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FINAL REPORT
on the
GEMINI MICROMETEORITE COLLECTION
EXPERIMENT S-10
Contract NAS 9-5637

Submitted by
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ABSTRACT

The purpose, design and execution of the S-10 micrometeorite experiment, flown aboard five of the Agena target vehicles used in the Gemini program, are described. Examination of four polished stainless steel plates, which were exposed to space for four months by means of this experiment, has revealed unequivocal evidence for micrometeorite impact events. The mass distribution of particles in near-earth space derived from measurements of the size and frequency of these events lies below the results from satellite microphone experiments but above those from the Pegasus and Explorer penetration experiments. A biological experiment included in the S-10 package yielded some observations on the ability of certain micro-organisms to survive the space environment.

Introduction:

The S-10 experiment flown aboard five of the Agena target vehicles during the course of the Gemini manned spacecraft program was designed primarily as a long-duration study of micrometeoroid impact phenomena ¹⁻⁴. It also contained a number of experiments intended to investigate the ability of micro-organisms to survive exposure to the space environment ⁵⁻⁷.

Experimental Technique:

Briefly the experimental exposure program involved the mounting of a box containing the sampling surfaces on the outside of the docking adapter section of an Agena Target vehicle which was then placed in earth orbit. A Gemini spacecraft would then rendezvous and dock with the Agena and, while the vehicles were docked, an astronaut during extra-vehicular activity would manually open the box thus exposing the internal surfaces to space. The Gemini vehicle would then separate and return eventually to earth. On a subsequent Gemini mission, a number of months later, the manned spacecraft would rendezvous with the Agena and an astronaut during extra-vehicular activity would close the S-10 unit, remove it from the Agena, replace it with a new unit and return the old unit to earth in the Gemini capsule. From a consideration of this experiment profile it was clear that the sampling surfaces would be

subjected to a certain amount of contamination by thruster debris and other spacecraft detritus during the various rendezvous maneuvers so that impact phenomena produced by small particles, e.g. less than about 10 microns diameter would be extremely difficult to distinguish from the background. However, against this, the long duration of the exposures possible in such an experiment would enhance the possibility of comparatively small areas recording the arrival of particles significantly larger than 10 microns.

Predictions based on satellite microphone data suggested that particles of 10 microns diameter and larger would be encountered approximately once per day by the S-10 surfaces which had a sampling area of approximately 300 cm^2 . Taking the Pegasus impact data, however, led to a predicted impact rate in the same size range of about one impact every year.

In view of the high velocities of cosmic particles, thought to be in the range 10 - 40 km/sec., it was not expected that a significant number of particles would survive impact and consequently the sampling surfaces were chosen in order to investigate micrometeoroid impact sites rather than the actual micrometeoroids themselves.

Figure I shows the way in which eight different sampling slides could be accommodated inside an S-10 unit. The slide in the upper right hand corner carried a biological experiment designed to assess the survivability of some common terrestrial micro-organisms

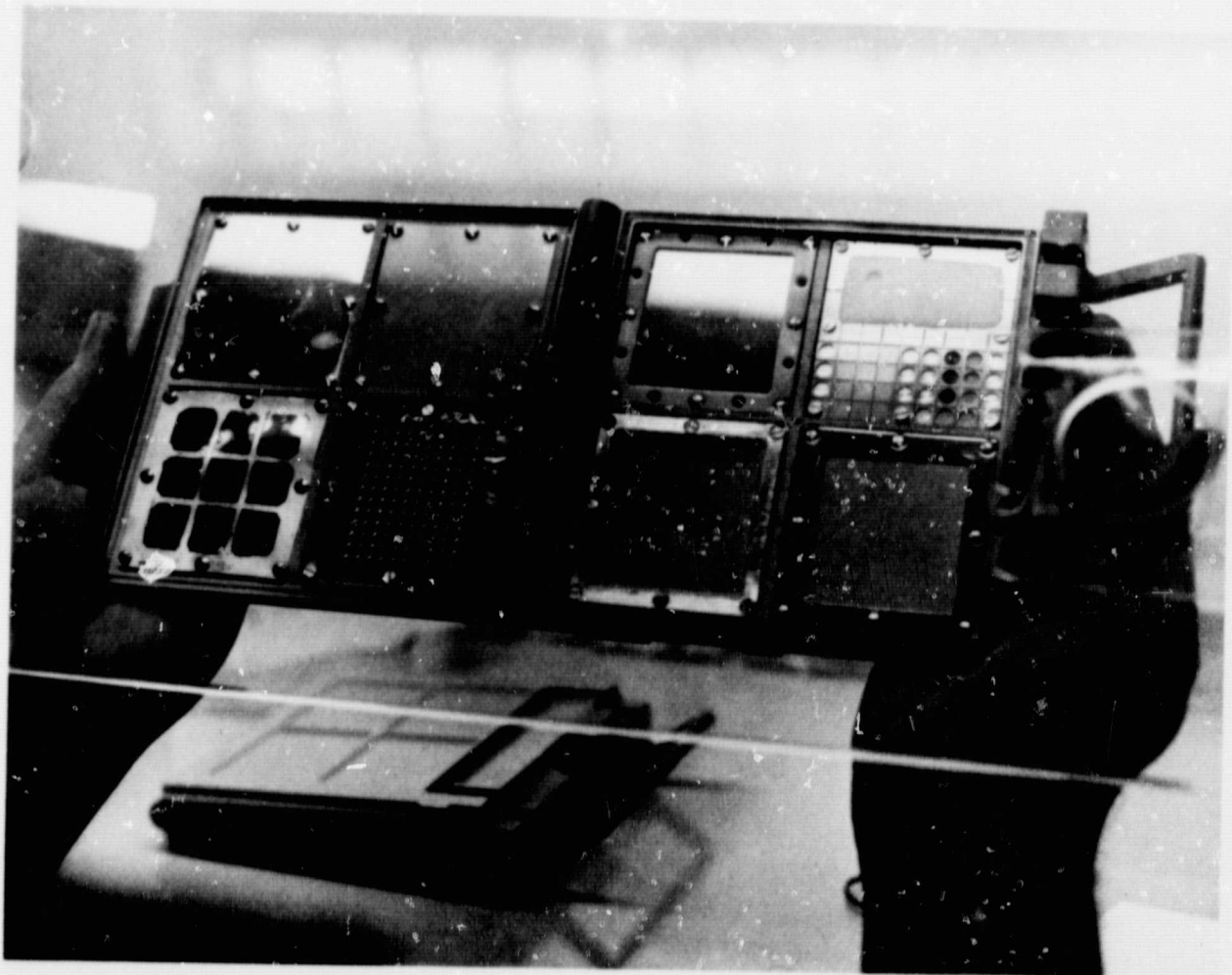


Fig.I S-10 collector unit in open position with samples loaded

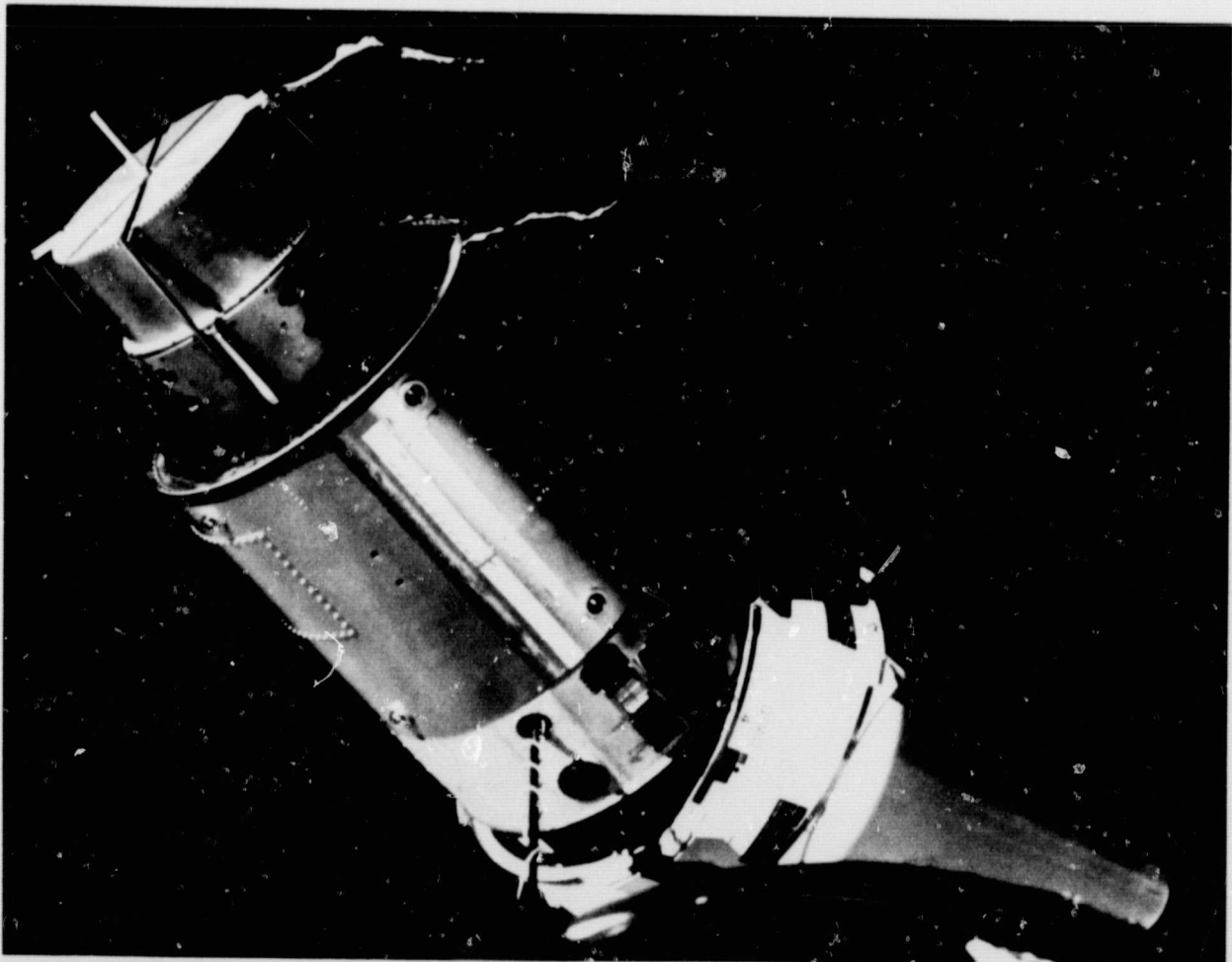


Fig.II ATDA, the "Angry Alligator" in orbit, showing the S-10 unit in position

in space. The remainder of the slides are for recording micrometeoroid impacts and Table 1 lists the surfaces used during the experiment for this purpose.

TABLE 1

Materials used in construction of sampling slides for the S-10 micrometeorite experiment:

Gold coated glass
Polished aluminum
Polished stainless steel
Gold foil - 2 microns thick
Lucite
Titanium coated glass*
Gold coated lucite
Polished Vycor**
Chromium coated glass*
Polished copper
Formvar film on copper mesh
Shielded nitrocellulose

* Surfaces were guest experiments prepared by Otto Berg at Goddard Space Flight Center.

** Surfaces were guest experiments prepared by Paige Burbank at Manned Spacecraft Center.

In addition, at the suggestion of astronaut Russell Schweickart, four polished stainless steel plates were attached to the outside

of the unit. Thus, if for any reason a unit was not opened at the start of its orbital life, its subsequent retrieval would still yield some impact data. In fact this was what happened to the S-10 unit on Agena 8. The Gemini 8 crew, after successfully docking with the Agena, suffered a control system malfunction which obliged them to separate prematurely from the Agena without an opportunity for opening the S-10 unit. Subsequently the crew of Gemini 10 rendezvoused with Agena 8 and during a period of extra-vehicular activity astronaut Collins was able to approach the Agena and retrieve the S-10 unit. Thus, thanks to the extraordinary skill of astronauts John Young and Michael Collins and their ground support teams, we have four stainless steel slides which have been exposed to space at an altitude of about 400 Km for 126.34 days.

None of the other S-10 units have, so far, been retrieved. Agena 9 suffered failure of its second stage motor and failed to achieve orbit. The Augmented Target Docking Adapter, used in lieu of an Agena on mission 9A, was placed in orbit but the astronauts were unable to dock with it because the nose cone shroud had failed to separate. Figure II shows the ATDA photographed from Gemini 9A while in orbit and the closed S-10 unit can be clearly seen. The S-10 unit on Agena 12 was opened in space by astronaut Aldrin, however malfunction of the Agena motor prevented it from being placed into a long-duration orbit. However Agena 10 with its S-10 unit in the closed configuration is still in orbit and the unit could conceivably be retrieved during some future manned space flight.

Figures III and IV show the Agena 8 unit before and after flight respectively and under the same conditions of side illumination in order to reveal any significant light scattering centers in or on the polished stainless steel plates. The numerous artefacts visible on the surfaces in Figure IV result from dirt and thruster debris accumulated in space, dirt from the astronaut's glove and from the inside of the spacecraft and micrometeoroid impact sites. Two of these impact sites were large enough to be visible to the unaided eye. The slide in the bottom right hand corner in Figure III contains a row of holes along its upper edge. These holes contained a biological survival experiment the results of which will be discussed later in the report. The remainder of the exposed area, approximately 144 cm^2 , consisted of the micrometeoroid impact experiment ¹.

Results:

The slides were scanned twice with a Leitz optical microscope at 100 power in a search for impact sites larger than 10 microns diameter. Three such sites were located and the slides were carefully cut to produce three small squares, each approximately 1 cm^2 in area and containing an impact site, suitable for mounting in the "Stereoscan" electron microscope. Figures V, VI and VII show these three impact sites as they appeared in the "Stereoscan". Table 2 gives the dimensions of the craters and estimates of the

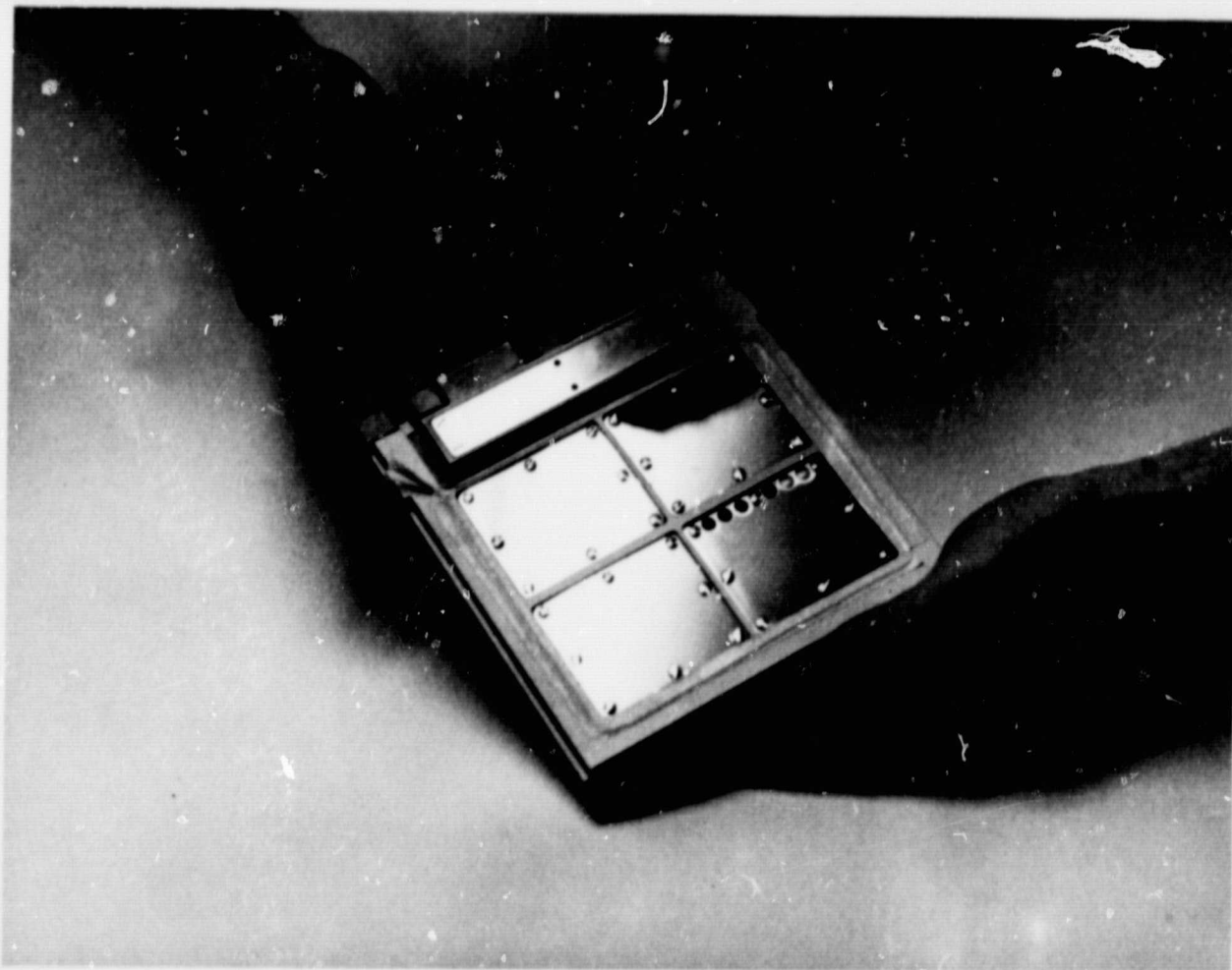


Fig.III S-10 collector showing condition of polished stainless steel sample slides prior to flight.

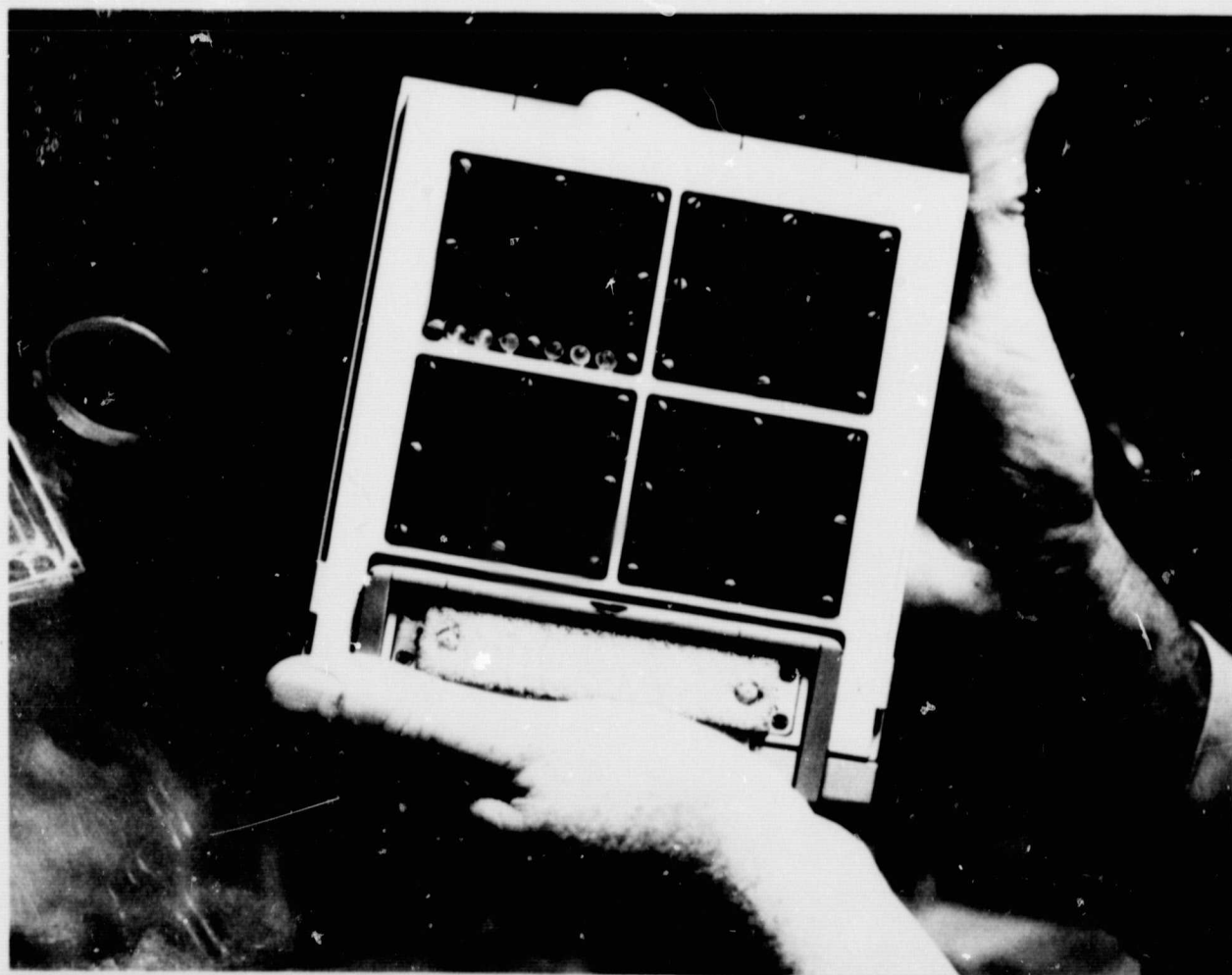


Fig.IV S-10 collector showing condition of polished stainless steel slides after four months in space.

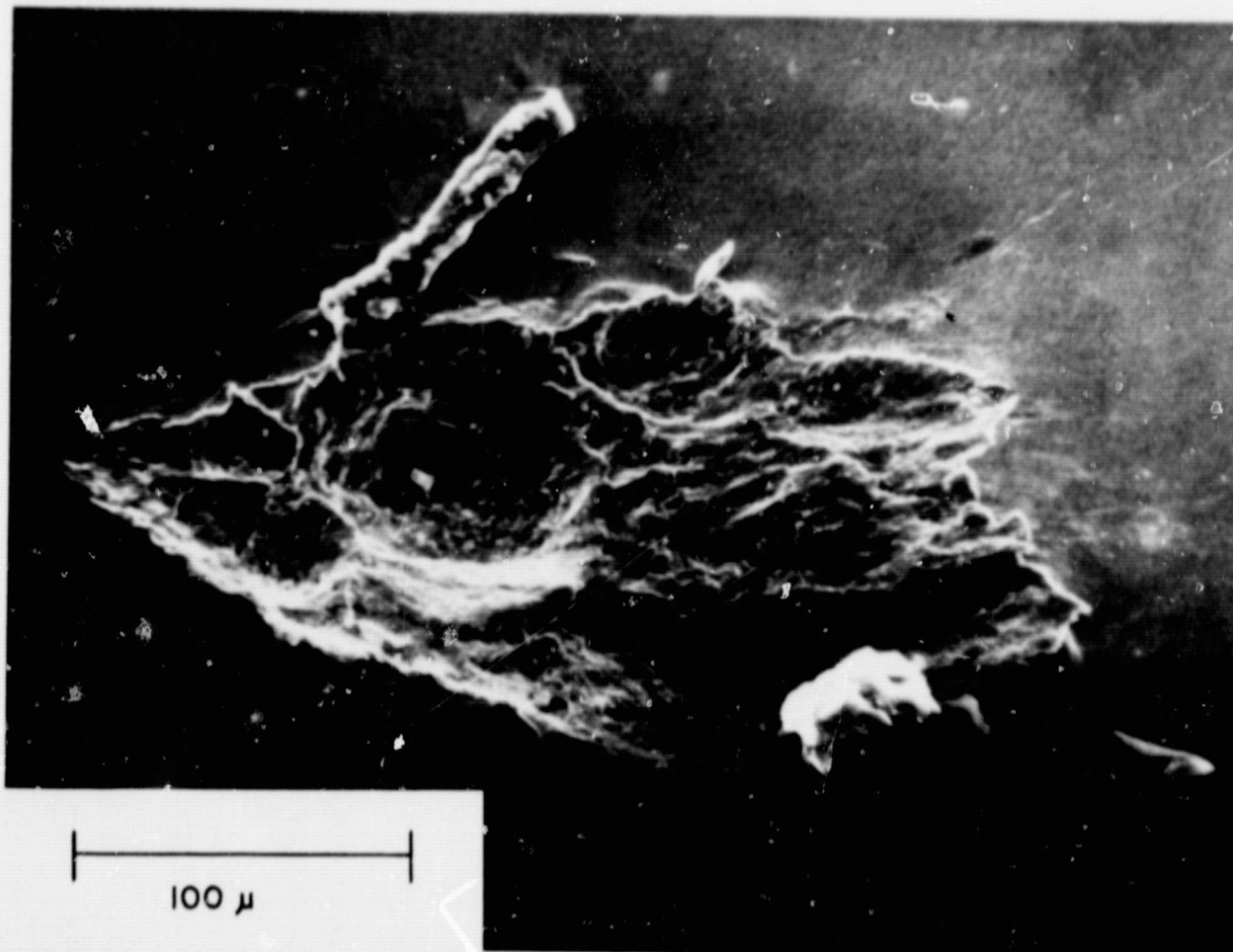


Fig.V 290 micron impact crater in polished stainless steel S-10 sample

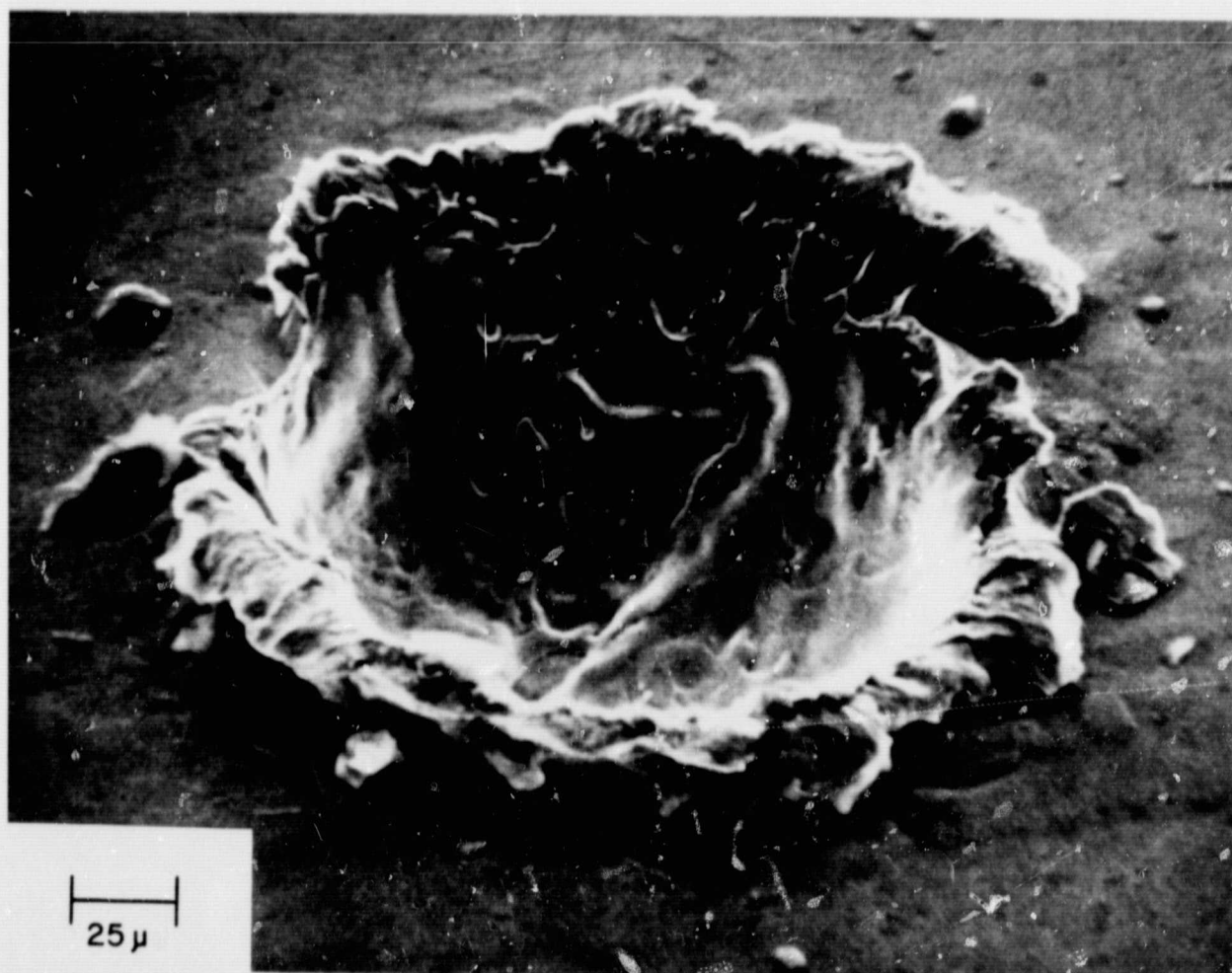


Fig.VI 160 micron impact crater in polished stainless steel S-10 sample

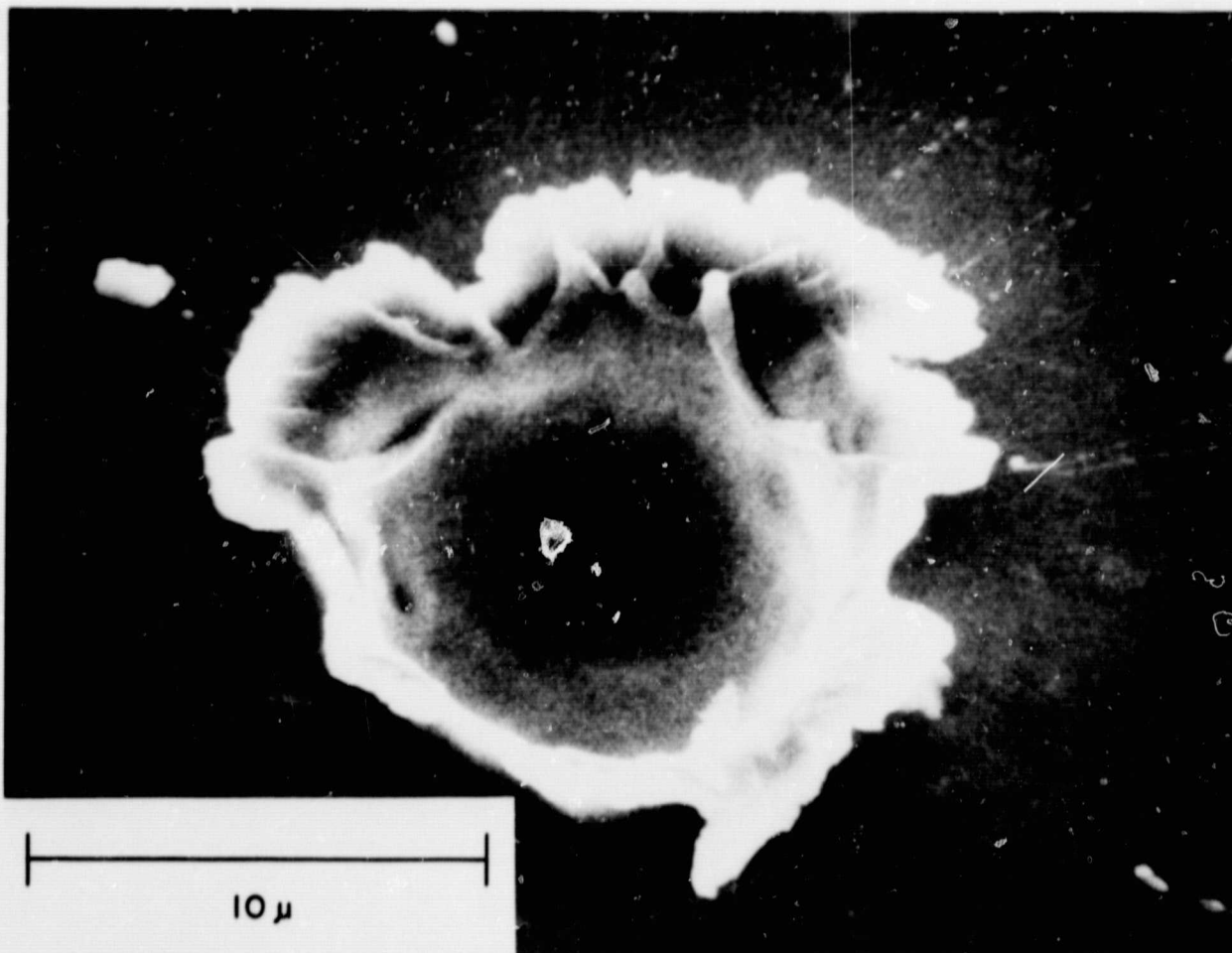


Fig.VII 17 micron impact crater in polished stainless steel S-10 sample

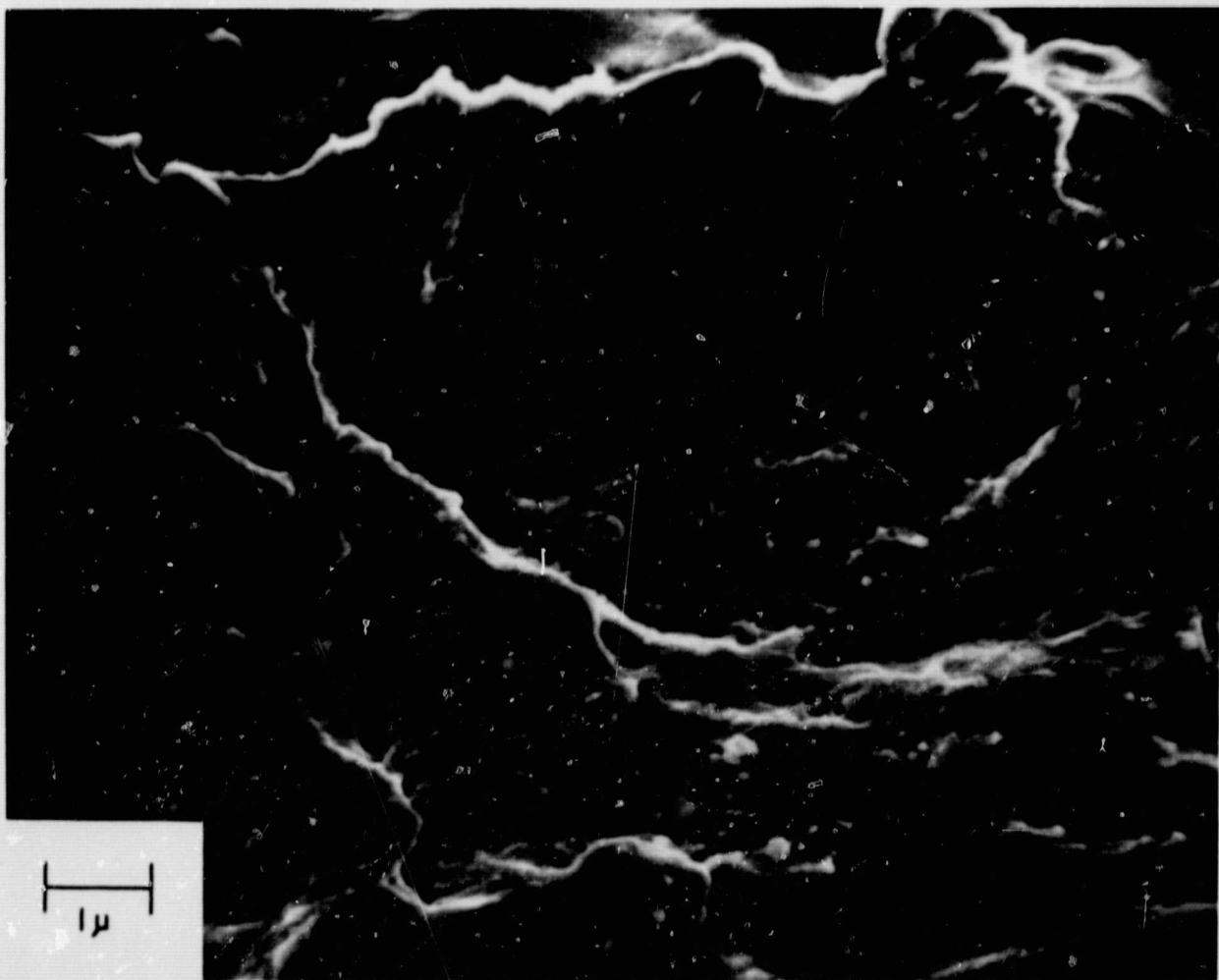


Fig.VIII Interior detail of the 293 micron crater

masses of the impacting particles. These mass estimates were derived, for different assumed initial velocities, from the results of laboratory tests using iron carbonyl particles accelerated in an electrostatic gun. For this calibration we are indebted to Otto Berg, of the Goddard Space Flight Center, who provided the equipment and much valuable assistance.

TABLE 2

Data for large micrometeorite craters in stainless steel

Dimensions in microns	Estimated particle masses (g) for different velocities		
	(10 km/sec)	(20 km/sec)	(40 km/sec)
290 x 180 x 32	1.6×10^{-7}	4.1×10^{-8}	1.0×10^{-8}
160 x 160 x 70	2.9×10^{-7}	9.8×10^{-8}	2.4×10^{-8}
17 x 17 x 7	4.7×10^{-10}	1.2×10^{-10}	2.9×10^{-11}

The origin of these craters as the result of micrometeoroid impacts is strongly supported by their detail appearance. In Figures VI and VII the raised, and in some cases overturned, rim characteristic of impact craters can be clearly seen. Figures VIII and IX show interior details of two of the craters at higher magnification. Evidence of localized melting and flow of material is visible, indicative of the high temperature experienced at the point of impact.

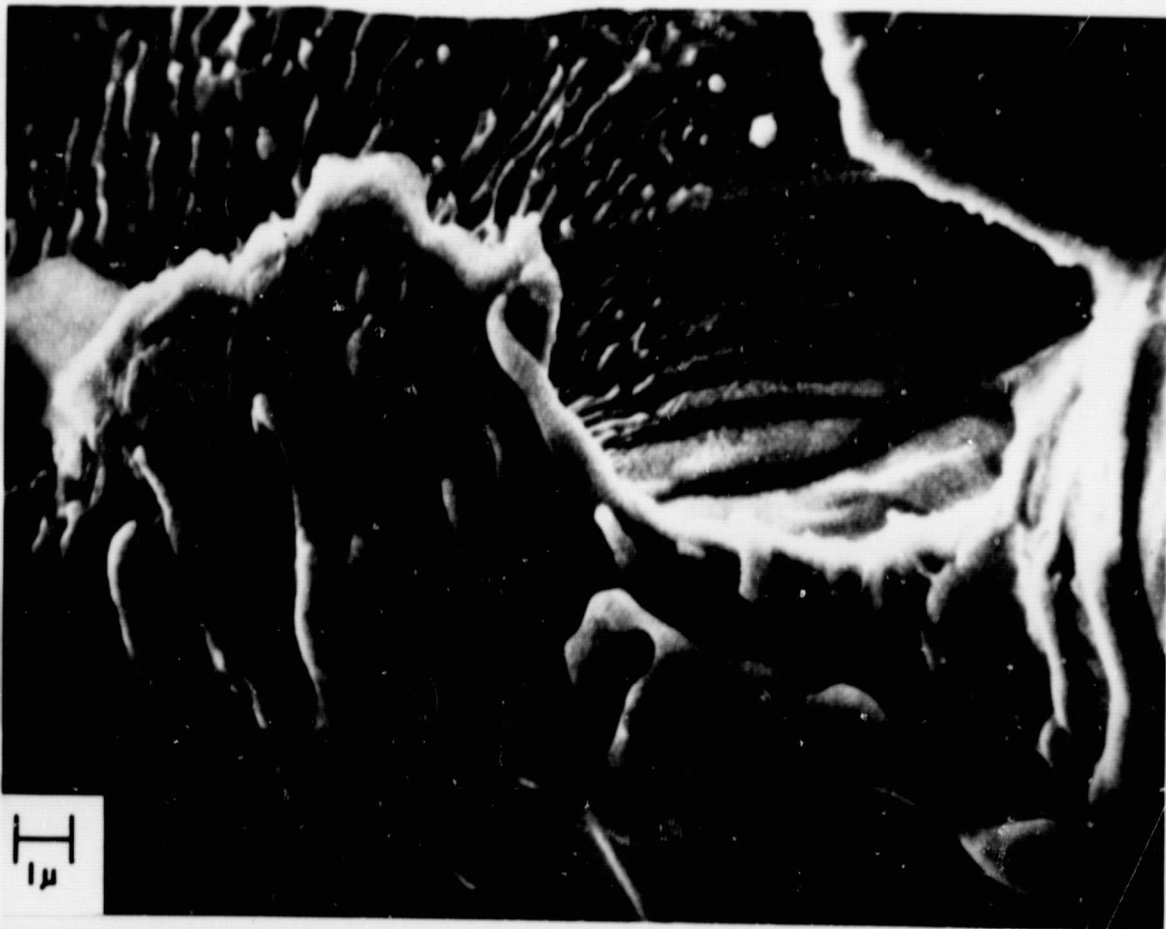


Fig.IX Structure occurring in the 160 micron crater



Fig. X Small gouge in a polished stainless steel S-10 sample.

Although contamination of the surfaces precluded use of the optical microscope at higher magnifications in a search for craters smaller than 10 microns an attempt was made to use the "Stereoscan" for this purpose. A magnification of 10,000 was employed and after two months' work an area of 2.5 mm^2 had been scanned revealing approximately 180 events which differed from any found in the control surfaces. Most of these had the appearance of the gouge shown in Figure X. A study of the angular distribution of major axes of these gouges revealed a strongly preferred orientation which corresponded with the direction in which streaks of thruster debris lay, Figure XI. Consequently it was concluded that these gouges were made by small high-velocity thruster debris particles impacting on the surfaces at a low angle of incidence, probably at the time of the emergency separation of Gemini 8 from the Agena ⁴.

After discarding all impact sites with directional orientation six small craters remained. These ranged in diameter from 0.40 to 1.10 microns and one of these is illustrated in Figure XII. Mass estimates were made for these craters as before and both these data and those for the three larger craters are plotted on the standard flux-versus-mass diagram shown in Figure XIII. ³ Although the statistics are poor because of the small number of events it seems that the flux curve suggested by these impact data falls between those derived from satellite microphone and penetration detectors respectively. In addition, reference to Figure V suggests

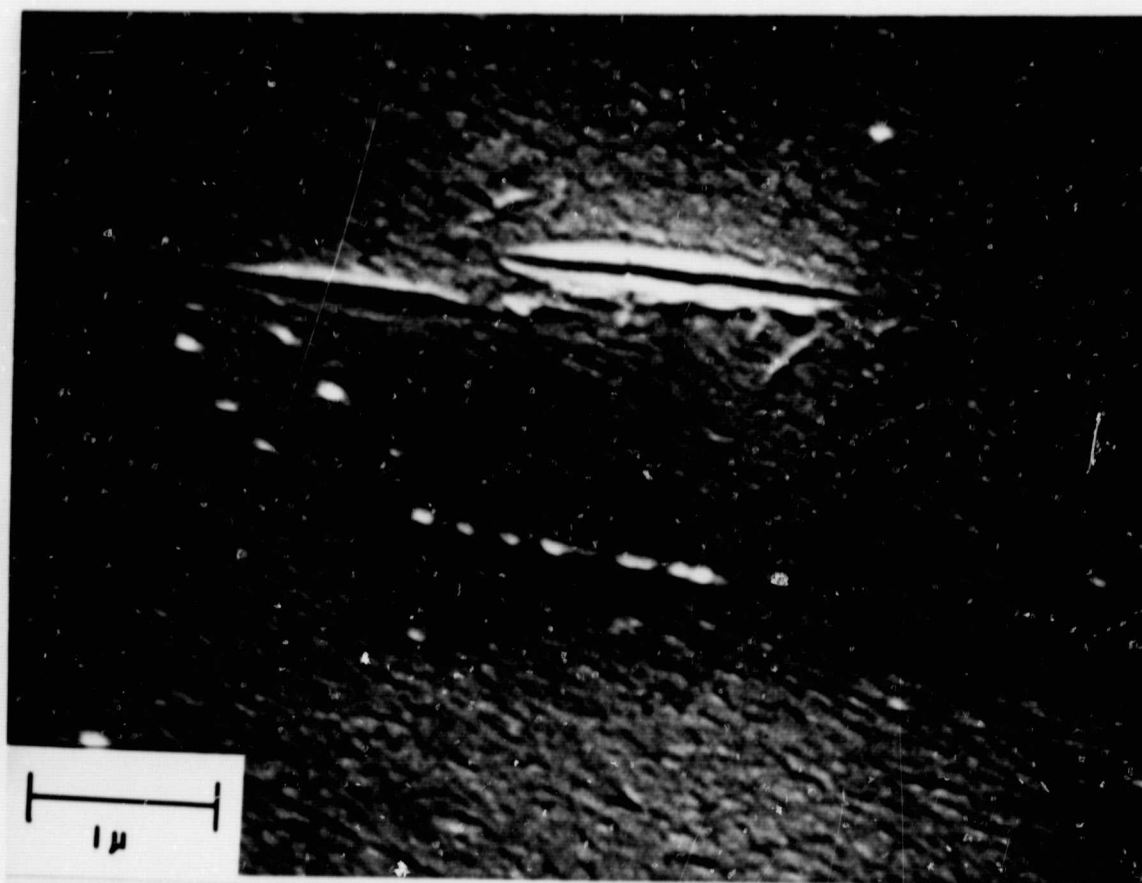


Fig.XI Small gouges, showing alignment with thruster debris.



Fig.XII Small crater of probable impact origin, in a stainless steel sample.

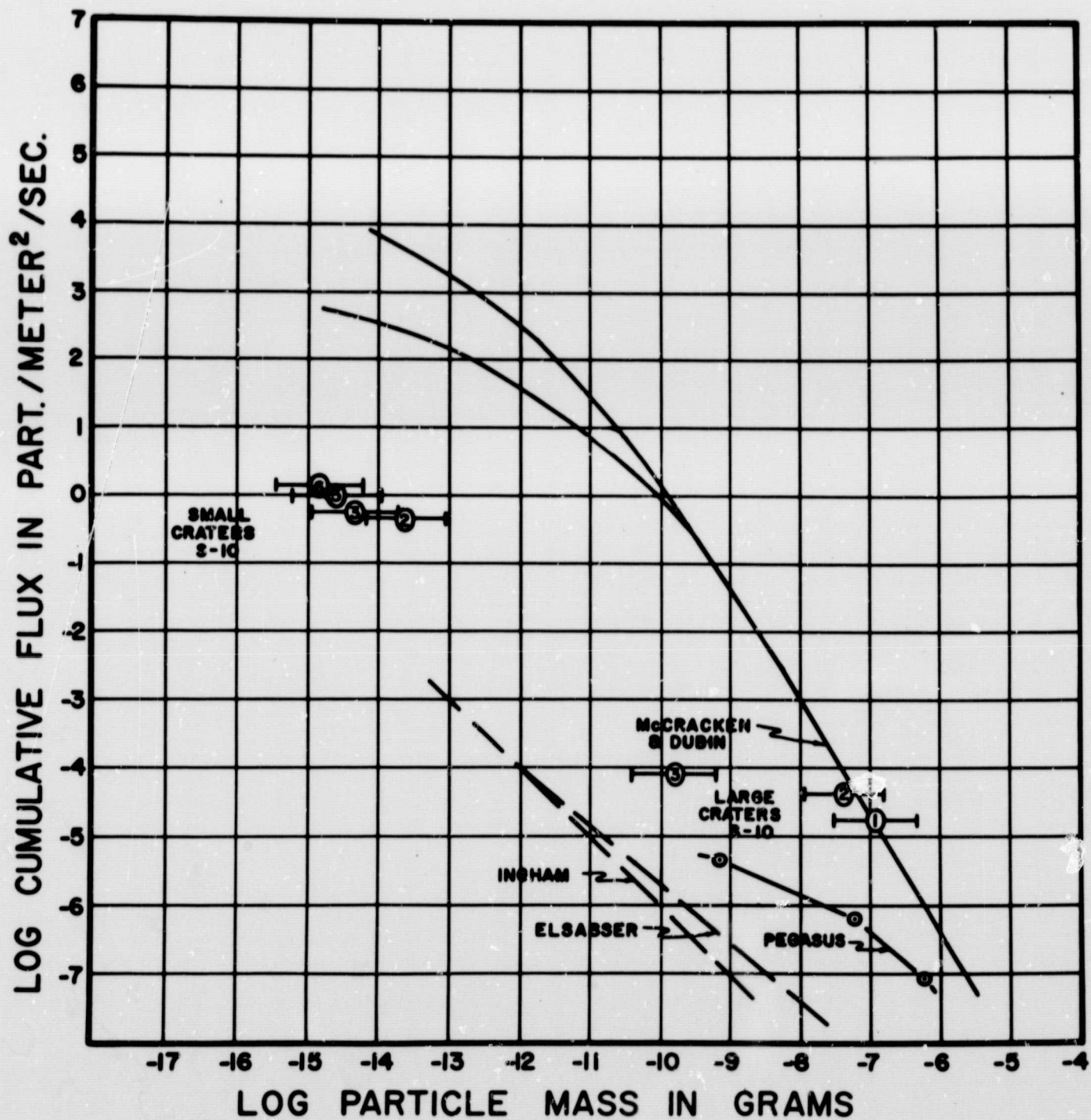


Fig.XIII Mass distribution curve.

a possible explanation for the discrepancy between these two earlier curves. This shallow multiple crater structure was apparently produced by a loosely agglomerated particle of which the penetrating power for any given mass, as measured by a detector such as Pegasus, would be clearly less than for a solid particle of the kind that produced the crater in Figure VI.

Apart from the possibility of employing electron probe micro-analysis on residual projectile material adhering to crater walls it is clear that impact experiments of this kind cannot yield information on the nature of cosmic dust particles. However in view of the unequivocally cosmic nature of the event which produced each crater we feel that this is an extremely powerful technique for the quantitative study of cosmic dust and that extension of this work on future recoverable spacecraft with larger sampling areas and longer exposure times would greatly increase our knowledge about the size distribution of particles in interplanetary space.

Biological Experiment:

Biological information derived from the Agena 8 experiment was necessarily limited by the fact that the box was not opened in space. However two significant observations were made⁵⁻⁷. In the first place, some of the micro-organisms inside the unit, which had been subjected to the vacuum in space but which were shielded from the solar ultra-violet radiation, survived to essentially the same extent as ground-level controls. These were Bacillus subtilis

strain Marburg and Penicillium Roqueforti Thom. The other micro-organism used in this experiment, Coliphage T₁ in both complete broth and synthetic broth, showed survival rates between one and two orders of magnitude less than laboratory controls.

The second result of note is the complete inactivation of all micro-organisms flown on the outside of the S-10 unit. It should be pointed out, however, that these organisms were subjected to the heat and air blast phenomena associated with the launch of the vehicle in addition to the vacuum and radiation conditions of space. It is therefore not possible at present to indentify the specific cause of inactivation.

A list of the publications resulting all or in part from this experiment is appended.

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