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PROGRESS TOWARD A COSMIC DUST COLLECTION FACILITY ON SPACE STATION

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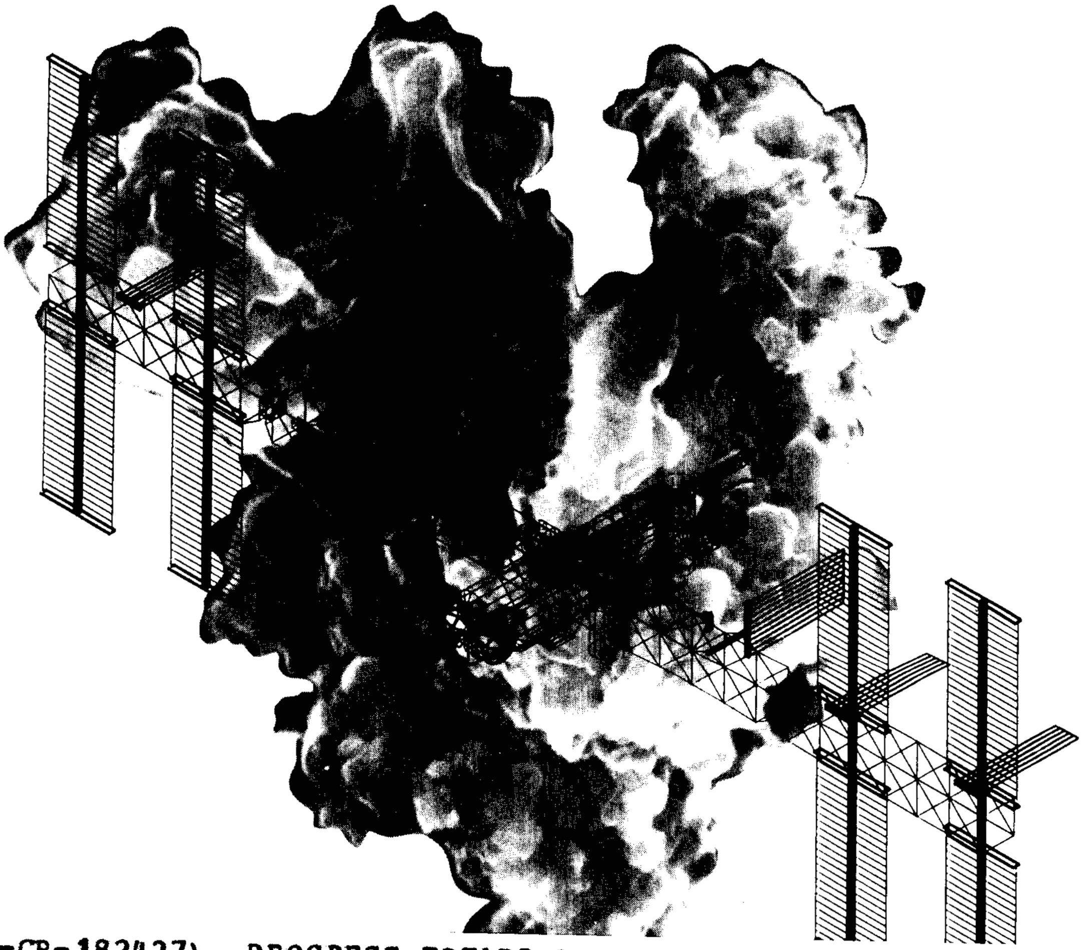

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PROGRESS TOWARD A COSMIC DUST COLLECTION FACILITY ON SPACE STATION

Edited by
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and
William C. Carey

A Report of the Workshop on Micrometeorite Capture Experiments

June 28-July 1, 1987

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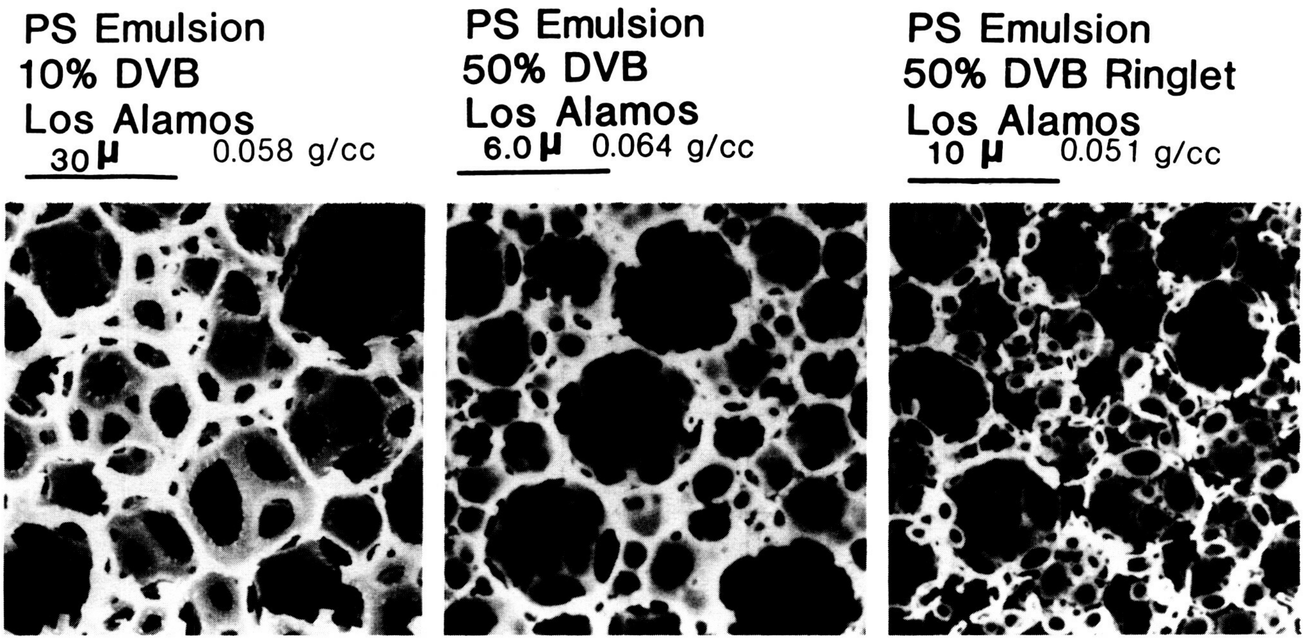

PS Emulsion
10% DVB
Los Alamos
30 μ 0.058 g/cc

PS Emulsion
50% DVB
Los Alamos
6.0 μ 0.064 g/cc

PS Emulsion
50% DVB Ringlet
Los Alamos
10 μ 0.051 g/cc

The microstructures of three promising candidates for cosmic dust collection cells. All are ultra-low density polystyrene emulsion foams. DVB refers to the divinylbenzene content. This figure is from: Wrobleski and Williams (1987) *Potential Materials for Cosmic Dust Capture,* Los Alamos National Laboratory, LA-UR-87-3478. This report is available upon request from Michael Zolensky, Code SN2, NASA/Johnson Space Center, Houston, TX 77058.

Preface

This report documents both scientific and programmatic progress toward the development of a Cosmic Dust Collection Facility for the proposed Space Station. This progress was reported and discussed by a wide range of cosmic dust community members at a workshop held at Carmel, California from June 28–July 1, 1987. Participants at the workshop represented subdisciplines such as planetary sciences, exobiology, orbital debris, orbital dynamics, cosmochemistry, and astrophysics. Members of these subdisciplines are expected to be major users of a Cosmic Dust Collection Facility on the Space Station.

The Carmel Workshop was convened by an *ad hoc* committee of active scientists from both the Exobiology and the Solar System Exploration Programs within NASA under the leadership of W. Carey of the McDonnell Center for Space Sciences, St. Louis. Other members of the *ad hoc* committee were T. Bunch, P. Tsou, and I. D. R. Mackinnon. The workshop committee members gratefully acknowledge generous support from the Lunar and Planetary Institute and its Director, K. Burke, as well as well-placed advice and guidance from F. Hörz of the NASA Johnson Space Center. Lebecca Turner provided exemplary logistics support prior to and during the workshop and the smooth operation of the program drew heavily upon Lebecca's expertise. This report was typeset and produced by the Lunar and Planetary Institute under the capable direction of Renee Dotson and Pam Thompson. The report content is the result of a community effort by many contributors, primarily including F. Hörz, H. Zook, and W. Carey, and coordinated by I. D. R. Mackinnon.

Program

Monday, June 29—Overview Session 8:00- 10:00 a.m.

Carey	Introduction
Mackinnon	Workshop aims and objectives
Quaide	HQ programmatic status of CDCF
Chang	Biology science goals/requirements
Walker	Planetary science goals/requirements

Monday June 29—Sample Analysis Session 2:00-6:00 p.m.

Co-chairmen: Chang, Mackinnon

Sandford	The use of infrared spectroscopy for analysis of samples returned from the Space Station Cosmic Dust Collection Facility
Cronin	Molecular analysis of IDPs: amino acids as indicators of the progression of organic chemical evolution
Hahn	Direct determination of aromatic hydrocarbons in meteorites by two-step laser desorption/multiphoton ionization mass spectrometry
Carey	Electron energy loss spectroscopy: light element analysis of collected cosmic dust
Rietmeijer	The necessity for micro-analytical characterization of laboratory shock experiments
Bradley	Automated point count analyses of thin-sectioned meteoritic materials using an analytical electron microscope equipped with digital beam control
Blake	Low voltage SEM of interplanetary dust particles
Hare	Limits of amino acid detection by chromotography
Peterson	Survival of organic molecules as result of simulated hypervelocity impact

Monday, June 29—Flight Opportunities Session 7:30-9:00 p.m.

Co-chairmen: Bunch, Stephenson

Yen	Cometary dust collection—mission options and strategy
Tsou	Concept for intact capture of cosmic dust collection on Space Station
Stephenson	Particulate capture in the European retrievable carrier program
Stephens	Detection of micrometeoroids and orbital debris using small satellites launched from the Space Shuttle

Tuesday, June 30—Multiple Film Media Session 8:00-10:00 a.m.

Co-chairmen: Rietmeijer, Williams

Wu	Computer simulation of hypervelocity impact of a particle on a membrane
Oyer	Calculation of velocity losses and estimation of cosmic dust integrity for hypervelocity impacts on thin foils
Hörz	Expected shock effects in cosmic dust particles caused by hypervelocity capture
Rietmeijer	Lessons from Solar Max
Dixon	Hypervelocity capture of glass microspheres
Tsou	Hypervelocity intact capture in multiple thin films

Tuesday, June 30—Multiple Film Media Session (continued) 2:00–3:00 p.m.

Co-chairmen: Rietmeijer, Williams

McKay	Impacts on Shuttle orbiter caused by the firing of a PAM D2 solid rocket: results of the STS 61B plume witness plate experiment and implications for a cosmic dust collection facility
Zolensky	The nature and consequences of particulate spacecraft debris material in the Space Station environment
Brownlee	Atomised capture of hypervelocity particles

Tuesday, June 30—Underdense Media Session 3:00–6:00 p.m.

Co-chairmen: Brownlee, Tsou

Tsou	The development of hypervelocity intact capture
Anderson	Collection of interplanetary dust particles by hypervelocity impact into low density media
Kromydas	A parametric analysis of hypervelocity intact capture data
Landel	Polymeric dust collection: physical property scaling laws of polymers and polymeric foams applicable to hypervelocity intact capture
Peng	A model for hypervelocity intact capture in underdense media
Young	Microcellular plastic foams
Wrobleski	Technology review of underdense target media
Clark	Search for methods of preserving organic components during cosmic dust collection

Tuesday, June 30—Space Station CDCF Concept 7:30–9:00 p.m.

Co-chairmen: Hörz, Carey

General discussion session to review in detail the current concept of the collection facility

Wednesday, July 1—Trajectory Determination (Techniques) Session 8:00–10:00 a.m.

Co-chairmen: Auer, Alexander

Alexander	Spatial density and trajectory of submicron particles in the inner regions of the Earth's magnetosphere: an adaptation of the CODEM experiment
Tuzzolino	New experimental methods for measurements of dust particles in space based on polarized film detectors
Auer	Non-destructive velocity/trajectory sensing of charged cosmic dust particles on the Cosmic Dust Collection Facility

Wednesday, July 1—Trajectory Determination (Theory) Session 2:00 - 6:00 p.m.

Zook	On cosmic dust trajectory measurements and experiment pointing considerations
Alexander	Enhanced spatial density of submicron lunar ejecta in the Earth's magnetosphere I: source characteristics
Alexander	Enhanced spatial density of submicron lunar ejecta in the Earth's magnetosphere II: cislunar space transport and dynamics between L values of 1.2 and 6.1
Gustafson	Interstellar grain trajectories through the solar system
Gustafson	Journey from a comet parent body to 1 AU, orbital evolution of dust particles
Jackson	Long term evolution of interplanetary dust trajectories: precision orbit generation with the Everhart Radau integrator

Wednesday, July 1—Science Definition/Requirements Session Part I 7:30–9:00 p.m.

Thursday, July 2—Science Definition/Requirements Session Part II 8:00–12:00 p.m.

Workshop Report

INTRODUCTION

This report summarizes the proceedings of a workshop held at the Carmel Valley Inn, Carmel, California from June 28th to July 1st, 1987. Workshop participants addressed both programmatic and scientific developments for the Cosmic Dust Collection Facility to be housed on the proposed Space Station. Activities directed toward an early Initial Operating Capability (IOC) deployment have increased considerably since the 1985 workshop held at the Lunar and Planetary Institute (LPI), Houston and reflect a growing enthusiasm for this endeavor throughout the space sciences community. The Carmel workshop was a logical outgrowth of strong community interest in low-Earth orbit sample collection initially expressed at the Long Duration Exposure Facility (LDEF) Workshop held at St. Louis in 1983. Many instrument concepts have evolved from this St. Louis workshop (hosted by R. Walker) as well as from the follow-up workshop at the LPI in 1985. Substantive developments presented at the Carmel workshop are summarized below, while abstracts of presentations that provide more detailed information follow.

The justification and format for the workshop arose out of discussions with representatives from Codes EB and EL at NASA Ames Research Center in February, 1987. The workshop format involved short overview sessions presented by invited speakers followed by detailed presentations on specific topics from individual scientists within the space sciences community. Details of the workshop schedule, including a list of speakers and titles of presentations are given in the Program printed at the front of this report. Since the scientific rationale for a Cosmic Dust Collection Facility (CDCF) had been exhaustively discussed at the 1985 LPI workshop and subsequently well enunciated in the accompanying technical report (*Trajectory Determinations and Collection of Micrometeoroids on the Space Station*, F. Hörz, ed., LPI Technical Report No. 86-05, 1986), there was less emphasis on this aspect during the Carmel workshop. However, attendees were requested to address the concerns listed in the Interim Report compiled by the Planetary Geosciences Strategy Committee chaired by Don Burnett.

As is evident from this report, many of those concerns have received considerable attention during the past eighteen months. In particular, both the theory and techniques of trajectory determination in low Earth orbit (LEO) have benefited from intensive study by a number of community members. In addition, very detailed presentations on new materials for both multiple film and low-density media capture designs were provided by experts in the field. Developments in the experimental aspects of this field were also well represented at the Carmel workshop and included impact experiments into low-density media; rapid, automated elemental analyses of individual interplanetary dust particles (IDPs); low-voltage electron microscopy for enhanced morphological information; and improved detection limits for the analysis of amino acids and other organic molecules. Extended discussion on the status of the CDCF Program within NASA Headquarters and the anticipated progress of these activities with respect to future space missions occupied a considerable period of time, both during the formal sessions and at more informal venues within the Carmel Valley Inn surrounds. A summary of the Carmel workshop proceedings, grouped by the major themes of the meeting, is given below.

TRAJECTORY SENSOR CONCEPTS

The 1985 LPI workshop (LPI Tech. Rpt. 86-05, 1986) identified a number of methods that are in principal capable of measuring cosmic dust trajectories in LEO. Some of these methods have a proven flight heritage and successful deployment in space. However, none of these concepts has ever been integrated with a particle capture device. In an ideal world, the optimum trajectory measurement device would not physically interfere with an incoming hypervelocity particle so that it may enter the capture device in as pristine a state as possible. In the early stages of this program, this ideal may not be achieved, because most current devices have structural or sensor elements that, if impacted, may degrade or even destroy the particle. Therefore, the challenge for trajectory sensor device development is to arrive at designs that minimize particle interference and degradation during trajectory measurement.

The need to measure particle trajectories—with substantially greater precision than in most previous flight applications—requires a minimum of two sensor planes. These sensor planes must be spaced at precisely determined distances for a direct velocity measurement. Furthermore, trajectory measurement requires that the *x/y* penetration locations through these sensor planes be known in order to establish a velocity vector. Knowledge of these vectors for each incoming particle enables the locus (or path) of the impactor in the capture device to be determined. These requirements for precise trajectory determinations present additional challenges for sensor development. Many presentations related to trajectory measurements at the Carmel workshop addressed these challenges, using for the most part relatively mature flight-proven concepts from earlier sensors as a basis for future development.

Charged Particle Sensor

A concept that closely approaches the ideal detector mentioned above entails the detection of naturally charged particles as they pass through highly transparent wire grids that are held at carefully controlled, constant potentials. The originator of this concept, S. Auer, presented his current thinking on a charged particle sensor. His presentation described a device of some 100 cm length that, using state-of-the-art amplifiers and other electronic technology, would be capable of measuring particle velocity (to an accuracy of 1%) and trajectory angles (to an accuracy of 1°) for the following particle parameters:

Velocity (km/s)	1	10	100
Particle radius (μm)	2	6	20

This concept requires efficient rejection of the ambient plasma in order to prevent interference with the particle-charge sensors. The electrical charge to be expected on particles at 500 km altitude in LEO is about 0.5V (± 0.2V) negative, due to charging by the upper terrestrial ionosphere. This charge is within the detection range of the proposed technique for the particle radii given above. Further definition of this concept for application in LEO will be necessary for flight readiness.

Thin-Film Penetration Sensors

Other than the above-mentioned charged particle sensor, all other devices described at the Carmel workshop derive their signals from the penetration of thin films or from impacts onto some target surfaces. Thus, piezo-sensors monitor the seismic energy emanating from a penetration event; alternatively, the plasma generated during impact may be detected, and the number of dipoles lost during penetration of PVDF foils can also be measured. All of these techniques suffer from the disadvantage that thin film penetration is needed and this penetration may interfere with particle capture objectives. Clearly, the thinner the detector foils, the less degraded an impacting particle of a given size should be upon capture. Exceptionally thin foils are required for this purpose, and this may pose problems either in manufacture (e.g., the thinnest PVDF foil currently available is 2 μm) or in the detection threshold. Thus, by either desire or design, very little projectile momentum or energy will be partitioned into the sensor foils and the signals generated will be substantially weaker than those traditionally measured.

The major thrusts of instrument development using these thin film penetration methods are as follows: (1) decrease the thickness of penetration foils to the thinnest possible; such efforts should not be confined to commercially available foils, but may include state-of-the-art technology at laboratories specializing in the manufacture of thin films; (2) define the implications and modifications in electronic design associated with signal acquisition from such thin films; and (3) provide preliminary design of an integrated sensor, specifying expected accuracy in velocity vector measurement, effective collection aperture of the sensor device, and the spacecraft resources needed (e.g., volume, weight, and power).

TRAJECTORY ACCURACY AND ORBITAL EVOLUTION

The reason for trajectory determinations on cosmic dust grains impacting the CDCF is to determine the origin of each collected grain. This procedure may involve numerically evolving the orbit of a detected dust grain backward in time until its orbit matches the orbit of some potential parent body at a convergent point in time. Possible sources of cosmic dust grains include comets, asteroids, the Moon, and interstellar dust. Small fragments of Earth-orbiting artificial satellites are also likely to be encountered. Scientific analyses carried out on captured grains whose origins have been determined then become, by proxy, analyses of the orbitally associated parent bodies. Such analyses should greatly expand our knowledge of the chemical, isotopic, and petrographic nature of many "primitive" parent bodies.

It is important to know how accurately dust trajectories should be determined in order to uniquely pair parent bodies with daughter dust grains. This knowledge is not yet in hand, however, and it will require some considerable study of the differential rate of divergence of parent-daughter orbits, after parent-daughter separation, to establish suitable accuracy requirements. Gravitational forces from the sun, the Moon, and planets primarily determine the orbital evolution of asteroids and comets that also undergo minor perturbations due to material ejection. On the other hand, small dust grain orbits strongly evolve also under the forces of radiation pressure, Poynting-Robertson (P-R) drag, and solar wind drag. Two analyses of dust orbit evolution that included all of these forces were presented at the Carmel workshop. Both studies showed that Earth and Venus play an important role in gravitationally scattering dust grains as they drift toward the sun under nongravitational forces. This effect was especially significant for low-inclination, low-eccentricity dust grains that may drift in from the asteroid belt.

Most investigators working on orbit evolution were optimistic that it would be possible, given sufficient trajectory accuracy, to uniquely recognize the parent bodies of nearly every dust grain that was emitted from a presently known comet. Identification of unique main belt asteroids using this same approach would be more difficult, although it was considered likely that a general origin in the main asteroid belt would be recognizable. Besides numerical evolution studies, all investigators felt that significant effort should be directed toward developing analytical constants (or near constants) of motion for small dust grains. Such constants, if found, could be used to distinguish dust grains originating from different source bodies. This type of constant may be similar to the empirical "D" factor developed by Southworth and Hawkins for meteor streams, or it may be similar to a modified "Tisserand invariant."

In summary, many Carmel workshop participants agreed that a high-priority near-term objective for the dust community should be to study dust-grain orbital evolution. These studies would be for the primary purpose of defining the accuracy with which trajectories must be measured in order to recognize the sources of incoming dust grains on the CDCF.

CDCF POINTING DIRECTION

Experiment sensors that point in the direction of spacecraft motion (e.g., the apex direction) are expected to experience meteoroid impact rates six to nine times higher than the rates on sensors that face in the antapex direction. However, impact velocities are expected to be much higher on a forward-facing sensor and it will be difficult to retrieve meteoroids that are not melted or vaporized. Therefore, an antapex facing sensor may be more desirable, as impact velocities down to about 4 km/sec are expected. A sensor that could be pointed in different directions at different times would be even more desirable. A response to predictions or astronomical observations that particles may arrive from a particular direction could then be implemented with minimal interruption to Space Station activities. Such a response, particularly if associated with robotic or telemetered control, could not be implemented with a fixed detector. However, pointable structures are more difficult and more expensive to construct. A more cost-effective compromise might be to utilize two or three detectors that each face in a different direction. It appears that nearly all Earth-orbiting space debris will approach the Space Station at angles <90° to the apex direction. These observations provide some constraints on the possible directions that collector surfaces may face.

Additional study is required on expected particle fluxes and velocity distributions for sensors that face in directions other than the forward and backward directions. The potential tradeoffs in particle fluxes and impact velocities need to be established with these additional studies. With their near-term completion, it will be possible to make informed decisions on the scientific and engineering priorities that establish final pointing directions for all collector surfaces. Detailed engineering designs can then be formulated.

DEVELOPMENT OF CAPTURE DEVICES

Nondestructive deceleration of particles that generally have kinetic energies in excess of their specific heats of fusion, if not vaporization, remains problematic. However, capture devices that minimize the peak pressures experienced by the projectile have been suggested. These devices utilize either low bulk-density foams (leading to low average peak stress) or ultra-thin films (leading to very short pulse durations and rapid pressure decay across the impactor). Such media hold promise for the capture of unmelted projectile remnants at impact velocities between 5 km/s and 8 km/s. Approximately every fifth impact on a collector that points in the antapex direction of the Space Station velocity vector will have such low encounter velocities.

At the Carmel workshop, a number of experimental and theoretical studies were presented that stressed that recovery of unmelted particles may indeed be accomplished in LEO. Positive proof comes from returned surfaces exposed by the Solar Max satellite that yielded unmelted cosmic dust components, including hydrated silicates. These Solar Max surfaces further demonstrate that valuable science can be gleaned from melts and vapors. Thus, previous small-scale impact experiments have been corroborated by the Solar Max studies. There is, however, a general consensus that even under favorable conditions some particle degradation appears unavoidable during hypervelocity capture. Many investigators take the realistic viewpoint that the majority of cosmic dust residues will occur in the form of melts and vapors. A progressive scheme outlining the loss of scientific information with increasing particle degradation and/or phase transformation was discussed. It is obvious that delineation of boundary conditions that lead to solid/liquid and liquid/vapor phase transitions under a wide variety of initial impact conditions is desirable. Without additional simulated impact experiments on well-characterized materials, this objective is difficult to accomplish in a quantitative fashion.

A general experimental and theoretical understanding exists for thin-film penetration mechanics and an understanding of cratering/penetration processes in ultra-low density, porous targets is emerging as well. However, at best, these data may be extrapolated only with extreme caution to the dimensional and energy scales applicable to cosmic dust collisions on the Space Station. While existing data must guide the development of suitable cosmic dust capture devices, future experiments and theoretical efforts must more closely resemble the conditions expected for the Space Station impacts. These future efforts must include the use of high-fidelity analog projectiles, containing some of the major phases identified in cosmic dust particles. By necessity, some experiments must be performed at relatively large scales due to the lack of suitable experimental launch facilities for particles a few tens of microns in diameter. Appropriate dimensional scaling of impactor and targets must be performed with such experimental configurations.

For example, based upon existing data, the thickness of thin-films or foam walls should be <0.01 times the diameter of the projectiles in order to prevent complete fragmentation of the impactor. Anticipating that such dimensional scaling is applicable to the Space Station collector itself, one very rapidly approaches state-of-the-art methods in the manufacture of thin films and foams. Using this formulation, penetration membranes should not exceed 0.1 μm in thickness. At present, this requirement seems to be more readily satisfied by the use of thin foils than by foams. "Low" bulk density of any target alone is not sufficient to ensure low peak stresses. Unless foam walls are substantially smaller than representative projectile dimensions, penetration of a foam can be simply modelled as a series of successive membranes, similar to multiple thin-film penetration.

Evaluation of the usefulness of any given capture device will strongly depend on total projectile yield, the physical state of impactor remnants from experiments at laboratory velocities, and the extrapolation of these results to natural impact speeds. In addition, the ease with which these remnants may be recovered and readied for analysis is an important aspect in the evaluation of any collector device. Ultimately, the choice of material composing the collector defines the compatibility of the device with specific cosmochemical objectives.

ANALYTICAL TECHNIQUES

Significant advances in the application of microanalytical techniques as well as their development and refinement have occurred in the interim since the 1985 workshop (LPI Tech. Rpt. 86-05, 1986). These advances have occurred in the analysis of biologically important compounds as well as the inorganic, or predominantly silicate, fraction. In the latter case, these techniques have been applied to fine-grained (submicrometer) interplanetary dust particles (IDPs) collected as part of the NASA Cosmic Dust Program. All of these technical developments build upon a growing expertise within the world-wide cosmic dust community in the preparation and analysis of very low mass materials. This expertise also extends to the analysis of plasma residues and thin coatings that commonly form from hypervelocity events. The ability to analyze such materials is an important and integral part of an overall systems capability in the early IOC time frame for the Space Station.

Spectroscopic techniques have provided a broad database on the bulk properties of a large number of IDPs, many of which are of the order of 15 μm in size. These data, particularly infrared (IR) spectra, have been used to broadly classify particles, as well as to provide a "fingerprint" of commonly-occurring minerals. These "fingerprints" have been subsequently confirmed in considerable detail by a complementary technique, analytical electron microscopy (AEM). The IR and Raman spectra of IDPs have also been compared with astrophysical observations of interstellar and solar system objects and have provided circumstantial evidence for the occurrence of similar hydrocarbon molecules in IDPs and cool interstellar clouds. There is some indication from preliminary studies that improvements in sample preparation will allow the use of IR spectroscopy on even smaller masses of IDPs.

Additional electron beam techniques recently applied to IDPs include low-voltage scanning electron microscopy (SEM), automated elemental analysis and electron energy loss spectroscopy (EELS). This latter technique may provide supplementary data for unambiguous identification of carbons and the spatial distribution of low atomic number (Z) elements in IDPs. Low voltage SEM, when applied to uncoated, fine-grained IDPs, provides a wealth of data on surface morphology and, if used in conjunction with AEM, allows the precise identification of distinctive features in different types of IDPs. In a field that is in great need of an enlarged database on the detailed mineralogy of individual IDPs, the use of automated elemental analysis, combined with image analysis techniques, shows great promise for a rapid increase in our understanding of IDP variability. These techniques combine the high spatial resolution of an AEM with statistical techniques to obtain complete characterization of an IDP section in a matter of hours.

Advances in the analysis of biologically important molecules have occurred for a number of very specific techniques such as laser desorption and liquid and gas chromatography. These techniqes have been attempted on very few IDPs due to their small sample size and the relatively low abundance of organic molecules in many IDPs. However, a combination of improved chemistry and chromatographic techniques has pushed the detection limits for amino acids down to the femtomole range. The use of amino acids to calibrate low-velocity impact experiments appears to have some promise for exobiology studies of cosmic dust. Two-step laser desorption techniques also hold great promise for sensitive analyses of organic molecules in IDPs. This technique is highly molecule selective and has been used to rapidly identify parent molecules from microgram samples of carbonaceous chondrite meteorites. Advances in the mass resolution of the instrument and refinements in sample preparation may soon allow the direct determination of aromatic compounds from even smaller quantities of extraterrestrial material.

PROGRAMMATIC PROGRESS

Representatives of the Solar System Exploration Division, EL, the Life Sciences Division, EB, and the Space Station Utilization Branch, SSU, were present at the Carmel workshop and significant progress was reported in a number of areas. For example, an evolutionary concept that entails a total sensor area of some 10 m^2 in the early IOC timeframe and a gradual build-up to a substantially larger facility (~50 m^2) during the mature Space Station era was adopted. All current plans for the Cosmic Dust Collection Facility (CDCF) on the Space Station refer to this 10 m^2 facility. However, all detailed designs for the IOC configuration must consider, and provide for, capabilities compatible with future growth.

The Cosmic Dust Collection Facility is considered a serious candidate for deployment during the early period of Space Station IOC. Within the tentative nature of current Space Station manifests, the CDCF is scheduled for assembly flight No. 3 which will be launched in the summer of 1994. The CDCF is also considered a strong candidate for harvesting and servicing by robotic means, because manned extra-vehicular activity time is already a limiting factor for many Space Station projects. The limitations imposed by available crew time are especially critical during the assembly sequence which requires 18 STS flights.

A Memorandum of Agreement has been reached between Codes EL and EB on the development of mutually beneficial Space Station projects. The memorandum states that Code EL will take the lead role in the development of the dust collection facility, while Code EB will be a supporting division. At the workshop, representatives from Code EL suggested plans for facility and instrument development and concurred with a widely held opinion that urgent development tasks need FY 88 financial support. The nature and level of this support was outlined, but uncertainties in the current fiscal environment make it difficult for Code EL to provide firm commitments. Nevertheless, some resources will be available for CDCF development during FY 88 and FY 89.

Johnson Space Center was selected as NASA Lead Field Installation for the CDCF development. Part of this development includes the design of general purpose capture devices that may initially occupy a large proportion of the facility. Upon retrieval, these general purpose collectors will be available to the scientific community at large through the JSC Curatorial Facility. This procedure will provide individuals with an opportunity to participate in the analysis program without the need to develop their own collectors. The remaining facility surfaces will be occupied by PI-owned instruments. Prospective PIs are encouraged to focus on the development of specialized devices that may address very specific cosmochemical objectives.

The Planetary Geosciences Strategy Committee, an advisory group to Code EL, is in the process of evaluating a number of suggested Space Station payloads, including the CDCF. A summary report by this committee is due to be released shortly. It is important to note that formal initiation of a new CDCF Project will occur at the earliest in late FY 89. The FY 88 and FY 89 pre-project study efforts must produce instrument and facility concepts capable of meeting the stated science objectives. Continued evaluations and critiques of these developments by nonadvocacy groups will take place throughout the next two years. Elevation to formal Flight-Project status remains a competitive process.

FLIGHT OPPORTUNITIES

Testing of instrument components or prototypes in LEO was considered an important aspect of instrument development during the 1985 workshop. The STS Challenger accident has seriously affected these plans. The Long Duration Exposure Facility (LDEF I) remains in orbit and prevents evaluation of first-order capture device concepts. The LDEF II project has been terminated and other free-flyers have been postponed. Given the current schedules for resumption of STS flights and associated manifests, there remains little opportunity for timely tests of components or prototypes in LEO. Many instrument designs may have to rely on limited simulations in terrestrial hypervelocity laboratories.

Nevertheless, space exposure and *in situ* testing of instrument components and prototypes remain high priorities in the development of Space Station dust instruments. While opportunities for conceptual instrument evaluations have virtually vanished, the need for operational shake-down and the demonstration of flight readiness in LEO remains unchanged for all flight candidates considered during the CDCF Project Phase.

A number of possible, near-term flight opportunities were discussed at the Carmel workshop and all are in various stages of planning and development. These opportunities include (a) the exposure of already fabricated capture devices as part of the Get Away Special (GAS) program and (b) use of the "Plume Witness Plate" designed and exposed previously in LEO to study manmade particulates. Both of these opportunities are STS-dependent and their success requires timely coordination with the STS Project Office. In addition, plans to accommodate small satellites inside GAS canisters and to launch them by STS were presented at the Carmel workshop. Such satellites could carry prototype collection and/or detection devices and could be operational for as long as five years.

European participants at the Carmel workshop discussed European Space Agency (ESA) interests and plans in the area of cosmic dust studies. ESA continues to support a variety of cosmic dust capture concepts and brief descriptions of the most opportune projects were presented. The European Retrievable Carrier (EURECA) will constitute a valuable platform for *in situ* cosmic dust research and will provide a test bed for the instrument concepts and their subsequent development on other missions. ESA plans to have an operational EURECA by the early 1990s. A still more ambitious plan in the form of a dedicated dust investigation mission exists in proposal outline. This plan calls for very large surface areas (30 m^2) and a launch in 1994. Participation by USA scientists on a co-investigator basis was invited and encouraged for both flight programs.

FACILITY DEVELOPMENT

Some specific issues relating to the actual architecture of the facility were formally discussed at the Carmel workshop, while others were implied by the thrust of many workshop presentations. Many design and construction precepts developed during the 1985 workshop (LPI Tech. Rpt. 86-05, 1986) are still valid for the proposed CDCF.

A reduction in scope from the larger and more ambitious facility that would expose a 50 m^2 collection area was in large measure caused by limited STS and Space Station resources. This facility, as defined in the Mission Requirements Document (MRD), produced during the 1985 workshop, was rejected from consideration as an early IOC payload. The major reasons for this rejection were excessive weight ($\sim$1600 kg) as well as projected volume (27 m^3) and continuous power requirements ($\sim$1 KW). The reduced facility, with only 10 m^2 exposed collection area, was estimated to weigh 350 kg, to occupy $\sim$10 m^3, and to demand only 0.25 KW power. The basic geometry of this facility may not necessarily be the cube geometry proposed at the 1985 LPI workshop.

Detailed discussions resulted in the recommendation that even the reduced facility should expose surfaces at different orientations relative to the Space Station velocity vector. Additional studies are necessary in order to relate the absolute particle flux and relative velocity distributions for surfaces pointing into specific directions. Trade-off studies between particle flux and mean encounter velocities will figure prominently in planning for facility structural architecture. In addition, the potential for intercepting particle streams needs detailed study as the results may determine whether some surfaces require modest articulation capabilities.

Most capture devices and trajectory sensor designs imply packaging into multiple arrays, thus suggesting a modular construction of instrument carrier frames, as previously determined at the 1985 LPI workshop. The desire to perform robotic harvesting requires standard modules, at least for the capture devices and preferably for the trajectory determination modules as well. A module design study that will address accommodation of both foam- and thin-film penetration capture devices will commence shortly at Johnson Space Center.

SUMMARY

The Carmel workshop marked the transition from a comprehensive, conceptual approach to cosmic dust collection to a more realistic and detailed outlook predicated upon the near-term prospect of actual LEO dust collection from the Space Station. This transition also highlighted the urgency with which many tasks need to be performed before the Project Phase of the CDCF. Many important scientific and technical questions must be answered rapidly in order to ensure maturity of this project in time for integration into the Space Station IOC. Some of these questions and tasks are listed below in no particular order of priority and emerge from the workshop as recommendations for future activity.

1. The Facility should meet essentially the same structural and ergonomic requirements listed in the 1985 workshop report (LPI Tech. Rpt. 86-05, 1986), with the exception that the exposed surface area be reduced to 10 m^2.

2. With the above reduction in power/weight requirements, the Facility should remain an integral part of planning for Space Station science and the Facility should be fully operational for Space Station IOC.

3. The near-term development plan for the construction of an IOC Facility should be rapidly implemented and should emphasize those elements of the CDCF that require better definition and that may influence the design of the CDCF.

4. Major elements of CDCF development that require emphasis during the near-term include:

(a) refinement and detailed definition of trajectory sensor concepts, particularly with respect to their LEO characteristics;

(b) additional theoretical studies of dust orbital evolution and the subsequent constraints upon Facility pointing directions or articulation;

(c) evaluation of capture device concepts, including laboratory impact experiments to optimize capture media for specific cosmochemical purposes;

(d) continued support for analytical investigations of fine-grained inorganic phases and subfemtomole quantities of organic phases; this support should include the development of new techniques and tests of their efficacy on currently available IDPs collected from the stratosphere, or on plasmas and residues collected in LEO;

(e) better definition of phase relations and potential phase transformations that may occur under the proposed capture conditions in LEO by the use of high-quality laboratory simulations of impact events.

5. The above near-term planning should also recognize the necessity for maintaining and encouraging a longer-term view for the CDCF, because with time, the Facility may develop in complexity and sophistication as Space Station capabilities evolve. This long-term view should also encourage the development of new procedures for handling and analysis of extraterrestrial materials, in both terrestrial and LEO environments.

6. Opportunities for international cooperation not only on the CDCF, but also on other planned cosmic dust experiments, should be continued, encouraged, and promoted at the highest levels of the NASA bureaucracy.

7. Administrative support through Codes EL and EB should be directed at the above scientific and technical objectives through a high level of cooperation and coordination, preferably with guidance from a CDCF Steering Group. The composition of the CDCF Steering Group should be representative of the Cosmic Dust Community.

In summary, the Carmel workshop recaptured the scientific excitement and enthusiasm for continued acquisition and analysis of extraterrestrial materials that was apparent at the previous 1985 workshop. There is considerable optimism that the scientific returns from Space Station-based Cosmic Dust collection activities will be very high and will provide critical data on early Solar System processes. The nature and level of support during the pre-project development phase will play a significant role in the achievement of these scientific payoffs.

ABSTRACTS

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ENHANCED SPATIAL DENSITY OF SUBMICRON LUNAR EJECTA IN THE EARTH'S MAGNETOSPHERE I: SOURCE CHARACTERISTICS; W. M. Alexander, W. G. Tanner, Jr., H. S. Goad and T. Hyde; Space Science Lab., Dept. of Physics, Baylor Univ., Waco, Texas 76798.

Particulate matter that exists in the inner regions of the earth's magnetosphere has several sources; i.e., interplanetary or cosmic dust, orbiting debris resulting from man's various activities in near earth space, particularly the multitude of satellite missions in the last 25 years, and lunar ejecta, especially in the micron and submicron size range. To what extent is lunar ejecta a component of particulate matter in the inner magnetosphere? To answer this question, the physical and dynamic characteristics of lunar ejecta at its source has to be defined as well as possible.

Initial results from the measurement conducted by the dust particle experiment on the lunar orbiting satellite Lunar Explorer 35 (LE 35) were reported by Alexander et al /1,2/ and the data interpreted as indicating that the moon is a significant source of micrometeoroids. The primary reason for this interpretation resulted from a significant change in the event rate detected by the experiment during periods associated with the passage of the earth-moon system through the major annual meteor streams. The event rate during non-meteor shower periods was the same as the interplanetary rates. Also, no enhancement of the event rate for nanogram size lunar ejecta which is consistent with the measurements reported by Gurtler and Grew /3/.

Hypervelocity meteoroid simulation experiments /4,5,6/ have provided ratios relating the mass of the impacting particle to the mass of ejecta produced. Schneider /4/ has found that a 10 mg particle with a velocity of 4 km /s impacting at normal incidence would produce ejecta which represented 7.5E-5 the mass of the incident particle and had a velocity > 3 km/s. Alexander /5/ has shown under similar conditions the ejecta mass ratio, e, would be higher by an order of magnitude (e = 5.0E-4). A recent study by Zook, et al, /6/ reported that oblique angle impacts would produce 200 to 300 times more microcraters (diameters = 7 um) on ejecta measuring plates than would be produced by normal incidence impacts. Given that 7 um diameter microcraters correspond to particles with m = 1E-12g /6/ and that the impact velocity was 6.7 km/s, one may infer that the fraction of ejecta mass with lunar escape velocity would also increase by 200 to 300 times (e = 1.5E-2). These three values for the "ejecta to incident particle mass" ratios are employed to establish the total lunar ejecta mass after the interplanetary flux at 1 AU has been determined.

Three recent dust flux models are used for the basic calculations that are reported in this paper. The first was given by McDonnell /7/. The second one is that of Grun, et al /8/, followed by the flux curve derived from lunar crater data as presented by Morrison and Zinner /9/. The first two curves in Fig. 1 are based primarily on in-situ measurements in space and are seen to be quite similar for cumulative masses >1E-12g. The most pronounced similarity which can be observed is the mass distribution index of both curves. One can observe that for masses <1E-12g, the divergence between the three mass models appears to be most drastic. Attention has been given to the variations in the cumulative flux of submicron particles suggested by these models. In summary, a bimodal particle distribution may exist near the moon, especially where the in-situ measurements are in selenocentric space. The Log differential mass flux vs. Log mass curves derived from the three mass models depicted in Fig. 1 are shown in Fig. 2 /10/; the total mass flux of sporadic meteoroids impacting the lunar surface is determined and given in Table I. The information contained in Table I provides the initlal basis for a model of the ejecta mass.

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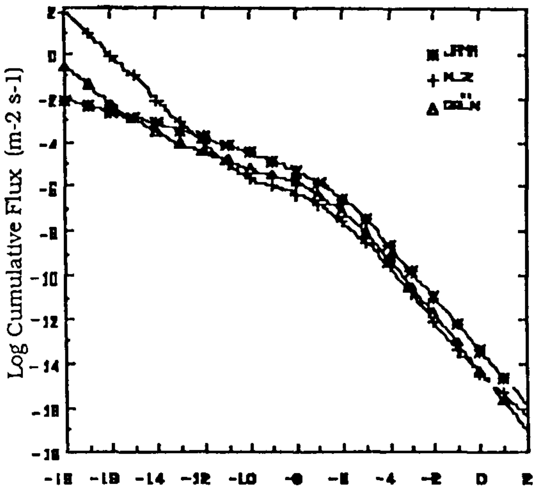

Figure 1.

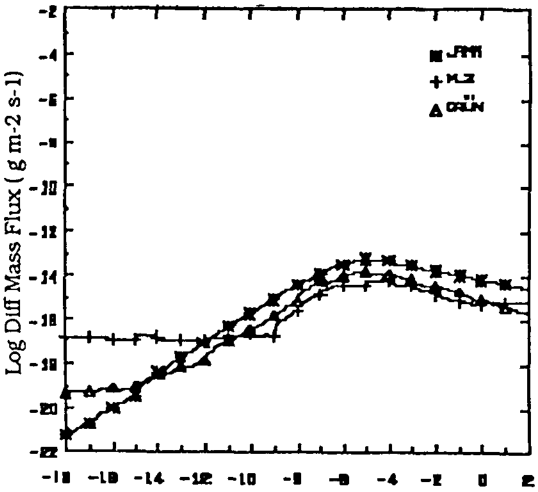

Figure 2.

TABLE I:LUNAR SURFACE

Model	Mass Flux g/m^2 sec	Total Mass g/Day
McDonnell	2.5E-12	8.3E+6
Grun	5.5E-13	1.8E+6
Morrison-Zinner	2.4E-13	8.0E+5

TABLE II:MASS DISTRIBUTION INDEX

Richards /12/	0.81
Alexander & Corbin /13/	0.83
Zook, et al /6/	0.81

Initial determination of mass index factors and ejecta cumulative flux distributions from hypervelocity studies was reported by Alexander & Tanner /11/. The mass index is given in Table II. The major difference in the early results, Richards /12/ and Alexander & Corbin /13/ and those of Zook /6/, is in the total amount of micron size ejecta mass.

TABLE III:TOTAL EJECTA MASS

	(g/m^2 sec)
Ref /13/ and McDonnell Model	1.25E-15
Ref /6/ and McDonnell	2.5E-13

Given the total ejecta mass of interest and the mass distribution index, the cumulative flux for the ejecta leaving the moon's sphere of influence can be estimated. This flux can be compared over the ejecta mass range to that of the sporadic micron cumulative flux. The ejecta spatial density near the lunar surface is given for comparison to that of interplanetary dust flux in Table I. Using the mass flux of Table III and ejecta velocity near the lunar surface of 3 km/sec, Ref /6/ and McDonnell, the spatial densities of the two results in Table III are 4E-19 g/m^3, Ref /12,13/, and 8E-17 g/m^3, Ref /6/. The above results show that the lunar ejecta spatial density /12,13/ near the lunar surface is essentially the same as the incoming interplanetary dust spatial density of 3.2E-19 g/m^3 over the same range of mass. In the second case /6/, the ejecta spatial density is greater than that of the interplanetary dust over the same range of mass. The above information defines the lunar ejecta source and is used for the earth ejecta computations.

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ENHANCED SPATIAL DENSITY OF SUBMICRON LUNAR EJECTA IN THE EARTH'S MAGNETOSPHERE II: CISLUNAR SPACE TRANSPORT AND DYNAMICS BETWEEN L VALUES OF 1.2 AND 6.1; W. M. Alexander, T. Hyde, W. G. Tanner, Jr., and H. S. Goad; Space Science Lab., Dept. of Physics, Baylor Univ., Waco, Texas 76798.

Analysis /1,2,3,4/ of the orbital dynamics of micron and submicron lunar ejecta in selenocentric, cislunar and geocentric space have shown that a pulse of these lunar ejecta, with a time correlation related to the position of the moon relating to the earth, earth-lunar phase angle (LPA) as seen in Fig. 1, intercepts the earth's magnetopause surface (EMPs). Alexander, et al, /5/ and Lily /6/ have shown that a significant enhancement of submicron lunar ejecta in the region of the magnetosphere between L values of 1.2 and 3.0 exists. In addition, Corbin /7/ has determined that the transport time of these particles through cislunar space to the magnetopause surface varies in such a manner as to effectively focus the particles due to this temporal variation. For example, 0.3u particles that leave the lunar surface when the LPA is about 105° will arrive at the earth's magnetopause (EMPs) within 7 days. A 0.05u particle released when the LPA is about 155° has a transport time to the EMPs of less than 2 days /7/. Thus, a lunar ejecta flux (LEFx) of 0.3 and 0.05u particles will arrive at the surface of the EMPs essentially at the same time.

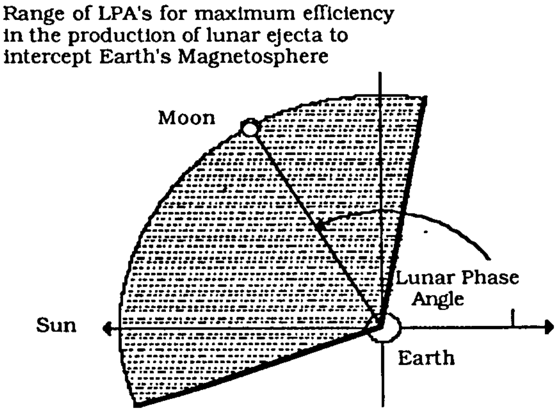

Figure 1.

When lunar ejecta arrive at the EMPs surface, they represent the mass leaving the moon at an LPA of 40° to 170° or about 1/3 of the time of a lunar orbit. However, the efficient LPA position for lunar ejecta transport with maximum EMPs interception is between 80° and 160° or over six days of a lunar orbit time, which is approximately 1/4 of a lunar period. When the lunar ejecta mass is intercepted at the EMPs boundary, the lunar ejecta cumulative flux, LECFx, is at its maximum for more than a day, traversing an LPA of 186° to 200°. Thus, a major portion of the LECFx of micron and submicron particles traverses the EMPs in a time of slightly more than one day. this represents a focusing effect of at least a factor of three, but not greater than a factor of six. The effect discussed above is depicted in Fig. 2 and 3 /5/.

In Fig. 2 /5/, the percent of lunar ejecta intercepted by the EMPs of four different size ejecta particles is shown as a function of LPA or position of the moon when the lunar ejecta was created. Fig. 3 /5/, shows the percent of lunar ejecta that is intercepted at the EMPs surface at essentially the same time. The moon is passing through an LPA of 194° ± 6° during this period.

An additional factor of major importance to this work is that of lunar longitude at the time of impact of a primary particle. While the LPA is the major determining lunar position factor, the combination of LPA and longitude produces the maximum LECFx onto the EMPs surface. This is demonstrated in Table I where all percentages are calculated for the LPA range (in 10° steps) from 10° to 160° /8/.

The most important factor regarding sensitivity to longitude is the occurrence of non-random impact flux events. This is quite noticeable for the periods known as major shower periods /9/. Initially, the LPA will determine if these ejecta will be transported to the EMPs surface. For an optimal LPA, the maximum LECFx will occur when the lunar quarter (by longitude definition) is in the most favorable impact position with respect to the meteor shower radiant. From Table I, a shower radiant that was essentially normal to the 3rd and 4th quarter with an LPA near 110°, would result in greater than 90 percent of the produced ejecta intercepting the EMPs surface.

TABLE I

LUNAR LONGITUDE QUARTER	AVERAGE PERCENT EMPs INTERCEPT	MAXIMUM PERCENT EMPs INTERCEPT	LPA°
1st	20.230	63.89	100
2nd	27.26	77.78	90
3rd	38.28	94.44	110
4th	33.25	90.28	110

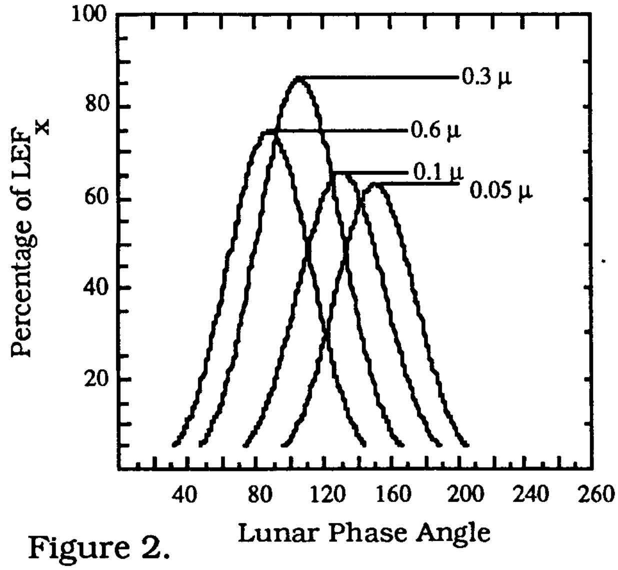

Figure 2.

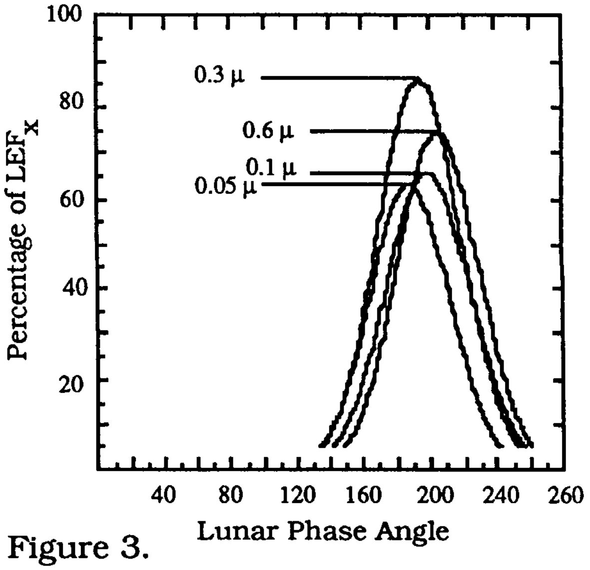

Figure 3.

It is generally accepted that particles acquire a charge in the environment of space. Studies have been made regarding charges particulate matter will have including numerous charging mechanisms. When an ejecta particle leaves the moon it is initially moving in the solar wind plasma as well as being subjected to solar photons. When an ejecta particle passes through the magnetopause surface then the intensity of the magnetic field and plasmas greatly increases while that of the solar photons remains the same. It is possible for the charge on the particle to change sign and magnitude in the magnetosphere. Lily /6/ has recently shown that there are conditions in the inner magnetosphere where the magnetic and electrostatic forces are such that closed orbits may occur as well as a significant amount of mirroring along magnetic field lines. This occurs between L values of 1.2 and 3.0. However, the gravity gradient effect among others seems to ensure that all of these particles will not be permanently trapped but the lifetimes are such that the spatial density for the sparodic caused lunar ejecta may easily be a factor of 50 or more times that of the same size particle in interplanetary space, and that of shower related many times more.

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SPATIAL DENSITY AND TRAJECTORY OF SUBMICRON PARTICLES IN THE INNER REGIONS OF THE EARTH'S MAGNETOSPHERE: AN ADAPTION OF THE **CODEM** EXPERIMENT;

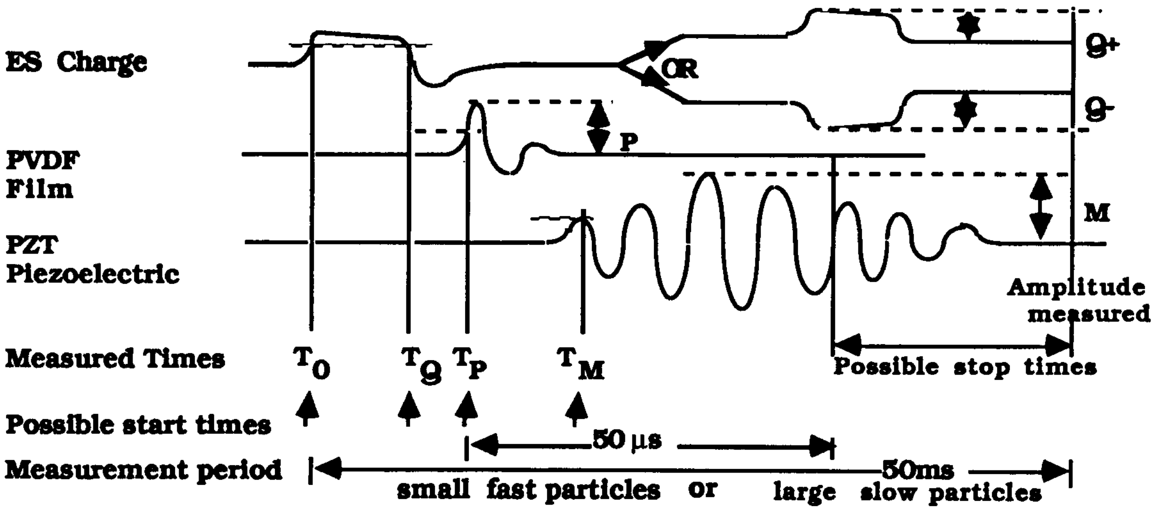
W. M. Alexander, W. G. Tanner, Jr., H. S. Goad and T. W. Hyde; Space Science Laboratory, Department of Physics, Baylor University, Waco, Texas 76798.

A **C**ometary **D**ust **E**nvironment **M**onitor experiment, **CODEM,** is one of the experiments on the **C**omet **R**endezvous and **A**steroid **F**lyby, **CRAF** mission of NASA /1/. The instrument will be explained briefly with particluar attention to the part of the system which has meaning for an inner magnetosphere dust particle measurement.

The two papers at the workshop,/2,3/, which have dealt with the characteristics of submicron particles, including lunar ejecta, are the basis for proposing a series of experiments to investigate the enhancement or trapping of submicron particulates near the Earth. The subsequent interaction of this mass with the upper-lower atmosphere of the Earth and the possible geophysical effects should be studied. In addition, these types of sensors can be used in combination with Space Station collision/collection devices, especially capture-cell types, to obtain the diagnotics of hypervelocity impact events in space. After exposure in orbit, information gained from retrieved material can greatly enhance laboratory investigations of hypervelocity impact events.

Scientific objectives of an experiment using **CODEM** "like" instrumentation entail the following measurements or activities:

a. The particle flux from cislunar space
b. Constant monitoring of submicron flux at a Space Station
c. Variations in dust population indices in low Earth orbits
d. The electrostatic charge on dust in the Earth's magnetosphere
e. The mass and velocity of incident dust paricles
f. Dust acceleration by plasma and radiation effects.



(Note: Waveforms not to scale.)

Figure 1. Analog Signals produced by the **CODEM** experiment.

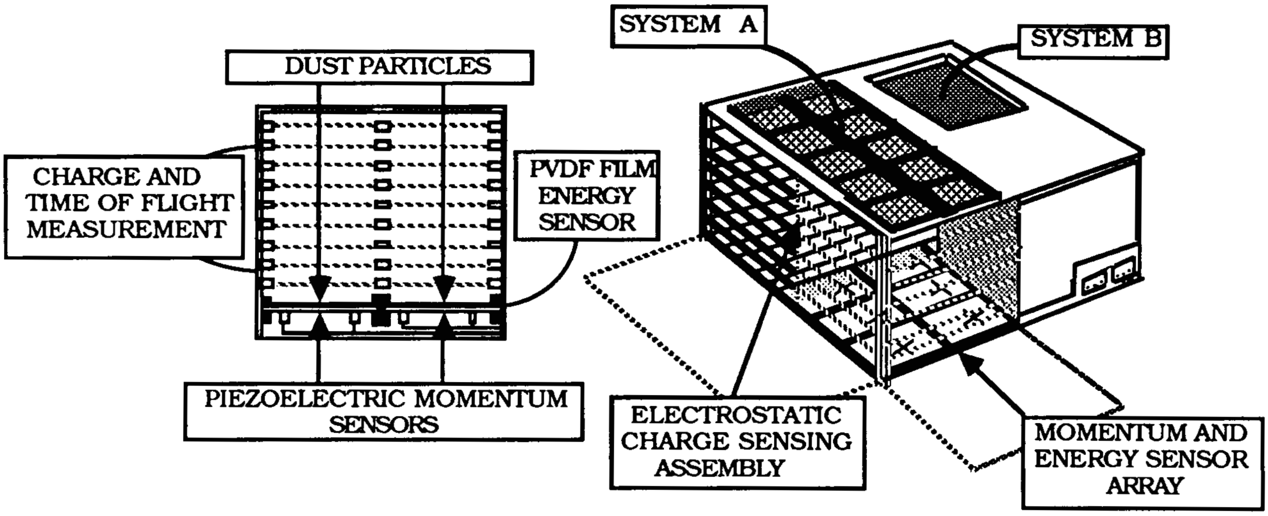


Figure 2. Current **CODEM** Multisensor Detector Array

The **CODEM** instrument is designed to detect low velocity particles, viz., $10\ m/s \le v \ge 1\ km/s$. This parameter determined which sensor would be used in the **CODEM** experiment. Other sensors are viable candidates for devices which could be used for in-situ measurements when the relative velocity $v > 1\ km/s$. Threshold detection ranges for several possible sensors are listed below:

1. Electrostatic charge on a particle; with a threshold sensitivity of $1\ X\ 10^{-15}$C, a picogram particle with ~1 μm radius will have a potential between 0.5 and 1.0 volts, a conservative lower limit. This sensor is the most successful means to perform non-destructive particle velocity measurements. The attainable accuracy is the result of the sensor array geometry within the detector.
2. Very thin films (~$3\ X\ 10^{-8}$m), have also been used for detection of a plasma generated upon impact and TOF systems. Particles of $1\ X\ 10^{-12}$g are easily detected at hypervelocity speeds.
3. PZT acoustic transducers respond to total impulse delivered to the impact surface. The current threshold sensitivity from low through hypervelocity particle impacts is $5\ X\ 10^{-12}$N/s. The threshold mass is $5\ X\ 10^{-16}$kg or $5\ X\ 10^{-13}$g at 10km/s velocities.
4. Capacitor microphone transducers: Sensor prepared for flight and launched with Lunar Explorer 35 Cosmic Dust experiment had threshold detection of $3\ X\ 10^{-12}$Ns; or at 10km/s, mass threshold of $3\ X\ 10^{-16}$kg or $3\ X\ 10^{-13}$g.
5. Detection of plasma on "stop" plate impacts; $m < 1\ X\ 10^{-12}$g.
6. PVDF sensor; particles $m < 1\ X\ 10^{-12}$g.

Reference:

1. W. M. Alexander, *et al,* Principal Investigator Instrument Proposal in response to NASA AO.OSSA-3-1985, Baylor Univ.(1985).
2. W. M. Alexander, *et al,* Workshop on the Cosmic Dust Collection Facility,**WCDCF**, LPI, 1987, p.1-2.
3. W. M. Alexander, *et al,* **WCDCF**, LPI, 1987, p.3-4.

COLLECTION OF INTERPLANETARY DUST PARTICLES BY HYPERVELOCITY IMPACT INTO LOW DENSITY MEDIA

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One possible way to collect small particles at high encounter velocities is to dissipate their kinetic energy over a long path length by allowing them to impact very low density materials such as foams [1,2,3]. Because of the high energies involved, a knowledge of the effects on the impacting particles is vital to evaluation of the usefulness of this technique to a particular application. One application is the sampling of interplanetary dust particles (IDP's) by spacecraft. A number of experiments have been performed to study various candidate target materials [1,2,4], but theoretical studies are also important because they allow identification of the properties which characterize a suitable target material. Theory is also important to extrapolations to target materials or conditions for which experimental data do not exist.

The basic physical principles of impacts into low density materials have been discussed previously [3]. Our current model improves on the previous, relatively simple model developed for polystyrene foam targets. The current model is more quantitatively accurate, allowing extrapolation to materials for which experimental data do not exist. The primary changes differences between the current model and its predecessor are the use of the Percus-Yevick (PY) equation of state in the current model to estimate the temperature of the shocked target material, as opposed to the previously used Van der Waals equation of state; and consideration of melting as the primary ablation process, rather than vaporization. The justification for the second change is that, for the pressures and temperatures at the surface of a particle, most materials will exist as a supercritical fluid. One major advantage of the use of the PY equation is that it requires knowledge of only a single material-dependent property (effective molecular volume), which is relatively easy to estimate.

Both models yield essentially the same results for aluminum projectiles, which have been used in most of the experiments. The current model, however, predicts somewhat higher survival rates for IDP's relative to the previous model in the absence of fragmentation.

Extrapolation to SiO_2-based foam targets indicates that at higher velocities, ablation is less severe than for polystyrene foams. Impact pressures, however are higher for particles entering SiO_2 foams. The pressures to which the IDP is subjected are important because of the possiblities of fragmentation and shock metamorphism of the particle.

Fragmentation of impacting IDP's is expected to be an important process for the high impact velocities characteristic of spaceflight encounters. Many IDP's collected from the stratosphere are fluffy aggregates of sub-micron grains. Such particles would disintegrate into their constituent grains making up the IDP's when entering the foam. More compact aggregates and single mineral crystals can fail by shearing due to the uniaxial stresses set up in the particles by impact. Whether fracturing actually occurs depends on whether the stresses exceed the shear strength of the particle under the proper conditions of compression or tension. If fragmentation does occur, an IDP would break down into smaller particles which are less likely to survive ablation.

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[2] Tsou, P., Brownlee, D., and Albee, A. (1984) Lunar Planet. Sci. XV, p. 866-867.

[3] Anderson, W. W., and Ahrens, T. J. (1987) Submitted to Proceedings of the Workshop on the Multi-Comet Mission.

[4] Tsou, P. (1986) JPL Interoffice Memorandum 313/4-245-PT:ja.

NON-DESTRUCTIVE VELOCITY/TRAJECTORY SENSING OF CHARGED COSMIC DUST PARTICLES ON THE COSMIC DUST COLLECTION FACILITY

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The determination of velocities and trajectories of cosmic dust particles has been recognized as an essential element of the Cosmic Dust Collection Facility. An array of highly transparent grids has previously been used in the laboratory, and is being considered for possible use on the Cosmic Dust Collection Facility, to sense dust particles by the electrical charges they carry and to determine their flight directions, locations within the array, and velocities, by means of a time-of-flight technique, as they pass through the grid array. Because of the high transparencies of the grids, most dust particles pass through the grid array without any mechanical interaction, before they are collected.

Theoretical predictions and experimental data of charges of cosmic dust particles are discussed. Dust charges at Space Station altitudes are expected to be extremely small, at a potential of approximately -0.4 Volt. To facilitate the measurement of such charges, ways of minimizing interferences by the ambient plasma, by photoelectrons, and by radiated and conducted electromagnetic noise from nearby sources are evaluated. The characteristics of low-noise charge amplifiers are reviewed, including the merits of transistor cooling, optoelectronic feedback and bootstrapping methods. Also, a concept of noise reduction is presented using matched filters and coincidence/anticoincidence circuitry, tailored to the proposed sensor.

Given the optimum conditions, such as path length of 1 meter, the instrument should be able to do the following:

- Detect dust particles with radii of 1 micron or larger, with a signal-to-noise ratio of 15:1;

- Measure velocity with an accuracy of 1 percent, and trajectory angles with an accuracy of 1 degree, for the following particles

Velocity	1km/s	10km/s	100km/s
minimum radius	2 micron	6 micron	20 micron; and

- Determine sizes of dust particles from the measured charges.

ELECTRON ENERGY LOSS SPECTROSCOPY (EELS): LIGHT ELEMENT ANALYSIS OF COLLECTED COSMIC DUST;

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First suggested in 1944 as a microanalytical technique (1) for elemental detection, the application of EELS has not yet achieved widespread use. Among several reasons for this situation is that the technique is intrinsically more operator intensive, and certainly more difficult to make quantitative than the more traditional Energy Dispersive X-ray Spectroscopy (EDS). This paper will review some of the advantages and disadvantages of the EELS technique, with particular reference to analyses of material captured by the Cosmic Dust Collection Facility.

Electron Energy Loss Spectroscopy (EELS) as the name suggests, is the study of the energy distribution of electrons which have interacted with a sample. Inner shell excitations occur at energies $\Delta E \geq E_F - E_B$, where ΔE is the energy loss, E_F is the fermi level energy and E_B the binding energy of the inner shell. The features observable in the spectrum corresponding to these losses appear as "core loss edges" on an otherwise rapidly decaying background. K and L core loss edges corresponding to chondritic elements fall in the ~ 50-2000 eV energy loss range. The light elements C, N and O however, possess K-edges in an extremely favorable region of energy loss (ΔE ~ 284-532 eV), as at higher energy, edge visibility is compromised due to the rapidly decaying spectrum intensity. An additional advantage is that the C, N and O edges are each separated by $\Delta E \geq 100$ eV.

Spectral Features: The main features of a typical EELS spectrum can be seen in Figure 1. This particular spectrum is from a crushed boron nitride fragment, disaggregated onto holey carbon film, and was recorded using a Gatan model 607 spectrometer attached to a JEOL 2000FX transmission electron microscope. The *zero loss peak* is usually the strongest feature visible (narrow peak on far left of figure). The intensity of the zero loss is determined by the number of electrons which have been elastically scattered in the sample (i.e. retain their original energy). The *low loss* region (up to ~ 50 eV) of the spectrum is dominated by the plasmon peak, which is a collective oscillation of the valence electron density in the sample. The *core loss* spectral region (≥ 50 eV) contains the inner-shell ionization edge features which are characteristic of a particular element, and is thus the most widely used portion of the spectrum for elemental microanalysis. Figure 1 exhibits three elemental edges, namely, boron-K (~ 188eV), carbon-K (~ 285 eV) and nitrogen-K (~ 402 eV). The peak denoted by G.C. is not an edge but a gain change introduced to enhance the edge visibility at higher values of energy loss where the scattered beam intensity falls off rapidly.

IDP Analysis: The recent development (2) of microtome thin-sectioning of stratospheric Interplanetary Dust Particles (IDP's) provides us with almost ideal specimens on which to use the EELS technique. We now present preliminary data taken from a microtome thin-section of the stratospheric particle Butterfly (r21-m4-8A). Normalized carbon and oxygen ratios, as determined by EELS are shown in Table 1 for different phases in the section. FTIR spectroscopy (3) has shown Butterfly to contain pyroxene as the dominant silicate phase; and ion-probe measurements (3) exhibit a large δD excess, up to $2705^{0}/oo$. These normalized C, O ratios do not take into account the contribution to the C edge from the carbon support film, but clearly demonstrate the heterogeneity of the C, O content in the sections. The data were normalized to the carbon content in a "tar-ball", as these components (2) consist of clumps of grains (≤ 1000 Å in diameter) in a carbonaceous matrix. Qualitatively these results indicate that the tar-balls are not the most carbon-rich component present, but appear to be oxygen enriched in comparison to other components. The procedure used to derive these atomic ratios from the raw data will be discussed, and typical spectra shown to illustrate both the advantages and problem areas of the technique.

Summary: EELS is shown to be a useful technique in the analysis of recovered extraterrestrial material. Both elemental (4) and local atomic structure (5) information can be derived from the spectra.

Continuing theoretical development and establishment of an empirical data base on edge position and shape are an important consideration.

Other factors affecting the suitability of collected samples for EELS analysis are:

a) contamination introduced by the collection medium itself should preferably be avoided, or at least, the extent of the contamination known to some degree (via simulation experiments?)

b) sufficient material is available for thin-sectioning. The ultramicrotome technique was first successfully applied on two chondritic particle impact residues on the Solar Max thermal blanket (6). The smallest fragment sectioned was ~ 4 μm.

c) a major problem of the sectioning process however, is the presence of light elements, particularly carbon, in the embedding epoxy medium. The development of alternative embedding media would benefit many other analytical techniques, in addition to EELS.

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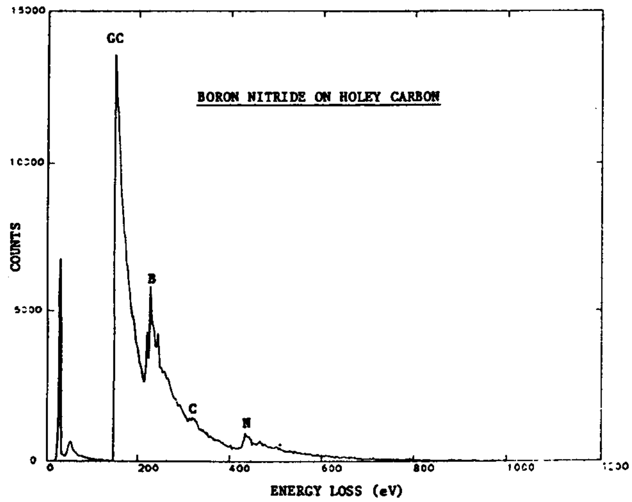

Figure 1: Energy loss spectrum of BN on holey carbon film. B, N and C edges can be seen after the gain change.

Analysis point	Carbon ratio (normalized)	Oxygen ratio (normalized)
1	1.42	2.59
2	1.00	1.60
3	1.00	1.00
4	1.59	0.68
5	0.89	0.84
6	3.79	0.61
7	3.07	-
8	-	-
9	0.77	0.36
10	0.77	0.24
11	1.71	0.20
12	1.10	0.31

Table 1: Carbon and oxygen ratio's normalized to analysis point number 3 (tar-ball), showing variation of C and O content in differing phases of a single thin-section of Butterfly.

MOLECULAR ANALYSIS OF IDP'S: AMINO ACIDS AS INDICATORS OF THE PROGRESSION OF ORGANIC CHEMICAL EVOLUTION.

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Organic chemical evolution is a galactic phenomenon. Chemical reactions in interstellar clouds provide abundant small molecules such as formaldehyde, hydrogen cyanide, and ammonia, that can, in theory, react further to form the molecular building blocks of life, e.g., amino acids, monosaccharides, alkanoic acids, and purines. Carbonaceous chondrites, a class of primitive meteorite, provide evidence that many of these potentially prebiotic molecules existed in the early solar system. A direct precursor-product relationship between interstellar compounds and at least some meteorite organic compounds is suggested by recent stable isotope (deuterium) analyses. It is important to more fully understand the time and space relationship between interstellar organic compounds and potentially biogenic compounds in meteorites and other solar system bodies.

Comets are widely regarded as repositories of primordial solar system material, i.e., relatively unaltered interstellar grains and condensable interstellar gas. Chondritic aggregate type IDPs may be derived from comets. If so, these particles should provide important insights to the progress of organic chemical evolution prior to, and during, the accretion steps of planetary evolution. For example, it would be of great interest to know the nature of the macromolecular carbon of native chondritic IDPs, the nature of their volatile and/or soluble molecular species, and the isotopic composition of both, for comparison with known interstellar and meteoritic material.

Whether organic chemical evolution has proceeded as far in chondritic IDPs as in CM chondrites might be assessed by amino acid analysis. The advantages of amino acids as a diagnostic criterion include (1) their significance in chemical evolution/origin of life research, (2) their unique characteristics as found in meteorites, (3) existing criteria for recognition of terrestrial contaminants, (4) their relative thermal stability, and (5) their relative involatility. On the other hand, both their intact recovery from IDPs and their analysis in the expected small amounts pose significant technical challenges.

HYPERVELOCITY CAPTURE OF GLASS MICROSPHERES

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The results of an experiment to investigate the non-destructive capture of simulated micrometeoroids is reported. Glass microspheres some 100μm in diameter were impacted into stacked foil arrays at velocities up to 8 km/s. The foil arrays consisted of aluminised 2.5μm polyester sheets with inter-sheet spacings of approximately 150μm.

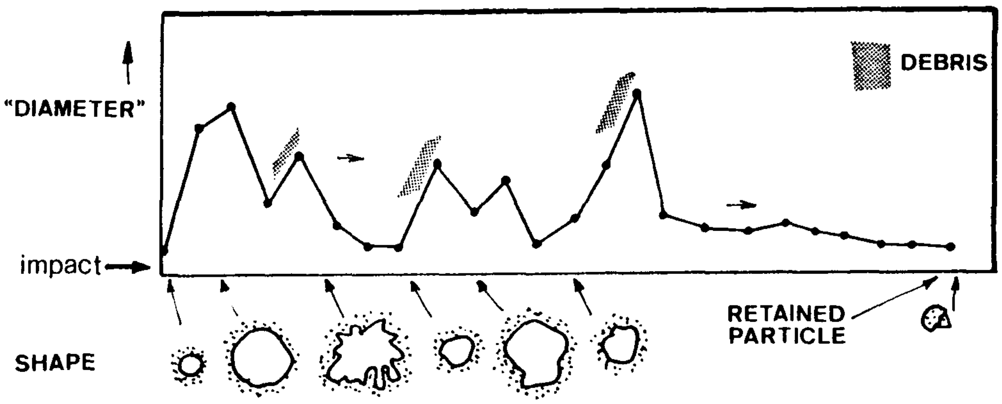
After impact the stacks were taken apart and each foil examined; the particle trajectory, damage caused, and retained debris were noted.

Figure 1 shows a schematic representation of the perforations along the deceleration path which is typical of the results found. Note that the first perforation is small and circular, showing the size and shape of the impacting particle. There follows a series of disintegration regimes and expansions where debris is deposited and then finally a "quiescent" deceleration path and a retained particle . Some particles were totally destroyed and were recoverable only as (typically)$<$30μm fragments whilst others managed to keep their spherical shape. Further examinations of the foil perforations, debris distributions and retained particles will be presented.

This work was performed at the Lehrstuhl Für Raumfahrttechnik, München. Thanks go to the European Space Agency for the provision of a research fellowship (DGD) and to Professor H.O. Ruppe for the use of laboratory facilities.

FIGURE 1

A schematic representation of the perforation sizes and shapes caused by a hypervelocity glass microsphere impacting a stacked foil array.



AUTOMATED POINT COUNT ANALYSES OF THIN-SECTIONED METEORITIC MATERIALS USING AN ANALYTICAL ELECTRON MICROSCOPE EQUIPPED WITH DIGITAL BEAM CONTROL. M. S. Germani and J. P. Bradley, McCrone Associates, Inc., Westmont, Illinois 60559

A cosmic dust facility on the space station would provide an excellent opportunity for collection of a large number of interplanetary dust particles (IDP's) for laboratory investigation. However, an important question regarding these IDP's will be the degree to which they have been modified during capture. Studies of Solar Max impact debris have suggested that some IDP's are severely traumatized by capture in space, while others can survive with minimal heating [1]. A logical way to assess the degree of alteration is to compare IDP's collected in space with those recovered from the stratosphere. In particular, stratospheric IDP's with high densities of solar flare tracks would provide a firm basis for comparison, because they have not been severely pulse heated during atmospheric entry.

Electron transparent thin-sections of stratospheric IDP's enable acquisition of large data sets of quantitative chemical information, which have already been successfully exploited to make intercomparisons between different classes of meteoritic materials [2]. A principle disadvantage of the method, however, is the time taken to collect a statistically significant set of data points from even a single thin section. Recently, we have used an analytical electron microscope (AEM) equipped with digital beam control, which automates both point count analyses and data reduction. Parameters that can be varied during data acquisition include the incident probe size, x-ray acquisition time (at each data point), the distance between points on a thin-section, and the total number of data points. A typical routine can acquire ~840 spectra (on a 29 x 29 grid) together with data reduction over an 8-10 hour period. The digital beam control makes no distinction between data points falling on mineral grains or pore spaces in the sections. However, during data reduction, those spectra whose total number of counts fall below a set threshold (~500 counts within a defined region of interest) are rejected.

At present, only stratospheric IDP's with chondritic compositions are being subjected to point count analyses. Between 400 and 800 individual spectra are being recorded from each thin-section and the data plotted on ternary diagrams. In principle, several thousand spectra can be obtained from multiple sections of the same IDP and the data can be subjected to statistical evaluation. Hopefully, this will reveal fundamental chemical differences between the various classes of chondritic materials and provide a useful basis for evaluation of (chondritic) materials collected by a cosmic dust collection facility on the space station.

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INTERSTELLAR GRAIN TRAJECTORIES TROUGH THE SOLAR SYSTEM. B. Å. S. Gustafson, and N. Y. Misconi, Space Astronomy Laboratory, University of Florida, Gainesville, Fl. 32609.

We present results extending our numerical study (1) of the interaction between interstellar grains and the solar wind, including the effects of solar cycle variations in the interplanetary magnetic field. The latter is shown to influence significantly regions of concentration and depletion of interstellar grains within the solar system. When the solar dipole field axis points north, the grains are diverted from the solar equatorial plane, mainly due to the action of the electrical part of the Lorentz force. The grains are concentrated towards this plane when the dipole field points south. Some 3 to 4 AU ahead of the Sun the streams cross the equatorial plane, creating an enhancement in the number density. The grains behind the Sun experience the oppositely directed magnetic field of that affecting them during the first half of the solar magnetic cycle, as they entered the solar wind cavity, thus creating a depletion zone in the wake of the Sun.

Our computations are almost insensitive to whether the reversal of the direction of the interplanetary magnetic field is instantaneous or whether it is as gradual as a sine function.

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JOURNEY FROM A COMET PARENT BODY TO 1 AU, ORBITAL EVOLUTION OF DUST PARTICLES. B. Å. S. Gustafson, N. Y. Misconi, and E. T. Rusk, Space Astronomy Laboratory, University of Florida, Gainesville, Fl. 32609.

Whereas the inner planets′ perturbations on meteoroids′ and larger interplanetary bodies′ orbits have been studied extensively, they are usually neglected in studies of the dynamics of dust particles. Forces acting on the dust are fairly well known (see ref. 1 for example) and include radiation forces and interaction with the solar wind. We have reported on some results from a comprehensive numerical study of the **combined** effect of these perturbations on dust trajectories including gravitational perturbations by the planets Venus, Earth, Mars, and Jupiter (2). In this paper we summarize the major results relevant to the "Cosmic Dust Collection Facility". The necessity of including effects of the inner planets in dust dynamics investigations is clearly demonstrated as all orbital elements are affected. One result is that the dust that may be intercepted at 1 AU was, on the mean, released at a later point in time than predicted based on drag forces alone, at least if the parent body was on a high eccentricity orbit which is typical for comets. In the case of comet P/Encke, this effect is of the same order as the frequency of the periodic terms in the comet′s orbit (10^3 years).

Sample trajectories of dust released from Comet P/Encke and the resulting distribution in orbital parameters as the dust reaches 1 AU will be discussed. Detailed trajectories as the dust particle spiral past the planets Jupiter, Mars, Earth and Venus will be shown and in some cases compared to samples of orbital evolution from low eccentricity ($e < 0.1$) orbits. The sample trajectories illustrate commonly occurring phenomenae, such as nonmonotonic changes in semimajor axis, eccentricity, inclination, and in the line of nodes.

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DIRECT DETERMINATION OF AROMATIC HYDROCARBONS IN METEORITES BY TWO-STEP LASER DESORPTION/MULTIPHOTON IONIZATION MASS SPECTROMETRY

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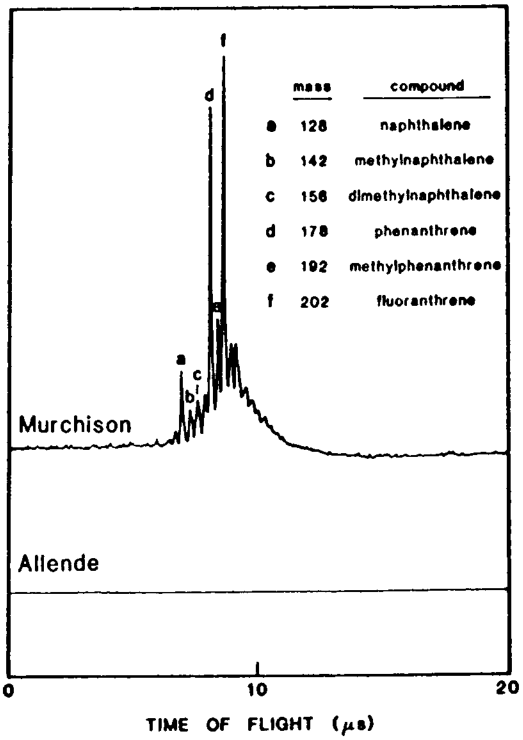
A complex array of organic molecules has been identified in carbonaceous meteorites (1). In typical analytical schemes, the compounds of interest are first extracted, then purified and separated chromatographically and finally identified by mass spectrometry. These processes are not only very time-consuming but artefacts may also arise because of contamination (2) or from chemical reactions occurring during extraction (3).

We report here the direct determination of aromatic compounds in carbonaceous meteorites, using a highly selective and sensitive two-step laser desorption/multiphoton ionization mass spectrometric technique (4). As a first step, the pulsed output of a CO_2 laser (λ = 10.6 µm) is directed onto the sample. Intact neutral molecules are released from the sample surface in a rapid laser-induced thermal desorption process. After a suitable time delay (~ 30 µs) the fourth harmonic of a Nd:YAG laser (λ = 266 nm) is utilized to induce 1 + 1 resonance enhanced multiphoton ionization (REMPI) of the desorbed molecules in an interaction region located a few mm from the surface. Finally, the ions are detected in a time-of-flight (TOF) mass spectrometer. Samples are prepared by pressing pulverized meteorite material (typically less than 100 mg) with glycerol binder into a small (~ 7 mm diam.) disk (pellet).

Combining the desorption of intact neutrals with the soft ionization characteristics of REMPI results in parent molecular ion signals dominating the mass spectrum. These features of our method easily allow us to interpret spectra of mixtures.

The figure shows a comparison of mass spectra obtained from 1 µg of Murchison and Allende, respectively, on the same sensitivity scale. It clearly demonstrates the presence of aromatics in Murchison, while



Allende is extremely poor in these compounds. The aromatic hydrocarbons found in Murchison span a mass range from 120 to 300 amu, which is consistent with previous results (5).

At present we are modifying the TOF instrument to provide much better mass resolution. We plan to use this technique to analyze a wide cross-section of meteorite types. In addition, we might investigate lunar soils, atmospheric dust, sediments, and polar ices. The features of our methodology, i.e., fast analysis, soft ionization, quantitative analysis, ultra-high sensitivity, and selectivity enable us to apply this new analytical method to many cosmic and geochemical problems.

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EXPECTED SHOCK EFFECTS IN COSMIC DUST PARTICLES CAUSED BY HYPERVELOCITY CAPTURE

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This contribution summarizes natural and experimental shock effects of minerals and phase assemblages applicable to the capture of cosmic dust particles. The physical and chemical changes taking place during hypervelocity impact must serve as guides for instrument design and for the interpretation of retrieved projectile remnants.

SOLID STATE EFFECTS: Most observations (see below) derive from optical studies. Typical shock deformation features, such as high fracture densities, mosaicism, twinning, kinking and "planar elements" are observed at scales >10 um and have not been systematically studied at SEM/TEM scales; such studies are needed to characterize cosmic dust particles and their remnants. X-Ray diffraction studies revealed progressive mechanical break-down of all silicate lattices; in the case of tecto-silicates, domain sizes of a few unit cells result, rendering the materials X-ray amorphous and optically isotropic (e.g. maskelynite). IR studies indicate little deformation of the unit cell, but line-broadening and decrease of amplitude is observed. Other techniques used to investigate solid state shock effects include thermoluminescence, Raman-spectroscopy and paramagnetic resonance.

PHASE CHANGES: First order reconstructive phase transformations take place during shock, albeit rarely. More commonly, a number of disproportionation / decomposition reactions occur when the melting temperatures of specific phases are approached, leading to different phase assemblages.

MELTING PHENOMENA: The peak-pressures required to melt specific minerals are fairly well in hand, at least for major minerals. Laboratory shock-recovery experiments demonstrate that the peak-pressures derived from single-crystal targets apply generally to dense, non-porous rocks in which selective melting of tecto-silicates is commonly observed over a pressure range of 45-70 GPa; whole rock melting requires mostly pressures in excess of 80 GPa. In porous, and especially particulate materials, generation of impact melts is very complex: deposition of energy is highly heterogeneous on scales of component grains due to shock reverberations on free grain surfaces that leads to highly localized melting along grain boundaries at modest equilibrium pressures (< 15 GPa); absolute melt fraction increases with increasing pressure and reaches 100% melt at 50 GPa. Study of lunar agglutinates pointed out that fine grained components (<10 um) tend to melt preferentially over "coarse" constituents of a polymict target. Many cosmic dust particles may be polymict and of highly heterogeneous grain-size distributions, ranging from fine-grained "matrix" to coarse components if not large "clasts"; it is thus possible that fractionated projectile melts will be recovered; conversely, the unmolten detritus surviving capture may be biased as well.

FRACTIONATION BY SELECTIVE VOLATILISATION: The loss of H2O is demonstrated for serpentine at pressures of some 10 GPa, that of CO2 from calcite at <15 GPa. Noble gas losses are generally not severe at < 20 GPa, but substantial or complete loss may occur during melting. Selective loss of major elements requires peak-stresses > 100 GPa. Generally, selective loss of "volatile" species is poorly characterized and study of impact induced vapor-condensates is needed.

In the following, a brief summary of shock effects in major minerals is presented:

QUARTZ: Fractures [1], planar elements [1,2,3] and decreased refractive indices [2,4] are the most prominent solid state shock effects up to 28 GPa.Diaplectic glass forms at 29-45 GPa [2,5] and melting commences at 45 GPa [5]. The structural state of shocked quartz was addressed via X-Rays [6,7] and IR [8]; the high pressure phases (HPP) coesite and stishovite are summarized by [9]; some limited SEM work exists [10], an equation of state (EOS) is available [11].
FELDSPARS: Fractures, planar elements, decreased birefringence and 2V are the most prominent solid state features [12,13,14]. Maskelynite was studied in detail by many, as summarized by [15]. Melting depends somewhat on composition, but generally commences at 45 GPa [13-18]. Structural states were examined via X-Rays [6,13,19], IR [8,20,21] and Raman spectroscopy [22]. Noble gas loss is insignificant up to 40 GPa [23]. EOS on a number of feldspars exist [11].

PYROXENE: Fracturing, twinning and mosaicism occur between 5 and 70 GPa [24,25, 26], but are not sensitively related to peak pressure. Melting starts at >70 GPa [27-29]. Lattice deformation via X-Rays [29] and IR [21] reveals also little systematic change. Pyroxene is highly resistant to shock and solid state deformations are difficult to calibrate systematically with peak pressure. Majorite is interpreted as shock induced HPP [30,31]. EOS is available [11].

OLIVINE: Fracturing and pervasive mosaicism dominate up to 70 GPa [32,33] and [33,34] report melting at 70 GPa. Some annealing and recovery of the shock defects is reported for the 55-70 GPa range, which may be accompanied by valance state changes of Fe [33,35]. X-Ray studies [6,7] yield modest systematics related to pressure history; IR [21] yields modest structural changes and [36] describe the effects of disproportionation; EOS are available [11]. In general, olivine is very resistant to shock deformation and solid state defects are not readily presssure calibrated.

GRAPHITE: Very little is known about the shock behavior of graphite/carbon, other than that it converts to HPP (cubic diamond [37,38] and hexagonal [39]) at comparatively modest stresses (<20 GPa). Being a highly compressible phase it may display great sensitivity to lattice deformation at low shock stresses, currently unexplored. EOS is available for many different forms of C [11].

KAMACITE/TAENITE: Twinning and Neumann bands are generated at < 10 GPa [40] and the phase transformation αFe to ϵFe occurs at 13-15 GPa [40,41], resulting in complex textures (="matte" structure), an important shock criterion in ironmeteorites [40]. Based on cooling history following shock, α Fe, ϵFe, and γFe may coexist.

PHYLLOSILICATES: Detailed mineralogical observations are confined to biotite and muscovite that readily develop kinkbands at < 5 GPa [42,43]. Diverse decomposition products upon melting/cooling/interaction with silicate melts are described by [44,45]. H20 loss in antigorite and serpentine at pressures 5-20 GPa was reported by [45,46]; loss of K from muscovite melts (35-40 GPa) was reported by [45].

A variety of solid-state shock effects as well as disproportionation during melting are described for a wide variety of accessory minerals such as TROILITE [40], ILMENITE [47], RUTILE [48], SPHENE [49], GARNET and APATITE [50].

ROCKS / PARTICULATE TARGETS : Most shock pressure calibrations obtained from single crystals or monomineralic targets described above do apply to dense, crystalline rocks such as a wide variety of granites [1,3,51] and basalts [24,52,53]. Similar shock effects are observed in porous and especially in particulate targets, but are produced in these media at substantially lower average shock stresses owing to multiple shock reverberations at the free surfaces of component grains and voids. In such materials, the shock energy is deposited in highly heterogeneous fashion on the scale of component minerals, as first described from sandstone [54,55] and from a variety of experimentally shocked, basaltic powders [27,56,57]. Melting along grain boundaries is pervasive and takes place already at equilibrium stresses of < 10 GPa [58]. Interest in the shock-compaction of clastic materials to form competent impact breccias [59 - 61] has contributed greatly to our understanding of shock processes in particulate media. The possibility of very fine grain sizes contributing preferrentially to small-scale impact melts was suggested by [62] and then experimentally verified by [63].

SUMMARY AND RECOMMENDATIONS: A great diversity of observational/analytical techniques have been applied to the study of naturally and experimentally shocked minerals and rocks. While this information will greatly assist in the interpretation of recovered projectile remnants relative to the pristine parent particle, it should be obvious that specific studies on scales appropriate to small, physically and chemically heterogeneous hypervelocity particles are needed; even first order characterisation on SEM/TEM scales of the above materials is highly fragmentary, at best. Long-term efforts are needed to obtain a systematic observational framework on the scale of microns and smaller both in experimentally as well as naturally shocked materials.

The present data base, however, appears sufficient to provide guidance for the design of capture devices. Based on equation of state data, either measured or modelled, the peak stresses for "realistic" projectiles impacting at cosmic velocities may be calculated. Peak pressures > 30 GPa should be avoided, if unmelted particle fragments are to be recovered. Recovery of totally intact, pristine cosmic dust particles is unrealistic, as tensile stresses of < 0.15 GPa [64] may lead to disruption of the impactor;

Expected Shock Effects in Cosmic Dust Particles

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LONG TERM EVOLUTION OF INTERPLANETARY DUST TRAJECTORIES: PRECISION ORBIT GENERATION WITH THE EVERHART RADAU INTEGRATOR

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It is important to know how to interpret the orbital elements of interplanetary dust particles that are intercepted at the earth. Recently [1] it has become evident that our knowledge of the evolution of dust orbits needs more refinement. It is not possible to separate the possible regimes of motion of particles in the size range of 10 to 100 microns. Not only must long term evolution under gravitational and radiation forces be considered but also strong gravitational interactions with the planets [2],[3],[4]. A task is being undertaken to generate precision particle trajectories in the inner solar system with the purpose of generating the orbital properties of dust orbits in the vicinity of the earth and to model the characteristics of the zodiacal dust cloud. If these kinds of orbits can be understood then progress in connecting microscopic bodies with their parent bodies can be made.

The dynamics of small interplanetary particles depend of the type and strength of the perturbing forces[5],[6]. The forces acting on the dust particle are gravity, radiation pressure, Poynting-Robertson (PR) drag, solar wind drag , distant coulomb drag and the Lorentz force. It is possible to solve the dynamics problem with special perturbation methods but when the number of gravitational perturbers becomes more than a few the problem loses it tractability. Thus a numerical attack is suggested.

In the current study only the forces due to gravitation and radiation are modeled. The acceleration of the particle is then given by

$$\ddot{\vec{r}} = k\left\{-\frac{\vec{r}}{r^3}+\frac{\beta}{r^2}\left[\left(1-\frac{\dot{r}}{c}\right)\frac{\vec{r}}{r}-\frac{\vec{v}}{c}\right]+\sum_{i=1}^{4} m_i\left(\frac{\vec{r}_i-\vec{r}}{|\vec{r}_i-\vec{r}|^3}-\frac{\vec{r}_i}{r_i^3}\right)\right\} \quad (1)$$

where k is the gaussian constant, β is the ratio of the radiation force to the gravitational force, $\vec{r}$ is the heliocentric radius-vector of the particle, $\dot{r}$ is the particle's radial velocity, $\vec{v}$ is the heliocentric velocity vector of the particle, c the speed of light, $\vec{r}_i$ is the heliocentric radius-vector and m_i is the mass of the i-th perturbing body. The planets Venus, Earth, Mars and Jupiter are placed and propagated in Keplerian orbits.

The second order equation (1) is integrated with the implicit Runge-Kutta procedure of Everhart using Gauss-Radau spacings[7]. This numerical integrator, called RADAU, can be written to a very high order of accuracy. Since RADAU has been used in several recent long term orbital evolutions, Everhart [7] and Carusi, et. al. [8], it is being evaluated in this study to access its applicability to the perturbed PR-drag trajectory problem. Accuracy and stability criterion can be found in Everhart [7] and Carusi,et.al. [8].

Figure 1. shows results for a two thousand year integration of a 30 micron particle from an orbit that starts with a semimajor axis of 1.1 AU, eccentricity of .1, inclination of 1.7 degrees , right ascension of ascending node of 107 degrees, argument of periapsis 0.0 degrees and started at perihelion.

It is evident that the slow decay of an orbit by PR drag can be masked by the distant and close encounters to planets. For prograde orbits that are close to the ecliptic PR drag that circularizes and contracts the orbit can cause low encounter velocities with the planets which will make the orbital elements fluctuate.

These computations are in agreement with Gustafson and Misconi [1] which show the importance of gravitational scattering of microscopic particles by the planets. It is hoped that these investigations will point the way to methods of connecting the orbits of microscopic bodies in the solar system with their possible parent sources.

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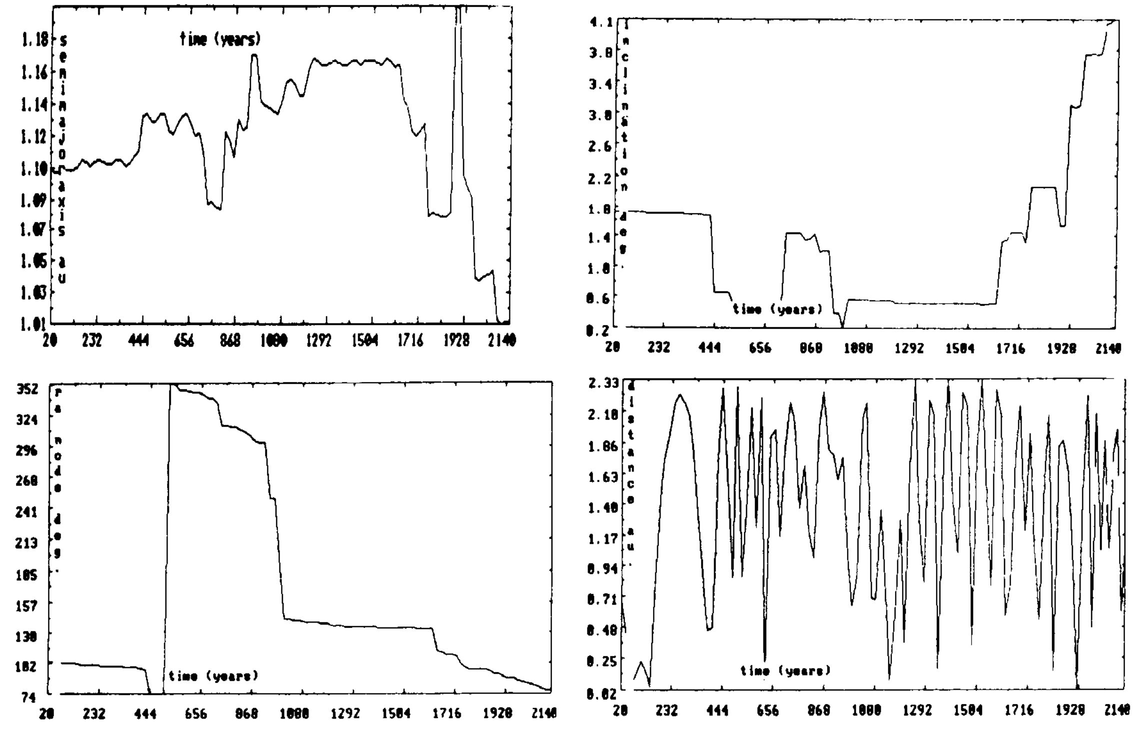

Figure 1. Semimajor axis,inclination right,ascension of ascending node and distance from earth of a 30 micron dust particel started in a 1.1 au orbit with an eccentiricty of .1.

POLYMERIC DUST COLLECTION: PHYSICAL PROPERTY SCALING LAWS OF POLYMERS AND POLYMERIC FOAMS APPLICABLE TO HYPERVELOCITY INTACT CAPTURE by Dr. Robert F. Landel and S. T. J. Peng; Jet Propulsion Laboratory, Pasadena, California

Polymeric materials have been suggested as cometary dust collectors ranging in form from encapsulating hardenable liquids, to sticky flypaper for slow-moving particles, to cushiony stopping material for fast-moving particles. The problem then is to understand polymer physical properties in these contexts and to rationally chose appropriate materials.

However, the physical properties of polymers are so enormously diverse that correlations between properties and polymer type are often taken to be hopelessly complex and susceptible to only the grossest comparisons. Yet the diversity in fact masks an underlying regularity and order. Moreover, individual properties such as modulus, tensile strength, breaking elongation and toughness tend to be treated as separate, individual entities when in fact they are all related.

Starting with the key features of polymer behavior of chain-like structure and local Brownian motion mobility, which is either enormously slow (in hard, glasslike polymers) or comparable to ordinary liquids (in soft polymers, elastomers and melts), scaling or similarity "rules" will be sketched out. Such rules can be used to understand and compare the various properties on a common basis and, more importantly, to make estimates of responses to be expected in novel applications. The talk will conclude with a brief discussion of the importance and application of such rules to the use of polymeric materials in comet dust collection.

PARTICULATE CAPTURE IN THE EUROPEAN RETRIEVABLE CARRIER PROGRAMME.

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The European Retrievable Carrier (EURECA) family is a class of spacecraft designed for routine unmanned access to the low Earth orbit (LEO) environment for extended periods. EURECA A, scheduled for launch in early 1991, is shuttle deployed but its successors are being considered as possible Ariane 5 payloads. The spacecraft itself is designed to be adaptable to a variety of scientific and technological missions - the first flight of EURECA A is ostensibly concerned with microgravity experimentation, but with some 'add on' instruments. As part of our continuing interest in LEO particulate capture, EURECA A will carry a capture cell experiment of simple configuration but with a novel feature allowing impact sites to be time resolved with a precision of a few days. This device, though of modest aperture and of fixed pointing with respect to the sun-earth line, will allow correlation of impact debris with meteor showers over a nine month period.

The method employed is in keeping with the simple (and inexpensive) philosophy of the instrument. A single thin foil, supported by an aluminium mesh plate, is mounted above the substrate with a spacing of half a millimetre. The choice of foil thickness, material and substrate material are not constrained by the design and it is intended that changes can be made at a late stage. Six combinations are possible, and it is to be hoped that results from a recovered LDEF will influence these choices.

An impact arriving at a non-glancing angle and of sufficient energy to perforate the foil will result in the now familiar features both on the foil and the substrate. The action of the Timeband Capture Cell Experiment (TICCE) is to displace the foil by a fixed amount in its own plane every few days. This will give rise to a number of hole/debris site pairs, each having a similar position laterally, and a likely substrate/foil relationship longitudinally. This relationship would correspond uniquely to a short period during the mission. There will most certainly be some ambiguities; but these will not be a large proportion of the total sites. Table 1 summarises the important parameters of this experiment.

The future of the EURECA class of spacecraft lies in its application to the whole spectrum of missions requiring the LEO environment. The European Space Agency is currently considering several payloads for possible dedicated missions; this means one discipline or even one experiment dominating the entire resources of the craft - 1 tonne, 1 kW. Using the baseline design of EURECA B, celestial pointing is available, and dependant upon the amount of slewing, unrefuelled flights of up to 2 years are possible.

As a response to an Announcement of Opportunity relating to all elements of the European Columbus project of which EURECA B is one, we have proposed DUSTWATCH. A specific adaptation to a non serviced platform has been undertaken - this required deletion of those parts associated with selective retrieval, and sizing an array to fit EURECA B's payload area.

DUSTWATCH is an array of panels incorporating position, charge and velocity sensing on both faces; one or more foils can be installed plus a capture substrate. Optionally a 20 cm deep underdense or multiple film capture arrangement can be substituted. Each panel is thus likely to cater for a different mass optimally. A general summary of a proposed dedicated DUSTWATCH/EURECA mission is given in Table 2.

TABLE 1 EURECA A - Timeband Capture Cell Experiment

Mass 5 Kg.

Power 400 Joules/week

Aperture 0.2 m^2 - for full science

0.5m^2 - for partial science

Field of view - close to 180^o

Time resolution - variable, but total of 50 steps available for a 9 month nominal mission

Orbit - 500 km, 28^o , circular,

Attitude - possible minor earth obscuration

Mission duration - 6 - 9 months.

TABLE 2 EURECA B - DUSTWATCH

Mass - 560 kg.

Power - 70 W

Aperture - 34m^2

Field of view - close to 180^o.

Time resolution - milliseconds.

Charge sensing

Velocity sensing (Direction resolution $\sim 5^o$.)

Mission duration - up to 2 years.

IMPACTS ON SHUTTLE ORBITER CAUSED BY THE FIRING OF A PAM D2 SOLID ROCKET: RESULTS OF THE STS 61B PLUME WITNESS PLATE EXPERIMENT AND IMPLICATIONS FOR A COSMIC DUST COLLECTION FACILITY

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The Plume Witness Plate Experiment (PWP) was flown on STS mission 61B in order to investigate the effects on the Orbiter of the plume from a PAM D2 solid rocket. The Orbiter and attached PWP were approximately 17 km from the rocket when it was first fired. The rocket burn lasted 96 seconds, and the witness plates were subjected to exhaust products from the entire burn. We have investigated selected parts of the exposed surfaces and have catalogued a variety of impact features associated with the rocket burn.

This study has relevance to the proposed cosmic dust collection facility *because it is the only data collected in space on impacts of known composition and morphology and known velocity range.* While the impact velocity of this experiment is relatively low (<2.1 km/sec), the velocity approaches the very low velocity tail (3-4 km/sec) for natural meteoroids striking a rearward facing collector (1). Consequently, data on these low velocities may have some applicability to true cosmic dust collection. Furthermore, aluminum oxide particulates from solid rocket exhaust are already present in space and will likely increase in abundance in coming years as space activities increase (2). Therefore, the impact properties of this material on potential collector surfaces is of interest, and applies to the not trivial problem of discriminating between impacts from orbital debris microparticles and impacts from true micrometeoroids.

Using primarily the scanning electron microscope (SEM), we investigated PWP targets of copper (99,99%), aluminum alloys (1100 and 6061-T6), stainless steel (15-5), Inconel 718, and fused quartz glass. We determined pit morphologies including diameters and depths, noted which pits contained projectiles or projectile residues, analyzed the residues using energy dispersive x-ray analysis, and in some cases, electron diffraction, and determined total flux distribution on each target.

Using large photo mosaics taken at 400X magnification combined with higher magnification photographs of smaller selected areas, we identified and measured approximately 300 impact craters on these surfaces. In the examined areas, all craters larger than 0.5um were identified and included in our tabulation. The overall mean crater density was 15.2 impacts per mm^2 for craters larger than 0.5 um. The size distribution of these craters was very sharply peaked to a diameter between 0.5 and 5um. Craters in this size range constituted 95% of the entire population, while 4% were between 6um and 10um and less than 1% (only one crater) were larger than 10um. While we likely overlooked on the large mosiacs some craters at the 0.5um size and smaller, selected high magnification photos did not reveal any craters in this size range.

Projectiles were retained in many of the craters. For the aluminum targets, 88% of the craters larger than 1 um still contained significant projectile material. This material was usually a fractured but often nearly complete sphere of aluminum oxide. For copper, 63% of the craters retained their projectiles, for stainless steel, 62%, and for Inconel, 48% still retained projectiles. None of the examined craters in quartz glass retained projectiles. Some of the projectile residue was transferred to grids for analysis in the transmission electron microscope and we found using electron diffraction data that alpha, gamma, and kappa forms of aluminum oxide were all present.

Depth to diameter ratios were measured on craters which did not retain projectiles. These ratios for the metal targets range from 0.08 to 0.77. These ratios were used to estimate impact velocity using laboratory calibration data (3). Our estimated impact velocities based on these measurements range from 0.5 to 2.1 km/sec. This range of velocities is similar to that predicted prior to the experiment by the modeling of the rocket burn.

Impacts in the fused quartz glass all formed spall zones in addition to a round central pit. The spall diameter is about five times larger than the pit diameter (mean 5.6) so that the damage area on the fused quartz glass target was about 30 times greater compared to the metal targets.

We conclude that projectiles are readily retained on metal targets when the impact velocity is in the range of about 0.5 to 2 km/sec in actual space tests. While the projectiles are always fractured, most of the original sphere is retained in these experiments. It would be simple to distinguish these impacts from micrometeoroid impacts. However, for craters which did not retain projectiles, the situation is not so simple, and careful measuring of crater morphologies including depth/diameter ratios, pit/spall ratios (for brittle targets) and other parameters may be necessary to discriminate between even a low velocity orbital debris impact and a hypervelocity micrometeoroid impact.

Metal surfaces have been used on LDEF as potential witness and capture surfaces for micrometeoroid impacts, and their use on the proposed cosmic dust collection facility may also be feasible. They have the virtue of being very simple and of allowing precise measurements to be made on a limited number of variable features. Determination of retained projectile chemistry is relatively easy on metal surfaces compared to other proposed collection devices. Metal surfaces should certainly be considered as an additional low cost collection device which would be complementary to more complex devices such as multilayer capture cells and foams. Metal surfaces may be the method of choice for relatively low velocity impacts from both micrometeoroid and orbital debris microparticles.

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CALCULATION OF VELOCITY LOSSES AND ESTIMATION OF COSMIC DUST INTEGRITY FOR HYPERVELOCITY IMPACTS ON THIN FOILS

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Successive penetrations of ultrathin foils is one possible technique for collecting mostly intact hypervelocity cosmic dust. To explore the feasibility of this method, we simulated the penetration of one foil with the two-dimensional hypervelocity hydrodynamic impact code, LASOIL, which includes the Tillotson equation of state and an elastic-perfectly plastic strength correction. We completed a four-by-five matrix of 20 impact simulations of 1.6-mm-diameter aluminum spheres striking polyethylene foils. The variable parameters were the sphere's impact velocity (3, 4, 5, and 6 km/s) and the foil's thickness (0.1, 0.3, 0.5, 0.7, and 1.0 mm)

In each case, the sphere decelerated with little damage. The velocity loss was primarily a function of increasing foil thickness, ranging from about 2 to 3% for the 0.1-mm foil to approximately 20% for the 1.0-mm foil. Peak pressures occurred at the sphere/foil boundary along the sphere's trajectory and were primarily a function of impact speed, ranging from 12.5 GPa for the 3 km/s cases to 30 GPa for the 6 km/s cases. The duration of the peak pressure pulses were of the order of 200 ns, and only a fraction of a percent of the sphere's mass was vaporized in each of the impacts.

A MODEL FOR HYPERVELOCITY INTACT CAPTURE IN UNDERDENSE MEDIA;

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Recently, underdense polymeric foams have been studied intensively as a viable candidate for passive intact cometary dust collector. Systematic capture experiments have been performed on the intact capture of metal (aluminum) particles at velocities ranging from 1 to 7 km/sec.$^{(1)}$ The experimental results show that particle penetration and erosion in foams are significantly different from those obtained from homogeneous solids, liquids or gases.

This paper proposes a model to describe these phenomena. The model consists of a particle erosion equation and a generalized equation of motion. The experimental results indicate that the mass loss of projectiles from impact on foams is mainly from erosion; moreover, from simplified one dimensional shock analysis, the shock pressure is too weak to cause dynamic fracture of metals. Therefore, a similar type of mass erosion equation used for ablating re-entry vehicle is considered.$^{(2)}$ Although the medium is different, the following equation seems to describe the particle mass loss:

$$\frac{dm}{m} = C\ VdV \qquad (1)$$

where, m is the mass of the particle, V the velocity, and C is the coefficient of erosion rate which is found to depend on the particle size and the target material. Eq (1) describes quite well the mass recovery ratio, m/mo where mo is the initial particle mass and m is the recovery mass (Fig 1). Furthermore, by assuming that C(a)=Co/a, where a is the radius of the particle size, one can predict the effect of the particle size quite well as shown in Fig. 1.

One of the very interesting features of the experimental results is the total track length of the projectile inside the foam.$^{(1)}$ The total track length with respect to the initial velocity, V_o can be divided approximately into three regions. Each region has a distinct physical phenomenon related to target and projectile. For low velocity region up to 1 Km/sec, the track length is linear in proportion to, Vo, and there is no particle mass loss. Furthermore, the ratio of the slope is proportional to the size of particle. As Vo increases into the second region, the slope of the curve gradually decreases, and finally, into the third region, the track length reaches the maximum and starts to decrease. In this region the resistance force increases drastically as Vo reaches a certain threshold to cause the reverse of the track length. The reverse phenomenon, also, is contributed by erosion of particle mass at the initial phase of particle-foam interaction.

In order to describe these phenomena, a generalized equation of motion of the projectile in the foam is proposed

$$F_R = -m(t)\frac{dV}{dt} \qquad (2)$$

where the mass, m, now is the function of time, t, (from the time of impact) or distance x in the foam. F_R is the total resistance the particle encounters in the foam, which depends strongly on the target properties, the projectile speed and projectile size. The general resistance force is postu-

A MODEL FOR HYPERVELOCITY INTACT CAPTURE

S. T. J. Peng and P. Tsou

lated as $F_R = \mu a^2 V^n$, where the coefficient μ may depend on target foam material. With Eq (2), we have

$$\mu a^2 V^n = -m(t)\frac{dV}{dt} \tag{3}$$

In region one, the total track is formed by a slow penetrating particle pressing the foam material forward and sideward (no particle mass loss). The formation of the track is more like a result of plug flow. Therefore, $n = 1$ ($F_R = \mu_1 a^2 V$) is proposed which describes and predicts the linearity of the curve; moreover, it predicts the slope to be a linear function of the diameter which is shown by the experiments (the effect of particle density also can be predicted). As Vo increases into region two, $n = 2$($F_R = \mu_2 a^2 V^2$) describes the trend quite well. Finally, in the region three of hypervelocity impact, the resistance force increases drastically, such that n becomes so large as to be best described by an exponential function such as

$$F_R = \mu a^2 e^{\alpha V^2} \tag{4}$$

Moreover, in this region, a significant erosion occurs. Therefore, the erosion equation (1) is employed to describe m(t). The resulting equation obtained from Eqs (2), (4), and (1) is given by

$$x_{tract} = \frac{2}{3}\frac{\pi \rho_p a}{\mu(\alpha - C)}\left[\exp(-CV_o^2) - \exp(-\alpha V_o^2)\right] \tag{4}$$

which describes the reverse phenomenon of total track length x_{tract}, (Fig 2). Moreover, it predicts the effect of the particle size (Fig. 2). Also, in this formulation, the effect of particle density can be predicted.

In conclusion, the model describes the erosion and track length quite well. Furthermore, the model is used to describe the projectile velocity profile in the foam, and estimates the particle mass recovery ratio for smaller particles or higher speed ranges which are not accessible to the current test apparatus. It is important to note that some constants are extracted from the experimental data. Physical significance of these constants will be investigated in the future.

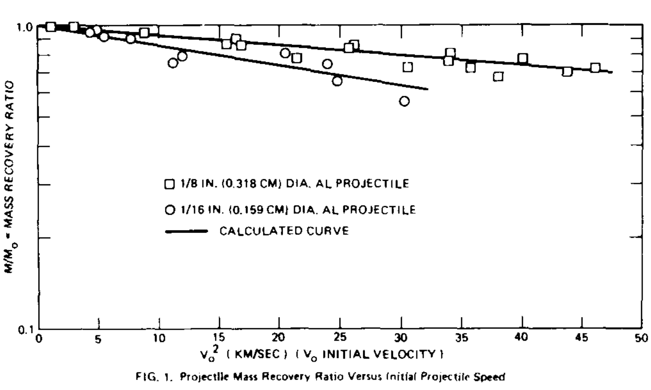

FIG. 1. Projectile Mass Recovery Ratio Versus Initial Projectile Speed

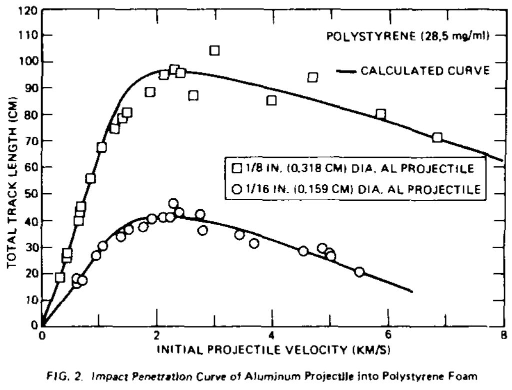

FIG. 2. Impact Penetration Curve of Aluminum Projectile into Polystyrene Foam

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SURVIVAL OF ORGANIC MOLECULES AS RESULT OF SIMULATED HYPERVELOCITY IMPACT.

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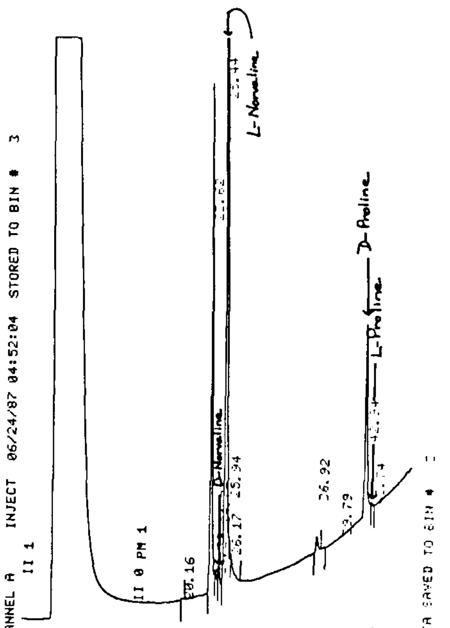
Small interplanetary particles or micro-meteoroids hold within their matrixes information that reveals something about their genesis and diagenesis as result of various chemical and physical processes since their time and point of origin. High temperatures and pressures from hypervelocity impact may destroy or greatly modify pertinent information with respect to carbon compounds, therefore, the major objective of this study is to evaluate various materials and media for the eventual collection of small particles by using amino acids as indicators of how much of the "indigeneous" organic matter will be lost during the collection process.

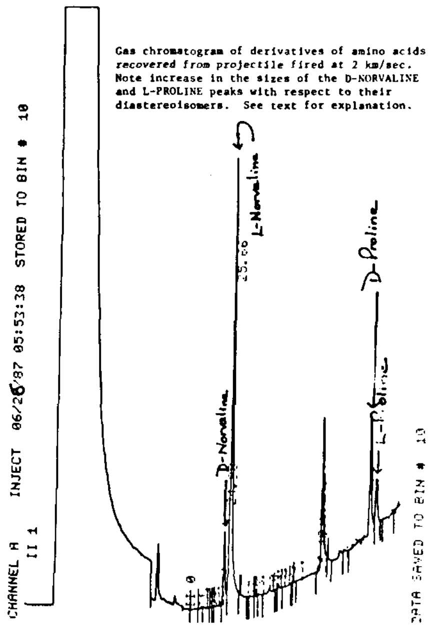
Amino acids are not only of primary importance in all living systems, but have been of particular interest to exobiologists since their discovery in the Murchison and Murray meteorites nearly two decades ago. Besides the importance of a select twenty-one of them as building blocks of proteins and enzymes, they possess a unique property called chirality, a left- and right-handedness. Because of their ubiquitous nature and chirality, they can serve as diagnostic tools. For instance, contamination, which may be attributed to poor handling of a sample during preparation, can be diagnosed by its "fingerprint" pattern. Their chirality (optical activity) is subject to change, a process called racemization. This is the conversion of half of the L-compound into its mirror image, the D-compound. The rate of racemization for each amino acid is different, and is greatly influenced mostly by temperature and pH. Hence, the extent of racemization may be used as a qualitative "thermometer". With these points in mind, small projectiles (1/8" o.d.) were prepared containing L-malic acid, a carboxylic acid with a decomposition temperature of 100°C, D-proline (215°C), and L-norvaline (ca. 305°C). The three components were chosen because of their decomposition temperatures, chirality, and they are not common contaminants. The projectile "matrix" materials were of various compositions, in some instances requiring bonding and curing to produce a hard, discrete projectile that would not disintegrate in flight. Previous failure and tight scheduling required that an alternate material be chosen which did not require special bonding: cement and sand. This was mixed with a stock solution containing the three components mentioned, and fashioned into projectiles. To accelerate the hardening process, the projectiles were dried at 70°C for seven days. A sample projectile was then fired in the Ames Vertical Gun at 2 km/sec., and collected in styrofoam (for details of hypervelocity intact capture studies, please refer to P. Tsou, et al, elsewhere in this workshop report). The recovered projectile was analyzed in parallel with a control projectile and pure standards of the added components. The general analytical scheme consists of (1) extraction of the organic components by dissolution of the solid "particle" in dilute hydrochloric acid, separation of the liquid from the solid residue; (2) ion exchange chromatography to isolate the amino acids (emphasis is placed on the two amino acids only) from the anions and other cations; (3) derivatization of the isolated amino acids with an optically active alcohol to form esters and subsequent acylation results in volatile, stable derivatives; (4) gas chromatographic separation of the diastereoisomers on a capillary column and detection with a flame ionization detector.

Despite certain problems, which can be remedied, these preliminary results show that racemization does take place during flight and subsequent impact over and above the racemization induced during the preparation of the projectiles. For pure standards the amount of either D-(norvaline) or L-(proline) enantiomer present is circa 1%. As a result of the heat treatment of the projectiles during the "curing" process, the amount of D-norvaline formed was 10%, and the amount of L-proline was 33%. After recovery and analysis of the fired projectile, the amount of D-norvaline had increased to circa 15%; the amount of L-proline to 44%, an increase of 11%. Quantitatively speaking, it does not appear that either the norvaline or proline was lost as the result of hypervelocity impact; nor were there losses due to ion exchange chromatography. The malic acid has yet to be analyzed, thus we cannot provide answers to any questions regarding loss of material due to decomposition. The heterogeneous distribution of heat within the projectile during impact complicates this problem. The ablation surface on the projectile's "bow" is subjected to higher temperatures than the "stern"; the interior is coolest. Although the experimental projectiles are much larger than expected for collected particles, scaled studies should provide chemical gradient and mineralogical modification data.

With regard to sensitivity, the current state of the art in gas chromatography extends into the femtomole range. This initial report deals with quantities in the nanomole range. Experimenting with smaller projectiles will be a future objective.



Gas chromatogram of derivatives of pure standards of L-NORVALINE and D-PROLINE indicating 1% peaks for their respective diastereoisomers.



Gas chromatogram of derivatives of amino acids recovered from projectile fired at 2 km/sec. Note increase in the sizes of the D-NORVALINE and L-PROLINE peaks with respect to their diastereoisomers. See text for explanation.

-LESSONS FROM SOLAR MAX.-

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The Solar Maximum Satellite (Solar Max) was launched on 14 February 1980 and was retrieved by the STS 41-C crew which returned some Solar Max surfaces to Earth after 4 years and 55 days of exposure to the near-Earth space environment. These surfaces include multilayered thermal control blankets and aluminum thermal control louvers. All surfaces were riddled with impact features, that is craters and penetration holes which contain a multitude of associated particles, <1.0 up to ±32 μm, in size [1 - 3]. On the thermal control blankets, it is not always clear what type of projectile is responsible for each particular impact feature [1, 4, 5]. However, on the thermal control louvers, projectile types are readily recognised in 86% of the craters [2]. For the following, I would like to draw upon the experience obtained from particle analyses on the main electronics box (MEB) thermal control blankets. Using their chemical compositions, particles were classified into (1) micrometeoroid debris, (2) particles of anthropogenic origin (such as Space Shuttle paints and orbital debris) and (3) particles of unknown origin [1, 4]. It seems probable that most particles in the last category also have an anthropogenic origin [5]. As a result, particles identified on the MEB thermal control blankets [5] and thermal control louvers [2] suggest that the debris flux exceeds the natural micrometeoroid flux by approximately two orders of magnitude. It is important to consider that Al-metal is present on all Solar Max surface materials. Thus, it is not possible to unambiguously identify impacts caused by Al-rich projectiles such as solid rocket effluent [6] and Al-rich micrometeoroids [7, 8].

Solar Max surfaces were studied by reflected-light microscopy for identification of impact feature types, morphology and associated phenomena such as the presence of spall zones and halos on the space-facing side of the first (Kapton) layer of the satellite [6]. Selected impact features were then studied using scanning electron microscopy (SEM). SEM imaging of impact features provided data for classification of rims around impact features, spray zones beneath penetration holes as well as to establish the presence and distribution of small-sized particles on Solar Max surfaces [6, 9, 10]. Energy dispersive spectroscopy in conjunction with SEM imaging provided the chemical data for particle classification [1, 4, 5, 11]. Scanning Auger microprobe analysis of surfaces around penetration holes did not show evidence for vapour deposits but found that the metallic Al-coating of the MEB blankets were oxidised by hypervelocity impact [6]. After SEM analysis, selected MSF (Mg-Si-Fe)-particles from an impact feature of probable micrometeoroid origin [12] were prepared for analytical electron microscopy (AEM) [13]. These particles were identified as forsteritic olivine (Fo_{66-83}; d_{010} = 10.13-10.24 Å) resulting from fragmentation of a single (±100μm diameter) olivine micrometeoroid [13, 14].

The experience gained from particle analyses of Solar Max show that several matters are important for the design of capture cells for exposure in low-Earth orbit:

(1) lack of a precise knowledge of materials used in capture cell materials impairs efficient SEM analyses of returned surfaces. For example, omnipresent Ca-P particles are an additive to the Mylar of the MEB blankets and, initially, its application was of a proprietary nature (in this case, the manufacturer's courtesy is appreciated in clearing this issue).

(2) pre- and post-flight cleanliness was improperly maintained as witnessed by wipe-marks and abundant Si-particles on the MEB blankets [6], although some fraction of the Si-particles may be related to Space Shuttle rendezvous [15]. Some contamination may be unavoidable, but it is clear that processing of capture cell surfaces should proceed in clean room facilities such as the Class-100 clean room facility at the NASA JSC Curatorial Branch.

(3) the Space Shuttle's dust environment added substantial amounts of particles to Solar Max surfaces as indicated by flaked-off paint particles that form an almost continuous spray on space-facing surfaces of the MEB blankets [1, 4].

(4) It seems advisable to catalog particles that have been recognised as contaminants as well as potential contaminants such as spacecraft materials. The purpose of this catalog is to *facilitate and standardise* recognition of non-extraterrestrial particles.

The Solar Max experience shows that light-optical, SEM and AEM studies generate a wealth of data, provided each step is carefully documented. The AEM study of recovered olivine particles [13, 14] showed that it is possible to succesfully identify impact debris as extraterrestrial material [13, 14] which is not possible using SEM information only [2]. The AEM results also show that (1) particles of a chemically well-characterised group of residue particles may occur with different morphologies [13] and (2) morphologically similar particles within a group may show variations in microstructure and chemical effects [14]. Of course these interpretations assume that *the properties of the projectile prior to impact are known*. For example, one assumes that deformation is introduced during impact. In the case of extraterrestrial olivines this assumption is tenuous as the meteorite record shows that shocked olivines may form during parent body regolith processes [16]. Yet, assuming that deformation and ablation or melting of olivine particles occured as the result of hypervelocity impact, the question becomes *whether terrestrial deformation experiments using geological constraints are representative for deformation processes as they may occur in these hypervelocity shock events.*

To illustrate this point, I would like to draw attention to the Table which is a listing of light-optical and AEM deformation features observed in shocked olivines as a function of peak pressure [16]. The dislocations in angular particles and presence of spherical particles of Solar Max olivines [14] suggest different thermal effects for individual fragments, respectively ±600°C (angular particles) and ±1000°C, or up to 1890°C ($T_{melting}$ of forsterite) for rounded particles. I suggest that it is necessary to perform hypervelocity shock experiments using well-characterised naturally occurring micrometeoroids in order to evaluate whether fine-scale thermal heterogeneities are common to hypervelocity impacts. It is also important to address any kinetic effects as they may occur for hypervelocity shock-induced deformations as a function of the impact energy, e.g. T(*ime*) - E(*nergy*) - D(*eformation*) (TED) diagrams. Finally, in conjunction with these experiments, it is necessary to increase the AEM data base of microstructures in fine-grained extraterratrial occurrences such as meteorites and interplanetary dust particles, as these data are complimentary to analogue shock experiments

In summary, I suggest that from a micrometeoriticist's viewpoint, the development of a Cosmic Dust Facility on the Space Station may benefit from the lessons taught by Solar Max: (1) contamination control is paramount and logically leads to the consideration of a specialised receiving and curation facility, (2) cataloging of contaminants, including *in situ* sampling of the near-Earth space environment [17], to improve our understanding of the near-Earth orbital debris population, (3) experiments to construct TED diagrams and (4) continued studies of fine-grained extraterrestrial materials [18, 19].

EQUILIBRIUM (?) SHOCK PRESSURE (GPa)	LIGHT-OPTICAL	X-RAY DIFFRACTION	ANALYTICAL ELECTRON MICROSCOPY	PHYSICAL CONDITIONS
0 - 35	No evidence			
0 - 45/51 or light shock	-Fracturing/cracks -Undulatory extinction -Crystallographically aligned planar features	Fragmentation with decreasing "block size; in single crystals; the "block size" -distribution is heterogeneous	Slip dislocation arrays [(110) and (100)] and [001] screw dislocations "Clean" Cracks	600-800°C;$\varepsilon = 10^{-5} s^{-1}$
5 - 45 or heavy shock	-Mosaicism -Granulation		"Clean" cracks and zones of high dislocation density, or "blunted cracks" Dislocation interactions Granulation (in veins)	<800-1000°C;$\varepsilon = 10^{-5} s^{-1}$
> ±60 or very heavy shock	-Recrystallization -Shock melting which eliminates dislocations		Curved dislocations and loops	~1000-1290 (1h) 1450 (0.01h)

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THE NECESSITY FOR MICRO-ANALYTICAL CHARACTERISATION OF LABORATORY SHOCK EXPERIMENTS.

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The stage leading to deployment of the Cosmic Dust Facility on the Space Station will be devoted to experimental studies of capture cell designs to optimise their efficiency to capture micrometeoroids, as well as to determine their trajectories [1]. Presently, light-optical and scanning electron microscopy (SEM) are most commonly used to characterise projectiles, or their residues, after impact with a target; while energy dispersive spectroscopy in conjunction with SEM and electron microprobes provide chemical data on projectile and target materials [2 - 5]. In rare instances, analytical electron microscopy (AEM) is used to characterise shocked target materials [6]. In general, laboratory shock experiments use chemically simple projectiles (e.g. Al-2017, ruby, stainless steel) which are fired into single phase targets (e.g. H_2O-ice, silicate single crystals, Kapton) or multi-phase targets such as diorite or gabbro [7 - 12]. Without question, these studies provided a wealth of data on cratering, projectile-target interactions and chemical changes in target materials. With the opportunity for experiments on the Space Shuttle, selected solid targets [13] and thin-foils exposed to space can be returned to Earth for study of impact efficiency [14].

Recently, experimental studies have been initiated which simulate impact of comet-like materials (such as epoxy-bonded olivine/FeS/glass microspheres and Allende meteorite powder) into media that are considered for deployment in the Cosmic Dust Facility [3, 15, 16]. If the Cosmic Dust Facility utilises a capture cell design, target materials need to be well-known and need to provide a degree of freedom with respect to targeted projectile capture. For example, capture cells may be designed to retain volatile ices, carbonaceous materials, solid debris from comets or high velocity interstellar dust. Captured materials may be contained as vapour deposits of the volatised sample or intact capture of solid debris. The latter is probably the most challenging contribution to the field of micrometeoritics. However, intact capture will depend on the preference of individual investigators. I will restrict myself to capture of fine-grained solids from small Solar System bodies, such as asteroids and comets, and interstellar dust. Assuming that these materials are to some extent already present in stratospheric dust collections [17], it is clear that these fine-grained materials occur with a range of sizes, morphologies and densities [18 - 20] and with a highly variable and complex mineralogy [20]. In addition, these particles reach near-Earth space with a wide range of velocities [1, 21].

From a micrometeoriticists point of view, intact capture implies *preservation of all original chemical, mineralogical, structural and physical properties of the projectile* [22]. In this respect, *original* is defined as *"those properties of the projectile prior to impact"* and may include effects introduced during Solar System sojourn, e.g. solar flare tracks, or due to parent body regolith processes, e.g. dislocation substructures in olivines [23].

Several issues may have to be addressed before we may reliably predict intact survival using the Cosmic Dust Facility. For example, a detailed knowledge of the chemical, physical and structural properties of the targets is a prerequisite (see companion paper). In addition, it is of paramount importance to generate detailed data on physical, mineralogical and chemical processes that may occur in projectile and target as a function of kinetic energy, such as comminution, structural deformation and loss of volatiles [12, 15].

State-of-the art analytical electron microscopy (AEM) will provide the type of data required for evaluations of capture cell efficiencies for intact capture. In fact, AEM is already established as a suitable technique for studies of lunar samples, meteorites, interplanetary dust particles [20, 24] and projectile debris recovered from impacts in Earth-orbiting spacecraft [25 - 27] and the experimental laboratory [6]. In addition, sample preparation techniques for AEM analysis are *pluriform*, *adaptable* and *flexible* to suit any desired analytical purpose. Nevertheless, it may be prudent to consider capture cell materials which facilitate sample preparation with a minimum of laboratory handling.

To illustrate the necessity for AEM analysis, I would like to draw attention to a preliminary study of recovered comet-like projectile material that was fired at 3.9 km/s into an underdense foam. Using SEM data, intact survival was reported for 13% of the recovered projectile, that is, the projectile showed "no visible melting or shock damage" [3, 16, 28]. The projectile is an epoxy-bonded mixture of olivine (Fo_{88-94}), iron-sulfide (FeS) and hollow glass microspheres. The addition of hollow spheres is to simulate low-density, porous comet dust. Ultramicrotomed thin sections of the shocked projectile, as well as an unshocked *-presumably-* reference sample, were prepared for AEM study for *in situ* mineralogical and chemical analysis. The shocked sample showed considerable mineralogical and chemical variations that were not observed in the unshocked sample. For instance, FeS occurred with a range of Fe/S-ratios: 0.71 - 0.80 (unshocked) and 0.75 - 1.04 (shocked). In the shocked sample Mg-rich, Ca-poor (CaO = 0.0 - 0.15 wt%) and Ca-rich (CaO = 25.5 wt%) pyroxenes occurred in addition to forsterite olivine which is similar to the unshocked olivine. The shocked glass, which is probably an alumina-silica glass with variable amounts of Ca, K and Na (feldspar glass?), lost its chemical identity almost completely. Calcium, sodium and alumina entered into the pyroxenes which formed by reaction of olivine with silica from the glass.

The AEM results show that the shocked projectile may have experienced serious mineralogical and chemical changes. While the recovered projectile may not show visible signs of shock damage, the AEM data show that intact capture did not occur, at least not from a micrometeoriticists point of view. This paradox may be resolved by using generally accepted definitions concerning *intact capture.* The response of minerals to shock metamorphism will depend on their compressibility and density. The approximate densities ($g.cm^{-3}$) of phases in the projectile are 3.2 (olivine), 4.6 (FeS) and 2.6 (feldspar). In general, the observed degradation of feldspar glass is consistent with the density distribution in the projectile. In addition, the porosity of the projectile introduced by the hollow microspheres will also affect the shock response of the projectile due to added frictional heating [1].

I wish to add the following caveats to the data: (1) sample selection may have been flawed as, *in retrospect*, it is not unambiguously clear that the unshocked sample is indeed a true reference sample, (2) the location of thin sections is not documented with respect to the leading-edge of the projectile as it penetrates the target and (3) conditions for complex shockwave propagation and sample interaction in the fine-grained, multi-component aggregate are poorly understood.

Nevertheless, the AEM results show that (1) high temperature reactions may occur in samples that apparently showed intact impact survival based on SEM results, (2) careful sample selection and AEM characterisation prior to the shock experiment is highly desirable, (3) laboratory procedures need to be reevaluated in order to minimise, or at least control, sample contamination (especially materials used in the experiment) and (4) an interdisciplinary approach will clearly benefit the engineering design studies of capture cells to be deployed on the Space Station.

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THE USE OF INFRARED SPECTROSCOPY FOR ANALYSIS OF SAMPLES RETURNED FROM THE SPACE STATION "COSMIC DUST COLLECTION FACILITY," Scott Sandford, NASA/Ames Research Center, Mail Stop 245-6, Moffett Field, CA 94035.

Mid-infrared (2.5-25 µm, 4000-400 cm^{-1}) spectroscopy provides a potentially useful technique for the analysis of microscopic quantities of extraterrestrial materials. The usefulness of transmission IR spectroscopy for small samples has already been demonstrated for the case of interplanetary dust particles (IDPs) collected in the stratosphere (1). IR absorption spectroscopy provides a powerful probe of molecular composition since the absorption of IR photons depends on changes in dipole moment during atomic vibrational transitions in a molecule The frequencies of the photons absorbed are determined by the masses of the vibrating atoms and the strengths of their mutual bonds. The result is that the vibrational transitions of most chemical subgroups produce distinctive IR spectral "fingerprints." Thus, the IR spectrum of an unknown material can provide strong constraints on the molecular composition of the sample.

As with most (all) experimental techniques, IR spectroscopy has certain advantages and disadvantages. In the case of collected IDPs, a major advantage is that the sample spectra can be directly compared to the spectra of astronomical objects, like comets and asteroids, that are potential sources of the dust (1,2). Another advantage of the technique is that it efficiently determines the presence of many molecular functional groups, even when these subgroups are not part of a crystalline solid. Disadvantages include poor sensitivity to molecular units with small oscillatory dipoles during a vibrational transition since these modes do not absorb strongly in the infrared. Also, it is often difficult to detect minor components of a sample, especially if the bands due to the minor component fall in the same spectral region as bands associated with a major component.

In the paragraphs that follow, more specific requirements for IR spectroscopy of small samples will be discussed.

Sample Size Requirements - The ability to obtain useful spectra from extraterrestrial samples as small as 15 µm in diameter has already been demonstrated (1). Recent improvements in the IR micro-sampling accessories available for scientific use should reduce sample size requirements below this value. The lower limit that can be effectively analyzed is ultimately determined by diffraction effects associated with the aperture used to mask the sample material. Because of these diffraction effects we will probably be limited to samples that have sufficient material to be dispersed over a 5x5 µm area.

Sample Integrity - The power of IR spectroscopy to probe the chemical bonds of a sample is largely lost if the sample is atomized during collection (with accompanying loss of initial molecular structure). Thus, the major usefulness of this technique will be largely limited to samples that have suffered lesser amounts of alteration. It should be noted, however, that IR spectroscopy may offer a good means of distinguishing between altered and unaltered samples. Since the technique is sensitive to small scale order it can be used to distinguish between "glassy" or amorphous vapor condensations and crystalline samples with small grain sizes.

IR SPECTROSCOPY OF SPACE STATION SAMPLES

Sandford, S.A.

Resolution Requirements - Since all the samples (silicates, carbonaceous materials, etc.) returned from the Space Station will be solids, only moderate spectral resolution will be required. Resolutions of 1 to 4 cm^{-1} should be sufficient.

Collection Substrates - Since IR spectroscopy is sensitive to all materials with allowed dipole transitions, it is highly desirable to use collection substrates that are IR "transparent." Possible materials include salts such as alkali-halides (CsI, KBr, etc.), Type IIa diamonds, and germanium or silicon wafers. The first set of materials have poor thermal and mechanical properties and are probably not suitable. Diamonds have very nice properties for this sort of work but are not practical for obvious reasons. Ge and Si wafers are acceptible (Ge has already been used on LDEF (3)), but have the disadvantage of being opaque at visible wavelengths. This greatly increases the difficulty in positioning samples in the aperture of the IR spectrometer. Samples deposited on thin plastic films can probably also be examined, although they will suffer from some spectral confusion since all plastics contain features a critical frequencies in the mid-IR.

Ultimately, the most desirable solution is to design the collectors in such a way that material can be removed and mounted in appropriate sample holders using techniques already being used in the stratospheric IDP field.

Ground-Based Work Required to Support the Space Station Facility - A certain amount of ground-based work should be done prior to the flight of the Space Station package. Two problems in particular should be addressed. First, techniques should be perfected so that we have the capability to take IR spectra from ultramicrotomed samples (4). This will facilitate comparisons between IR and transmission electron microscope studies. It would also greatly increase our ability to calculate the absorption coefficients of the samples. Present "crush and dispersion" methods make this impossible. Second, we need to explore the capabilities and limitations of the latest generation of IR microsampling accessories, especially in an attempt to determine the lower mass limit that can presently be analyzed.

Summary - Infrared spectroscopy offers a powerful technique for the analysis of microscopic extraterrestrial samples. The technique is especially effective when used in conjuction with other experimental techniques. Infrared spectroscopy has the unique advantage of allowing for direct comparisons between the samples and possible source objects. Some preparatory IR laboratory work needs to be done prior to launch of the collectors.

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NEW EXPERIMENTAL METHODS FOR MEASUREMENT OF DUST PARTICLES IN SPACE BASED ON POLARIZED POLYMER FILM DETECTORS. *

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A dust particle experiment having the capability of measuring in space dust particle mass, velocity, particle trajectory, and charge state (0, ±) would provide important scientific information on space dust. With this information and a determination of the elemental and isotopic composition of individual particles (either by sample recovery or *in situ* analysis) it becomes possible to determine the sources of the particles.

We have developed a new class of dust particle detector, the PVDF dust detector (1) which will measure particle mass at high velocity (few km/s to ~ 100 km/s) (2), and at low velocity (~ 100 m/s) (3). The high velocity capabilities of PVDF dust detectors were demonstrated by their excellent performance in the University of Chicago dust experiments (DUCMA) aboard the U.S.S.R. VEGA-1 and VEGA-2 spacecraft during the Halley comet encounters in March 1986 (4-6). In this report we discuss briefly some new instrument developments based on the PVDF dust detector which provide for in-flight measurements of the above dust parameters over a wide range of particle mass and velocity.

We have developed large-area (500 cm^2) PVDF detectors which have been assembled into mosaics of 0.2 m^2 area. A number of such mosaics may be unfolded in space or on a space station and provide for large (> 10 m^2) geometry factor in regions of space where the dust flux is expected to be low. Various designs have been proposed for dust masses > ~ 10^{-13}g (3).

PVDF dust detectors have been developed which determine the x,y coordinates of impact as well as particle mass. This concept is illustrated in figure 1 and is derived from our earlier development of position sensing semi-conductor/silicon detectors for cosmic ray nucleon trajectory determination (7). This development makes it possible to design an instrument to determine the direction of arrival of fast dust particles and can be combined with a time-of-flight arrangement using thin PVDF detectors to determine particle velocity and mass (3). These position sensing dust detectors may be arrayed so that a particle (or its secondary fragments) will come to rest in a capture cell so that subsequent recovery of such an instrument for analysis on Earth becomes a powerful means for the identification of individual dust particles and determination of their origin.

Based on the concept for dust velocity measurements used in dust accelerators, we have shown that space instruments can be designed which measure the magnitude and sign of the charge carried by a charged dust particle, thus providing for a determination of the charged/neutral ratio of dust particles in space. A method which provides for measurements of the charge, mass, and velocity of a dust particle is illustrated in figure 2.

The dust instruments based on PVDF detectors we have described here demonstrate the great versatility of this new type of dust detector which, when used in various combinations, can provide for all of the required parameters for the measurement and identification of dust particles in space.

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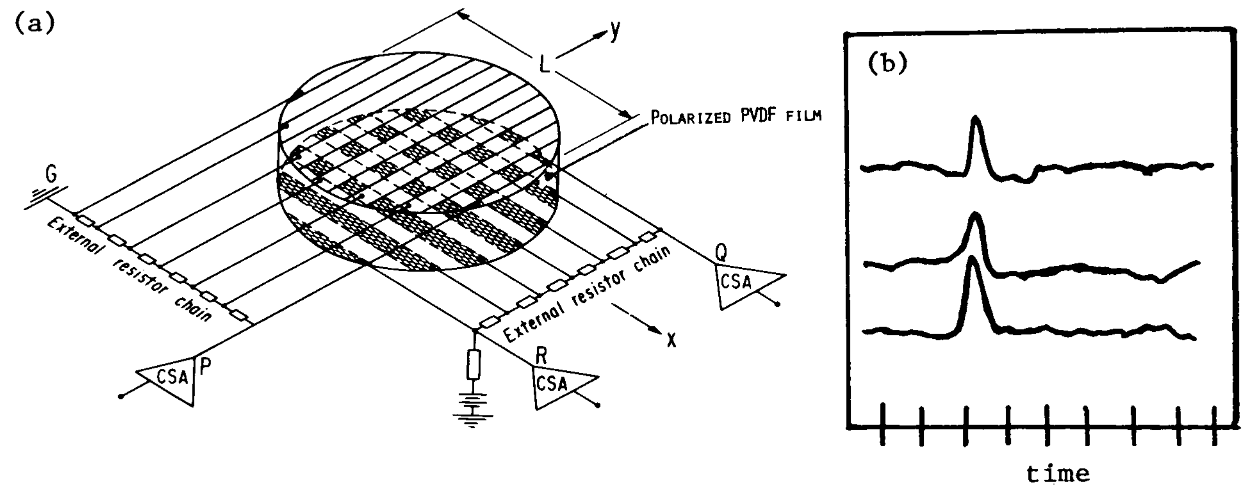

Fig. 1.(a) Schematic drawing of two-dimensional position-sensing PVDF dust detector using external resistive charge division. The end-strip contacts labeled P,Q,R are connected to charge-sensitive preamplifiers (CSA) and then to shaping amplifiers. (b) Output signals from the P (upper trace), Q (middle trace) and R (lower trace) shaping amplifiers resulting from an impacting iron particle of mass $3.8x10^{-11}$g and velocity 4.6 km/s. From the amplitudes of the three signals, the x,y coordinates of impact are determined. Horizontal scale = 50 μs/div.

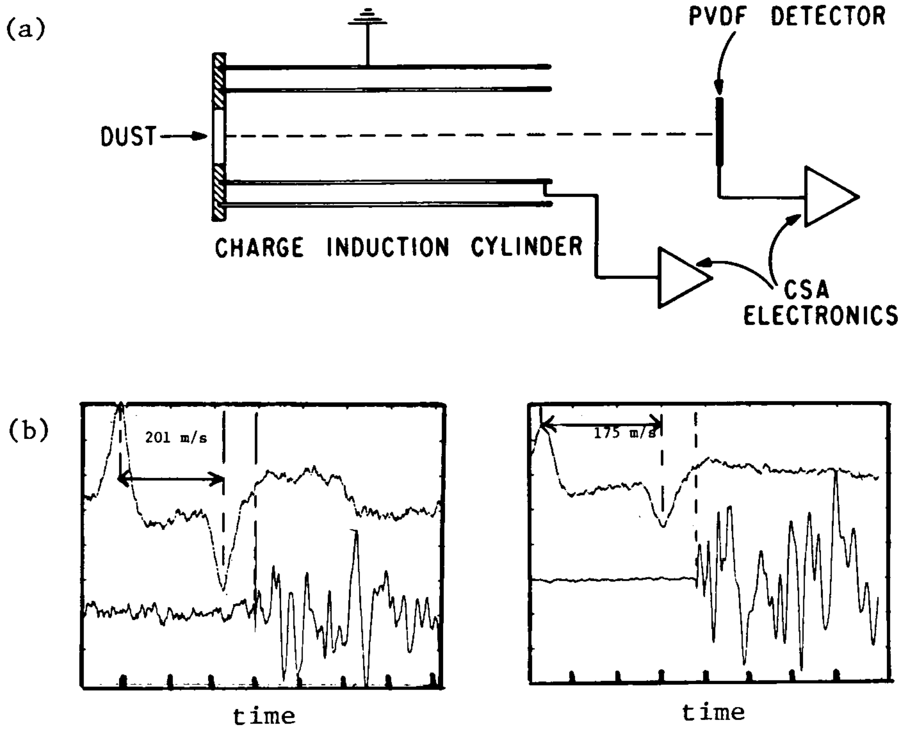

Fig. 2. (a) Schematic drawing of portion of dust instrument for measurement of dust particle charge, velocity, and mass. (b) Response of inner cylinder (upper traces) and 6 μm thick PVDF detector (lower traces) placed 2.5 cm behind cylinder to charged ZnCds crystallites. The crystallites enter and exit the cylinder and impact the PVDF detector. Horizontal scale = 125 μs/div.

DETECTION OF MICROMETEOROIDS AND ORBITAL DEBRIS USING SMALL SATELLITES LAUNCHED FROM THE SPACE SHUTTLE, J. R. Stephens and I. B. Strong, Los Alamos National Laboratory, Los Alamos, NM 87545

For several years, NASA has sponsored a program of Get-Away-Special (GAS) experiments, carried on a space-available basis in standardized containers mounted in the Shuttle bay. Such flights are intentionally cheap and relatively simple to integrate, not least because they are completely self-contained with the exception of a few commands which can be given by the Shuttle crew. At a small extra cost an opening door on the top of the cylindrical GAS is available. An exciting recent addition has been a system that can eject the experimental package from the GAS can after the door has been opened, making the GAS can into a low-cost satellite launcher for putting 150 lb spacecraft into low Earth orbit.

The availability of such a low cost alternative to standard satellites could allow detection of micrometeoroids and orbital debris and the determination of particle trajectories with time and cost scales much less than for other orbital platforms. Such small satellites may also provide a relatively inexpensive opportunity to test several generations of particle detectors prior to the incorporation of expensive hardware in the Space Station.

Defense Systems Inc. (DSI) which was responsible for the GLOMAR satellite, one of only two such small spacecraft thus far launched, is now completing construction of the first three of a series of chemical release experiment satellites for the Los Alamos National Laboratory. This first set is intended for use in a USAF program for releasing rocket fuels in space for observation of interactions with the local space environment. Working with DSI, we have now begun conceptual design work for a satellite intended to monitor the directional, mass, and velocity distributions of small particles in the neighborhood of the Earth. Provided we are able to inject the satellite into a high enough orbit we can find these distributions as a function of time, and as the satellite's orbit decays this is simultaneously also a function of altitude. Due to the low event rate all the data can be stored on board to be transmitted as convenient to the simple ground stations for analysis. In addition to the event data and the requisite house-keeping information, the attitude of the satellite will need to be monitored to determine the absolute direction of incidence of the particles detected. It is hoped to achieve a lifetime of five years or more, which will give around five thousand events per square meter of detector area.

CONCEPTS FOR INTACT CAPTURE OF COSMIC DUST ON SPACE STATION

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INTRODUCTION The need for early science return from Space Station offers the unique opportunity for a passive intact capture experiment of cosmic dusts. A Space Station intact cosmic dust collection instrument would allow for a serviceable, long-duration science facility for the collection of cosmic dusts not obtainable on the surface of the Earth; and the collected cosmic dust would be unprocessed by the atmosphere. This paper presents the instrument concepts developed for the Space Station intact cosmic dust collection experiment. The technology for the passive intact capture of hypervelocity particles is based upon the on going technology development [1].

EXPERIMENT OBJECTIVES This Space Station intact capture of cosmic dust experiment is scoped by a set of science and engineering desires as:

- To collect all sizes and speeds of cosmic dusts expected in the Space Station environment but at least as much as the following:
  - thousands of grains in the micron-sized range,
  - hundreds of grains in the tens-of-micron-sized range, and
  - tens of grains of hundreds-of-micron-sized range,
- To retain sufficient capture track information to enable the identification of the captured dust size, direction, and speed,
- To provide a record of the timing and location of capture, and
- To minimize the contamination of captured particles by space debris and other artificial sources.

COSMIC DUST ENVIRONMENT Cosmic dusts in the Earth vicinity can be grouped into these categories:

- regular activity - predictable dust activity generated from Earth's interception of an orbital stream of interplanetary materials,
- periodic activity - predictable dust activity generated from Earth's interception of a noncontinuous swarm of interplanetary materials,
- sporadic activity - unpredictable and untractable dust activity intercepted by Earth's orbit from planetary or other sources.

Capturing cosmic dusts from either regular and periodic meteor showers will allow a high potential for identifying the parent source of the captured dust; furthermore, the dust flux will be significantly higher than background activity. Sporadic dust will be captured best sporadically, by chance, since the sources can not be identified; however, some of the dusts may be extra solar!

INTACT CAPTURE EXPERIMENT CONCEPT Since the flux of smaller dust is significantly greater than larger sized dusts, a relative smaller percentage of collecting surface area will be allocated for smaller dusts. Three types of passive underdense media will be needed to optimize the collection of three size ranges of dusts. Simple acoustic location and recording systems will be used to provide impact timing for specific impact information which will be essential in post-Earth-return dust source identification analysis. Such acoustic approach is commercially available and has been used to pinpoint the location of hypervelocity impacts.

Penetration tracks left from dust captures underdense media will be able to provide the needed information on dust impact direction and speed with sufficient accuracy for the dust source identification [2]. The recording of acoustic sensors will allow the reconstruction of dust impact timing and location. Along with the Space Station system clock and orbital information, the trajectory history of the individual captured dust can be reconstructed and compared with known dust source orbital trajectory information. Orbital trajectory agreement will indicate the association with a known dust source.

The collectors are best contained in standard sized trays to facilitate handling and refurbishments. A group of twenty one trays can be mounted on a standard carrier conforming to Shuttle payload requirements as shown in Figure 1. Standard Remote Manipulation System will used to facilitate handling on the Space Station as well by the Shuttle. This carrier will fit within one standard Space Station truss face. Various types of underdense media can be mounted within the standard trays. The edge of the trays serves to protect and contain the fragile underdense media. The height of the tray edge will be dictated by the depth of penetration required for the hundreds-of-micron-sized dusts.

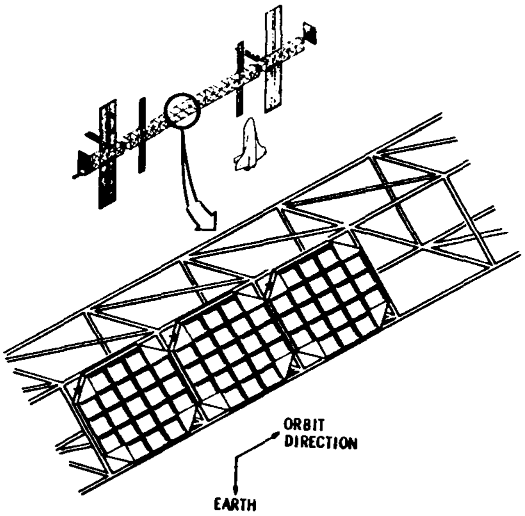

Figure 1. Collector Concept

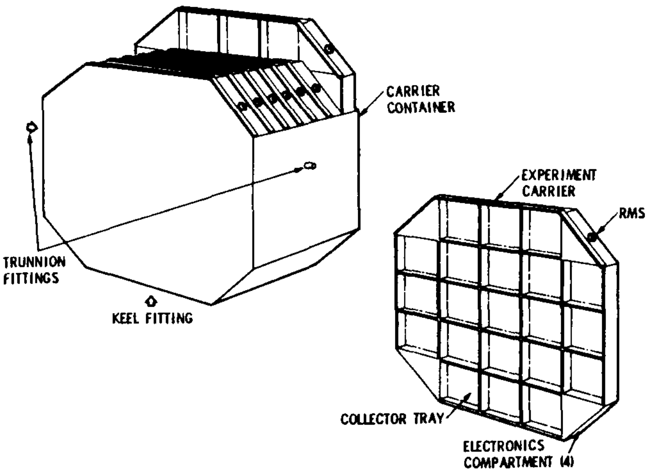

Figure 2. Deployment Concept

Timing and location recording electronics can be located in the four corners of the unused space as shown in Figure 1. Four acoustic sensors will be located in the four corners of the each of the standard tray. Electronic signals from the sensors will be conducted through multiple pin corrector on the standard trays. Power for the electronics can be provided through the standard Space Station mounting interface or through a self contained simple solar-cell-battery system. Solid state recording device will used to store the compressed sensors outputs.

Since Space Station orbits at 7 km/s, dust capture in the anti-orbital direction of Space Station will experience a 7 km/s reduction in dust capture speed. This reduction will enhance greatly the possibility of capturing even greater portions of dust intact. In order to facilitate handling of collector trays and the control of contamination during installation and retrieval, a carrier container with standard attachment trunnion for Shuttle longeron would be used to transport the collector carriers as shown in Figure 2. Extended lip on each carrier serves as a cover.

ACKNOWLEDGEMENTS This work was carried out, in part, by the Jet Propulsion Laboratory, California Institute of Technology, under NASA contract.

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INTACT CAPTURE OF HYPERVELOCITY PARTICLES IN MULTIPLE FILMS

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INTRODUCTION The intact capture of cometary coma material at low hypervelocity encounter speeds with passive underdense media is within the technology [1]. To broaden the applicability of this technology and to open additional comet coma sample return mission opportunities, greater hypervelocity capturing speeds are required. The multiple-layered-thin-films collector is another possible technique for intact capture of hypervelocity particles. This multiple-layered-thin-films arrangement is also a good simulator for underdense foams with controllable cellular parameters. This paper reports the recent results from these simulation experiments.

MOTIVATION Underdense polymer foams have performed well as hypervelocity intact collectors at around 7 km/s [2]; however, polymer foams have complex microstructures that make it difficult to control the microstructure parameters of the underdense media. Multiple layers of thin films can simulate underdense foams, where the thickness of the film, analogous to foam cell-wall thickness, and the separation distance between films, analogous to foam cell size, can be controlled.

The recovery of extraterrestrial particles from the Solar Max thermal blanket [3] provided further motivation to explore multiple layer films as a possible type of intact collector.

EXPERIMENT Polyvinylidene chloride, polyethylene, polystyrene, polyester, and organic tissue films were used in the experiments. The films were wrapped between pins inserted on a baseboard predrilled with evenly spaced holes. In the span of 1.52 m, as many as 2400 layers can be wrapped, and the film thickness can be varied from 200 um to 1.5 um. Due to the static clinging effect of thinner polymer films and the difficulty of ensuring even film tension during wrapping, a constant and equal film separation spacing could not be easily maintained; films often bunched together in various sections.

The projectiles used were mostly polished aluminum spheres 1.6 to 4.8 mm in diameter. At the NASA Ames Vertical Gun Range, the projectiles were accelerated with a two-stage light-gas gun to speeds as great as 6.8 km/s and with a powder gun for speeds less than 3 km/s. All capture experiments were performed under vacuum around 0.01 atmosphere.

RESULTS Numerous types of films were tested. However, systematic data were obtained with polystyrene and polyester films that were impacted by 1.6- and 3.2-mm-diameter aluminum projectiles for speeds less than 7 km/s. Polystyrene film was selected because it shares the parent resins of the styrofoams, for which we have a good data base. However, polyester films provided the widest range of film thickness, 10 to 1.5 um.

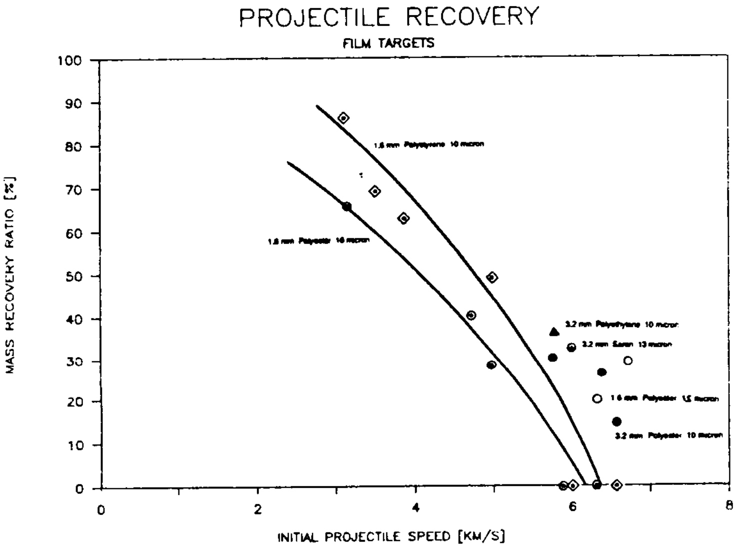
Projectile recovery with respect to projectile speeds for the different types of films are shown in Figure 1. For the same film thickness, higher mass recovery for larger projectile size is shown in Figure 1. Thinner films yielded higher projectile mass recovery for the same projectile size, as evident from Figure 1 as well. Since larger projectiles require greater number of layers of films, the target chamber height limited the recovery range and, in turn, prevented lower-speed data for the 3.2 mm projectile with 1.5 um films.

The depths of film penetration for polyester and polystyrene films for various projectile initial speeds are shown in Figure 2. These two curves look very similar to penetration curves for foams [4]. With additional data in the lower speeds, full equivalents can be determined.

FINDINGS The polystyrene curve shown in Figure 1 is higher than the polyester curve indicating that besides film thickness film material comes into play in intact recovery. This is a significant finding that material properties comes into play in projectile recovery; the material properties ranged widely as shown:

Parameter	Polyester	Polyethylene	Polystyrene	Saran
Melting Point, [^{o}C]	250	106	105	275
Tensile Strength, [psi]	10,000	1,000	5,000	11,000
Density, [g/ml]	1.4	.93	1.1	1.6

Our preliminary assessment is for film thicknesses less than 1 um may yield intact recovery comparable to that of underdense foams in the 20 - 30 mg/ml densities. This may indicate that the hypervelocity recovery of sub-um-thick multiple-layer films of about three to four thousand layers be equivalent to that of underdense polymer foams for projectile speeds of than 7 km/s. On the whole, the multiple-layer-thin-films do not capture as much mass intact as foams for equivalent thickness of foam cell wall to film thickness.



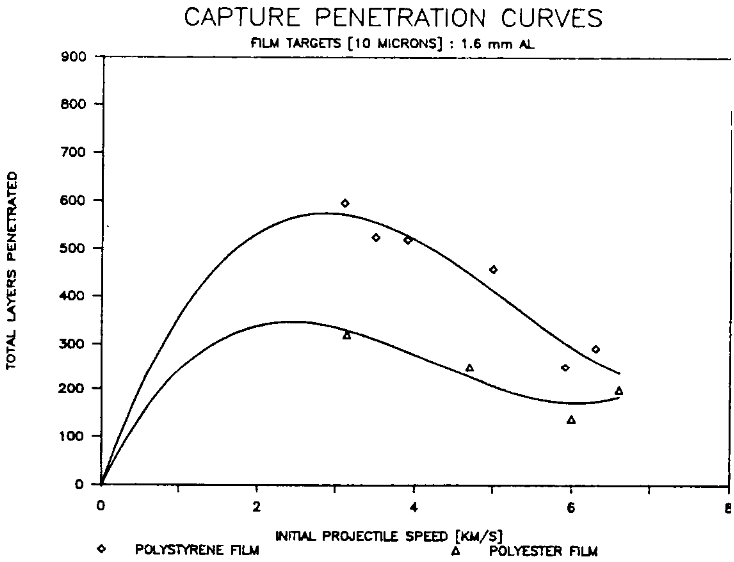


Figure 1. Polymer Films Figure 2. Film Penetration

ACKNOWLEDGEMENTS The cooperative support of the NASA Ames Vertical Gun Range is much appreciated. This work was carried out, in part, by the Jet Propulsion Laboratory, California Institute of Technology, under NASA contract.

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TECHNOLOGY DEVELOPMENT FOR INTACT CAPTURE OF HYPERVELOCITY PARTICLES

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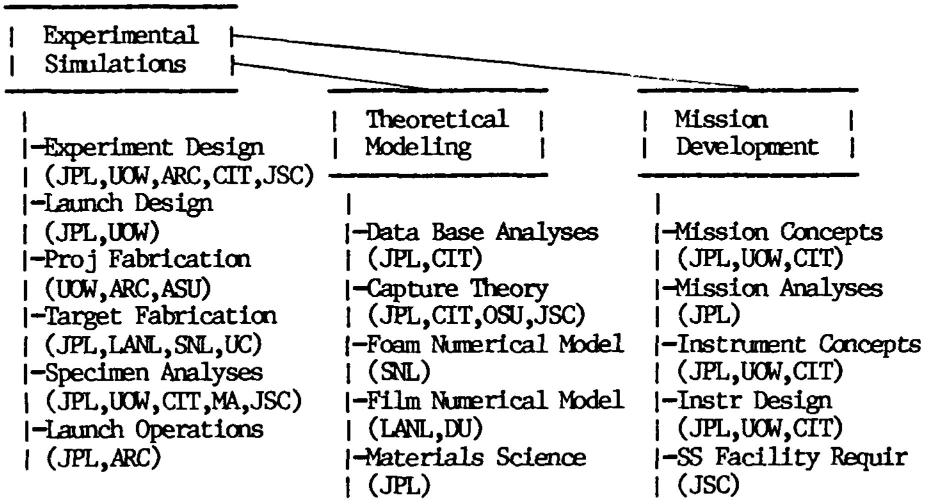
The possibility of capturing cometary or cosmic dust intact in Earth orbit or in a comet coma offers a very desirable means of sample return for planetary and exobiology sciences. Such samples could help answer major questions on the processes involved in formation and evolution of the Solar System. Enabling technology development has been carried out to attain intact capture of hypervelocity particles [1]. This paper describes the scope of the technology development effort and some of the recent advances.

INTRODUCTION

Intact capture refers to the capture of portions of hypervelocity cosmic particles 'intact' unaltered, as opposed to the approach of purposely atomizing the particles to facilitate hypervelocity capture [2]. The intact capture concept described here uses relatively inexpensive passive underdense media to absorb the hypervelocity energy as gently to preserve the largest portion of the particle intact. Coupled with simple acoustic detection and recording, the passive media will be able to preserve the essential capture trajectory information (time, direction, and speed) adequate for dust source identification analysis.

DEVELOPMENT APPROACH

This technology development enables the design of a flight instrument to capture intact, single grain cosmic dust particles at medium hypervelocities (8 to 12 km/s). The technology development efforts cover an extended cooperative network of disciplines and participants, as shown in in the following figure. Experiemental simulations generate the basic data under various conditions for hypervelocity intact capture. Based upon the gathered data, theoretical models are formulated to understand and predict the capture phenomenon to guide further experimentations and collector media development. Developing realistic missions will guide the eventual flight instrument design. Early integration of planetary and exobiological sample analyses requirements into the technology development will reduce the needs for subsequent redesign and refabrication of the flight instrument.



Experimental Simulations
- Experiment Design (JPL,UOW,ARC,CIT,JSC)
- Launch Design (JPL,UOW)
- Proj Fabrication (UOW,ARC,ASU)
- Target Fabrication (JPL,LANL,SNL,UC)
- Specimen Analyses (JPL,UOW,CIT,MA,JSC)
- Launch Operations (JPL,ARC)

Theoretical Modeling
- Data Base Analyses (JPL,CIT)
- Capture Theory (JPL,CIT,OSU,JSC)
- Foam Numerical Model (SNL)
- Film Numerical Model (LANL,DU)
- Materials Science (JPL)

Mission Development
- Mission Concepts (JPL,UOW,CIT)
- Mission Analyses (JPL)
- Instrument Concepts (JPL,UOW,CIT)
- Instr Design (JPL,UOW,CIT)
- SS Facility Requir (JSC)

DEVELOPMENT STATUS

Extensive systematic experimental data has been obtained on the capture of 3.2 and 1.6 mm aluminum projectiles by commercial polystyrene foams [3]. To assess projectile composition effects on recovery, other metals and glass projectiles are being used. Commercial underdense media tested have been mostly large-cell structured. In an effort to seek controlled foam structure analogs, multiple layered thin films have been studied [5]. Preliminary analytical modeling efforts have yielded surprising predictive capability [5]. Application of existing numerical models has yielded fruitful results [6,7]. Contributions from materials science and polymer synthesis have indicated better target media [8]. Mission possibilities for cosmic dust collection are being explored [9] and concepts for Space Station dust collection instrument have been formulated [10].

RECENT ADVANCES

Some significant specific advances in experimental simulations are cited here; other advances are reported in other papers of this workshop.

Small Projectile Launch Technology Although the expected size of cometary dust is in the range of 100 um in diameter, no reliable method exists yet to launch this small a projectile intact with known speed. Using the new lead-follow technique, 100 um particles were launched intact with reliable speed determination in the 3 km/s range.

New Underdense Media Customized microcellular polymer foam has captured nearly 50% projectile by mass more than standard polystyrene foam [11]. This increased mass capture indicates the new foam has the potential capability of capturing particles at even higher speeds.

Instrumented Projectiles External instruments to measure the status of the projectile during capture have presented insurmountable challenges. The mixing of witness materials in the projectile has proved to be very effective method to measure temperature profile of the projectile during capturing: amino acids are mixed in the projectile material to assess the projectile internal temperature during recovery [12]; shock profile within projectile can also be recorded by mixing selected material with known shock-threshold signatures.

ACKNOWLEDGEMENTS

All of the cooperative contributors are especially recognized. This research was carried out, in part, by the Jet Propulsion Laboratory, California Institute of Technology, under NASA contract.

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EXPERIMENTAL DATA FOR HYPERVELOCITY INTACT CAPTURE

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*Jet Propulsion Laboratory +Johnson Space Center #University of Washington @California Institute of Technology

INTRODUCTION

Experimental work in intact capture of hypervelocity particles has been conducted to enable the collection of extraterrestrial dust particles. A wide range of polymer underdense media were used as targets in intact capture experiments as reported previously [1]. In these experiments, small spherical projectiles ranging from 1.6 to 6.4 mm in diameter were accelerated to speeds of 0.3 to 7 km/s with a two-stage light-gas gun at the NASA Ames Vertical Gun Range. Systematic experiments have allowed the collection of a parametric data base for hypervelocity intact capture in underdense media. Parametric analysis of the data collected from these experiments offers an understanding for the intact capture phenomenon and can lead to the identification of the fundamental mechanisms which determine optimum collector material properties.

SCOPE OF EXPERIMENTS

Most of the experiments conducted thus far have used aluminum projectiles and polystyrene targets. Varying projectile size and target microstructure/density within these baseline experiments has facilitated the collection of a data base for the intact capture of hypervelocity particles. Varying other parameters such as projectile and target material types has provided a better understanding of the capture process in underdense media. Projectile material types include: aluminum, steel, annealed pyrex glass, iron, lead, zinc and some simulated cometary aggregates consisting of powdered olivine, FeS, and hollow glass microspheres bonded with epoxy. Target materials have included polystyrene, polyethylene and polyimide with bulk densities ranging from 9 to 50 mg/ml.

DATA REDUCTION TECHNIQUE

During a hypervelocity capture, kinetic energy is transferred from the projectile to the target material as the projectile eventually comes to a complete stop within the target. Depending on the initial speed of the projectile different mechanisms will occur that reduce the projectile's speed.

Analysis of the data indicates that the total track length (depth of projectile penetration into the target) and intact projectile recovery ratio (%, final projectile mass/initial projectile mass) are two key parameters useful for characterizing the hypervelocity capture process. Projectile recovery ratios and total track lengths for 1.6 and 3.2 mm aluminum projectiles into three different polymer foams (polystyrene, polyimide and polyethelene) with respect to projectile initial speeds are shown in Figures 1 and 2, respectively. The recovery plots in Figures 1A-1C illustrate the effects of projectile size and target material type upon: (1) the speed at which projectile erosion begins, and (2) the rate at which projectile erosion continues at higher initial speeds. The resulting capture penetration curves in Figures 2A-2C are high order polynomials fitted by the method of least squares. The characteristic shape of these curves has proven to be a good indicator for the type and/or change of energy transfer mechanisms occurring during capture, and has aided the development of a model for hypervelocity intact capture in underdense media [2]. It should be noted that each penetration curve is not a profile for one particular experiment, but rather the result of several intact capture experiments at various initial projectile speeds.

A representitive capture penetration curve is shown in Figure 3. This curve has been divided into three regions defined by the boxed legend in the bottom of the figure, with the boundaries of each region marking distinct changes in the shape of the curve. Each region is associated with a distinct physical phenomenon related to the projectile and the target. It is hypothesized that the boundaries of these regions define points of transition between the types of energy transfer mechanisms occurring during capture. At initial low speeds, shearing and mechanical deformation of the target seem to be the only mechanisms of energy transfer. In fact, the relationship between total track length and initial projectile speed is linear for polystyrene foams below 1 km/s and is directly proportional to the diameter of the projectile as illustrated in Figure 4. In this region there is no change in state of the projectile or the target. In the region between 1 km/s and the peak of the penetration curve the target material shows evidence of melting and the projectile shows some surface blemishes, but no measurable projectile mass loss. Near the peak of the penetration curve (between 2 and 3 km/s) the target material begins to char and the projectile begins to show significant signs of erosion and mass loss which is consistent with the recovery plot for 3.2 mm aluminum projectiles shown in Figure 1A. At higher initial speeds (up to 6 km/s) the projectile's penetration becomes short again, dominated by severe charring of the target material and a steady decrease of projectile mass.

ACKNOWLEDGEMENTS

The cooperative support of the NASA Ames Vertical Gun Range is much appreciated. Special projectile fabrication and specimen analyses from M. Lawrence is recognized. This work was carried out, in part, by the Jet Propulsion Laboratory, California Institute of Technology, under NASA contract.

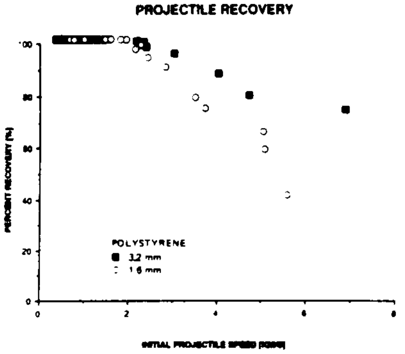


Figure 1A

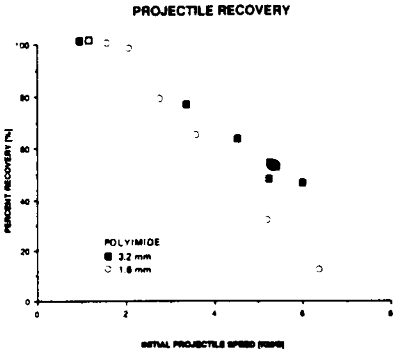


Figure 1B

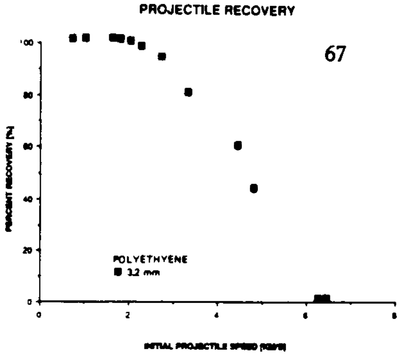


Figure 1C

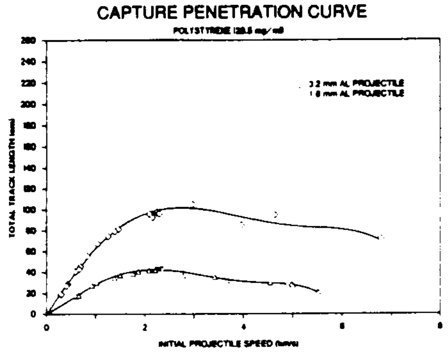


Figure 2A

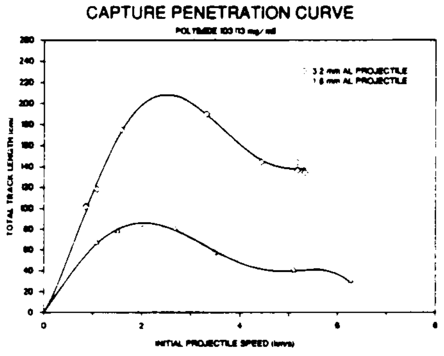


Figure 2B

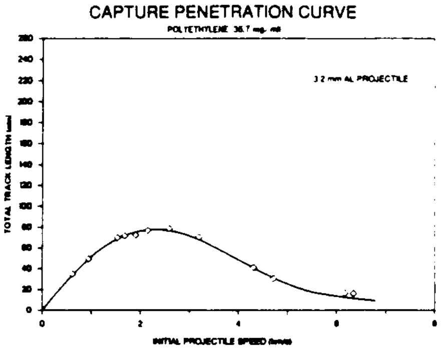
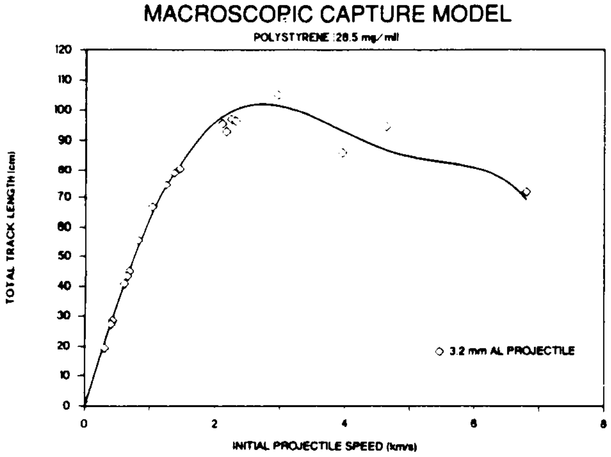


Figure 2C



PROJECTILE	NO CHANGE IN STATE	SLIGHT SURFACE EROSION (NO MEASURABLE MASS LOSS)	SIGNIFICANT EROSION AND MASS LOSS INCREASING WITH HIGHER INITIAL PROJECTILE SPEEDS
TARGET	NO CHANGE IN STATE SHEARING AND MECHANICAL DEFORMATION	MELTING AND SHEARING	CHARRING, MELTING AND SHEARING WITH CHARRING BECOMING MORE DOMINANT AT HIGHER INITIAL PROJECTILE SPEEDS

Figure 3

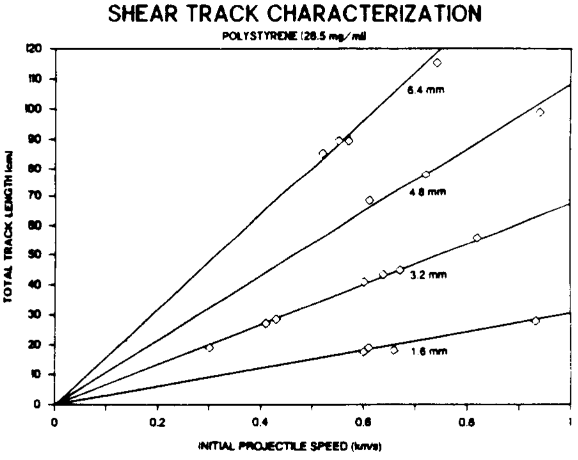


Figure 4

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TECHNOLOGY REVIEW OF UNDERDENSE TARGET MEDIA

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Cosmic dust particles on the order of 10-20 microns(μ) with impact velocities of 5-20 km/sec are the particles of interest for capture on the Space Station. Consequently, material requirements for nondestructive capture media for micrometeroids are very severe. The thickness of the walls in microcellular polymeric foams or the thin foils for stacked films is one of the critical factors for determination of a good candidate capture material. In order to capture particles with minimal damage, low density porous media with wall thicknesses of less than 1 μ are desired.(1) In addition, choice of material for capture media is dependent upon the objectives for analysis of the particle. Elements of interest would need to be absent from the capture medium. This requires that a number of practical capture media be available. Primary candidates for capture media include low density materials such as high porosity foams or stacked thin foil films. This review is intended to introduce a range of different materials with the required properties for nondestructive capture of cosmic dust.

Many low density materials can be classified as foams. A broad, working definition of a foam is any structure that consists of domains of a given material separated by voids. The types of foams available range from polymeric foams such as polystyrene to inorganic foams such as aerogels. In a one dimensional sense, stacked thin films and metal smokes can also be considered as foam-type materials.

Many polymeric low density foams commercially available consist of closed cell blown foams with large cell size and wall thickness, undesirable characteristics for cosmic dust capture. One route to microcellular foams is by the phase separation process(2) developed at Los Alamos. A process currently under development at Los Alamos(3) that yields similar foam material is the emulsion polymerization of polystyrene. These polymeric foams are open cell structures with densities below 0.10 gm/cc, cell sizes of ~10 μ and pore size of ~1 micron. A few commercial products are available including polypropylene foam with density of ~0.15 gm/cc with pore size of ~1 μ available from PORELON (Johnson Wax) and a polypropylene foam consisting of submicron fibers with density 0.06 gm/cc from PALL. In addition carbonized foams in the density range of 0.06-0.35 gm/cc are available from UNION CARBIDE. Other carbon foams with smaller cell sizes and wall thicknesses are under special development in a number of laboratories.

Another class of foams consists of inorganic aerogel foams. Commercially available silica foams with densities of 0.08 gm/cc and lower are manufactured by Airglass AB, Lund, Sweden. Early work has shown that aerogels can be made of a number of metal oxides such as alumina, ferric oxide, stannic oxide and nickel oxide.(4) The aerogels are friable, transparent foams with sub-micron particle size.

Thin metal foils for capture cells are available from commercial vendors such as LEBOW, Co. The metals available include Al, Be, B, C, Cr, Co, Cu, Au, Ge, In, Fe, Pb, Mg, Mn, Mo, Ni, Nb, Pt, Se, Si, Ag, Ta, Tb, Sn, W, V, Yb, Y, Zn, Zr. Foil thicknesses of submicron ranges are available, although a major problem with thin foils is pinholes. Workers at Los Alamos have prepared pinhole free 500 Å thick Al and B foils on a wire mesh support.(5) This technique could be applied to other metals. Another related technology is the deposition of low density metal blacks or metal smokes on thin foils.(5,6) By stacking thin foils coated with metal smokes, a low density collector could be developed in which the metal smokes act as spacers between the thin foil films.

There are a number of good candidates for micrometeorite capture media. By using a combination of different densities of the same or different materials one can fine tune the material to capture a given particle size.

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COMPUTER SIMULATION OF HYPERVELOCITY IMPACT OF A PARTICLE ON A MEMBRANE

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ABSTRACT

Foamed material is proposed for collecting cosmic dust. As a dust particle hits the foam it impacts the large number of internal walls in the foam and decelerates until it is caught with certain amount of loss of mass provided the foam is designed properly for the mass, size, and velocity of the particle.

Experimental as well as numerical investigations can be conducted to study the impact phenominon of the particle with the structural membrane of the foam so that appropriate foam may be designed and the dust particles may be trapped with minimum loss of mass. However the experimental testing is a costly and tedious process and existing particle accelerators are not able to supply the needed range of particle masses and velocities. In this work computer was utilized to simulate the normal impact of a particle on a thin membrane. In computer simulation parameters such as density, size, velocity of the particle and thickness, material constants of the membrane can be easily varied. With limited amount of experiments the results from the numerical calculation can be used to aid the design of the foam.

The basic computer program used for the work is a finite-element Lagrangian program named as DEFEL which is derived from the EPIC-2 program originally developed to simulate high-velocity impact in matels and later modified to handle explosive-metal interaction. After years of improvement DEFEL can accurately handle the sliding between two materials and failure of elements.

For simplilcity in the simulation the particle was assumed to have a spherical shape. The particle was represented by an assemblage of triangular elements of different size, bigger inside the particle and smaller on the surface. The membrane was handled by one layer of composite elements each of which consists of two triangluar elements. Elements of both the particle and the membrane were allowed to fail based on criteria such as melting temperature, effective strain and so on. The temperature and pressure rise at the particle surface, the momentum loss of the particle were recorded. Reasonable results were obtained. Figure 1 shows the geometry plot of the system after the impact and errosion is seen on the particle surface. Figure 2 shows the momentum loss for membrane thickness of 10 and 1.5 micon with different initial velocities.

With further improvements of the program, more calculations, and comparison of the results with experiments material constants of the membrane and failure criteria of both the particle and the membrane can be correctly selected. Therefore the relations between the amount of errosion, momentum loss of the particle and the thickness, material constants of the membrane can be accurately obtained. The data from the calculations will facilitate better design of the foam material for the dust collector.

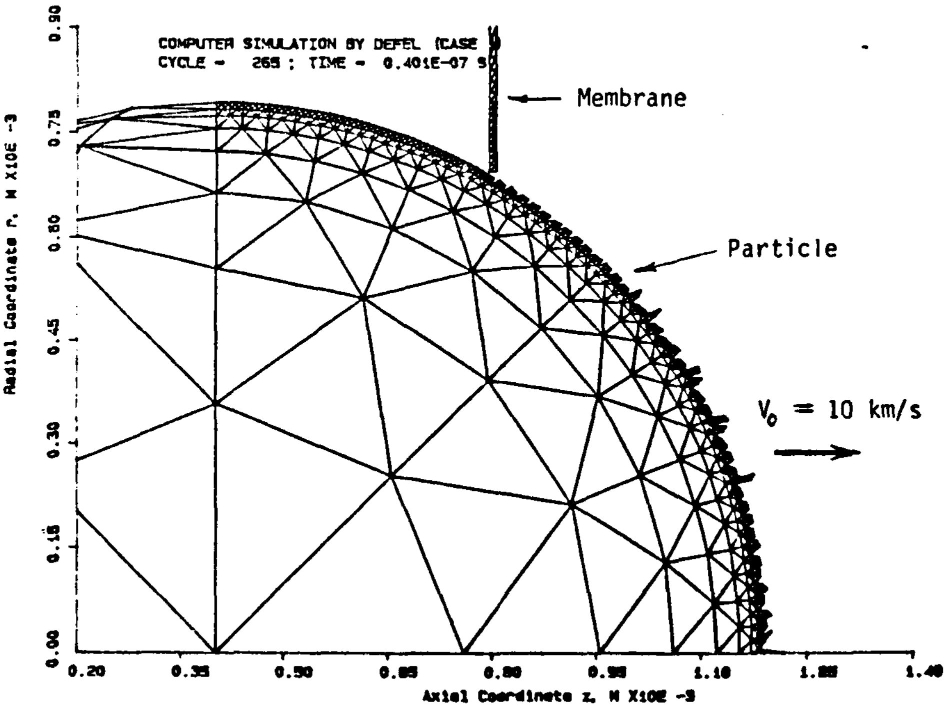
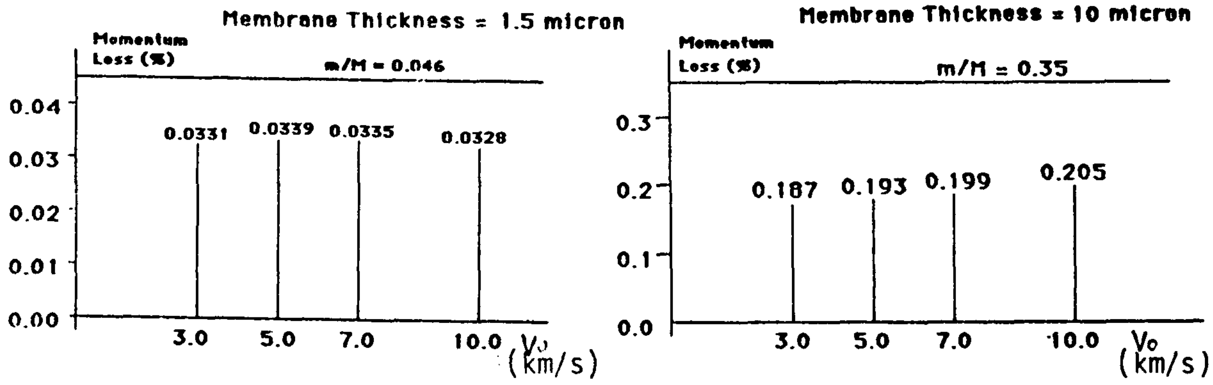


Figure 1. Geometry of the System Atfer Impact, Erosion Is Seen On the Particle Surface.



Fiqure 2. Momentum Loss Predicted by Computer Simulation.

MICROCELLULAR PLASTIC FOAMS

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Collection and analysis of extraterrestrial dust particles can provide extensive information about the formation and evolution of our solar system. Thus, one of the major goals in the science of our solar system is large-scale sample return of interplanetary and comet dust particles. Large-scale sampling can also aid scientists in answering questions such as what degree of contribution the asteroids and comets make to the interplanetary dust cloud.(1)

A low-cost, simple, fly-by mission has been proposed to sample a comet coma and return the coma materials to earth using a free-return trajectory.(2) Extensive research is being conducted by scientists at NASA's Jet Propulsion Laboratory in Pasadena, California, on a variety of methods of capturing intact comet coma material for just such a mission. The results of this study using low density materials as the capture medium are summarized elsewhere in this workshop technical report.(3)

Extensive work has been done at Los Alamos and elsewhere on the development of low density, microcellular plastic foam materials for a variety of high-energy physics experiments.(4) An example of just such a material, i.e., a low density TPX foam, can find application as an intact capture medium. TPX is a commercially available polymer composed of poly(4-methyl-1-pentene) copolymer with <5% polyoctene and polyhexene. The TPX foams are not commercially available, but are prepared by a relatively new process called a phase separation process.

Presently, the requirements for a good capture foam is low density (~0.02 g/cm^3) and as low of cell size as possible (preferably <1 μ). These requirements eliminate virtually all commercially "blown" plastic foams for this application. Such commercial foams can be obtained with densities down to ~0.01 g/cm^3, but with cell sizes in the hundreds of microns. Usually one has to prepare blown plastic foams in the density range of ~0.1 g/cm^3 before cell sizes in the desired range are obtained. TPX foams can be made at densities of 0.02 g/cm^3 and with cell sizes in the 10-μ region.

We found that a phase separation process could be used to manufacture rigid plastic foams suitable for intact particle capture. The basic technology explores a variety of physical and chemical approaches which result in the formation of two phase systems, one of the phases being composed of a rigid polymeric structure. In the initial stages of the process, a single, homogeneous liquid phase is prepared. By applying a nonsolvent, chemical, or thermal cooling process to this homogeneous solution in a controlled manner, two distinct phases are obtained. These phases are made up of a rigid plastic phase and a phase consisting of either a continuous rigid plastic phase with "droplets" of the solvent dispersed throughout or two bicontinuous phases where both the plastic and the solvent are interpenetrating, continuous labyrinthine phases. In either case, removal of the solvent phase leaves the desired plastic foam.

In the process for the preparation of the TPX foam, a homogeneous solution of the polymer is cooled at an elevated temperature under controlled conditions until the solution gels. Immediately after gellation, crystallization of the polymer occurs. This crystallization is important in the subsequent isolation of the foam. For most linear polymers, like polyethylene and polypropylene, gel states can be obtained from appropriate solvents; however, many of these polymer gels collapsed when attempts were made to remove the solvent phase. Those systems in which a minimum amount of dimensional change occurs during solvent removal happened to involve those linear polymers which showed a high degree of crystallinity in the final foam state.

The phase separation process offers a wide variety of rigid, low density, microcellular foams for study in dust collection. For example, aerogels can be made by a chemically induced process with subsequent removal of the methanol solvent by evaporation at its critical point. Linear polymers can also be converted to foams if high molecular weight materials are used and the solvent is first exchanged with liquid CO_2 and the CO_2 is then removed at its critical point. These materials offer opportunities as intact collectors in future studies.

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THE NATURE AND CONSEQUENCES OF PARTICULATE SPACECRAFT DEBRIS MATERIAL IN THE SPACE STATION ENVIRONMENT

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Introduction The primary purpose of the Cosmic Dust Collection Facility for the Space Station is to permit collection of extraterrestrial particles with their trajectories and velocities. However, anthropogenic material will be unintentionally collected as well. In order to determine the nature and abundance of particulate material in low-earth orbit workers have recently examined hardware surfaces returned from the Solar Maximum Satellite [1-3]. Since these space exposed surfaces (thermal blankets and louvers) served as unintentional debris collectors no efforts were made by the original designers to provide for the intact collection of particulate samples. Thus, examination of impact craters in these Solar Max surfaces has revealed that the vast majority of impacting particles were completely melted and/or vaporized, with the loss of critical structural and compositional information.

In a complementary study representative chemical, structural, and morphological analyses of the solid particles from three impaction collection surfaces, which sampled in the stratosphere with no damage to the particles, have been performed [4-6]. These collections sampled the stratosphere at approximately 17-19 km in altitude during 1976, 1981, and 1984. For these sampling periods the total stratospheric solid particle number densities have been determined to be 0.085, 0.16, and 1.8 particles/m of air, respectively. This rise in solid particle number density for the stratosphere over the collection period is likely due to the influx of solid rocket exhaust, and rocket and satellite debris into the atmosphere in increasingly larger amounts with time. Some of this material is shed from spacecraft during ascent through the atmosphere, but the majority is probably provided by the descent of material from the growing belt of debris in low-earth orbit. The number of spacecraft debris particles, as measured in the stratosphere, has presently grown to the point where it exceeds that of extraterrestrial particles by at least a factor of ten, a relation which will worsen with time. The consequences of this sudden (and continuing) increase in spacecraft debris particle abundance for Cosmic Dust collection efforts at the Space Station are summarized.

Nature As summarized by others [6], there should be four main sources of solid particulate spacecraft material in low-earth orbit. These are (1) solid rocket fuel exhaust, (2) solid rocket motor (SRM) ablation, (3) thermal reflective paint from the outer hulls of spacecraft and (4) ablating hardware from satellites and discarded rocket sections, some of which have exploded.

Solid rocket fuel containing an aluminum additive produces spherical grains composed predominently of various phases of alumina. SRM parts most subject to abrasion (and consequent shedding of particulates) are (1) the nozzle, composed of asbestos, graphite, Fe-Ni-Cr alloys, and ceramic refractories, (2) a carbon phenolic cloth liner and (3) motor insulation, composed of asbestos, silica and carbon composites. The thermal reflective paints most commonly employed for spacecraft contain, variously, alumina, TiO_2, ZnO, potassium silicates, CoO, Co_2O_3, Zn_2TiO_4, CaO, $CaSiO_3$, NiO, MgO, talc, sulfates and poorly graphitized carbon.

NATURE AND CONSEQUENCES OF PARTICULATE SPACECRAFT DEBRIS MATERIAL

M. E. Zolensky

The ablation of satellites and spacecraft provides an almost endless variety of solid particulate material, but this should consist mainly of metallic aluminum and Fe-Ni-Cr alloys.

Consequences Since the majority of the spacecraft debris materials are composed of refractory metals, oxides and silicates it will, on a first order basis, be possible to distinguish <u>most</u> captured spacecraft debris particles from <u>most</u> extraterrestrial particles. However, it may generally be impossible (or extremely tedious, at the very least) to distinguish captured spacecraft debris particles from refractory interplanetary dust particles [7]. There is also much carbonaceous material present within spacecraft [6]. It may be very difficult to discriminate between this material and extraterrestrial carbonaceous particles, the collection of which is a primary goal of the Cosmic Dust Facility.

Most of the spacecraft debris particles in low-earth orbit have a velocity of approximately 7 km/sec [6], and a significant fraction of micrometeoroids will have a similar velocity, relative to a rear-facing, flat, Space Station sampling plate [8]. These (relatively) low-velocity extraterrestrial particles will be the easiest to capture in an unmelted state, and are thus of great interest. Thus, from the perspective of the operation of the Space Station Cosmic Dust Facility, it may be impossible to distinguish this important subset of extraterrestrial particles from a volumetrically superior population of spacecraft debris grains.

Since the majority of particle impacts upon the Cosmic Dust Facility will be due to spacecraft debris particles, the contamination of extraterrestrial particles by the melt and vapor residues from impacting debris will be a major problem. Extraterrestrial particles with the largest velocities may penetrate more deeply into some capture cells, escaping the contamination threat, but these particular particles are also the most likely to be completely vaporized during collection. Since most of the spacecraft debris material is composed of refractory elements [6], this contamination problem will most severely compromise refractory extraterrestrial materials [7].

Finally, numerous impacts upon the facility capture cells by spacecraft debris material will increase the rate of erosion of capture cell media by ionized oxygen and nitrogen atoms present in the Space Station environment. It may be necessary to engineer guards against this process into capture cells.

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ON COSMIC DUST TRAJECTORY MEASUREMENTS AND EXPERIMENT POINTING CONSIDERATIONS

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With the addition of the Cosmic Dust Facility to the upcoming multinational Space Station, it should be very possible to do important new cometary, asteroidal, and other science on dust grains collected with this Earth-orbital facility. Such science will certainly follow for those individual grains, as noted earlier (1), for which one can uniquely associate a single parent body (comet, asteroid, moon, interstellar grain, or an Earth-orbiting man-made satellite). The association in mind here is an orbital association between parent body and daughter dust grain. When the association is established, analyses of the dust grain then become analyses of the associated parent body. Even when a unique association is not possible, it may still be possible to associate a dust grain with some broad family of parent bodies (e.g., the main belt asteroids).

There are two requirements that must be fulfilled in order to make an orbital association: (1) The orbit of the dust grain must be established through an accurate measurement of the trajectory of the dust grain when it impacts the detector, and (2) the different evolutionary paths of the orbits of the parent body and dust grain since separation must be understood. It should be a high priority current effort to establish the latter understanding for a variety of potential parent objects. This effort should probably proceed on both analytical and numerical analyses grounds. For example, on analytical grounds it is known that the "Tisserand invariant" is, indeed, approximately invariant (2) under gravitational scattering when a particle passes near a planet. Also, under Poynting-Robertson (P-R) drag alone, there is another constant, C, of the motion (3), where $C=a(1-e^2)e^{-4/5}$. Orbital inclination, argument of perihelion, and ascending node also remain unchanged under P-R drag. If, however, multiple scattering by Jupiter occurs while P-R drag is operating, followed by P-R drag alone and then, perhaps, scattering by Earth and Venus before being detected, it is not now clear what signature of its original orbit is still carried by the particle. For this reason, it is important to carry out numerical analyses of the possible evolutionary paths such as those done by Burkhardt (4) and Gustafson and Misconi (5). Insights may be gained through such analyses that would be difficult to obtain under mathematical analyses alone.

It is possible that most of the grains smaller than about 100 microns in diameter at 1 AU derive from the main belt of asteroids via P-R drag (6; Note also IRAS observations, 7). Such grains would undergo multiple scattering by the Earth and Venus (4,5) and it may be difficult to recognize individual sources for these grains; but it may well be possible to ascribe them to the main belt. It has to be examined whether or not they can be separated by some criteria from such low relative velocity streams as the Bielids (16 km/s), the Giacobinids (23 km/s), or the Taurids (30 km/s) (e.g. 8,9). Streams that intersect the Earth with high relative velocity should present few problems.

Finally we should consider how a cosmic dust sensor should be pointed relative to the orbital motion of the space station to which it is attached. Zook (10) noted that from 6 to 9 times as many meteoroids are likely to impact a sensor facing in the apex (or forward-looking) direction of spacecraft motion as would impact a sensor facing in the antapex direction. However two disadvantages accrue from facing in the apex direction: (1) mean impact velocities are typically 7 or 8 km/s higher on the apex-facing sensor than on the antapex-facing sensor, and (2) the accuracy of velocity measurement is degraded by a factor of about two. The first disadvantage means that it will be much more difficult to recover relatively intact dust projectiles from an apex-facing sensor than from an antapex-facing sensor. The second disadvantage will only be important if experimental trajectory measurements are not able to obtain sufficient trajectory accuracy to cleanly identify cosmic dust grains from different source bodies and recognize their different origins. Whether or not this is a significant problem awaits further study of the parent-daughter recognition problem.

One may also want to point somewhat upward away from the Earth to avoid Earth shielding as much as possible. At 500 km the Earth's horizon is about 22 degrees below the local horizontal. Again here, one will have to decide whether one wants increased flux at, perhaps, some cost in increased velocity and the associated increased damage to the impacting meteoroid.

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