN FIRST X-Y QUADRANT AT',
     1//,27X,3A6,//,5X,'TOTAL NO. AT EQUIVALENT POSITIONS ON S/C IS',I4)
      WRITE(6,1599)
  500 DO 510 I=1,KO
      READ(5,1601)IDUMY1,RS(I),PKACC(I),VAP(I)
      WRITE(6,1601)IDUMY1,RS(I),PKACC(I),VAP(I)
  510 CONTINUE
 1599 FORMAT(1H0,////,2X,'I',11X,'R(I)',9X,'PKACC(I)',9X,'VAP(I)')
 1601 FORMAT(I3,3X,1P3E15.5)
   27 CALL RELEAS                            @ DET.PART.RELEASE PARAM.
      DO 8001 I=1,18
 8001 VANGDS(I)= 0.0
      DO 8000 I=1,5
 8000 WNET2(I)= 0.0
C     ALGORITHM TO PACK VAP ARRAY
      VAP2(1)= ABS(VAP(1))
      IJ=2
      ISFUN(1)=1
      DO 8100  I=2,KO
      DO 8200  II=IJ,KO
      ISFUN(I)=II
      IF(ABS(VAP(II)).LE. 0.5*ABS(VAP(IJ-1))) GO TO 8300
 8200 CONTINUE
 8300 IFIX=ISFUN(I)
      VAP2(I)= 0.5*(ABS(VAP(IJ-1))+ABS(VAP(IFIX)))
      IQUIT=I
      IF(ISFUN(I).EQ. KO) GO TO 8400
      IJ=ISFUN(I)+1
 8100 CONTINUE
 8400 CONTINUE
      IQUIT=IQUIT+1
      VAP2(IQUIT)=ABS(VAP(KO))
C     EXIT WITH GROUP POINTING ARRAY IN ISFUN(I),IQUIT IS NO. OF GROUPS,
C     AND VAP2(I) IS GROUP VEL. ARRAY
      DO 955 IT=1,IHICUP
  955 DUMMY=RANDNO(1.,0.)   @ INCREMENT THE SYSTEM RANDOM NUMBER GEN.
      DO 40 J=1,N2                           @ INNER MONTE CARLO INDEX
      WRITE(6,2) IPYRO,J
    2 FORMAT(1H1,///,1X,'PYRO NO.',I3,5X,'POSITION NO.',I5)
      DO 4000 I=1,5
 4000 WNET(I)=0.0
      DO 4001 I=1,18
 4001 WANGDS(I)=0.0
      CALL RNDPOS                            @ DETERMINE IMPACT LOCATION
      DO 29  K=1,3
      POSHID(K)=POSVEC(K)
   29 NEWPOS(K)=POSVEC(K)
      CALL SHADE
      ISHHID=ISHADE
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      IPHID=IPANEL
      ISEHID=ISECTR
      CALL VNORML                                          @ NORMAL UNIT VECTOR @POSVEC
      WRITE(6,709)      POSVEC,ISHADE,IPANEL,NPNL,ISECTR
  709 FORMAT(1H0,'THE RANDOM POSITION VECTOR IS',
     13(G9.4,2X),//,1X,'ISHADE=',I2,2X,
     2'IPANEL=',I2,2X,'NPNL=',I2,2X,'ISECTR=',I2)
      WRITE(6,710) VELNRM
  710 FORMAT(1H0,'THE NORMAL VECTOR FOR THIS CASE IS  ',3(G10.4,2X))
      IF(ISHADE.NE.0) GO TO 31
      CALL EFIELD
      PHIO=PHIEL(JPOT)
      GO TO 32
   31 PHIO=PHIED(1)
   32 CONTINUE
      PHIDE=PHIO
      DO 5000  JSIZE=IGML,IGMU  @  JSIZE.EQ.K1D  GRAIN LOOP
      DIM=DDIA(K1D)*1.0E-6
      COEFRP=-7.E-6*PI*.25*(DIM/SR)**2          @ RADIATION PRESSURE FORCE IN SUN
      CONSTA=2.*PI*EPSILN*DIM        @ CONVERT ¬PHI TO ¬Q
      GMASS=DRPIC6*(DIM**3)
      DO 6000 JVEL=1,IQUIT @JVEL EQUIV. KOD .GRAIN VEL LOOP
C     CALCULATE RELATIVE PROBABILITY OF JSIZE,JVEL PAIR
      IF(JVEL .EQ.1) GO TO 9001
      IF(JVEL .EQ. IQUIT)  GO TO 9003
      IFIX=ISFUN(JVEL)
      IFIX1=ISFUN(JVEL-1)
      P3VELC=PRBDIA(JSIZE)*(PRBVEL(IFIX,JSIZE)-PRBVEL(IFIX1,JSIZE))
      GO TO 9002
 9001 P3VELC=PRBDIA(JSIZE)*PRBVEL(1,JSIZE)
      GO TO 9002
 9003 P3VELC= PRBDIA(JSIZE) * (1.-PRBVEL(KC,JSIZE))
 9002 CONTINUE
      WEIGHT=P3VELC*ANNORM          @TOTAL GRAINS THIS SIZE AND VEL REMOVED BY MT
      VELMAG= VARD(JVEL)
      DO 35  NN=1,3                                    @ VELOC. VECTOR (INITIALLY)
      POSVEC(NN)=POSHID(NN)
   35 VELVEC(NN)=VELMAG*VELNRM(NN)       @ BUILD INITIAL VELOCITY VECTOR.
      PHIO=PHIDE
      PRTCHG=CONSTA*PHIO
      ISHADE=ISHHID
      IPANEL=IPHID
      ISECTR=ISEHID
      ATEST=WEIGHT*FLTOT
      SMTEST=SMTEST+ATEST
      IF(WEIGHT .LE. .001.OR.ATEST.LE.0.05) GO TO 5999
      IF(GMASS.LE.0.) GO TO 800  @ DEBUGGING
      VMAX=SQRT(-10.*COEFRP*PATHMX/GMASS)  @ 5 TIMES THE MINIMUM ESCAPE VEL.
      IF(VMAX.LT.VELMAG.AND.NPNL.NE.-1) GO TO 36
      IF(VELVEC(3).LE.0..AND.NPNL.NE.-1) GO TO 810  @ DEBUGGING
      CALL CONTAM  @ TEST CASE TRAJECTORY ANALYSIS
      IF(NRMISS.EQ.1)  WNET(3)=WNET(3)+WEIGHT
      IF(ILOST.EQ.1)  GO TO 38
      IF(IHIT(1).EQ.1) WNET(1)=WNET(1)+WEIGHT
      IF(IHIT(2).EQ.1) WNET(2)=WNET(2)+WEIGHT
      IF(IHIT(2).EQ.1)  GO TO 3000
      GO TO 6000
 3000 CONTINUE
C     THIS PRINTS THE TRAJECTORY OF THE PRECEEDING RECONTAMINATION EVENT.
      DO 3500 NN=1,3
      POSVEC(NN)=POSHID(NN)
 3500 VELVEC(NN)=VELMAG*VELNRM(NN)      @ BUILD INITIAL VELOCITY VECTOR.
      PHIO=PHIDE
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      PRTCHG=CONSTA*PHIC
      ISHADE=ISHHIC
      IPANEL=IPHID
      ISECTR=ISEHID
      WRITE(6,2CCO)J,JSIZE,JVEL
 2CCC FORMAT(1H1,'POSITION',I6,4X,'GRAIN SIZE GROUP',I6,4X,
     1'GRAIN VELOC. GROUP',I6)
      WRITE(6,711)       DIM,COEFRP,CONSTA,PRTCHG,GMASS
     1,PRBDIA(JSIZE)
  711 FORMAT(1HC,///,1X,                    'DIM=',G9.4,2X,'COEFRP=',G9.4,2X,
     1'CONSTA=',G3.4,2X,'PRTCHG=',G9.4,2X,'GMASS=',G9.4,2X,'PRBDIA=',G9.
     24)
      WRITE(6,712)       VELMAG,PBVELC,WEIGHT,VELVEC
  712 FORMAT(1X,                  'VELMAG=',G9.4,2X,'PBVELC=',G9.4,2X,
     1'WEIGHT=',G9.4,2X,'VELVEC=',3(G9.4,2X))
      CALL CONTM2    @ REDO THE CONTAM CALC. W/PRINTING.
      GO TO 6000
   36 CONTINUE
      DO 37 I=1,3
   37 NEWVEL(I)= VELVEC(I)
   38 WNET(4)=WNET(4)+WEIGHT
      WNET(5)=WNET(5)+SQRT(NEWVEL(1)**2+NEWVEL(2)**2+NEWVEL(3)**2)
     1*WEIGHT
      THETA=-ATAN(NEWVEL(3)/SQRT(NEWVEL(1)**2+NEWVEL(2)**2+1.E-9))+PI/2.
      IARG=THETA*17.99/PI+1.
      WANGDS(IARG)=WANGDS(IARG)+ WEIGHT
      GO TO 6000
 5999 CONTINUE
 6000 CONTINUE   @GRAIN VEL LOOP END
 5CCC CONTINUE   @GRAIN SIZE LOOP END
      IF(WNET(4).GT.C.)  WNET(5)=WNET(5)/WNET(4)
      WRITE(6,6666)
 6666 FORMAT(1X,15(/,1X))
      WRITE(6,9100)POSHID
 9100 FORMAT(1HC,'BOX SCORE FOR RANDOM POSITION',2X,1P3E9.2)
      WRITE(6,9101) (WNET(I),I=1,4)
 9101 FORMAT(1HC,'NO. SAFEHITS',2X,G9.5,/,1X,'NO. RECONTAM HITS',2X,G9.5
     1,/,1X,'NO. NEAR MISSES',2X,G9.5,/,1X,'NO. ESCAPES',2X,G9.5)
      IF(WNET(4).GT.C.)  WRITE(6,9102) WNET(5)
 9102 FORMAT(1X,'AVE. ESCAPE VEL.  ',G9.5)
      DO 9200 I=1,5
 9200 WNET2(I)=WNET2(I)+WNET(I)
      DO 9201  I=1,18
 9201 VANGDS(I)= VANGDS(I)+WANGDS(I)/N2
      IF(SMTEST.LE.0.5) GO TO 9470
   40 CONTINUE  @ POSITION LOOP END
      GO TO 9475
 9470 WRITE(6,9474) IPYRO,SMTEST
 9474 FORMAT(1HC,'THE PYRO NUMBER',I6,2X,/,1X,'YIELDED ONLY',G12.4,
     12X,'RELEASED GRAINS.',/,1X,'GO ON TO THE NEXT PYRO CASE')
 9475 WNET2(5)=WNET2(5)/N2
      WRITE(6,9300)   IPYRO,N2
      WRITE(6,6666)
 9300 FORMAT(1H1,'BOX SCORE FOR ONE PYRO OF TYPE NO.',I3,2X,
     1/,1X,'SUMMED OVER',I6,2X,'POSITIONS')
      WRITE(6,9101) (WNET2(I),I=1,4)
      WRITE(6,9102) WNET2(5)
      ACCUM1=ACCUM1+WNET2(1)*FLTOT
      ACCUM2=ACCUM2+WNET2(2)*FLTOT
      ACCUM3=ACCUM3+WNET2(3)*FLTOT
      IVESC=IVESC+WNET2(4)*FLTOT
      SUMFL=SUMFL+FLTOT
      SMVESC=SMVESC+WNET2(5)*FLTOT
      DO 9400 J=1,18
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9400 ANGDIS(J)=ANGDIS(J) +VANGDS(J)*FLTOT
     WRITE(6,9500)
9500 FORMAT(1H1)
     GO TO 5
  50 CONTINUE
C    *    *    *
     SAFENO=ACCUM1/N2
     HITNO =ACCUM2/N2
     ANRMIS=ACCUM3/N2
     IVESC= IVESC/N2
     SIGTOT=SQRT(HITNO)
     WRITE(6,100)
 100 FORMAT(1H1,'BOX SCORE FOR OVERALL ENSEMBLE OF PYROS')
     WRITE(6,9469) SUMFL
9469 FORMAT(1X,'TOTAL NO. OF PYROS IN ENSEMBLE DURING MISSION',G10.4)
     WRITE(6,9101) SAFENO,HITNO,ANRMIS,IVESC
     WRITE(6,6666)
     WRITE(6,9103) SIGTOT
9103 FORMAT(1H0,'STANDARD DEVIATION FOR NO. OF RECONTAMINATION HITS IS'
    1,2X,G9.5)
     RPROB=1.-EXP(-HITNO)
     VAVESC = SMVESC/ SUMFL
     WRITE(6,760)  VAVESC
 760 FORMAT(1H0,1X,'THE AVERAGE ESCAPE VELOCITY IS',2X,1PG9.4,
    12X,'M/SEC')
     DO 320 K=1,18
 320 ANGDEG(K)=10.*K
     WRITE(6,765)  (ANGDEG(I),ANGDIS(I),I=1,18)
 765 FORMAT(1H0,'THE ANGULAR DISTRIBUTION FOR THE ESCAPED VELOCITY VECT
    1OR RELATIVE TO THE +Z DIRECTION',//,1X,'DEG.',4X,'NO. ESCAPES',//,
    218(1X,0PF4.0,4X,1PG10.3,/))
     WRITE(6,335) RPROB
 335 FORMAT(1H0,4(1X,/),1X,'RECONTAMINATION PROBABILITY IS',G12.5)
C    *    *    *
     STOP
 800 WRITE(6,801)
 801 FORMAT(1X,'THE MASS VALUE GMASS IS INCORRECT')
 802 STOP
 810 WRITE(6,811)
 811 FORMAT(1X,'THE VELOCITY VECTOR IS INCORRECT')
 812 STOP
     END
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FUNCTION RANDND

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      FUNCTION RANDNO(BTMLIM,UPRLIM)
C     **** NASA JPL            ****  9/12/74 **** D.EDGARS, BIONETICS ****
C     ****
C     RETURNS A RANDOM NUMBER UNIFORMLY SELECTED FROM THE INTERVAL
C     (BTMLIM,UPRLIM).  DUMMY IS A SUPERFLUOUS VARIABLE
C     ****
      R=UNIFRM(DUMMY)
      RANDNO=BTMLIM*(1.-R)+UPRLIM*R
      RETURN
      END
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SUBROUTINE RELEAS

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      SUBROUTINE  RELEAS
C     ****   NASA   JPL              ****   9/12/74 **** D.EDGARS, BIONETICS ****
C     THIS SUBROUTINE IS THE ADAPTION OF THE PARTICLE RELEASE STUDY SOFTWARE
C     DEVELOPED AT JPL BY  C. BAUERLE AND J. B. BARENGOLTZ (1973).
C     THE OUTPUT IS IN THE FORM OF TWO THREE-DIMENSIONAL ARRAYS OF DATA
C     CORRESPONDING TO THE [redacted]         INPUT PARAMETERS.
C     * * * *
C     INPUT PARAMETERS:  (FOR SURFACE BEHAVIOR AFTER METEROID IMPACT)
C         1)RS - AN ARRAY OF RADIAL DISTANCES FOR THE VELOC. AND ACCEL. ARRAYS
C         2)PKACC - THE PEAK ACCEL. @ A DISTANCE RS FROM IMPACT
C         3)VAP - THE SURFACE VELOC. @ ACCEL. PEAK.
C         4)KO - THE RS, PKACC, AND VAP ARRAY DIMENSION.
C     OUTPUT PARAMETERS:
C         1)DDIA - THE ARRAY OF EJECTA DIAMETERS (10-100 MICRONS).
C         2)K1 - THE ARRAY DIMENSION OF DDIA.
C         3)  CR(K1) ARE THE CLEARING RADII.
C         4)PRBVEL.THE ARRAY OF EJECTION PROBABILITIES.VS.(VAP,DDIA) VALUES.
C     ******                   ******                     ******
          DIMENSION  VAP(35)
      DIMENSION R(35),A(35),RF(35,10),AK(10,35),PVEL(35,10)
C     COMMON BLOK01 CONNECTS DATAIN, MAIN AND RELEAS.
      COMMON /BLOK01/ AKM,DRHO,K1,PRBVEL(35,10),CR(10),SIG,DDIA(10)
     1,ANPART,ANNORM,PRBDIA(10)
C     COMMON BLOK05 CONNECTS DATAIN, MAIN, RELEAS AND YANG1
      COMMON /BLOK05/ KO,PMASS,PRHO,RS(35),FVAP(35),FPKACC(35),RHO
      EQUIVALENCE(PRBVEL(1,1),PVEL(1,1)),(RS(1),R(1))
      EQUIVALENCE (FVAP(1),VAP(1)),(FPKACC(1),A(1)),(IMAXI,KO)
C
C     NUMBER OF CASES (M) MUST BE .LE.  NM
C
      DEFINE  DIS(D)=1./(D*D)
      ANNORM= 0.0
      IMAXII=IMAXI-1
      PI=3.14159
      C1=(PI*DRHO*9800.*01.E-12)/6.
      SQRT2=SQRT(2.)
C
C     CALCULATION OF PERCENT REMOVED
C
      DO 1 II=1,10
      DDIA(II)=II*10
      DD=DDIA(II)*DDIA(II)*C1
      DO 2 IJ=1,IMAXI
      Y=DD*A(IJ)
      AK(II,IJ)= ALOG10(Y)
      X=ABS(AKM-AK(II,IJ))/(SQRT2*SIG)
      IF(AK(II,IJ) .LT. AKM)  GO TO 3
      RF(IJ,II) =0.5*(1.+ERF(X))*100.
      GO TO 2
    3 RF(IJ,II)= 0.5*ERFC(X)*100.
    2 CONTINUE
    1 CONTINUE
C
C     CALCULATION OF CLEARING RADIUS,CR(M.) AND RELEASE VELOCITY
C     PROBABILITY, P(V .GT. VO)
C
      DO 5 II=1,10
      CR(II)=R(1)**2.
      PVEL(1,II)=CR(II)
      DO 6 IJ=1,IMAXII
      CR(II)=CR(II)+RF(IJ,II)*R(IJ)*(R(IJ+1)-R(IJ))/50.
    6 PVEL(IJ+1,II)=CR(II)
      CR(II)=SQRT(CR(II))
      DO 8 K=1,IMAXI
    8 PVEL(K,II)=PVEL(K,II)/(CR(II)*CR(II))
```

SUBROUTINE RELEAS

```
    5 CONTINUE
      DO 1000  I=1,10
      PRBDIA(I)=PI*CR(I)*CR(I)*(DIS(DDIA(I)-5.)-DIS(DDIA(I)+5.))
     1*ANPART/DIS(5.)
      ANNORM=ANNORM+PRBDIA(I)
 1000 CONTINUE
      DO 2000  I=1,10
 2000 PRBDIA(I)=PRBDIA(I)/ANNORM
      RETURN
      END
```

SUBROUTINE RNDPOS

```
      SUBROUTINE RNDPOS
C     ****  NASA  JPL               ****  9/12/74 **** D.EDGARS, BIONETICS ****
C     THIS ROUTINE PRODUCES A RANDOM POSITION ON THE SPACECRAFT AS DEFINED.
C     X,Y,Z ARE THE POSITION COORDINATES.
C     IS  IS INDEX IDENTIFING SECTOR OF IMPACT  (1 OR 2)
C     NP IS 1 FOR TOP PANELS AND -1 FOR THE UNDERSIDE OF THE SOLAR PANEL
C     * * *                             * * *
C     COMMON BLOKC2 CONNECTS CHKHIT, MAIN, RNDPOS AND SHADE.
      COMMON /BLOKC2/ AL(4)
C     COMMON BLOK03 CONNECTS ESURF,  MAIN AND RNDPOS.
      COMMON /BLOK03/ ASP,ATP,ATS,PRI,ATOT,ABP,ABCS,AII
C     COMMON BLOK11 IN CONTAM,EFIELD,MAIN,RNDPOS,SPHIT,TRAJEC,VNORML.
      COMMON /BLOK11/ POSVEC(3)
C     COMMON  BLOK16 CONNECTS CONTAM,MAIN,RNDPOS,SHADE AND VNORML.
      COMMON /BLOK16/ NPNL
C     COMMON BLOK18 IN DATAIN,EFIELD,ESURF,MAIN,RNDPOS,SCPLOT,SHADE.
      COMMON /BLOK18/ SP1,SP2,SP3,SP4
C     COMMON BLOK19 CONNECTS DATAIN, EFIELD, ESURF,MAIN, RNDPOS AND SCPLOT.
      COMMON /BLOK19/ SP01,SP02,SP03
C     COMMON BLOK20 IN CHKHIT, EFIELD, MAIN, RNDPOS, SHADE AND VNORML.
      COMMON /BLOK20/ TANTH1,TANTH2,TANTH3,TANTH4
C     COMMON BLOK21 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,SPHIT,SCPL
      COMMON /BLOK21/ Z1,Z2,Z3,Z4,Z5
      EQUIVALENCE(NPNL,NP),(ISECTR,IS)
      EQUIVALENCE(POSVEC(1),X),(POSVEC(2),Y),(POSVEC(3),Z)
      PR=RANDNO(0.0,1.)
      WRITE(6,101)PR
  101 FORMAT(1H0,'PR=',G9.4)
      NP=0
      IF(PR.GE.PRI) GO TO 10                      @(DETERMINE SECTOR FOR EVENT)
      GO TO 60
   10 CONTINUE       @ IN SUN OR UNDER PANEL    (WEIGHTED BY THE EXPOSED SURFACE)
      IF(PR.LE.(PRI+ATP/ATOT))                    GO TO 20
      IF(PR.LE.(PRI+(ATP+ATS)/ATOT))              GO TO 30
      IF(PR.LE.(PRI+(ATP+ATS+ASP/4.)/ATOT))       GO TO 40
      IF(PR.LE.(PRI+(ATP+ATS+ASP/2.)/ATOT))       GO TO 45
      IF(PR.LE.(PRI+(ATP+ATS+3.*ASP/4.)/ATOT))       GO TO 50
      IF(PR.LE.(PRI+(ATP+ATS+ASP)/ATOT))          GO TO 55
      GO TO 70
   20 X=RANDNO(0.,SP01)                           @ TOP FLAT SECTION
      AY=SQRT(SP01*SP01-X*X)
      Y=RANDNO(0.,AY)
      Z=Z5
      NP=1
      GO TO 70
   30 ETA=RANDNO(0.,1.57)                         @ SECTOR 1 CONE AREA
      RAD=RANDNO(SP01,SP2)
      X=RAD*COS(ETA)
      Y=RAD*SIN(ETA)
      Z= SQRT(X*X+Y*Y)*TANTH3          + AL(3)
      GO TO 70
   40 X=RANDNO(SP2,SP3)                           @ ABOVE SOLAR PANEL (1)
      Y=RANDNO(0.,SP1)
      Z=Z4
      NP= 1
      GO TO 70
   45 X=RANDNO(0.,SP1)                            @ ABOVE SOLAR PANEL (2)
      Y=RANDNO(SP2,SP3)
      Z=Z4
      NP= 1
      GO TO 70
   50 X=RANDNO(SP2,SP3)                           @ UNDER SOLAR PANEL (1)
      Y=RANDNO(0.,SP1)
      Z=Z4
```


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      NP=-1
      GO TO 70
   55 X=RANDNO(0.,SP1)                               @ UNDER SOLAR PANEL (2)
      Y=RANDNO(SP2,SP3)
      Z=Z4
      NP=-1
      GO TO 70
   60 ETA=RANDNO(0.,1.57)                            @ SECTOR 2 CONE SURFACE
      RAD=RANDNO(SP02,SP4)
      X=RAD*COS(ETA)
      Y=RAD*SIN(ETA)
      Z= SQRT(X*X+Y*Y)*TANTH2        +AL(2)
   70 RETURN         @ POSITION ESTABLISHED
      END
```

SUBROUTINE SCPLOT

```
      SUBROUTINE SCPLOT(IGOON)
C     **** NASA  JPL              ****  9/12/74 **** D.EDGARS, BIONETICS ****
      DIMENSION X(16), Y(16)
C     COMMON BLOK18 IN DATAIN,EFIELD,ESURF,MAIN,RNDPOS,SCPLOT,SHADE, AND CONTAM
      COMMON /BLOK18/ SP1,SP2,SP3,SP4
C     COMMON BLOK19 CONNECTS DATAIN, EFIELD, ESURF,MAIN, RNDPOS AND SCPLOT.
      COMMON /BLOK19/ SPO1,SPO2,SPO3
C     COMMON BLOK21 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,SPHIT,SCPL
      COMMON /BLOK21/ Z1,Z2,Z3,Z4,Z5
C     *    *    *
C     THIS SUBROUTINE PLOTS (ON 8.5X11 PAPER) THE MODEL AS PER THE INPUT
C     DATA TO INDICATE THE GEOMETRIC COMPATABILITY.  THE ARGUMENT IGOON
C     TELLS THE REMAINING PROGRAM TO EITHER CONTINUE (1) OR  ABORT(-1)
C     BECAUSE OF UNUSABLE DATA.
C     *    *    *
C     ARRAY CONSTRUCTION:
C     *    *    *
      A=AINT(Z1)    -1.
      X(1)= SP4
      X(2)= 0.
      X(3)= 0.
      X(4)= SPO2
      X(5)= SP4
      X(6)= SPO3
      X(7)= 0.
      X(8)= 0.
      X(9)= SP1
      X(10)= SP3
      X(11)= SP2
      X(12)= SPO1
      X(13)= 0.
      X(14)= 0.
      X(15)=0.
      X(16)=1.
      Y(1)= Z2
      Y(2)= Z2
      Y(3)= Z3
      Y(4)= Z3
      Y(5)= Z2
      Y(6)= Z1
      Y(7)= Z1
      Y(8)= Z4
      Y(9)= Z4
      Y(10)= Z4
      Y(11)= Z4
      Y(12)= Z5
      Y(13)= Z5
      Y(14)= Z4
      Y(15)=A
      Y(16)=1.
      DETERMINE PARAMETER USABILITY
      IF(SP4.LE.SPO2) GO TO 1000   @ PARAMETERS INCONSISTENT
      IF(SP4.LE.SPO3) GO TO 1000   @ PARAMETERS INCONSISTENT
      IF(SP3.LE.SP2) GO TO 1000    @ PARAMETERS INCONSISTENT
      IF(SP2.LE.SPO1) GO TO 1000   @ PARAMETERS INCONSISTENT
      IF(SP2.LE.SP1) GO TO 1000    @ PARAMETERS INCONSISTENT
      IF(Z5.LE.Z4)     GO TO 1000   @ PARAMETERS INCONSISTENT
      IF(Z4.LE.Z3)     GO TO 1000   @ PARAMETERS INCONSISTENT
      IF(Z3.LE.Z2)     GO TO 1000   @ PARAMETERS INCONSISTENT
      IF(Z2.LE.Z1)     GO TO 1000   @ PARAMETERS INCONSISTENT
      GO TO 16
 1000 WRITE (6,1001)
 1001 FORMAT(1X,'INPUT SPACECRAFT PARAMETERS INCONSISTENT;',//,5X,'RUN--
     1ABORTED')
```

```
      IGOON=-1
      GO TO 110
   16 CONTINUE
C     *    *    *
C     PRODUCE PLOT OF SPACECRAFT
C     *    *    *
   20 CALL PLOTS
   30 CALL PLOT(1.0,2.0,-3)    @ ESTABLISH ORIGIN.
   50 CALL AXIS(0.,0.,15HZ AXIS (METERS),15,7.,90., A,1.)    @   Z AXIS DRAWING.
   40 CALL AXIS(0.,0.,17HX,Y AXES (METERS),-17,6.,0.,0.,1.) @ X,Y AXES DRAWING.
      CALL LINE(X,Y,14,1,1,1)    @ PLOTS THE CRAFT OUTLINE.
   80 CALL SYMBOL(2.,5.6,.21,21HCONE SPACECRAFT MODEL,0.,21)      @ TITL
   90 CALL SYMBOL(2.,5.2,.14,25H**(INITIAL GEOM. CHECK)**,0.,25)  @ TITLE
      CALL PLOT(12.0,0.0,999)
  100 IGOON=+1
  110 RETURN
      END
```

SUBROUTINE SHADE

```
      SUBROUTINE  SHADE
C     ****  NASA  JPL              ****  9/12/74 **** D.EDGARS, BIONETICS ***
C     ****
C     THIS ROUTINE DETERMINES WHETHER THE PARTICLE IS EXPOSED TO THE SUN
C     OR IS SHADED BY A PORTION OF THE SPACECRAFT.  WE USE (VIA COMMON
C     BLOCK) THE FIXED CONSTANTS ABOUT THE SPACECRAFT GEOMETRY OBTAINED
C     DURING INPUT.
C     DEFINITIONS:
C     (1)(X,Y,Z) IS THE NEW PARTICLE POSITION VECTOR.
C     (2) ISE  IS INPUT TO INDICATE SECTOR OF SPACECRAFT MODEL@
C                   (A) 1= PARTICLE IN UPPER SECTOR.
C                   (B) 2= PARTICLE IN MIDDLE SECTOR.
C                   (C) 3= PARTICLE IN LOWER SECTOR.
C     (3) IP  INDICATES:            (OUTPUT)
C                   (A) 1= PARTICLE IS UNDER A SOLAR PANEL.
C                   (B) 0= PARTICLE IS NOT UNDER A SOLAR PANEL.
C     (4) ISH INDICATES:            (OUTPUT)
C                   (A) 1= PARTICLE IS SHADED OUTSIDE WAKE.
C                   (B) 0= PARTICLE IS NOT SHADED.
C                   (C)-1= PARTICLE IS SHADED INSIDE WAKE.
C     ****
      REAL  NEWPOS
C     COMMON BLOK02 CONNECTS CHKHIT, MAIN, RNDPOS AND SHADE.
      COMMON /BLOK02/ AL(4)
C     COMMON BLOK03 IN CHKHIT,CONTAM,MAIN,SHADE,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK03/ NEWPOS(3)
C     COMMON BLOK14 CONNECTS CONTAM, EFIELD, MAIN, SHADE AND TRAJEC.
      COMMON /BLOK14/ IPANEL,ISHADE
C     COMMON BLOK15 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,VNORML.
      COMMON /BLOK15/ ISECTR
C     COMMON  BLOK16 CONNECTS CONTAM,MAIN,RNDPOS,SHADE AND VNORML.
      COMMON /BLOK16/ NPNL
C     COMMON BLOK18 IN DATAIN,EFIELD,ESURF,MAIN,RNDPOS,SCPLOT,SHADE.
      COMMON /BLOK18/ SP1,SP2,SP3,SP4
C     COMMON BLOK20 IN CHKHIT, EFIELD, MAIN, RNDPOS, SHADE AND VNORML.
      COMMON /BLOK20/ TANTH1,TANTH2,TANTH3,TANTH4
C     COMMON BLOK21 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,SPHIT,SCPL
      COMMON /BLOK21/ Z1,Z2,Z3,Z4,Z5
C     COMMON BLOK23 CONNECTS EFIELD, MAIN AND SHADE.
      COMMON /BLOK23/ XYWAKE,ZWAKE , JPCT
      EQUIVALENCE (NEWPOS(1),X),(NEWPOS(2),Y),(NEWPOS(3),Z)
      EQUIVALENCE (ISECTR,ISE),(ISHADE,ISH),(IPANEL,IP)
C     DETERMINE ISECTR
      ISE=1
      IF(Z.GT.Z4)  GO TO 50
      IF(Z.EQ.Z4.AND.NPNL.GE.0)  GO TO 50
      IF(Z.GE.Z2)  GO TO 10
      IF(Z.GE.0.) GO TO 11
      ISE=4
      GO TO 50
   10 ISE=2
      GO TO 50
   11 ISE=3
   50 GO TO(100,200,300,300),ISE
C     ****
C     DETERMINE WHETHER PARTICLE IS ABOVE A SOLAR PANEL
C     ****
  100 IF((Y.GE.SP2.AND.Y.LE.SP3).AND.(X.GE.0.0.A
     1ND.X.LE.SP1)) GO TO 110
      IF((Y.GE.0.0.AND.Y.LE.SP1).AND.(X.GE.SP2.A
     1ND.X.LE.SP3)) GO TO 110
C     ****
C     NOT ABOVE/BELOW A SOLAR PANEL.
C     ****
```

```
  115 IP=0
  106 ISH=0                   @ PARTICLE IS UNSHADED.
      RETURN
C     ****
C     IS ABOVE/BELOW A SOLAR PANEL.
C     ****
  110 IP=1
      IF(ISE-2) 106,250,260
C     ****
C     PARTICLE IS IN THE MIDDLE SECTOR.
C     ****
  200 SPT=SP2
C     ****
C     DETERMINE IF PARTICLE IS SHADED IN EITHER SECTOR 2 OR 3.
C     ****
  205 IF((X.GE.SPT.AND.X.LE.SP3).AND.(Y.GE.0.0.AND.
     1Y.LE.SP1)) GO TO 110
      IF((X.GE.0.0.AND.X.LE.SP1).AND.(Y.GE.SPT.A
     1ND.Y.LE.SP3)) GO TO 110
      IP=0
      GO TO 260
C     ****
C     PARTICLE NOT SHADED
C     ****
  250 ISH=1
  255 RETURN
C     * * *
C     CHECK CIRCULAR CONSTANT
C     * * *
  260 C=X*X+Y*Y
      S=SPT*SPT
      IF(C.GT.S.AND.IP.NE.1)  GO TO 106   @ NOT SHADED
      IF(ISE.EQ.2)  GO TO 250
      ZW=SQRT(C)*TANTH4        +AL(4)
      IF(Z.LT.ZW)  GO TO 250
      ISH=-1                   @ SHADED INSIDE OF THE WAKE.
      GO TO 255
C     ****
C     PARTICLE IN SECTOR THREE.
C     ****
  300 SPT=SP4
      GO TO 205
      END
```

SUBROUTINE SPHIT

```
      SUBROUTINE  SPHIT
C     ****
C     THIS ROUTINE DETERMINES WHETHER THE PARTICLE HAS HIT A SOLAR PANEL.
C     DEFINITIONS:                                  BIONETICS**DEE**3/13/74**
C     (1) Z IS THE NEW PARTICLE POSITION Z COMPONENT.
C     (2) VZ IS THE NEW PARTICLE VELOCITY Z COMPONENT.
C     (3) Z4        IS A SPACECRAFT DIMENSION FROM INPUT PREPROCESSOR.
C     IH1     IS THE INDEX DENOTING:
C                                 (A)  C - DID NOT HIT PANEL.
C                                 (B)  1 - DID CONTACT PANEL.
C     ****
      REAL NEWPOS,NEWVEL
C     COMMON BLOK04 CONNECTS CONTAM, MAIN, PARPOT, SPHIT AND TRAJEC.
      COMMON /BLOK04/ COEFPP,CONSTA,PRTCHG,PHIO
C     COMMON BLOK09 IN CHKHIT,CONTAM,MAIN,SHADE,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK09/ NEWPOS(3)
C     COMMON BLOK10 CONNECTS CONTAM,MAIN,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK10/ NEWVEL(3), DELTAT
C     COMMON BLOK11 IN CONTAM,EFIELD,MAIN,RNDPOS,SPHIT,TRAJEC,VNORML.
      COMMON /BLOK11/ POSVEC(3)
C     COMMON BLOK13 CONNECTS CHKHIT, CONTAM, MAIN AND SPHIT.
      COMMON /BLOK13/ IHIT(2)
C     COMMON BLOK21 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,SPHIT,SCPL
      COMMON /BLOK21/ Z1,Z2,Z3,Z4,Z5
      EQUIVALENCE (NEWPOS(3),Z),(NEWVEL(3),VZ),(IHIT(1),IH1)
      EQUIVALENCE  (POSVEC(3),Z0)
      DZ=Z-Z4
      ADZ=ABS(DZ)
      AVZ=ABS(VZ)
C
C     WITHIN RANGE AND CLOSING.
      IF(DZ/VZ.LE.C.C.AND.ADZ/AVZ.LE.DELTAT)  GO TO 300
C
C     SOLAR PANEL PENETRATION.
      IF(Z.EQ.Z4)  GO TO 300
      IF((Z0-Z4)/(Z4-Z).GT.C.)  GO TO 300
C
  250 IH1=0
      RETURN
  300 IH1=1
      RETURN
      END
```

SUBROUTINE THINPL

```
      SUBROUTINE THINPL
C     **** NASA  JPL                **** 9/12/74 **** D.EDGARS, BIONETICS ****
C     THIS ROUTINE IS A MODIFIED VERSION OF THE METEOROID IMPACT STUDY
C     SOFTWARE PREPARED IN ITS LATEST VERSION PRIOR TO THIS MODIFICATION.
C     IN DECEMBER, 1973 BY C. BAUERLE AND J. B. BARENGOLTZ AFTER THE ANALYSIS
C     OF THE PHYSICAL PROBLEM BY J. YANG.
C     *   *   *                                            *   *   *
C
C     DECK FOR FIRST PRESSURE FUNCTION
C
      PARAMETER         MAXPTS=500
      REAL              I,NU
      REAL              T(MAXPTS),WDOT(MAXPTS),W1(MAXPTS),W2(MAXPTS)
C     COMMON BLOCK07 CONNECTS THINPL AND YANG1.
       COMMON /BLOCK07/ TO,VAP,PKACC,EE,EH,ANU,EPO,R,ES,ERHO
      EQUIVALENCE (EE,E),(EH,H),(EPO,PO),(ES,S),(ERHO,RHO)
      EQUIVALENCE  (ANU,NU)
C
C     COMPUTES FIXED EXPRESSIONS FOR LATER USE
C
      NDELT=500           @ MUST BE DIVISABLE BY 10.
      ND24=NDELT-24
      ND25=NDELT-25
      NDTEN=NDELT/10
      AND28=NDELT-28
      AND3=NDELT-3
      AND101=NDTEN-1
      PI = 3.14159
      ABAR = PO * S
      D=E*H**3/(12.0*(1.0-NU**2))
      B=(D/(RHO*H))**0.5
      I=PI*S*ABAR
      P=S/(4.0*B) *S
      Q=R/(4.0*B)      * R
C
C     COMPUTE AND STORE WDOT ARRAY
C
      Z=ABAR/S*EXP(-R**2/S**2)
      WIDTH = TO /4.
      TEMP = Q/(WIDTH * PI)
      IF  (TEMP .GT. 2.)  GO TO 200
      N=2
      TMIN=Q/(4.*PI)
      GO TO 230
200   IF   (TEMP .GT. 48.)   GO TO 210
      N=3
      GO TO 220
210   N = SQRT ( (TEMP/12.)+ 12.)
220   TMIN = Q/(2 * N * PI)
      IF  (TMIN .GT. SQRT(P*Q))  GO TO 230
      N = SQRT(P*Q) / (2.* PI)   + 1
      TMIN = Q / (2. * N * PI)
230   T(1) = 0.0
      WDOT(1) = 0.0
      TA = Q/((2*N + 6) * PI)
      IF   (N .GT. 3)    GO TO 240
      TMAX=2.*Q/PI
      DT = (2.*Q/PI - TA)/AND28
      GO TO 250
240   TMAX = Q/((2*N - 7) * PI)
      DT = (TMAX - TA) / AND3
250   T(2) = TA - DT
      WDOT(2) = 0.0
      DO 20  J=3, ND25
```

```
16      PT2=P**2+TA**2
        T(J)=TA
        WA=ABAR/(RHO*H*S)*P**2/PT2
        WB=EXP(-P*Q/PT2)
        WC=COS(Q*TA/PT2)
        WD=SIN(Q*TA/PT2)
        WDOT(J)=WA*WB*(WC+TA/P*WD)
18      TA = TA + DT
20      CONTINUE
        IF    (N .GT. 0)    GO TO 260
        DT = (TMAX - 2.*Q/PI) / 25.
260     TA = T(ND25)+DT
        DO 25  J=ND24,NDELT
        PT2=P**2+TA**2
        T(J)=TA
        WA=ABAR/(RHO*H*S)*P**2/PT2
        WB=EXP(-P*Q/PT2)
        WD=SIN(Q*TA/PT2)
        WC=COS(Q*TA/PT2)
        WDOT(J)=WA*WB*(WC+TA/P*WD)
        TA = TA + DT
25      CONTINUE
C
C       COMPUTE W2 ARRAY
C
        KEY=7
        HMIN=1.0E-8
        HMAX=1.0
        HSTAR=HMIN
        ERMAX=1.0E-4
        DT = (TMAX - TMIN) / AND101
        TSAVE=T(2)     @ FOR VAP CALCULLATION BELOW.
        TLO = T(2)
        THI = TMIN
        DO  80   J=1, NOTEN
        CALL ROMBS (TLO,THI,TT,FOFTT,HSTAR,HMIN,HMAX,ERMAX,ANS,K,KEY)
     60 FC=0.0
        FC = -2. / (TC * (1 + (THI-TT)/TC)**3)
     70 TW=TT
        CALL SLUP (TW,FCC,FP,T,WDOT,NDELT,2)
        FOFTT=FC*FCC
        CALL ROM2
        IF (K.EQ.1) GO TO 60
        W2(J)=ANS*2.59E-6        @ TO CONVERT TO KILOGEE FROM ENGLIAH.
        THI=THI+DT
     80 CONTINUE
C
C       COMPUTE W2MAX
C
    100 W2MAX=0.0
        DO 110 J=1,NOTEN
        IF     (W2(J) .LE. W2MAX)    GO TO 110
        W2MAX = W2(J)
        JACK=J
110     CONTINUE
C
C       THIS CALCULATES 1 VALUE OF VAP AT TIME WHEN THE ACCELERATION IS
C       AT THE MAXIMUN VALUE.
C
        TLO=TSAVE
        AJ=JACK
        THI=TMIN+(AJ-1.)*DT
        CALL ROMBS (TLO,THI,TT,FOFTT,HSTAR,HMIN,HMAX,ERMAX,ANS,K,KEY)
        FS = 1. / ((1 + (THI-TT)/TC)**2)
```

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SUBROUTINE THINPL

```
 40 TW=TT
    CALL SLUP (TW,FSS,FP,T,WDOT,NDELT,2)
    FOFTT=FS*FSS
    CALL ROM2
    VAP=ANS*.0254          @ CONVERT TO M/SEC
C
C   CHECK SIGN OF VAP
C
    IF(VAP.GE.0.)  GO TO 525
    GO TO 120
C
C   COMPUTE W1 ARRAY WHEN TRIAL IS POSITIVE.
C
525 DT=(TMAX-TMIN)/AND101
    TLO = TSAVE
    THI = TMIN
    DO 550  J=1,NDTEN
    CALL ROMBS (TLO,THI,TT,FOFTT,HSTAR,HMIN,HMAX,ERMAX,ANS,K,KEY)
530 FS=0.0
    FS = 1. / ((1 + (THI-TT)/TO)**2)
540 TW=TT
    CALL SLUP (TW,FSS,FP,T,WDOT,NDELT,2)
    FOFTT=FS*FSS
    CALL ROM2
    IF (K.EQ.1) GO TO 530
    W1(J)=ANS*.0254       @ CONVERT VELOCITY TO M/SEC
    THI=THI+DT
550 CONTINUE
    VAP=0.
    W2MAX=0.
    DO 600  J=1,NDTEN
    IF(W1(J).GE.0.)  GO TO 600
    IF(W2(J).LE.W2MAX) GO TO 600
    W2MAX=W2(J)
    VAP=W1(J)
600 CONTINUE
120 PKACC = W2MAX
    RETURN
    END
```

SUBROUTINE TRAJEC

```
      SUBROUTINE  TRAJEC
C     ****  NASA  JPL             ****  9/12/74 **** D.EDGARS, BIONETICS ****
C     *****                    *****                    *****
C
C     SUBROUTINE  TRAJEC  CALCULATES THE INCREMENT IN THE PARTICLE TRAJ-
C     ECTORY.  THIS REQUIRES INFORMATION ABOUT THE CURRENT PARTICLE
C     CHARGE  AT THE LOCATION TO BE MOVED FROM, THE SUN/SHADE CONDITION,
C     THE CURRENT VELOCITY VECTOR AND THE ELECTRIC FIELD FROM THE CHARGED
C     SPACECRAFT.  CALLS TO SUBROUTINES  EFIELD  AND  PARPOT  PROVIDE THE
C     FIELD AND CHARGE INFORMATION.  THIS SUBROUTINE CALCULATES A SUITABLE
C     TIME INTERVAL FOR THE STANDARD KINEMATICAL EQUATIONS OF MOTION BY
C     PRECALCULATING A DELTA T FOR A VELOCITY DEPENDENT, FORCE-FIELD
C     DEPENDENT AND A DRASTIC ELECTRIC POTENTIAL CHANGE DOMINANT CASE AND
C     USES THE SMALLEST OF THE THREE.  BY THIS METHOD WE MAINTAIN A FAIRLY
C     UNIFORM FOUR CENTIMETER INCREMENT SIZE EXCEPT WHEN THE ELECTRIC
C     POTENTIAL DIFFERENCE WOULD BE TOO LARGE OVER THE DISTANCE SPECIFIED
C     (4 CM) AND THUS, IN ESSENCE, WE SMOOTH THE SUN/SHADE BOUNDRY
C     TRAVERSAL.
C
C     *****                    *****                    *****
      DIMENSION RPOS(3),RVEL(3),DELTAR(3),DPOS(3),DVEL(3) ,E(3)
C     COMMON BLOKC4 CONNECTS CONTAM, MAIN, PARPOT, SPHIT AND TRAJEC.
      COMMON /BLOKO4/ COEFRP,CONSTA,PRTCHG,PHIG
C     COMMON BLOK09 IN CHKHIT,CONTAM,MAIN,SHADE,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOKO9/ NEWPOS(3)
C     COMMON BLOK10 CONNECTS CONTAM,MAIN,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK10/ NEWVEL(3), DELTAT
C     COMMON BLOK11 IN CONTAM,EFIELD,MAIN,RNDPOS,SPHIT,TRAJEC,VNORML.
      COMMON /BLOK11/ POSVEC(3)
C     COMMON BLOK12 CONNECTS CONTAM, MAIN AND TRAJEC.
      COMMON /BLOK12/ GMASS ,VELVEC(3) ,ILOST
C     COMMON BLOK14 CONNECTS CONTAM, EFIELD, MAIN, SHADE AND TRAJEC.
      COMMON /BLOK14/ IPANEL,ISHADE
C     COMMON BLOK25 CONNECTS CONTAM, EFIELD, MAIN AND TRAJEC.
      COMMON /BLOK25/ EVEC(3)
C     COMMON BLOK27 CONNECTS PARPOT AND TRAJEC
      COMMON /BLOK27/ PHICNG
      EQUIVALENCE (ISHADE,ISH),(EVEC(1),E(1))
      EQUIVALENCE (RPOS(1),POSVEC(1)),(RVEL(1),VELVEC(1))
      EQUIVALENCE (DPOS(1),NEWPOS(1)),(DVEL(1),NEWVEL(1))
      CALL EFIELD
C
C     CALCULATION OF THE POTENTIAL DEPENDENT TIME INTERVAL.
C
      CALL PARPOT
      DELT3=10.
      IF(ABS(PHICNG).LE.0.1)  GO TO 2
      DELT3=1./ABS(PHICNG)
    2 TFRP=0.      @ IN SHADE
      IF(ISH.EQ.0)  TFRP=COEFRP     @ IN SUN
C
C     VELOCITY DEPENDENT DELTA T.
C
      DELT1 =0.04/(SQRT(RVEL(1)*RVEL(1)+RVEL(2)*RVEL(2)+RVEL(3)*RVEL(3))
     1+1.E-6)
C
C     FORCE DEPENDENT DELTA T
C
      DELT2=SQRT(0.08*GMASS/(ABS(TFRP)+ABS(PRTCHG)*SQRT(E(1)*E(1)+
     1E(2)*E(2)+E(3)*E(3))+1.E-20))
C
C     THE MINIMUM DELTA T OF THE THREE CHOICES
C
```

SUBROUTINE TRAJEC

```
      DELT  =AMIN1(DELT1,DELT2)
      DELTAT=AMIN1(DELT,DELT3)
    5 DTSOTM=DELTAT*DELTAT/(2.*GMASS)
      K3=0
   10 DO 15 K=1,3
      IF(K.EQ.3)   K3=1
   15 DELTAR(K)=DTSOTM*(TFPP*K3+ PRTCHG*E(K))+RVEL(K)*DELTAT
      DO 40  K=1,3
      IF(DELTAR(K).GT.0.04)  GO TO 50
   40 CONTINUE
      GO TO 31
   50 DELTAT=DELTAT/2.
      GO TO 5
   31 DO 35 K=1,3
      DPOS(K)=RPOS(K)+DELTAR(K)
   35 DVEL(K)=2.*DELTAR(K)/DELTAT-RVEL(K)
      DELTAQ=CONSTA*PHICNG*DELTAT  @ CHANGE IN PARTICLE CHARGE.
      PHIO=PHIO+PHICNG*DELTAT    @ NEW PARTICLE POTENTIAL.
      PRTCHG=PRTCHG+DELTAQ
      RETURN
      END
```

SUBROUTINE TRANSL

```
      SUBROUTINE TRANSL
C     ****  NASA  JPL             ****  9/12/74 **** D.ECCARS, BIONETICS ****
C     THIS ROUTINE TRANSLATES THE PARTICLE POSITION AND VELOCITY BACK INTO
C     THE FIRST OCTANT BECAUSE OF SYMMETRY TO EASE THE CALCULATIONS
C     (X,Y,Z) IS THE POSITION WHICH REQUIRES TRANSLATION - (NEW COORDINATES)
C     (VX,VY)=THE VELOCITY WHICH REQUIRES TRANSLATION - (NEW VELOCITY)
C     *   *   *                               *    *    *
      REAL NEWPOS, NEWVEL
C     COMMON BLOK09 IN CHKHIT,CONTAM,MAIN,SHADE,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK09/ NEWPOS(3)
C     COMMON BLOK10 CONNECTS CONTAM,MAIN,SPHIT,TRAJEC AND TRANSL.
      COMMON /BLOK10/ NEWVEL(3), DELTAT
      EQUIVALENCE (X,NEWPOS(1)),(Y,NEWPOS(2)),(NEWVEL(1),VX),(NEWVEL(2),
     1VY)
      IF(X.LT.0.0.AND.Y.GT.0.0) GO TO 100
      IF(X.LT.0.0.AND.Y.LT.0.0) GO TO 200
      IF(X.GT.0.0.AND.Y.LT.0.0) GO TO 300
      RETURN   & DOES NOT ALTER PARAMETERS
  100 XP=Y
      YP=-X
      VXP=VY
      VYP=-VX
      GO TO 400
  200 X=-X
      Y=-Y
      VX=-VX
      VY=-VY
      RETURN
  300 XP=-Y
      YP=X
      VXP=-VY
      VYP= VX
  400 X=XP
      Y=YP
      VX=VXP
      VY=VYP
      RETURN
      END
```

ORIGINAL PAGE IS
OF POOR QUALITY

SUBROUTINE VNORML

```
      SUBROUTINE VNORML
C     ****  NASA  JPL            ****  9/12/74 **** D.EDGARS, EIONETICS ****
C     * * *                             * * *
C     THIS ROUTINE CALCULATES THE NORMAL UNIT VECTOR AT THE SURFACE IMPACT ZONE
C     THE VECTOR IS ALONG (Z-AXIS) FOR SOLAR PANEL CONSIDERATION.
C     (IT THEN ADDS A 10 PERCENT BIAS TO ONE OF THE VELOCITY COMPONENTS.)
C     NP=+1 ... ABOVE PANEL: -1 ... BELOW PANEL.
C     * * *
      DIMENSION VEL(3)  , TANT(4)
C     COMMON BLOK11 IN CONTAM,EFIELD,MAIN,RNDPOS,SPHIT,TRAJEC,VNORML.
      COMMON /BLOK11/ POSVEC(3)
C     COMMON BLOK15 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,VNORML.
      COMMON /BLOK15/ ISECTR
C     COMMON  BLOK16 CONNECTS CONTAM,MAIN,RNDPOS,SHADE AND VNORML.
      COMMON /BLOK16/ NPNL
C     COMMON BLOK18 IN DATAIN,EFIELD,ESURF,MAIN,RNDPOS,SCPLOT,SHADE.
      COMMON /BLOK18/ SP1,SP2,SP3,SP4
C     COMMON BLOK20 IN CHKHIT, EFIELD, MAIN, RNDPOS, SHADE AND VNORML.
      COMMON /BLOK20/ TANTH1,TANTH2,TANTH3,TANTH4
C     COMMON BLOK21 IN CHKHIT,CONTAM,EFIELD,MAIN,RNDPOS,SHADE,SPHIT,SCPL
      COMMON /BLOK21/ Z1,Z2,Z3,Z4,Z5
C     COMMON BLOK22 CONNECTS MAIN AND VNORML.
      COMMON /BLOK22/ VELNRM(3)
      EQUIVALENCE (NPNL,NP) ,(VELNRM(1),VEL(1))
      EQUIVALENCE (POSVEC(1),X),(POSVEC(2),Y)
      EQUIVALENCE(POSVEC(3),Z)
      TANT(1)=TANTH1
      TANT(2)=TANTH2
      TANT(3)=TANTH3
      TANT(4)=TANTH4
      XYDIST=SQRT(X*X+Y*Y)
      IF(NPNL.NE.0)  GO TO 100
      IS=4-ISECTR
      FX=-X*TANT(IS)/XYDIST
      FY=-Y*TANT(IS)/XYDIST
      FZ=+1.
      DENOM=SQRT(FX*FX+FY*FY+FZ*FZ)
      VEL(1)=FX/DENOM
      VEL(2)=FY/DENOM
      VEL(3)=FZ/DENOM
      GO TO 300
  100 VEL(1)=0.
      VEL(2)=0.
      RN=NP
      VEL(3)=RN                         @ + OR - Z DIRECTION AS PER NP
  300 CONTINUE
      NO=RANDNO(1.,3.99)  @ ADD TEN PERCENT TO ONE OF THE COMPONENTS.
      GO TO(310,320,330),NO
  310 VEL(1)=VEL(1)+.1
      GO TO 400
  320 VEL(2)=VEL(2)+.1
      GO TO 400
  330 VEL(3)=VEL(3)*.9
  400 RETURN
      END
```

SUBROUTINE YANG 1

```
      SUBROUTINE YANG1                  @   THE SURFACE IMPACT ANALYSIS
C     ****  NASA  JPL                ****  9/12/74 **** D.EDGARS, BIONETICS ****
C     THIS ROUTINE IS A MODIFIED VERSION OF THE METEOROID IMPACT STUDY
C     SOFTWARE PREPARED IN ITS LATEST VERSION,PRIOR TO THIS MODIFICATION,
C     IN DECEMBER, 1973 BY C. BAUERLE AND J. B. BARENGOLTZ AFTER THE ANALYSIS
C     OF THE PHYSICAL PROBLEM BY J. YANG.
C     *    *    *                                         *    *    *
C     ***************
C
C     DR--BASIC DATA ARRAY FOR RADII
C     RR--RADIUS ARRAY FOR INITIAL POINTS
C     FR--FINAL RADIUS ARRAY
C     RPKACC--INITIAL ARRAY FOR PEAK ACCELERATION AT VALUES IN RR
C     FPKACC--FINAL ARRAY FOR PEAK ACCELERATIONS FOR VALUES IN FR
C     RVAP--ARRAY FOR VELOCITIES AT PEAK ACCELERATIONS  AT RR RADII
C     FVAP--FINAL ARRAY FOR VEL. AT PEAK ACCELERATIONS AT FR RADII
C
C     ************
C
C
      REAL  NU
      DIMENSION  RR(14), RPKACC(14), RVAP(14), DR(14)
      DIMENSION  FR(35),                            RMID(2), AMID(2),
     2     VMID(2)
C     COMMON BLOK05 CONNECTS DATAIN, MAIN, RELEAS AND YANG1
      COMMON /BLOK05/ KO,PMASS,PRHC,RS(35),FVAP(35),FPKACC(35),RHO
C     COMMON BLOK06 CONNECTS DATAIN, MAIN AND YANG1.
      COMMON /BLOK06/ E,H,NU,PO,ISKIP
C     COMMON BLOK07 CONNECTS THINPL AND YANG1.
       COMMON /BLOK07/ TO,VAP,PKACC,EE,EH,ANU,EPO,R,ES,ERHO
C     COMMON BLOK17 CONNECTS DATAIN, MAIN AND YANG1.
      COMMON /BLOK17/ PVEL,ACCMIN
      EQUIVALENCE(FR(1),RS(1))       @ YANG1
      EQUIVALENCE (KO,IMAXI)
      DATA   DR  / .01, .02, .03, .04, .06, .08, .1, .2, .4, .7, 1.,
     2  0.,0.,0. /    @ THE OLD CODING HAD INTEGER ZERO'S.
 1000 FORMAT(1HO,1X,'THE PLATE WAS PUNCTURED')
      ANU=NU
      NDELT=500
      ISKIP=0
C
      WRITE(6,470) PMASS,PVEL,PRHO,E,H,NU,RHO,PO
  470 FORMAT(1HO,'THE FOLLOWING VALUES ARE RESPECTIVILY',/,1X,'-PMASS--P
     1VEL--PRHO--E--H--NU--RHO--PO',/,1X,8(1PG9.4,2X))
      DO 7    I=1, 14, 1
      RR(I) = DR(I)
7     CONTINUE
      PI = 3.14159
C
C     CALCULATE PR-PARTICLE RADIUS, TO, AND S
C
      PR = CBRT( (3. * PMASS) / (4. * PI * PRHO)  )
C
C     DETERMINE WHETEHER CONDITIONS EXIST FOR PLATE PUNCTURE BY METEOROID.
C
      P=CBRT(12.*PMASS*PVEL*PVEL/(PI*PO))*.5
      IF(P.LE.H)  GO TO 8
 C    PLATE PUNCTURED.
      TO=8./3.*PR*(PO/(2.*PRHO))**(1./6.)*PVEL**(-4./3.)*(1.+
     13.*RHO*H/PR*CBRT((PVEL/2.)**4/(PRHO*PO*PO)))
      WRITE(6,1000)
      GO TO 9
C     PLATE NOT PUNCTURED.
```

```
    8 TC = 8. * PR * (1. + (8. * RHO * PVEL * PVEL ) / PC)
     2      * 10.**(ALOG10(PC/(2.*PRHO))/6. - (4./3.)* ALOG10(PVEL) )/3.
    9 CONTINUE
      S = (PR/3.) * CBRT((2. * RHO * PVEL * PVEL) / PC)
      J = 5
C
C     ACCMIN IS THE MINIMUM ACCELERATION OF INTEREST
C
C     VARIABLES CHANGED FROM METRIC TO ENGLISH SYSTEM
C
      EE=E*1.45E-4
      EH=H*39.37
      ERHO=RHO*9.356E-8
      EPO=PO*1.45E-4
      ES=S*39.37
C
C     VALUES FOR PEAK ACCELERATION AND VELOCITY AT PEAK ACCELERATION ARE
C     CALCULATED FOR INITIAL VALUES OF RADII.  AT LEAST 2 RADII MUST
C     BE USED.  AFTER THAT IF THE LARGEST VALUE FOR A PEAK ACCELERATION
C     HAS BEEN PASSED AND THE PEAK ACCELERATION IS LESS THAN ACCMIN,
C     CALCUALTIONS STOP.
C
      DO 10   J=1, 11
      R = RR(J)
      R = R * 39.37
      CALL THINPL
      R = R / 39.37
      RPKACC(J) = PKACC
      RVAP(J) = VAP
      IF   (J .LT. 2)    GO TO 10
      IF   (RPKACC(J-1) .LT. PKACC)   GO TO 10
      IF   (PKACC .GT. ACCMIN)   GO TO 10
      JJJ = J
      GO TO 15
10    CONTINUE
      JJJ = J
   15 CONTINUE
11    CONTINUE
      ACCMAX = RPKACC(JJJ)
      KKK = JJJ
C
C     SEARCH FOR THE MAXIMUM VALUE OF PEAK ACCELERATION IF AVAILABLE.
C     IF IT IS NOT, THREE MORE VALUES OF RADII ARE CHOSEN TO FIND IT.
C     ONLY THE ONES NEEDED ARE USED, WHEN MAXIMUM IS FOUND NO MORE
C     ARE CALCULATED.

      DO 20   J= 2, JJJ
      I = JJJ + 1 - J
      IF   (RPKACC(I) .LT. ACCMAX)   GO TO 35
      ACCMAX = RPKACC(I)
      KKK = I
   20 CONTINUE
      KKK = 2
      DIST = (RR(1) -   S*1.1)/3.
      DO 30   I =1, 3
      R = RR(1) - DIST
      R = R * 39.37
      CALL THINPL
      R = R / 39.37
      JJJ = JJJ + 1
      DO 25   J = JJJ, 2, -1
      RR(J) = RR(J-1)
      RPKACC(J) = RPKACC(J-1)
      RVAP(J) = RVAP(J-1)
```

```
25    CONTINUE
      RR(1) =, R
      RPKACC(1)=PKACC
      RVAP(1) = VAP
      IF   (RPKACC(1) .LT. ACCMAX)   GO TO 35
      ACCMAX = PKACC
   30 CONTINUE
C
C     IF THE MAXIMUM PEAK ACCELERATION IS NOT FOUND THE FINAL ARRAYS
C     FORMED ARE PRINTED AND CALCULATIONS CEASE FOR THIS CASE.
C
      IMAXI=JJJ
      DO  32   I=1, JJJ, 1
      FR(I)=RR(I)
      FPKACC(I)=RPKACC(I)
      FVAP(I)=RVAP(I)
32    CONTINUE
       GO TO 79
35    CONTINUE
36    CONTINUE
      LLL = 0
C
C     A FIBONACCI SEARCH IS DONE TO FIND THE MAXIMUM PEAK ACCELERATION.
C     THE TWO VALUES BRACKETING THE MAXIMUM PREVIOUSLY FOUND ARE USED AS
C     THE STARTING END POINTS.  RUPPER--LARGEST VALUE OF R,  AUPPER AND
C     VUPPER CONTAIN THE CORRESPONDING PEAK ACCELERATION AND VELOCITY.
C     RLOWER--LOWER VALUE OF R.  RMID(1)--LESSER CENETER VALUE OF R.
C     RMID(2)--THE GREATER CENTER VALUE OF R.
C     WHEN A VALUE OF RUPPER IS DISCARDED FROM THE SEARCH IT IS KEPT
C     IN THE FR ARRAY AS PART OF THE FINAL RESULTS.
C
      RUPPER = RR(KKK+1)
      AUPPER=RPKACC(KKK+1)
      VUPPER = RVAP(KKK+1)
      RLOWER = RR(KKK-1)
      RDIFF = RUPPER - RLOWER
      R = RLOWER + .381967 * RDIFF
      R = R * 39.37
      CALL THINFL
      R = R / 39.37
      RMID(1) = R
      AMID(1) = PKACC
      VMID(1) = VAP
      III = 1
      LL = 2
      R = RUPPER - .381967 * RDIFF
40    CONTINUE
      III = III + 1
      IF   (III .GT. 11)   GO TO 60
      R = R * 39.37
      CALL THINFL
      R = R / 39.37
      RMID(LL) = R
      AMID(LL) = PKACC
      VMID(LL) = VAP
      IF   (AMID(1) .GT. AMID(2))   GO TO 50
      RLOWER = RMID(1)
      RDIFF1 = RUPPER - RMID(2)
      RDIFF2 = RMID(2) - RLOWER
      IF   (RDIFF1 .GT. RDIFF2)   GO TO 45
      R = RLOWER + RDIFF1
      LL = 1
      GO TO 40
45    RMID(1) = RMID(2)
```

```
      AMID(1) = AMID(2)
      VMID(1) = VMID(2)
      R = RUPPER - RDIFF2
      LL = 2
      GO TO 40
   50 LLL = LLL + 1
      IF  (LLL .EQ. 1)   GO TO 54
      DO 52  I= LLL, 2, -1
      FR(I) = FR(I-1)
      FPKACC(I) = FPKACC(I-1)
      FVAP(I) = FVAP(I-1)
52    CONTINUE
54    FR(1) = RUPPER
      FPKACC(1) = AUPPER
      FVAP(1) = VUPPER
      RUPPER = RMID(2)
      AUPPER = AMID(2)
      VUPPER = VMID(2)
      RDIFF1 = RMID(1) - RLOWER
      RDIFF2 = RUPPER - RMID(1)
      IF  (RDIFF1 .GT. RDIFF2)   GO TO 55
      R = RUPPER - RDIFF1
      LL = 2
      GO TO 40
55    RMID(2) = RMID(1)
      AMID(2) = AMID(1)
      VMID(2) = VMID(1)
      R = RLOWER + RDIFF2
      LL = 1
      GO TO 40
60    IF  (LLL .EQ. 0)   GO TO 67
      DO 65   I= 1, LLL, 1
      J = I + 10
      FR(J) = FR(I)
      FPKACC(J) = FPKACC(I)
      FVAP(J) = FVAP(I)
   65 CONTINUE
   67 RDIFF = (RUPPER - S)*.1
C
C     THE FINAL ARRAY INCLUDES TEN EQUALLY SPACED VALUES FOR RADIUS
C     BETWEEN THE MAXIMUM PEAK ACCELERATION AND THE CRATER WALL.
C
      DO  70   I= 1, 10, 1
      FR(I) = FR(11) - (11 - I) * RDIFF
      FPKACC(I) = FPKACC(11) * FR(11) / FR(I)
      FVAP(I) = FVAP(11) * FR(11) / FR(I)
70    CONTINUE
C
C     VALUES FROM THE INITIAL ARRAYS ARE ADDED TO THE FINAL ARRAYS.
C
      LL = KKK + 1
      DO 75   I= LL, JJJ, 1
      J =  9 + LLL + I - KKK
      FR(J) = RR(I)
      FPKACC(J) = RPKACC(I)
      FVAP(J) = RVAP(I)
75    CONTINUE
      M =  9 + LLL + JJJ - KKK
      IMAXI=M
   79 CONTINUE
   81 WRITE(6,300)
  300 FORMAT(1H0)
      DO 250  M1=1,K0
      IF(FPKACC(M1).LE.0.) ISKIP=1
```

SUBROUTINE YANG1

```
 250 WRITE(6,275) M1,FR(M1),M1,FPKACC(M1),M1,FVAP(M1)
 275 FORMAT(1X,'FR(',I3,')=',G9.4,2X,'FPKACC(',I3,')=',G9.4,2X,
    1'FVAP(',I3,')=',G9.4)
     IDUMMY=0
     DO 260 IY=1,KO
     WRITE(7,1601) IY,IDUMMY,FR(IY),FPKACC(IY),FVAP(IY)
 260 CONTINUE
1601 FORMAT(2I3,1P3E15.5)
     RETURN   @ WAS GO TO 5
     END
```

APPENDIX D

IMPLEMENTATION GUIDELINE

The general model processors have three basic forms: (1) the fully deterministic complete driver with intermediate data output (FULDET), (2) the driver (FULBPS) that bypasses the meteoroid model/surface response model and operates on the intermediate data output generated in a type (1) execution, and (3) the driver for the pyrotechnic simulation (PYROM). Presented below are the computer control card runstreams with the proper sequence for the execution of a case study. In each example, the data cards are preceded by a line indicating the format. The basic assumption here is that the model exists on a magnetic tape compatible with a Univac 1108 major computer system. On the tape are three files corresponding to FULDET, FULBPS, and PYROM processors respectively.

Example case studies are given below:

(1) The fully deterministic model, FULDET, allows the sequential selection of meteoroid mass and velocity groups with the option of setting the range of dust-grain diameters and the number of random impact positions. The data card used for this run is of the form

MML MMU MVL MVU IGML IGMU N2 IHICUP

where MML and MMU are the meteoroid-mass index limits (may use integers from 1 to 10, as in Table 3, MVL and MVU are the meteoroid-velocity index limits (may use integers from 1 to 3, as in Table 3), IGML and IGMU are the ejecta-diameter limits (may use integers from 1 to 10 corresponding to 10 to 100 μm), N2 is the number of positions to be randomly selected per each meteoroid mass-velocity group, and IHICUP increments the 1108 system random number generator (because the computer produces the same set of random numbers for each case, unless manually incremented on to new numbers). A set of acceleration and velocity vs. range data cards is output for each mass-velocity group (for use with FULBPS). Table D-1 provides a sample runstream where the contents of file one of the magnetic tape are copied, the element DATAIN is updated for a particular mission when appropriate (cards from the first @ DELETE to the @ PREP card may be omitted when DATAIN is acceptable), and execution commences. This particular run is for meteoroid-mass groups

2 through 10, meteoroid-velocity group 3, grain-diameter of 10 μm only, and 1 random position. This would be typical for a run that is meant to produce only the acceleration and velocity vs. range data cards.

(2) Similarly, Table D-2 depicts a FULBPS runstream for a case study involving meteoroid-mass group 3, velocity group 1, and all 10 ejecta diameter possibilities for 100 random positions. The three types of data cards (format indicated in Table D-2) are:

N2 KPLOT

with N2 (integer) positions, KPLOT index indicating whether to plot (via Calcomp) the spacecraft outline for the integer 1 or to skip the plot when 0 is entered,

IHICUP KO IGML IGMU PVEL PMASS IMV IML SM1

where KO is the dimension of the following data array, IGML and IGMU are the grain diameter limits (1 to 10), PVEL is the meteoroid velocity, PMASS is the meteoroid mass, IMV and IMM are the meteoroid velocity and mass indices (as per Table 3) and SM1 is the corresponding value related to the flux and velocity of this particular M-V group by

$$SM1 = FLUX (IMM, IMV)*12/PVEL, \qquad (D1)$$

and finally the acceleration and velocity vs. range array where the data is in the form of

I R(I) A(I) V(I)

with KO entries.

(3) Lastly, the pyrotechnic event runstream appears in Table D-3. The only essential difference between this runstream and the one for FULDET is the data card preceding the acceleration and velocity vs. range array. The form of this card is

IHICUP KO IGML IGMU IPYRO NPYRO PRMIN PRMAX ANAME

where IPYRO indicates the identifying number assigned to this type of device, NPYRO indicates how many pyrotechnic devices of this type are on the spacecraft, PRMIN and PRMAX are the localizing parameters defined in Appendix B and ANAME is an 18-space alphanumeric spacecraft zone name used for printout purposes (see Table 2b for example).

TABLE D1. SAMPLE FULDET EXECUTION RUNSTREAM

```
@RUN   FULDET,ETC.
@ASG,T     TAPE.,T,XXXXX
@REWIND TAPE.
@COPY,G    TAPE.,TPF$.
@FREE TAPE.
@DELETE,A   .FULABS
@DELETE,SR    .DATAIN
@FOR,IS     .DATAIN,.DATAIN
   (THE NEW DATAIN DECK)
@PREP
@MAP,IS    .FULMAP,.FULABS
 IN   .FULDET
 IN .DATAIN
 LIB  LIB*JPL$.
 LIB  LIB*PLOT$.
@XQT   .FULABS
 * * FORMAT(8(I3,3X)) * *
  2     10      3      3      1      1      1      1
@FIN
```

TABLE D2. SAMPLE FULBPS EXECUTION RUNSTREAM

```
@RUN    FULBPS,ETC.
@ASG,T      TAPE.,T,XXXXX
@REWIND     TAPE.
@MOVE   TAPE.,1
@COPY,G      TAPE.,TPF$.
@DELETE,SR  .DATAIN
@DELETE,A    .FULBPA
@FOR,IS     .DATAIN,.DATAIN
  (THE NEW DATAIN DECK)
@PREP
@MAP,IS    .FULBPM,.FULBPA
 IN  .FULBPS
 IN     .DATAIN
 LIB    LIB*JPL$.
 LIB    LIB*PLOT$.
@XQT  .FULBPA
 • • FORMAT(2I10) • •
       100          0
 • • FORMAT(4(I3,2X),10X,2E12.5,1X,2(I2,2X),E9.4) • *
  1   19    1   10                .14458+05   .10000-11   1   3   .1088-08
 • • FORMAT(I3,3X,1P3E15.5) * *
  1          7.56170-05      1.67486+01     -1.43073-01
  2          8.73974-04      1.44910+00     -1.23788-02
  3          1.67233-03      7.57313-01     -6.46925-03
  4          2.47069-03      5.12601-01     -4.37883-03
  5          3.26904-03      3.87415-01     -3.30945-03
  6          4.06740-03      3.11373-01     -2.65986-03
  7          4.86576-03      2.60284-01     -2.22344-03
  8          5.66411-03      2.23597-01     -1.91005-03
  9          6.46247-03      1.95974-01     -1.67408-03
 10          7.26083-03      1.74426-01     -1.49001-03
 11          8.05919-03      1.57147-01     -1.34241-03
 12          8.20090-03      1.54935-01     -1.32672-03
 13          8.42989-03      1.52737-01     -1.31693-03
 14          9.02959-03      1.40803-01     -1.21274-03
 15          1.00000-02      1.24262-01     -1.06287-03
 16          2.00000-02      6.59525-02     -6.16022-04
 17          3.00000-02      4.44363-02     -3.83329-04
 18          4.00000-02      3.44277-02     -3.00458-04
 19          6.00000-02      2.33319-02     -2.04667-04
@FIN
```

TABLE D3. SAMPLE PYROM EXECUTION RUNSTREAM

```
@RUN    PYROM,ETC.
@ASG,T     TAPE.,T,XXXXX
@REWIND     TAPE.
@MOVE    TAPE.,2
@COPY,G      TAPE.,TPF$.
@FREE     TAPE.
@DELETE,A .PYROMA
@DELETE,SR    .DATAIN
@FOR,IS     .DATAIN,.DATAIN
   (THE NEW DATAIN DECK)
@PREP
@MAP,IS    .PYROMS,.PYROMA
 IN   .PYROM
  IN   .DATAIN
 LIB    LIB*JPL$.
 LIB   LIB*PLOT$.
 * . FORMAT(2I10) . *
       100          0
 . * FORMAT(6(I3,2X),2E12.5,3A6) . *
002   06  001   10  001  004    .22+00       .54+00SECTOR ONE CONE
 . . FORMAT(I3,3X,1P3E15.5) * *
  1           5.2-04        1.00+02       -1.65+01
  2           8.0-02        2.80+01       -4.60+00
  3           2.5-01        3.00+00       -2.70-01
  4           5.0-01        8.00-01       -6.80-02
  5           7.5-01        4.00-01       -3.90-02
  6           1.00+00       1.00-01       -2.70-02
@FIN
```


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