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one of the most interesting newcomers in the field, has appeared in this magazine previously and had a story in Fredrik Pohl's STAR SCIENCE FICTION NO. 5.

AUGUST DERLETH —

equally prominent in the mystery field as the creator of the inimitable Solar Pons pastiches, is of course the author of some superb material in the Lovecraft tradition.

GORDON R. DICKSON —

appears only once in Don Day's monumental Index to the SF magazines 1926-'50. Since then, he has appeared in every magazine in the field and is the author of several novels.

JOHN BRUNNER —

prominent British SF and fantasy writer and novelist, makes one of his rare appearances in this haunting story about the adventures of Gerald Howson, Psi.D., Curative Telepath First Class, W.H.O. The sequel will appear next month.

LESTER DEL REY —

needs no introduction to any reader of SF and fantasy.

WENZELL BROWN —

author of more than twenty novels about contemporary matters makes, we believe, a first appearance in the field with this article.

Dr. LESLIE R. SHEPHERD —

distinguished British physicist and space-travel authority, writes on SPACE PHYSICS in an article published here through the courtesy of Mr. Sam Moskowitz, former editor of SCIENCE FICTION PLUS.

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PHYSICS OF SPACE

by LESLIE R. SHEPHERD, Ph.D.

RECENT advances in the field of rocket propulsion have brought nearer the possibility of flight above the Earth's atmosphere. Few people doubt now that this will lead eventually to the successful accomplishment of interplanetary travel. It is not easy to predict how far we are from this ultimate achievement, but we can say that flight into space is possible today, since we already have vehicles capable of penetrating far into the void.

The space between the planets is a vacuum, several million times more tenuous than the best we have been able to produce in the laboratory. Flight in this environment will introduce a host of new problems, partly from the extreme variations in conditions from one point to another, but mainly from the absence of a protective envelope of air. Some of these problems are chemical and biological, such as that of providing and maintaining a breathable atmos-

phere inside a vehicle. Others are matters of physics—problems connected with heat balance, cosmic radiation, solar radiations, and meteors. It is to these that we shall give our attention here, beginning with the problem of maintaining a correct heat balance inside a space vehicle. An appreciation of the nature of this problem can be obtained by studying the exchange of heat to and from bodies isolated in a vacuum.

The Temperature Of objects in Space

THE TEMPERATURE of an object at some fixed position in our solar system is not a unique quantity. It depends upon the nature of the surface of that object, its size, shape, and even its *attitude*. Indeed, these factors can make considerable difference in temperature, so much so that one object placed at Jupiter's orbit might reach a higher temperature than another at the orbit of Mercury.

An object in space can gain or lose heat only by the absorption or emission of electromagnetic radiation. The sun itself emits radiation of widely varying wavelengths, ranging from one hundred-millionth of a centimeter (low energy X-rays), up to many hundreds of meters (radio waves). A high proportion of this radiation lies in the visible spectrum with wavelengths between 0.38 and 0.76 microns, (10,000 microns = 1 centimeter), the maximum intensity lying at 0.47 microns and only a small proportion being emitted above 1.5 microns or below 0.25 microns.

All objects radiate electromagnetic energy with a continuous spread of wavelengths. The hotter the object, the shorter the wavelengths. Thus, while the sun at 6,000° K* emits with maximum intensity at 0.47 microns the maximum intensity from a good emitter at 6,00° K occurs at 4.7 microns (the two quantities are inversely proportional).

The rate of emission of radiation depends very sharply on the surface temperature of the object. Radiation from a perfect emitter varies as the fourth power of the temperature, a tenfold increase in the absolute temperature resulting in a ten-thousandfold increase in the rate of radiation. A perfect emitting surface at 1,000° K emits 5.7 watts per square centimeter.

Not only temperature, but also the nature of a surface determines the rate of emission of radiation. The ability of a surface to emit radiation of a given wavelength is proportional to its power to absorb that radiation. The perfect emitter is a body which is completely absorbent to radiation of all wavelengths. Such a body looks black, of course, and is consequently called a black body. The emissivity of a surface measures its ability to emit radiation in com-

parison with a black body. Thus a surface with an emissivity of 0.5 emits radiation at only half the rate of a black body, at the same temperature and with equal area. Generally speaking, the emissivities of surfaces are temperature dependent; emission is consequently not exactly proportional to the fourth power of the temperature.

Surfaces can be roughly divided into three classes. In the first class are those which *absorb and emit radiation almost perfectly*, over a wide range of wavelengths, so that they can be considered to be black bodies. The soot deposited from burning camphor or acetylene comes nearest to providing such surfaces. In the second class are surfaces which absorb and emit low wavelengths more readily than long wavelengths. Polished metal surfaces come into this class; silver for example, absorbs about 7% of solar radiation, but at low temperature (long wavelengths) emits only 2% as much radiation as a black body. The extreme example is polished zinc, which absorbs 55% of solar radiation but has only 5% of black body emission at low temperatures. Finally, there are surfaces which absorb and emit long wavelength radiation more readily than they emit short wavelengths. In this class are metal oxides, pigments, and most paints. White metal oxides, in particular, are very poor absorbers of solar radiation (magnesium oxide surfaces can be made which absorb only 2%), but on the other hand, they approach black body performance in the emission of heat at low temperatures. Zinc oxide for example, has 95% of the ideal black body emission at low temperatures but absorbs only 15% of solar radiation.

If the three types of surface were exposed to the sun's radiation in space, the polished metal surfaces would reach the highest tempera-

*The absolute zero of temperature is - 273° centigrade. This is 0° K. To convert temperatures from Kelvin to centigrade, add 273.

tures, the oxide or pigment surfaces the lowest temperatures, the black body surface falling somewhere between (see page 72). This appears, perhaps, to be a surprising result to those who have been accustomed to thinking of polished metal surfaces as best for maintaining low temperatures inside spaceships venturing near the sun. *The temperature is determined, in fact, not by the ability of a surface to absorb the sun's radiation, but how this compares with its ability to re-emit this radiation at low temperatures.*

The equilibrium temperature of a surface exposed to the sun also depends upon its *orientation*. A surface at right-angles to the sun's rays will intercept more radiation than an identical surface inclined to these rays, and one lying parallel to the rays, intercepts scarcely any radiation, and would tend to go to a very low temperature. The total surface area of a sphere, is four times its greatest cross-section, so the average equilibrium temperature of a sphere would be lower than that of a flat plate of identical surface properties, set at right-angles to the sun's rays.

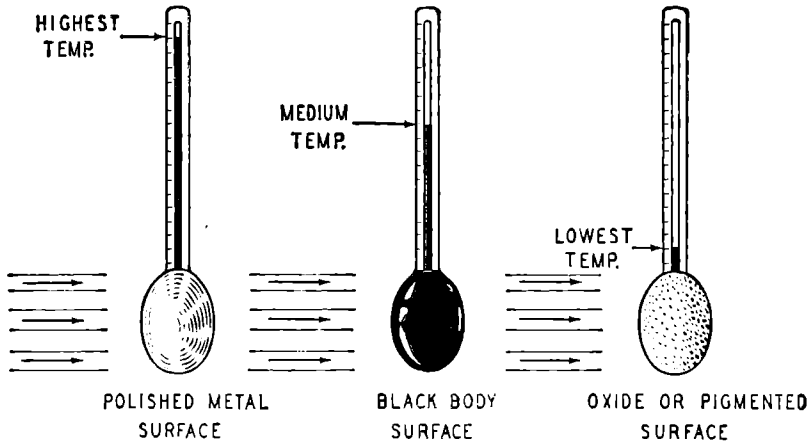
The determination of *equilibrium temperature* in the case of a flat surface is very simple. At the Earth's

orbit, 15 million kilometers from the sun, a surface set at right-angles to the rays receives solar energy at the rate of 0.15 watts per square centimeter (at Mercury's orbit it is 1 watt per square centimeter and at Pluto only one twelve-thousandth of a watt). Supposing that the surface is a black body, and that it may re-radiate only on the exposed side (the other side assumed to be covered by a perfect heat insulator), then it will absorb all of the solar heat. *At equilibrium it must radiate energy at the same rate.* The temperature at which a black body emits 0.15 watts per square centimeter is 127° centigrade, so this is the equilibrium temperature of a single-sided black body surface at the Earth's orbit. The corresponding value for a polished zinc surface is 460° C., and that for a zinc oxide surface is -22° C. *The zinc surface would actually melt.*

A case of some interest is that of a spherical spaceship, in which the surface is kept at the same temperature all over, by circulating a *heat-transfer* fluid round the walls to convey heat from those regions receiving direct sunlight to those parts which are in the shadow (see p. 72) The equilibrium temperatures for

Position in Space	Solar Energy (watts per square meter)	Temperature in degrees Centigrade		
		Sphere 1	Sphere 2	Sphere 3
Mercury	10.000	183	13	561
Venus	2.900	65	-62	345
Earth	1.500	10	-95	246
Mars	650	-41	-127	152
Jupiter	55	-149	-195	-45
Saturn	16	-162	-216	-106
Pluto	0.8	-230	-246	-193

The higher figures in column 3 may be rather inaccurate because of increase in emissivity with temperature. The table shows that a comfortable temperature at the Earth's orbit is obtained in a black sphere; at Mercury's orbit in the zinc-oxide-coated sphere; and somewhere in the asteroid belt in the polished zinc sphere.

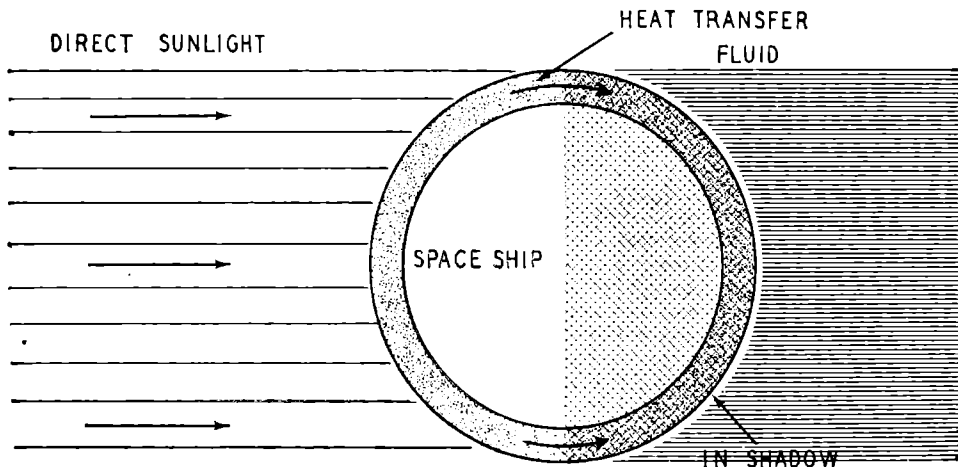


such spheres at various points in the solar system are given in the following table. Three types of surface are considered, sphere 1 being a black body, sphere 2 a zinc oxide coated surface, and sphere 3 a polished zinc surface. It is assumed that *no heat is generated inside the vehicle.*

The heat received by a vehicle in the shadow of the Earth is a point of some interest. Assuming an average surface temperature of 280°K , and an emissivity of 0.5, the average heat flux just above the atmosphere would be 170 watts per square centimeter (comparable to the solar heat in the asteroid belt). A one-sided surface exposed to this heat would reach an equilibrium temperature of -45°C . The nature of the surface

would be unimportant in this case, because the distribution of wavelengths in the incident and emitted radiation is about the same.

So far only external heating, by the sun, has been considered. In a space vehicle there inevitably would be sources of heat (waste heat from power plants, etc.), which might have a considerable influence on the temperature. All waste heat would be conducted eventually to the walls, unless it were excessive, in which case it would have to go to special radiating fins. Surprisingly little heat would be required to maintain a comfortable temperature inside a spaceship, even out in interstellar space where the heat received from the sun and stars would be negligible.



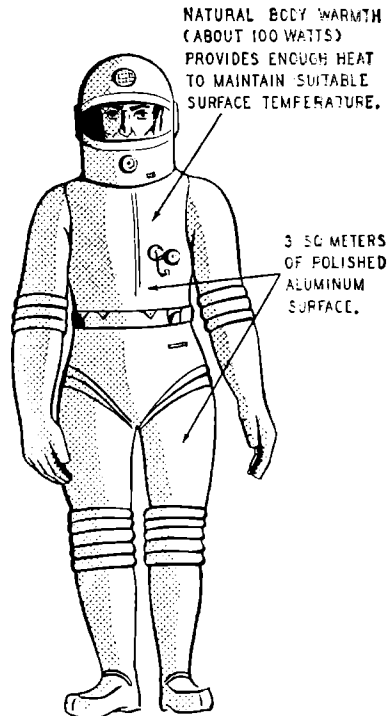
A polished silver surface with an emissivity of .02 would lose heat at the rate of only 9 watts per square meter at 20° C. With such a surface, a sphere of 10 meters radius would need only about 11 kilowatts to maintain a pleasant internal temperature. About 50 kilowatts would be required in the case of polished aluminium walls (emissivity .08).

It is interesting to note that a man in a spacesuit having about 3 square meters of polished aluminium surface would feel comfortably warm in deep interstellar space. His natural bodily warmth (about 100 watts) would provide enough heat to maintain a satisfactory surface temperature (see page 73).

Very high-power sources inside space vehicles would probably be a considerable embarrassment. A great deal of the power would eventually appear as heat, which could be dissipated only by radiation. Such a power plant might be part of a propulsion system, like an ion-rocket, in which the waste heat might be hundreds of megawatts. 100 megawatts of heat would require large radiated fins, about 2,000 square meters of black surface at 1,000° K, for example, or 400 square meters at 1,500° K. It appears likely that spaceships will be rather luminous objects.

The Effect of Meteoric Material

The density of solid meteoric material in space, in the vicinity of the Earth, is about 10^{-23} grams per cubic centimeter. This is distributed in a wide range of sizes, from huge chunks of rock and iron, down to microscopic particles with masses of about 10^{16} grams (one-ten-million-millionth of a gram). Lower mass particles cannot orbit around the sun, because the pressure exerted by sunlight falling on them is sufficient to push them out of the solar system. The size distribution of meteors is



such, that there are *ten* times as many between 1 and 10 grams as there are between 10 and 100 grams, and *ten* times as many between 0.1 gram and 1 gram as between 1 and 10 grams, and so on.

The number of meteors with mass greater than *one* gram which enter the Earth's atmosphere in the course of a day is only about 200,000. *It is easy to see from this that it is about two million to one against a meteor heavier than one gram hitting a spherical vehicle of ten meters radius.* The chances are *two thousand to one* for meteors down to *one* milligram, and only *two to one* against a collision with a meteor of a microgram or more. The really microscopic particles in the region of 10^{-16} grams would bombard the vehicle at a rate of millions per day.

The worst effect to be expected from the continuous bombardment by minute meteors would be a very gradual deterioration of polished surfaces. More serious consequences would result from the fairly rare col-

lisions with particles in the range of 1 to 10 milligrams, although the average frequency of such collisions would be several years. Iron meteors in this mass range would have diameters in the region of a millimeter. The range of meteor velocities would depend upon the position and the velocity of the vehicle. If it were moving in the vicinity of the Earth at a low relative speed, then the maximum meteor velocity would be about 70 kilometers per second.

Grimminger has attempted to derive formulae for the penetration of meteors into stainless steel and dural. He assumed that meteors behaved like solid spheres and the target behaved like a dense compressible fluid. On this basis one finds that an iron meteor of mass 1 milligram, moving at 70 kilometers per second, would penetrate to a depth of 3 millimeters in steel and about 1 centimeter in dural.

Grimminger's assumption that the steel or dural wall would behave like a fluid is a natural consequence of the high stresses set up in the material by the impact. These would be so great that all materials, no matter what their tensile strength, would flow freely like liquids. However, this would apply equally to the meteor itself, which would behave therefore like a drop of liquid, rather than a solid sphere. On striking the wall, the drop would spread laterally as it penetrated. Momentarily, there would exist, in the region of the impact, a fluid mixture of meteor and wall, with terrific internal pressure. This pressure can be calculated easily from simple hydrodynamics. It would exceed 10,000,000 times atmospheric pressure, in the case of the very fast meteors. Obviously a fluid under such high pressure would explode outwards. Some of the fluid would be driven further into the wall, until the strength of the material took a hand and prevented fur-

ther flow. Most of the fluid would be blown back out, since there would be little to resist it in that direction. This would actually reduce the damage which the meteor might otherwise cause. The net result of the impact would be in fact a crater whose depth and radius, at the most, would be not much greater than the diameter of the meteor in the case of strong materials. The amount of the material excavated would be roughly proportional to the energy imparted by the meteor, and it would be smaller in materials with high tensile strength than in those with low strength.

This picture is quite different from that given by Grimminger and we may well doubt the validity of his penetration formulae. On the whole, one would expect Grimminger's theory to overestimate the depths of penetration and underestimate the lateral damage.

Whipple has suggested the use of thin sheets of material surrounding the walls of space vehicles, to act as *meteor bumpers*. The meteor and the region of the bumper where it strikes would be converted into a fluid at high pressure, which would then explode outward both from the *front and rear of the bumper*, leaving a considerable hole. However, when the exploding envelope reached the true wall of the vehicle, it would do no serious damage other than to heat up the surface (see page 75).

An interesting result of the presence of the meteoric matter in the solar system is its effect in scattering the light from the sun. The zodiacal light seen after sunset and the counter-glow in the night sky are believed to result from the reflection of sunlight from meteors. *If this is the case, then space would not appear black to the voyager in the inner region of the solar system.* Anywhere inside the orbit of Mars there would be an appreciable background glow.

Radiations Presenting a Possible Hazard

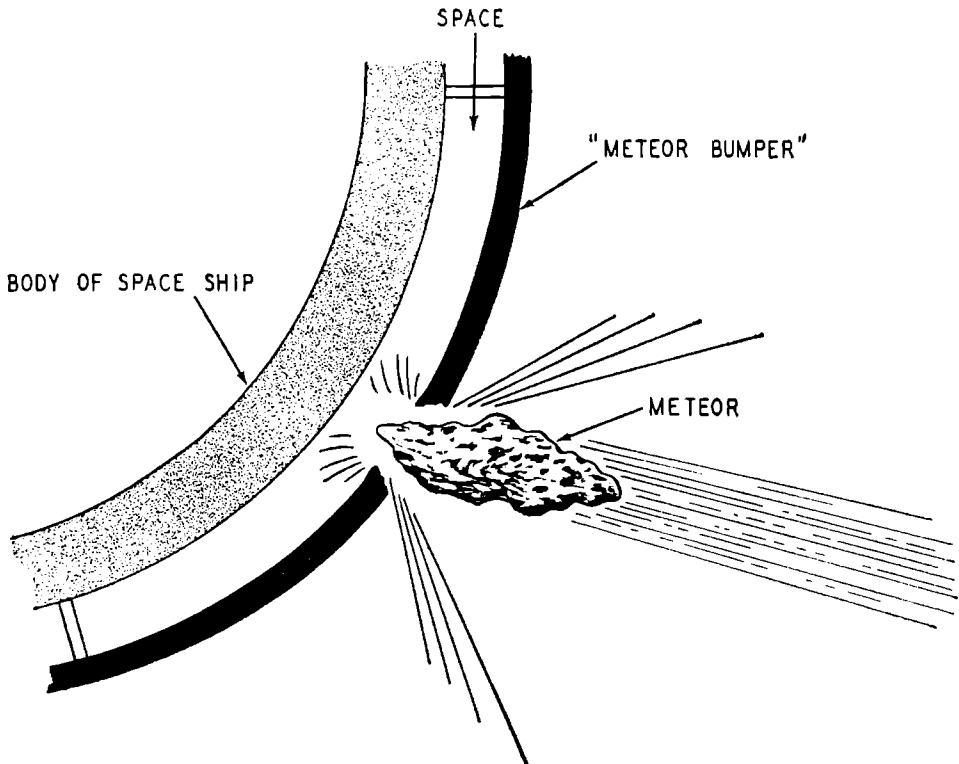
Ultraviolet radiations with wavelengths down to about 0.12 micron and X-rays of about .001 micron have been identified by means of instruments carried in V2 rockets. These radiations are absorbed in the upper reaches of our atmosphere at heights of about 100 Kms. The X-rays do not actually come from the sun itself, but from the solar corona, a band of very tenuous material extending outward for a million miles or more from the sun. The effective temperature of the gaseous part of the corona is believed to be about one million degrees centigrade. The ability of the corona to emit X-rays is due to this very high temperature and the consequent high degree of ionization existing in the gases of the Corona.

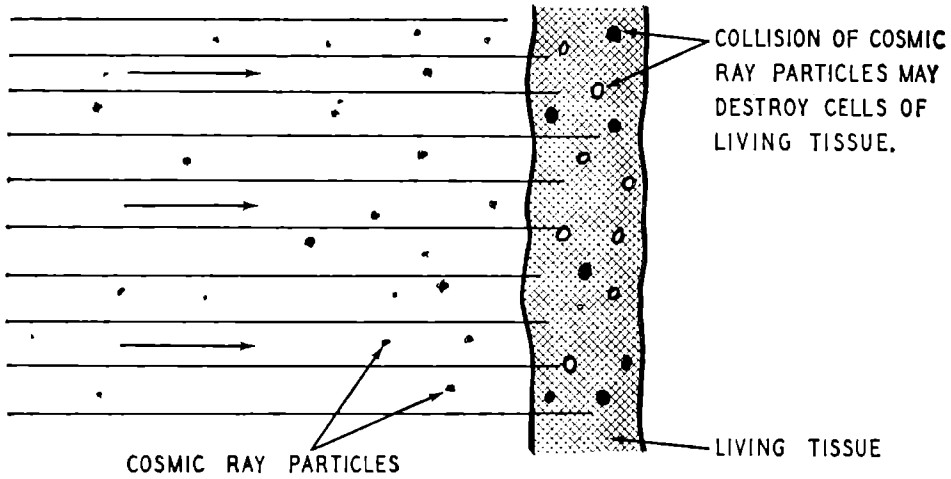
Soft X-rays and ultraviolet radiation can cause serious damage to the skin of people exposed to them,

though the depth of penetration into the body is very small. Acute sunburn is caused by ultraviolet radiation below about 0.32 micron. Very little of this radiation and none below 0.28 micron can reach the surface of the Earth.

Fortunately, all these radiations are easily absorbed. A very thin wall of steel would absorb the radiation entirely, while ordinary glass is opaque to all the solar rays below about .34 micron. Quartz, on the other hand, is transparent down to about 0.17 micron and is therefore unsuitable.

One important effect of the ultraviolet and X-radiation, is its action upon glass windows in space vehicles. Haber has pointed this out. The effect has been known for many years in connection with the use of glass vessels and windows, with highly radioactive materials. The absorption of ionizing radiation in





many transparent materials leads to the formation of color centers, gradually resulting in loss in light transmission. Over a period of 1 year the change in transmission, due to the solar X-rays alone, would be quite marked. This effect is easily overcome, however. The addition of cerium oxides in small concentrations inhibits the formation of color centers and reduces coloration by factors up to 10,000. Alternatively, the use of plastics might be considered. Lucite, for example, appears to be about 1,000 times as resistant to coloration as is glass.

A more difficult problem is undoubtedly that set by cosmic radiation, which is made up of a representative sample of the atomic nuclei of the Universe, moving at truly remarkable velocities, *mostly greater than 90% of the speed of light*. If we measured the flux of these rays at a small distance from the Earth, yet sufficiently far to be out of the Earth's magnetic field, we should find that about two particles crossed an area of *one* square centimeter every second. About 80% of these particles would be protons; 19% alpha-particles (helium nuclei), and the remaining 1% nuclei of carbon, nitrogen, oxygen, and various elements up to iron. Probably still heavier

nuclei are present, but in such small proportions that measurements have not so far proved their existence.

These nuclei carry high electrical charges since they are atoms stripped of the extra nuclear electrons. When they pass through matter they exert strong forces on the electrons in that matter and pull them out of their atoms, leaving behind a trail of charged atoms and loose electrons (referred to as ions). The density of the ionization along the track of the particle depends upon the velocity of the particle and its electric charge. It is a minimum when the particle is moving at 0.97 times the velocity of light, and increases very rapidly as it slows down. A proton at 0.97 C produces 30,000 pairs of ions per centimeter in moving through water; a helium nucleus at the same speed produces 120,000 pairs per centimeter; while a charged iron nucleus produces 20 million pairs per centimeter.

Another effect produced by cosmic radiation involves a very energetic nuclear explosion which results when a cosmic ray particle collides with an atomic nucleus in the material through which it travels. Most cosmic-ray particles end their career in this manner when they penetrate matter. If we attempted to absorb these cosmic particles in steel, we

should find that a proton moved on an average about 15 centimeters before making a collision, a helium nucleus about 11 centimeters and an iron nucleus about 5 centimeters. The main consequence of these nuclear explosions is that high-energy protons, neutrons, and mesons are knocked out of the nucleus, and these in turn can produce fresh explosions when they too make nuclear collisions. The result is that, although the number of original cosmic-ray particles decreases steadily the further they penetrate into the target material, the number of nuclear explosions actually increases at first and then falls off rather slowly. Thus, although we could absorb most of the heavier cosmic-ray particles by interposing 10 centimeters of steel, a worthwhile reduction in the rate of nuclear explosions would require much greater thicknesses of material.

The nuclear explosions produce, in addition to high-energy fragments, also medium-and low-energy alpha particles, protons, deuterons, and tritons. These, because of their low velocity, produce very dense ionization along their tracks.

The importance of cosmic rays in space flight lies in their possible biological effect. The ionization produced along the tracks of these particles can cause damage to the cells

which make up living tissue, and thereby lead to their destruction. The effectiveness of this ionization in producing cell destruction depends upon its density along the particle tracks. The consequence of this is that the most serious contribution to biological damage caused by cosmic rays, will come from the heavier particles (the nuclei ranging from carbon up to iron) on the one hand and the nuclear explosions on the other. The contributions from the two appear to be about equal.

Calculations indicate that cosmic rays present a borderline hazard. Exposures, measured in days or even weeks, should lead to no serious consequences, but periods of about a year in space might result in excessive damage to the human tissues. In that case some shielding would be necessary to reduce the heavy cosmic-ray primaries and the nuclear explosions. The latter in particular might require excessive thicknesses of material to effect worth-while reductions. *Materials of low atomic weight are, mass for mass, more effective than high atomic weight materials for this purpose.* If such shielding were necessary, one would attempt to utilize some useful material such as essential fuel or water supplies, which of course would be carried along anyway.