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SURVEY OF METEOROID PROPERTY AND DISTRIBUTION
DATA RELEVANT TO SNAP 8
REACTOR AND SHIELD DESIGN

AEC Research and Development Report

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

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NAA-SR-8127
REACTOR TECHNOLOGY
SYSTEMS FOR NUCLEAR
AUXILIARY POWER (SNAP) -
REACTOR SNAP PROGRAM
40 PAGES

SURVEY OF METEOROID PROPERTY AND DISTRIBUTION
DATA RELEVANT TO SNAP 8
REACTOR AND SHIELD DESIGN

By
C. R. HARDER

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.
P.O. BOX 309 CANOGA PARK, CALIFORNIA

CONTRACT: AT(11-1)-GEN-8
ISSUED: JUL 20 1963

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ABSTRACT

This report is a survey of existing literature relative to the properties and distributions of meteoroids. Its objective is to predict the criteria which may be used to calculate the impairing effect of this meteoroidal phenomenon on the SNAP 8 space system and/or its components and other space vehicle structures.

I. INTRODUCTION

Recent space probes and anticipated planetary exploration have stimulated considerable interest in space environmental conditions. Among the phenomena to be encountered in space, and the ones with which this report is concerned, are meteoroids, which represent the primary impairing effect on the SNAP 8 space system and/or its components. A single encounter with a meteoroid of sufficient mass to penetrate certain structural components, such as coolant piping or the LiH shield casing, could terminate the useful life of the system. In anticipation of such encounters, the system must be armored to a degree which insures a 0.95 to 0.999 probability of no penetration during the mission lifetime. The degree of protection must be defined by reliability requirements and our current knowledge and estimates of the magnitude of the meteoroid problem. Obviously, an assessment of the degree of the problem demands knowledge of the physical properties and distribution of the meteoroid particles. As yet, this information is not available in its entirety because a truly definitive measurement has yet to be made. There is, on the other hand, a wealth of information available from several fields of study that is pertinent to estimating the nature of the material. The most significant information has been obtained from telescopic and radio-echo observations and satellite and space probe experiments. Unfortunately, the data generated by these different methods are seldom in agreement and several points of contention pertinent to estimating the degree of hazard remain unresolved.

This report attempts to review many of the conflicting points of view regarding properties and distributions of meteoroids so as to ascertain the most suitable set of parameter values relevant to near-earth space structure design.

II. PHYSICAL PROPERTIES

A. ORBITAL CHARACTERISTICS

In the past, there has been a cleavage of opinion regarding the origin of meteoroid material. One theory holds with an interstellar origin whereas the other postulates a solar system origin which in recent years has gained considerable support. With the highly improved observational techniques now available, few particles are detected with velocities greater than that which would be expected on a closed elliptical orbit about the sun. This absence supports the suggested solar system origin, since a velocity greater than the limiting or parabolic velocity must define particles on hyperbolic or unclosed temporary orbits about the sun originating in interstellar space. The majority of meteoroid material appears to be minute pieces or conglomerates of stone, moving in closed orbits in the solar system. Occasionally, the earth encounters concentrated groups of material with common radiants known as shower streams, which provide a display of meteor activity in which the earth influx rate may rise to many times the normal rate. The remainder of the material seems to move in ungrouped or random orbits and is termed sporadic, although some recent investigations indicate the so-called sporadic background may itself be concentrated into a very large number of shower orbits. Gallagher and Eshleman suggest there may be upward to a million such orbits in the solar system, leading to the concept of a sporadic shower contribution.¹

Most orbital motions appear to be generally within 15° of the ecliptic plane, although there are some indications that approximately 15% of the material moves in orbits with inclinations grouped around 60° and 120° . Hawkins predicts that a large proportion of the smaller particles are moving in nearly circular orbits, tilted at a steep angle to the ecliptic.² More than 99% of the sporadic meteors seem to be moving in direct orbits rather than retrograde as indicated by the velocities measured (vector), which appear to be from behind the earth. (See Figure 1.)

B. METEOROID VELOCITY

Due to the motion of the earth about the sun, most meteoroid encounters occur on the leading face or morning side of the earth. (See Figure 2.) This sweeping effect infers an earth orbital velocity greater than that of meteoroids

Figure 1. Distribution of Meteoric Orbital Directions³

Figure 2. Distribution of Meteoric Encounters³

in the direction of the earth's motion and establishes a lower limit for the meteoroid relative incident velocity of approximately 11 km/sec, which is the escape velocity from earth. The upper limit for the relative incident velocity has provoked much discussion regarding the aforementioned meteoroid origin. The limiting heliocentric or parabolic velocity at the earth's orbital distance from the sun is 42.1 km/sec. If meteoroid velocities exist which exceed this value, they

must define an interstellar origin of the material, contrary to the presumed cometary origin proposed by Whipple and others. Experimental data do not support the hyperbolic orbit theory, thus establishing a maximum relative velocity of 72 km/sec which would result from a head-on collision of earth with a retrograde meteoroid with parabolic velocity. Therefore, depending upon whether the particle is in a direct or retrograde orbit, the limiting range of relative velocities is between 11 and 72 km/sec. Again, since most orbits are direct, the inferred maximum probable velocity of encounter is 42 km/sec corresponding to normal incidence to earth's orbit. (See Figure 3.) Most likely, incidence will occur at some oblique angle defining an average incident velocity between 11 and 42 km/sec, or approximately 27 km/sec.

It has been suggested by Whipple that particle velocity is mass dependent, resulting from radiation pressure effects which manifest themselves as the "Poynting - Robertson Effect."⁴ The force involved is clearly of interest concerning meteoroid velocities since it leads to a separation of particles according to their size and hence a variation of orbital characteristics. In support of a reduced value for the average velocity are observations made of the smallest detectable particles entering the atmosphere. These particles are characterized by more circular direct orbits with velocities relative to the earth which are generally lower than the deduced average. Whipple suggests that a reasonable value for smaller particles might be 15 km/sec. Figure 4 illustrates this velocity variation with mass as resolved from the photographic data of Whipple and his associates at Harvard.

The results of radio-echo velocity observations conducted by McKinley are illustrated in Figure 5, which indicates a trend to higher velocities and a significant retrograde contribution. These data represent an analysis of 10,933 meteors, collected over a period of 15 months. The sample includes shower as well as sporadic contributions and masses to the eighth visual magnitude.

C. METEOROID DENSITY

There is little agreement concerning the density estimates of particles in the micrometeoroid and meteoroid range. Density assumptions range from 0.05 to 7.8 gm/cc. The more dense material is assumed to be of asteroidal origin, whereas the less dense material is assigned a cometary origin. If, as generally noted, only 10% of the meteoroid population is of asteroidal origin and

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Figure 3. Theoretical Relative Meteoric Velocity

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Figure 4. Whipple Velocity Distribution

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Figure 5. Radio-Echo Velocity Distribution (McKinley)⁵

of these only 3% is of the iron-nickel variety, then it is reasonable to speculate that a density lower than 7.8 gm/cc will predominate. On the other hand, the minimum value of 0.05 gm/cc, as determined from brightness measurements during the Harvard Photographic program, should be considered only with the range of meteor mass measurements in mind (~ 0.2 gm). It seems reasonable to expect that meteoroids of lesser mass will not have the lacy porous structure associated with the value of 0.05 gm/cc, but that the density will increase as one goes down the mass scale, eventually approaching the specific gravity of stone, the suggested nonvolatile component of comets. This author's personal preference at this time is a value of approximately 0.34 gm/cc in the photographic and radio-echo ranges of mass, whereas a value of approximately 3 gm/cc might be assumed in the micrometeoroid range or that range monitored by satellite experiments. The density value of 0.34 gm/cc will be justified in a later section of this paper.

In addition, the preliminary reduction of data from the first two "Trailblazer" experiments conducted by the Smithsonian Institute indicates a density value, in the large mass range (10^{-4} to 100 gm), within the limits of 0.3 to 1.2 gm/cc, depending on particle geometry. (Refer to Bibliography 22.) A value of 0.6 gm/cc has been postulated from these experiments, assuming a flattened spheroidal shape for meteoroids entering the atmosphere.

III. METEOROID DETECTION AND MASS DISTRIBUTIONS

A. VISUAL, TELESCOPIC, AND RADIO-ECHO SURVEYS

Prior to 1957, the bulk of our information concerning meteoroid material in the vicinity of the earth was obtained from two basic sources: (1) by visual, telescopic, and radio-echo observations of the luminous and electrical phenomena produced by meteoroids penetrating the atmosphere (meteors) and (2) from examination of particles which have impacted on the earth's surface (meteorites). Prominent among the work in this field is the Harvard Astronomical Observatory program wherein many thousands of meteor photographs were taken simultaneously from two stations.⁶ A method of cataloging was devised similar to stellar classification in which a magnitude is assigned as a measure of brightness. The magnitude may be interpreted as a measure of mass according to the following formula:

$$M = 2.5 \log_{10} \left(\frac{m_0}{m} \right)$$

where M is the magnitude, m_0 the mass of a zero magnitude meteor, and m is the mass of the meteor under consideration. The reduction from magnitude to mass is thus a function of the value assigned to m_0 . The translation generally used in the past was due to Whipple, who calculated m_0 to lie between 1 and 30 grams with 25 grams being the preferred value. (See Figure 6.) Watson, on the other hand, proposed a value of m_0 as small as 250 mg, based on visual and telescopic observation.⁵ A revised value of the mass of the zero magnitude meteor is available as a result of the initial Trailblazer experiments conducted by the Smithsonian Institute. The new value as indicated by the cumulative mass distribution curve generated by the Trailblazer data (Figure 10) is approximately 0.39 grams.

The range of magnitude observed in a photographic program is from approximately -3 to +5 with the majority of observations falling in the 0 to +5 range. A magnitude of +5 on this scale is just discernable with the naked eye. In ranges of greater magnitude, as far as +15, radio-echo or radar techniques are used to detect the ionization trails left by the smaller particles as they traverse the atmosphere. A magnitude rating of +15 is actually fictitious, since luminous displays no longer prevail. The radio-echo surveys have a distinct

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Figure 6. Meteoroid Mass vs Magnitude (Whipple 1957)⁷

advantage over photographic meteor studies in that they may be conducted during daylight hours as well as at night.

Noting that, within the radio-echo and photographic data, the meteoroid influx seemed to vary inversely to the mass, Whipple extrapolated the meteor data to small masses, assuming that a constant mass-per-magnitude relation exists. These data and extrapolation are illustrated in Figure 7 by the shaded region with the data curve of Watson⁵ included for reference. The width of the shaded region is due to the range of possible values of m_0 , Whipple's old preferred value being near the top of the range. Table I, which contains the 1957 preferred Whipple data, illustrates the variable velocity character of particles where orbital eccentricities and dimensions have been reduced. Also included in Table I is the incident kinetic energy of the particle which has been calculated directly from the assumed values of mass and velocity. The influx rates listed in the last column of Table I have been corrected for a 50% earth-shielding effect. The degree of uncertainty between experiments is illustrated by the estimates of Watson and Whipple in Figure 7, the upper limit being some 400 times

TABLE I
METEOROID DATA

Visual Magnitude	Mass (gm)	Assumed Velocity (km/sec)	K. E. (ergs)	No. Striking 3-m Sphere per day
0	25.0	28	1.0×10^{14}	
1	9.95	28	3.98×10^{13}	
2	3.96	28	1.58×10^{13}	
3	1.58	28	6.31×10^{12}	
4	0.628	28	2.51×10^{12}	
5	0.250	28	1.0×10^{12}	2.22×10^{-5}
6	9.85×10^{-2}	28	3.98×10^{11}	6.48×10^{-5}
7	3.96×10^{-2}	28	1.58×10^{11}	1.63×10^{-4}
8	1.58×10^{-2}	27	5.87×10^{10}	4.09×10^{-4}
9	6.28×10^{-3}	26	2.17×10^{10}	1.03×10^{-3}
10	2.5×10^{-3}	25	7.97×10^9	2.58×10^{-3}
11	9.95×10^{-4}	24	2.93×10^9	6.48×10^{-3}
12	3.96×10^{-4}	23	1.07×10^9	1.63×10^{-2}
13	1.58×10^{-4}	22	3.89×10^8	4.09×10^{-2}
14	6.28×10^{-5}	21	1.41×10^8	1.03×10^{-1}
15	2.5×10^{-5}	20	5.10×10^7	2.58×10^{-1}
16	9.95×10^{-6}	19	1.83×10^7	6.48×10^{-1}
17	3.96×10^{-6}	18	6.55×10^6	1.63
18	1.58×10^{-6}	17	2.33×10^6	4.09
19	6.28×10^{-7}	16	8.2×10^5	1.03×10
20	2.5×10^{-7}	15	2.87×10^5	2.58×10
21	9.95×10^{-8}	15	1.14×10^5	6.48×10^2
22	3.96×10^{-8}	15	4.55×10^4	1.63×10^2
23	1.58×10^{-8}	15	1.81×10^4	4.09×10^2
24	6.28×10^{-9}	15	7.21×10^3	1.03×10^3
25	2.5×10^{-9}	15	2.87×10^3	2.58×10^3
26	9.95×10^{-10}	15	1.14×10^3	6.48×10^3
27	3.96×10^{-10}	15	4.55×10^2	1.63×10^4
28	1.58×10^{-10}	15	1.81×10^2	4.09×10^4
29	6.28×10^{-11}	15	7.21×10	1.03×10^5
30	2.5×10^{-11}	15	2.87×10	2.58×10^5
31	9.95×10^{-12}	15	1.14×10	6.48×10^5

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Figure 7. Comparison Curves — Influx vs Mass (Whipple-Watson)

greater than the lower limit. It seems evident that any estimate of meteoroid population that is based on these early estimates alone could only be very crude. The Trailblazer distribution, also illustrated in Figure 7, is the current and seemingly more reliable interpretation of the telescopic and radio-echo data accumulated during the Harvard program. Using experimentally determined luminous efficiencies, which may still be questionable, the accumulated data, in part, were again analyzed to establish the new curve.

B. PHOTOMETRIC STUDIES (ZODIACAL LIGHT)

Further estimates and evidence of space debris is furnished by photometric studies of the zodiacal light in the night sky. This light, forming a tapered band stretching up from the horizon, is attributed to sunlight reflected from a vast number of small particles (1 to 300 μ diameter) in interplanetary space. The origin of the dust is thought to be cometary, since a mechanism of replacement is necessary to satisfy the theoretic removal of the dust from space by spiraling into the sun, and the now present zodiacal cloud of particles. The zodiacal dust

is also thought to be more highly concentrated in the plane of the ecliptic as indicated by the sun's Fraunhofer Corona. The F-Corona, or portion of the solar corona attributed to the zodiacal particles, is shaped by the absorbing medium through which the sunlight passes. Since there is no reddening of the light, the individual particles cannot be as small as very fine dust (Rayleigh Limit) and hence a lower limit to the size of the contributing particles is suggested. Another physical lower limit is defined by the particle mass which can just balance the radiation pressure exerted on it by the sun. In addition, as the particle size increases, the contributions to the zodiacal light decreases rather rapidly with no significant contributions attributed to particles of greater diameter than 300μ . From these cited limitations, attempts have been made to define a mass distribution for zodiacal particles. Beard gives the following estimates of the concentration of these particles:⁸

- 1) 10^{-14} to 10^{-15} particles/cc at earth's mean orbital distance from the sun
- 2) 10^{-10} to 10^{-11} particles/cc at earth's surface due to gravitational attraction.

C. DIRECT MEASUREMENTS (ROCKETS, SATELLITES, AND SPACE PROBES)

To remove the uncertainties which existed concerning the physical characteristics and distribution of meteoroids, new and independent measurements of selected parameters were needed. Recently, artificial earth satellites and space probes have become available to make direct measurements of the interplanetary debris, in particular, the mass distribution of the very small micrometeoroids. Detectors have been developed which are capable of detecting individual dust particles with masses as small as 10^{-13} grams and have been used as sensors to measure momentum, kinetic energy, and penetration and fracture properties of incident particles. The detectors developed and used for direct measurement experiments⁹ are listed and described in the following paragraphs:

1. Microphone System

The particle sensor consists of a piezoelectric-crystal microphone attached to a metallic sounding board. Impacting particles deliver a mechanical impulse to the sounding board which in turn generates an electrical signal that is amplified and pulse-height-analyzed to determine information about the incident particle. The direct measurements can be expressed in terms of particle mass subject to minor uncertainties in calibration theory, average speed assumption

(relative to the carrier), and hyper-velocity impact characteristics of the sounding board. Meteoroid distributions can then be inferred after appropriate correction factors have been computed. These factors include the effects of earth shielding, solid viewing angle of the sensors, and orientation of the solid viewing angle relative to the apex of the earth's motion.

2. Photomultiplier System

The basic detector unit is a photomultiplier tube with a lucite or glass surface that is exposed to micrometeoroid impact. Light-flash signals emitted by impact on the exposed surface are detected and amplified by the photocathodes. Measurements of the intensity and duration of the flash provide information about the particle kinetic energy. Conversion of measurements to particle mass is subject to corrections similar to those defined for the microphone system.

3. Fracture System

The fracture-type sensor consists of a continuous wire wrapped around insulating support material. A meteoroid impact event is observed when the colliding dust particle fractures the wire and causes an open circuit. Obviously, each unit detects a single event only.

4. Penetration Systems

Four types of penetration sensors have been developed. The first type consists of a chromium strip deposited on a pyrex glass surface. The resistance of the strip is monitored to register an impact. The second type consists of two hermetically sealed and pressurized zones. A puncture of either zone is detected by a differential pressure transducer which monitors the pressure between the zones. The third type consists of a CdS cell covered by a thin mylar film that is made opaque by vapor-depositing aluminum on both sides. The mass of the impacting particle is determined by the amount of sunlight allowed through the puncture which, in turn, changes the resistance of the CdS cell. The fourth type consists of a variable-thickness stainless steel plate mounted in front of a foil gauge. A particle penetration of the stainless steel and foil gauge causes an open circuit and resultant detection of the event.

The direct measurements obtained with the microphone and photomultiplier systems are plotted in Figure 8 from the data in Tables II, III, IV, and V

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Figure 8. Direct Measurement Data from Microphone and Photomultiplier Systems⁹

TABLE II
DIRECT MEASUREMENTS OBTAINED WITH MICROPHONE SYSTEMS
ON THE O.S.U. ROCKETS⁹

Rocket	Particle Velocity (km/sec)	Mass Sensitivity (gm)	Number of Impacts	Exposure h > 100 km (m ² sec)	Cumulative Influx Rate (particles/m ² /sec)
AEROBEE No. 80	70	$>8.6 \times 10^{-11}$	49	5.0	9.8
	70	$>4.3 \times 10^{-10}$	10	5.0	2.0
	40	$>2.5 \times 10^{-10}$	3	50	6.0×10^{-2}
	40	$>7.5 \times 10^{-10}$	1	50	2.0×10^{-2}
AEROBEE No. 88	20	$>6.5 \times 10^{-11}$	6	3.0	2.0
	20	$>1.0 \times 10^{-9}$	1	3.0	3.3×10^{-1}
	35	$>1.3 \times 10^{-10}$	17	30	5.7×10^{-1}
	35	$>2.9 \times 10^{-10}$	7	30	2.3×10^{-1}
NIKE-CAJUN AF-2	40	$>1.5 \times 10^{-10}$	45	31	1.5
		$>3.0 \times 10^{-10}$	15		4.8×10^{-1}
		$>1.0 \times 10^{-9}$	3		9.7×10^{-2}
NIKE-CAJUN AA6.203	35	$>8.6 \times 10^{-11}$	55	37	1.5
		$>8.6 \times 10^{-10}$	3		8.1×10^{-2}
NIKE-CAJUN AA6.204	40	$>1.8 \times 10^{-10}$	32	33	9.7×10^{-1}
		$>7.5 \times 10^{-10}$	1		3.0×10^{-2}
NIKE-CAJUN AA6.206	35	$>4.3 \times 10^{-11}$	12	24	5.0×10^{-1}
		$>2.9 \times 10^{-10}$	1		4.2×10^{-2}
		$>2.0 \times 10^{-10}$	6		2.5×10^{-1}
SPAEROBEE 10.01	60	$>8.3 \times 10^{-11}$	20	8.1	2.5

TABLE III

DIRECT MEASUREMENTS OBTAINED WITH MICROPHONE SYSTEMS
ON UNITED STATES SATELLITES AND SPACE PROBES⁹

Spacecraft	Mass Sensitivity (gm)	Effective Area (m ²)	Exposure Time (sec)	Number of Particles	Cumulative Influx Rate (particles/m ² /sec)	
					Observed	Corrected
EXPLORER VIII	$1.0 \times 10^{-9} - 1.0 \times 10^{-8}$	7.0×10^{-2}	3.5×10^6	~3650	1.5×10^{-2}	3.0×10^{-2}
	$1.0 \times 10^{-8} - 1.0 \times 10^{-7}$			~75	3.1×10^{-4}	6.2×10^{-4}
	$> 1.0 \times 10^{-7}$			1 or 2	$\sim 5.0 \times 10^{-6}$	$\sim 1.0 \times 10^{-5}$
VANGUARD III	$> 3.3 \times 10^{-9}$	4.0×10^{-1}	6.9×10^6	~3500	1.3×10^{-3}	2.0×10^{-3}
EXPLORER I	$> 8.3 \times 10^{-10}$	2.3×10^{-1}	7.9×10^4	145	8.4×10^{-3}	1.7×10^{-2}
PIONEER I	$> 5.0 \times 10^{-11}$	3.9×10^{-2}	1.1×10^5	17	4.0×10^{-3}	4.0×10^{-3}
RANGER I	$> 1.0 \times 10^{-11}$	8.0×10^{-4}	1.1×10^4	64	7.3	4.0×10
MIDAS II	$> 1 \times 10^{-10}$	6.9×10^{-2}	4.0×10^3	67	2.5×10^{-1}	5.0×10^{-1}
SAMOS II	$\gtrsim 1 \times 10^{-10}$	6.9×10^{-2}	?	?	3.4×10^{-1}	6.8×10^{-1}
SLV-1	$\gtrsim 3 \times 10^{-9}$	8.0×10^{-1}	9.5×10^2	10	1.3×10^{-2}	2.6×10^{-2}

TABLE IV

DIRECT MEASUREMENTS OBTAINED WITH MICROPHONE SYSTEMS
ON THE SOVIET UNION ROCKETS, SATELLITES, AND SPACE PROBES⁹

Vehicle	Mass Sensitivity (gm) Revised for $v = 30 \text{ km/sec}$	Effective Area (m ²)	Exposure Time (sec)	Number of Particles	Influx Rate (particles/m ² /sec)	
					(Nazarova)	Cumulative
SPUTNIK III	$1.4 \times 10^{-8} - 4.8 \times 10^{-8}$	0.34	$\sim 8 \times 10^5$	?		$< 1 \times 10^{-4}$
	$4.8 \times 10^{-8} - 2.7 \times 10^{-7}$					
	$2.7 \times 10^{-7} - 1.0 \times 10^{-5}$					
	$> 1.0 \times 10^{-5}$					
LUNIK I	$4.4 \times 10^{-9} - 2.7 \times 10^{-8}$	0.2	3.6×10^4	<16	$< 2 \times 10^{-3}$	$< 2.9 \times 10^{-3}$
	$2.7 \times 10^{-8} - 3.6 \times 10^{-7}$			< 4	$< 5 \times 10^{-4}$	$< 7.0 \times 10^{-4}$
	$> 3.6 \times 10^{-7}$			< 1	$< 1 \times 10^{-4}$	$< 1.4 \times 10^{-4}$
LUNIK II	$3.6 \times 10^{-9} - 1.1 \times 10^{-8}$	0.2	1.1×10^5	0	$< 5 \times 10^{-5}$	
	$1.1 \times 10^{-8} - 2.7 \times 10^{-8}$			0	$< 5 \times 10^{-5}$	
	$> 2.7 \times 10^{-8}$			2	9×10^{-5}	9.1×10^{-5}
INTERPLANETARY STATION	$1.8 \times 10^{-9} - 5.3 \times 10^{-9}$	0.1	2.3×10^4	1	4×10^{-4}	3.0×10^{-3}
	$5.3 \times 10^{-9} - 1.4 \times 10^{-8}$			5	2×10^{-3}	2.6×10^{-3}
	$> 1.4 \times 10^{-8}$			1	4×10^{-4}	4.3×10^{-4}
GEOPHYSICAL ROCKET I	$\gtrsim 2.5 \times 10^{-9}$	4	1.3×10^2	?	6×10^{-2}	6×10^{-2}
GEOPHYSICAL ROCKET II	$\gtrsim 2.5 \times 10^{-9}$	4	1.5×10^2	?	5×10^{-2}	5×10^{-2}
GEOPHYSICAL ROCKET III	$\gtrsim 2.5 \times 10^{-9}$	4	8.5×10	?	7.5×10^{-1}	7.5×10^{-1}

TABLE V

DIRECT MEASUREMENTS FROM PHOTOMULTIPLIER SYSTEMS
ON UNITED STATES ROCKETS AND SATELLITES⁹

	Half-Angle of Detector Cone of Vision	Exposure (m ² sec)	Number of Particles	Influx Rate (particles/m ² /sec)	Omnidirectional Influx Rate
AEROBEE NRL 25	80°	0.63	101	160	390
JUPITER AM-28	80°	2.2	4	1.63	4
EXPLORER VIII (preliminary)	60°	4.3	110	25	200
RANGER I (preliminary)	75°	8.5	179	21	114

as a cumulative mass distribution curve.⁹ The results derived from the penetration and fracture experiments are plotted separately in Figure 9 from the data in Table VI, with the data uncertainties indicated.⁹ Within the uncertainties shown, Figure 9 confirms the mass distribution curve (Figure 8), defined by the more extensive data obtained from the microphone and photomultiplier systems in the range of 10^{-7} to 10^{-8} grams.

TABLE VI

DIRECT MEASUREMENTS FROM PENETRATION AND FRACTURE
EXPERIMENTS ON UNITED STATES SATELLITES⁹

Satellite	Data Point (Figure 9)	Type of Dust Particle Sensor	Range of Threshold Particle Mass (gm)	Exposure (Corrected) (m ² -sec)	Number of Particles	Predicted Influx Rate $P_1 = 0.99$ (particles/m ² -sec)
Vanguard III	1	Pyrex-Chromium Strip	4.0×10^{-8} - 1.2×10^{-7}	7.0×10^1	0	6.2×10^{-2}
	2	Pyrex-Chromium Strip	4.0×10^{-8} - 1.2×10^{-7}	1.4×10^2	0	3.3×10^{-2}
	3	Mylar - CdS Cell	1.2×10^{-9}	8.7×10^1	0	5.3×10^{-2}
	4	Magnesium Zones	3.0×10^{-7} - 9.0×10^{-7}	7.2×10^5	0	6.4×10^{-6}
Explorer VII	5	Mylar - CdS Cell	1.2×10^{-9}	3.9×10^1	1	1.2×10^{-1}
Explorer XIII	6	Stainless Steel	1.1×10^{-8} - 3.3×10^{-8}	3.4×10^4	0	1.4×10^{-4}
	7	Stainless Steel	8.8×10^{-8} - 2.6×10^{-7}	8.5×10^3	0	5.6×10^{-4}
	8	Wire Grids	2.0×10^{-7} - 6.0×10^{-7}	1.7×10^3	0	2.7×10^{-3}
	9	Wire Grids	6.7×10^{-8} - 1.8×10^{-7}	7.7×10^2	0	6.0×10^{-3}
Explorer I	10	Wire Grids	4.2×10^{-9} - 1.2×10^{-8}	3.6×10^3	0	1.3×10^{-3}
Explorer III	11	Wire Grids	4.2×10^{-9} - 1.2×10^{-8}	2.4×10^2	2	6.4×10^{-3}
Midas II	12	Wire Grids	4.2×10^{-9} - 1.5×10^{-8}	2.0×10^3	0	2.3×10^{-3}
Samos II	13	Wire Grids	4.2×10^{-9} - 1.5×10^{-8}	1.1×10^4	8	8.0×10^{-4}

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Figure 9. Average Influx Rates Computed from Penetration and Fracture Experiments on U. S. Satellites (Based on a probability of 0.99 of at least one impact)⁹

IV. DATA ANALYSIS

A. DIRECT MEASUREMENT ANALYSIS

All of the microphone data (Tables II, III, IV, and V) for the mass range of 10^{-10} to 10^{-7} grams have been compared to and analyzed in the light of the recent Explorer VIII results. The Explorer VIII data are especially significant in that they represent over 3600 events measured in an interval of 40 days and extend over 3 orders of magnitude in impact threshold sensitivity. The large number of events seems to provide sound statistical weight for the data points established in the ranges of highest sensitivity and thus predicts the shape of this segment of the cumulative mass distribution curve. The photomultiplier results, as a study of Table V and Figure 8 will indicate, allows a debatable extension of the curve of microphone data to $\sim 10^{-13}$ grams. In the same low range of mass (to 10^{-12} grams), the rocket collection experiments (Venus Flytrap), indicate a somewhat higher influx rate. This is attributed to a possible abundance of deaccelerated microparticles at the 80- to 150-km altitude range. It should be recognized that the results for particles in the range of low mass (10^{-10} to 10^{-13} grams) represent initial measurements which are more uncertain than the microphone data in the 10^{-10} to 10^{-7} range of mass.

Two characteristics of the direct measurement data used in establishing the cumulative mass distribution curve in the low mass range should be emphasized. First, the impact rates are corrected to omnidirectional values and scaled to a one-square-meter spherical surface area. Secondly, the curve represents data in the near-earth vicinity only and cannot be extrapolated to interplanetary regions with any degree of certainty, since secondary particle sources, such as the lunar injection system suggested by Whipple, cannot be completely discounted. Furthermore, a secondary particle source may warrant more careful examination as a possible source of the low density material predicted by the Trailblazer interpretation of the Harvard program data.

B. COMPARISON OF DATA

The extrapolation of meteor observation results (Figure 10) has, in the past, represented the primary method of estimating incident influx rates of micro-meteoroid material. The meteor observation tabulations of Watson, Whipple, and others followed the convenient constant mass-per-magnitude relationship,

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Figure 10. Cumulative Mass Distribution Curves

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thus rendering the extrapolation to smaller particles relatively easy. This extrapolation, totally without experimental verification, has had considerable usage in the past. It has even received preference over early direct measurement data in the range of mass in question and over contradictory results of other early experiments, notably those of Milman and Burland, and Hawkins and Upton.⁹ The disregard of early direct measurements was in part due to the meagerness of data and its early interpretation. Actually, two alternative interpretations were possible.⁹ They were:

- 1) The indicated mass distribution and spatial density of interplanetary dust particles differed significantly from the linear extrapolation of results from observation of meteor activity.
- 2) The direct measurements indicated the existence of a geocentric concentration of interplanetary particles.

Numerous theories were proposed to account for the geocentric concentration,¹⁰ thus establishing a degree of compatibility between the linear extrapolation data and direct measurements. It was not until the recent Explorer VIII microphone system data sample was obtained that quantitative arguments in favor of the first interpretation could be formulated. In view of the statistical significance of the Explorer VIII data and the apparent accord with other satellite data, it is this writer's feeling that the direct measurement data at least repudiate the linear extrapolation based on meteor data in the range of small particle mass and provides a more reliable foundation for future mass distribution estimates. Of course, arguments against complete reliance on satellite data are to be considered, since calibration technology of the instrumentation is not particularly well developed. The impulse delivered to the microphone system sensor as a dust-particle impact is almost certainly greater than the assumed impact-momentum of the particle, but remains unknown. The proper calibration factor probably lies between 2 and 3 times the momentum impulse transferred. Other factors, such as oblique impacts and earth shielding effects, can combine to cancel the presumed underestimated impulse delivery. Since all direct measurements have been interpreted in a consistent manner, we may assume that minor corrections in calibration will change only the position of the direct measurement data on the cumulative mass distribution curve without changing the shape, that is, the slope of the curve defined by these points. In as much as the primary point of contention is an extrapolation of meteor data, the

assumed calibration inadequacies fail to provide any basis for such an attempt with disregard for direct measurements. The same argument should apply to any extrapolation of the recent Trailblazer analysis revision of the Harvard data by Whipple et al.

C. PROPOSED DISTRIBUTION

It is difficult to disregard the preponderance of data in the respective ranges of applicability of either the satellite or telescopic and radio-echo measurement techniques. Each represents an arduous analysis by thoroughly competent individuals. It therefore seems reasonable that any estimate of the cumulative mass distribution curve must unite the opposing camps in their own range of measurement. A recent observation by Eshleman and Gallagher at Stanford University seems to provide a possible link.¹ Using radar measurement techniques, a small increase in count rate was detected near the fifteenth visual magnitude (Whipple 1957 scale) wherein a decrease might have been expected due to limiting instrument sensitivity. Assuming the effect to be real, a mass distribution estimate is proposed which consists of an extrapolation of direct measurement data to the fifteenth visual magnitude where the curve may join a constant mass-per-magnitude curve similar to Whipple's 1957 preferred curve, but at a lower influx rate. The curve labeled "proposed" in Figure 10 illustrates the proposed cumulative mass distribution. The constant mass-per-magnitude portion of the curve shifts the mass of a zero magnitude meteor to ~ 0.43 grams and in a rough estimate defines a meteoroid material density of ~ 0.34 grams per cc in this upper mass range. The density estimate is based on the assumption that the following quantities remain constant over the density and mass change indicated:

- 1) Energy required to obliterate one gram of material
- 2) Efficiency of the energy exchange
- 3) Fraction of energy converted to light.

V. SHOWER CONTRIBUTIONS

Figure 11 shows the variation of activity of the sporadic meteor background throughout the year for day and night periods and the peaks due to the major showers encountered. The effect of the showers is an increased influx rate for the duration of each shower. A convenient method of evaluation is to interpret the shower activity as equivalent increased exposure time to the normal sporadic background. This estimate, of course, introduces a degree of error in that it presupposes a shower mass distribution similar to the sporadic distribution and takes into account no particle velocity variation between individual showers. The data from Lovell tabulated in Table VII gives the time correction factors which may be applied depending upon the shower encounters anticipated.⁶

TABLE VII
METEOR SHOWER TIME CORRECTION FACTORS

	Arietids + Perseids	B - Taurids	Quadrantids	Perseids	Geminids	Others (primarily summer)
Number of days of activity	16	11	2	9	6	23
Average per day	12.1	2.2	31	6.3	23	6.1
Ratio: shower sporadic	3.9	0.7	10	2	7.2	2
Additional effective days	62.4	7.7	20	18	43.2	46

Average sporadic per day = 3.1

One year shower correction = 197.3 days

∴ One year effective exposure = 365 + 197 = 562 days

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Figure 11. Meteor Activity Throughout the Year for Day and Night Periods
(Radio-echo data)⁶

VI. METEOROID HAZARD EVALUATION

Evaluation of the meteoroid hazard divides itself naturally into two categories:

- a) Estimating the flux and physical properties of individual particles as a function of their mass and velocity
- b) Estimating the effects of a collision between meteoroid particles and the exposed target area.

This paper has been confined to the first of these categories, discussing meteoroid velocities, densities, and distributions. The second category will be defined here in a limited sense for purposes of illustrating the calculative methods involved in an assessment of the hazard presented by meteoroids.

One of several empirical relations generated by experimental data may be selected to illustrate penetration effects of high speed particles. As an illustration, we will use the NASA Ames penetration criteria as follows:¹¹

$$P = 4.25 \, m^{1/3} \, \rho_p^{1/3} \left(\frac{v}{\rho_t c} \right)^{2/3}$$

(modified for thin-sheet targets)

P = penetration

m = mass of incident particle (meteoroid)

ρ_p = density of incident particle

v = velocity of incident particle

ρ_t = density of target material

c = velocity of a longitudinal wave (sound) in the material.

The variables related to the incident particle may be deduced from the preceding discussion. The velocity of the particle as suggested by Whipple is mass-dependent, reaching a maximum value of ~ 28 km/sec. On the other hand, radio-echo determinations, which include shower contributions as well as sporadic, define a most probable velocity for direct orbit meteoroids as 35 to 40 km/sec. Since the radio-echo data sample includes only meteors more massive than the eighth magnitude, a most probable velocity less than 40 km/sec will be assumed on the basis of the Whipple findings relating meteoroid mass

and velocity. A reasonable value seems to be 30 km/sec, which is used in the interpretation of satellite data. As mentioned previously in this report, a reasonable density estimate is that of stone or ~ 3 grams/cc. All that remains, other than target-material properties, which may be selected to fit the situation, is an estimate of the maximum probable incident particle mass. In this matter, a meteoroid cumulative mass distribution curve defined in Figure 10 may be applied to armour considerations in the following manner:

- a) Define a Poisson probability for zero penetrating events as:

$$P(0) = e^{-\lambda A t}$$

where

λ = influx rate

A = effective exposed spherical area

t = time of exposure including shower correction.

- b) Solve for λ and determine the maximum probable mass for which armour must be defined from Figure 10. These calculations assume no earth shielding effects which are a function of the mean-orbital altitude.

Having defined the maximum probable mass to be encountered in any single event, we are now in a position to determine armour requirements which will effectively just deny penetration. The curves shown in Figures 12 and 13 were generated using the Ames criteria as a function of the incident particle mass for several target materials at room temperature and 1000°F respectively.

As an example of the preceding procedure, the armour requirements for the SNAP 8 LiH shield casing would be determined with the following parameters:

Actual target area = 17.75 ft²

Effective spherical area = 11.15 ft² = 1.04m² (See Appendix)

Orbital operation lifetime = 10⁴ hr = 3.6 x 10⁷ sec

Shower correction time = 197 days = 1.7 x 10⁷ sec

Effective exposure time = 5.3 x 10⁷ sec

Define a 0.95 Poisson probability of zero penetrating events.

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Figure 12. Stopping Mass vs Impacting Particle Mass for Certain Target Materials at Room Temperature

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 Figure 13. Stopping Mass vs Impacting Particle Mass for Certain
 Target Materials at 1000°F

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$$\therefore 0.95 = e^{-\lambda At}$$

$$\therefore \lambda = 9.32 \times 10^{-10} \text{ particle/m}^2\text{-sec}$$

$$\log \lambda = -9.03$$

In these sample calculations, the cumulative mass distribution curve labeled "Trailblazer" (Figure 10) will be adopted to determine the corresponding maximum probable incident particle mass. This curve satisfies the empirical equation:

$$\log \lambda = -1.34 \log m - 13.9$$

$$\therefore \log m = -3.66$$

$$\therefore m = 2.19 \times 10^{-4} \text{ grams}$$

The effective stopping mass can be determined from Figures 12 and 13. Assuming the casing to be made of steel, the stopping mass and depth of penetration are as follows:

<u>Temperature</u>	<u>Stopping Mass</u>	<u>Penetration</u>
70°F	2.20 gm/cc	110 mils
1000°F	2.85 gm/cc	143 mils

The stopping mass divided by the density of the target material gives the required armor thickness which will just deny penetration. This value does not take into account any spalling effects from the back surface.

VII. REFERENCES

1. V. R. Eshleman and P. G. Gallagher, "Radar Studies of 15th Magnitude Meteors," *Astronomical Journal*, Vol. 67, No. 5, June 1962
2. G. S. Hawkins, "Radar Determination of Meteor Orbits," *Astronomical Journal*, Vol. 67, No. 5, June 1962
3. G. S. Hawkins, "A Radio Echo Survey of Sporadic Meteor Radiants," *Astronautical Society Monthly*, Vol. 116, No. 1, 1956, pp 92-104
4. F. L. Whipple, "The Meteoritic Risk to Space Vehicles," Paper 499-57, *American Rocket Society*, 1957
5. F. G. Watson, "Between the Planets," *Harvard University Press*, 1956
6. A. C. B. Lovell, "Meteor Astronomy," *Oxford, Clarendon Press*, 1954
7. M. Alperin, M. Stearn, ed; "Vistas in Astronautics," *Pergamon Press*, 1958
8. D. B. Beard, "Interplanetary Dust Distribution," *Astrophysics Journal*, Vol. 129, No. 2, 1959, pp 496-506
9. W. M. Alexander, C. W. McCracken, L. Secretum, and O. E. Berg, "Review of Direct Measurements of Interplanetary Dust from Satellites and Probes," Paper presented at the COSPAR meeting, May 1962
10. F. L. Whipple, "The Earth's Dust Belt," VII Annual Meeting American Astronautical Society, Dallas, Texas, January 1961, Preprint (61-46)
11. J. L. Summers, "Investigation of High Speed Impact: Regions of Impact and Impact at Oblique Angles," *NASA TN-D-94*

VIII. BIBLIOGRAPHY

1. F. S. Johnson, "Satellite Environment Handbook," Stanford University Press, 1961
2. F. I. Ordway (ed.), "Space Science and Technology," Vol. 3, Academic Press, 1961
3. C. W. McCracken, W. M. Alexander, and M. Dubin, "Direct Measurements of Interplanetary Dust Particles in the Vicinity of Earth," NASA TN-D-1174, December 1961
4. W. M. Alexander, C. W. McCracken, and H. E. LaGow, "Interplanetary Dust Particles of Micron Size Probably Associated with the Leonid Meteor Stream," NASA TN-D-1154, December 1961
5. H. E. LaGow and W. M. Alexander, "Recent Direct Measurements of Satellites of Cosmic Dust in the Vicinity of the Earth," NASA TN-D-448, September 1960
6. E. H. Davison and P. C. Winslow, Jr., "Space Debris Hazard Evaluation," NASA TN-D-1105, December 1961
7. R. K. Soberman and L. D. Lucca, "Micrometeorite Measurements from the Midas II Satellite (1960)," GRD Research Note No. 72, November 1961
8. C. W. McCracken and W. M. Alexander, "The Distribution of Small Interplanetary Dust Particles in the Vicinity of Earth," Preprint of Paper to be published in 1962 in the series, Smithsonian Contributions to Astrophysics
9. W. J. Rae and H. P. Kuchnir, "Quarterly Progress Report on a Study of Meteoroid Impact Phenomenon," Cornell Aeronautical Laboratory Inc., Report No. RM-1655-M-1, Buffalo, New York, March 1962
10. R. L. Bjork and C. Gazley, Jr., "Estimated Damage to Space Vehicles by Meteoroids," U.S. Air Force Project Rand Research Memorandum RM-2332, February 20, 1959
11. G. S. Hawkins and R. B. Southworth, "The Statistics of Meteors in the Earth's Atmosphere," Smithsonian Contributions to Astrophysics, Vol. 2, No. 11, Washington, D. C., 1958
12. A. R. Hibbs, "The Distribution of Micrometeorites Near the Earth," Journal of Geophysical Research 66-371 (1961)
13. T. N. Nozarova, "Investigation of Meteoric Particles by the 3rd Soviet Satellite," ARS Journal, Vol. 31, No. 9, September 1961, pp 1341-1344
14. V. I. Krasowskii, "Results of Scientific Investigations Made by Soviet Sputnik and Cosmic Rockets," ARS Journal, Vol. 30, No. 1, January 1960, pp 27-33

15. C. R. Nysmith and J. L. Summers, "Preliminary Investigation of Impact on Multiple Sheet Structures and an Evaluation of the Meteoroid Hazard to Space Vehicles," NASA TN-D-1039
16. R. D. Collins, Jr. and W. H. Kinard, "The Dependency of Penetration on the Momentum per Unit Area of the Impacting Projectile and the Resistance of Materials to Penetration," NASA TD-D-238
17. R. L. Bjork, "Meteoroids Versus Space Vehicles," Paper presented at American Rocket Society Semi-Annual Meeting, Los Angeles, California, May 9-12, 1960, Rand Corporation P-1963, April 4, 1960
18. T. W. Nozorova, "The Results of Studies of Meteoric Dust by Means of Sputnik III and Space Rockets," Proceedings of the First International Space Science Symposium, Nice, January 11-16, 1960, edited by Brjl, North Holland Pub. Co., Amsterdam, 1960
19. M. Dubin, "IGY Micro-Meteorite Measurements," Space Research, Proceedings of the First International Space Science Symposium, Nice, January 11-16, 1960, edited by Brjl, North Holland, Pub. Co., Amsterdam, 1960
20. F. L. Whipple, "Photographic Meteor Orbits and Their Distribution in Space," Astronomical Journal, Vol. 59, p 201, 1954
21. G. S. Hawkins and E. K. L. Upton, "The Influx Rate of Meteors in the Earth's Atmosphere," Astrophysical Journal, Vol. 128, p 727, 1958
22. Letter; Dr. Allen F. Cook, Smithsonian Astrophysical Observatory, to S. Lieblein, NASA Lewis Research Center, November 1, 1962

APPENDIX
GEOMETRY CORRECTION VIEW FACTOR
(R. T. LANCET – C. R. HARDER)

Total flux incident on a body = F_t

$$F_t = \sum_0^n F_{\alpha_i \theta_j} A_{p \alpha_i \theta_j} \quad n \rightarrow \infty$$

$A_{p \alpha_i \theta_j}$ = projected area normal to flux

$F_{\alpha_i \theta_j}$ = unidirectional flux defined by α_i , θ_j per unit area.

Assuming flux constant from all radiant points, then

$$F_{\alpha_i \theta_j} = F_{\alpha_j \theta_i} \text{ etc. } = F$$

$$\therefore F_t = F \sum_0^n A_{p \alpha_i \theta_j}$$

multiply and divide by (n)

$$F_t = nF \sum_0^n \frac{A_{p \alpha_i \theta_j}}{n} \quad \dots (1)$$

but

$$\sum_0^n \frac{A_{p \alpha_i \theta_j}}{n} = \bar{A}_p = \text{average projected area.}$$

$$\therefore F_t = nF \bar{A}_p$$

Must define nF . Determine F_t for sphere from Equation 1

$$\therefore F_t = nF \pi r^2$$

determine for unit area of sphere.

$$\frac{F_t}{A_{\text{sphere}}} = \lambda = \frac{nF \pi r^2}{4 \pi r^2} = \frac{nF}{4}$$

λ = quantity defined in meteoroid data, i.e., particles/m²-sec on a spherical surface.

$$\therefore F_t = 4 \lambda \bar{A}_p \quad \dots (2)$$

Now define a view factor V_f as:

$$F_t = \lambda A V_f \quad \dots (3)$$

where $A V_f$ defines the equivalent spherical area of a body.

Combining Equations 2 and 3

$$4 \lambda \bar{A}_p = \lambda A V_f$$

$$\therefore V_f = \frac{4 \bar{A}_p}{A} = \frac{\bar{A}_p}{A/4}$$

A = true area of body. May form sphere of equal surface area. Then $A/4$ = projection of sphere or a circular surface = A_{p_s}

$$\therefore V_f = \frac{\bar{A}_p}{A_{p_s}}$$