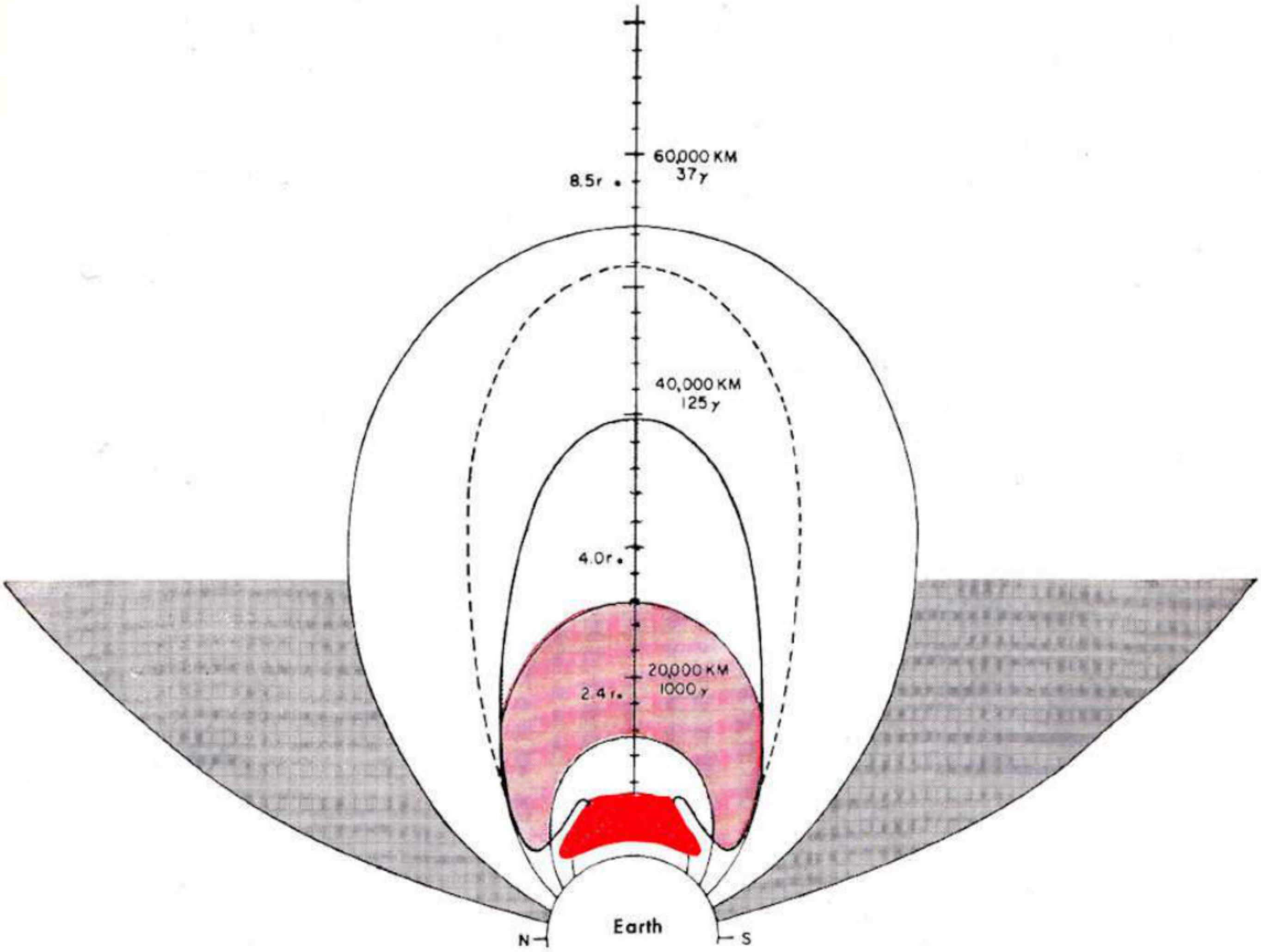


# THE DANGER ZONE

## *Earth is wrapped in deadly belts of radiation*


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The principal aim of this article is to discuss the current state of knowledge of the energetic particles which have been found to be trapped in the magnetic field of the earth. These trapped particles are of overwhelming biological importance for manned space flight. Moreover, it is a reasonable presumption that corresponding radiation belts exist around all other magnetized celestial bodies of (at least) our solar system, including the sun itself. Recent observations show that radio noise emissions from Jupiter are strongly polarized and are most plausibly interpreted as meaning that Jupiter has magnetically trapped radiation of very much greater intensity and of very much higher electron energy than that of the earth. The tentative evidence for auroral emissions from Venus suggests similar phenomena there. Hence, the earth's radiation belts may well constitute the accessible prototype of a quite general astronomical phenomenon.

By means of equipment prepared by myself and students at the State University of Iowa and flown in U.S. satellites Explorer I and Explorer III, it was found that an immense region around the earth is occupied by a very high intensity of charged particles (protons and electrons), temporarily trapped in the geomagnetic field. Detailed experimental and theoretical study of this radiation has become a major field of investigation during the past two years by workers in the United States and in the Soviet Union. Although knowledge of the trapped radiation is still incomplete, substantial progress has been made in observing and interpreting

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ble to the astronaut because of the absence of light-scattering gaseous matter. He will become aware of them only when he is moving through them in which case the sun is blocked out of the black sky. This is satellite night—an abrupt transition from bright sunshine to black darkness as was experienced by both Gagarin and Titov in their orbital flights.

The satellite night is always shorter than the satellite day. At our standard orbit, for example, night lasts only 33 minutes as compared with 61 minutes of daylight. Moving through the penumbrae represents dusk and dawn for the satellite occupants and lasts only several minutes at our orbital attitude. But there are, of course, many variations in the duration of the phases of the satellite day-night cycle, dependent upon the inclination of the orbit to earth's equator. This day-night cycle situation requires artificial day-night cycling of the astronaut's phases of sleep, rest, and activity, which will also be greatly influenced by the state of weightlessness.

These are some of the novel environmental conditions that will affect just two of man's senses when he ventures into them. Space, of course, is an environment that we are just beginning to understand. Much more remains to be learned before we can fully understand the relationship of the human organism to this alien environment. ■ ■

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this newly discovered phenomenon.

### Nature Of Trapped Radiation

It is now established beyond all reasonable doubt that this observed radiation consists of charged particles trapped in the earth's magnetic field in the manner visualized by Poincaré, Störmer, and Alfvén in classical theoretical studies of the motion of charged particles in a static dipole magnetic field. The nature of the particles and their detailed energy spectra are much more difficult to establish conclusively.

On the grounds of their universality in nature it is reasonable to suppose that electrons are present. Moreover, among the many nuclear possibilities, protons are likely to predominate because of the preponderance of hydrogen as an atomic constituent of matter.

The simplest working hypothesis, then, is that the trapped radiation consists of electrons and protons. If this be granted, then the problem becomes one of measuring the absolute differential energy spectrum of each of the two components as a function of position, direction, and time.

It is immediately evident from the extensive Explorer IV observations that there is no simple universal answer to the above problem. The composition of the radiation and its intensity are strong functions of position in space, of direction, and of time. A thoroughly satisfactory study of the problem is still not available.

Meanwhile, the presently available observations (obtained with relatively rudimentary equipment, by laboratory standards) have served to provide a good reconnaissance of the nature of the trapped radiation. Indeed, it is my opinion that the present state of knowledge is such that the full determination of the nature of the radiation, when finally available, will be interesting and valuable but probably not markedly different than that sketched here:

1. The observations with the diversity of detectors carried by Explorer IV, Sputnik III, Pioneer IV, and Lunik I demonstrate conclusively that the nature of the radiation (i.e., its composition and the energy spectra of its components) in the inner zone is quite different from that in the outer zone—more different, that is, than the nature of the radiation in different positions within either one of the two zones considered separately.

2. The integral range spectrum of the radiation in the inner zone falls rapidly (though not precipitously).

On the basis of crude range and specific ionization measurements in Explorer IV, the more-penetrating component is tentatively identified as consisting of protons having energies of the order of magnitude of 100 Mev.* The less-penetrating radiation is quite likely electrons having energies up to about 1 Mev. and having a spectrum rising strongly (though not so rapidly as that of the auroral soft radiation) toward lower energies.

3. The outer zone has a quite different nature. All evidence is consistent with an exclusive electron content, in so far as the characteristics of detectors used thus far permit observations. The energy spectrum apparently resembles that of the auroral soft radiation—rising sharply toward low energies from a practical upper limit of several hundred kilovolts.

4. The inner zone is relatively stable as a function of time during the period of available observations, though occasional fluctuations have been observed.

5. There are marked temporal fluctuations in the "slot" between the two zones, and fluctuations of very great magnitude in both intensity and spatial structure in the outer zone. These fluctuations are apparently associated with solar activity.

With equipment shielded in about the manner that ordinary, minimum structural considerations for space vehicles would dictate, exposure levels of some 20 r/hr** have been observed in the heart of the inner zone; and exposures of several times this level, in the heart of the outer zone.

The radiation level in the inner zone is only mildly reduced by 4 g/cm$^2$ of lead. But the radiation level in the outer zone is reduced by a factor of at least 500 by the same lead shield (Pioneer IV).

* 1/10,000 of a volt.

** Roentgens per hour.

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Of course, the exposure levels on the exposed skin of a space vehicle are many times as great, especially in the outer zone.

Within the approximate geographic latitude range 40°N to 40°S and for all longitudes the trapped radiation appears to be of negligible intensity below an altitude of about 400 km. Hence the radiation hazard in prolonged flights of man and animals within this region is simply that due to the ordinary cosmic radiation.

It is of interest to remark that the relative absence of trapped radiation below 400 km is due to the relatively high atmospheric density there (i.e., compared to that at, say, 2000 km). The increasing atmospheric density at lower altitudes does, of course, limit the flight lifetime of satellites because of air drag.

However, flight lifetimes of several years are possible if the altitude of perigee is greater than approximately 250 km. The combination of the two criteria just mentioned leads to the suggestion that nearby space stations which are to be operated and inhabited by man for periods of several years should have a perigee altitude greater than 250 km and an apogee altitude less than 400 km.

It appears prudent to use orbital inclinations not greater than 40° to the earth's equatorial plane. Orbits of higher inclination are subject to the considerably enhanced leakage (or precipitation) of trapped radiation down to low altitudes in the auroral zones.* Usually the auroral radiation is easily shielded (1 mm of lead), but there are sporadic bursts of more penetrating radiation of substantial intensity. Overall, the biological risk to man is probably not great; but present evidence suggests that this risk should not be accepted unless there are compelling reasons for orbits of high inclination. Meanwhile, it is of importance to extend radiation observations to high latitudes with low- and high-altitude satellites.

The exposure level in the heart of the inner zone is about 20 r/hr within a shield of 1 g/cm$^2$ of iron. Owing to the great penetrability of the high-energy protons therein, effective shielding is quite beyond engineering feasibility in the near future. Hence, the inner zone must be classed as an uninhabitable region of space as far as man is concerned.

A nearly circular satellite orbit having a period of 24 hours has a radius of about 6.6 earth radii. As shown by Pioneer IV observations, such an orbit may be expected to be engulfed, from time to time, by very intense radiation, and, of course, enormously greater exposures on the outer skin. The energetic portion of the radiation appears to consist mainly of electrons which can be absorbed in a low-Z* material.

Perhaps the more usual geophysical situation is represented not by that encountered by Pioneer IV (March 3, 1959) subsequent to an intense solar outburst in latter February, 1959, but by that encountered by Pioneer I on October 11, 1958, by Pioneer III on December 6 and 7, 1958, and by Lunik I on January 2, 1959. In these cases, the intensity at 6.6 earth radii was down from its peak value (at about 3.5 earth radii) by a factor of over 500. Nonetheless, very great fluctuations may be expected in the outer reaches of the earth's magnetic field.

Present evidence suggests that satellite orbits having their perigees at more than 15 earth radii from the center of the earth are subject to a negligible intensity of trapped radiation, though there is speculation that the bursts of solar plasma which pass outward through the solar system may contain sufficiently energetic particles to constitute a significant, though perhaps short-term, radiation hazard. The interplanetary observations with Pioneer III, Pioneer IV, Lunik I, and Pioneer V are contrary to this line of speculation but do, of course, constitute a meager temporal coverage of the matter. At present, it appears more probable that the trapped particles gain most of their observed energy in accelerative processes associated with the geomagnetic field. But the question is still moot and will be settled only by prolonged radiation measurements in interplanetary space, remote from the earth.

Consideration will now be given to space missions involving prompt escape from the earth. With Pioneer IV as an example, the trapping region can be completely traversed in about 6 hours with some 2 hours being spent in the high-intensity region. Hence the cumulative dosage on a trajectory of this nature would be of the order of 10 r in a lightly shielded craft (1 g/cm$^2$.) In any case it appears wise to evade the inner zone, and this is not difficult to do, since its latitudinal and radial extent is limited.

The outer zone is much more difficult to avoid. There do appear to be "cones of escape" over the north and south geomagnetic poles. The half-angle of these outward-opening cones is about 20°. The detailed nature of these cones has not yet been examined by direct observations.

The Argus experiments have demonstrated that a quite high radiation intensity of trapped, high-energy electrons can be produced artificially in selected regions of space for short periods of time. The full implications of this demonstration are quite considerable. The detailed results should be studied with care by all those who have responsible concern for future space flight.

The radiation tolerance of electronic and other physical equipment is in general vastly greater than that of animals. Typically, cumulative dosages of the order of millions of roentgens are required to produce important effects, though the characteristics of semiconductors in critical circuits may be appreciably affected by smaller dosages. It is believed that the earlier discussion and reference to original papers provide a basis for engineering assessment in any specific case.

The successful operation of the solar batteries and the transmitter of

* Area approaching the Polar regions.

* Indicates ability to absorb radiation.

Vanguard I (Satellite 1958 Beta) for over two years (as of present date of writing) and the successful operation of similar equipment in Sputnik III (Satellite 1958 Delta) over a similar period provide the most direct evidence for the survival of electronic equipment in space vehicles. The integrated radiation exposures in these two cases are still much below the level at which serious deterioration may be expected.

But, though mechanical and electronic equipment can operate within the high radiation areas, a living organism cannot survive this level of radiation damage. Hence, all manned space flight attempts must steer clear of these two belts of radiation until adequate means of safeguarding the astronauts has been developed. ■ ■

## Spaceman's Enemy—The Sun *continued from page 17*

earth. The steadiness, of course, is a good thing for man, for even small variations of a few percent would have the effect of making the conditions of life on earth more variable and thus more difficult.

The close-up view of the sun, however, reveals a wealth of detail and subtler changeability. And to a space traveler this variability may be a far more important fact than the rigorous uniformity of the total energy output of the sun. In the space environment, beyond the protective shield of earth's gaseous mantle, man's concern about solar variability will shift to the extreme short wavelength regions of the spectrum and to the sun's output of charged particles.

These violently changing radiations appear to be connected to variations of certain of the visible features of the sun. But the exact nature of the physical connections is very much of a mystery right now.

The surface of the sun, when viewed in a telescope of modest size, appears at first glance to be a luminous disk of smoothly varying brightness, slightly more brilliant at the center than near the edges. This disk, the "photosphere" of the sun, is the layer of the sun that defines its gaseous surface. At this level, just a few tens of kilometers change the gases from essentially transparent to essentially opaque gases, for all wavelengths of visible light.

On closer examination, however, the sun's disk reveals a structure of great complexity and interest. Most noticeable are the large sunspot groups that dot the surface irregularly.

The length of the sunspot cycles has averaged, since the year 1750, about 11.4 years, counting from the minimum of one fluctuation to the minimum of the next. The range of fluctuations of the area of sunspots on the disk is by large factors. In some years sunspots have been extremely rare, and when present generally have been small. Such a period came around 1800 to 1825. At other times, as in recent years, the sun's disk has frequently been covered with over a hundred spots, some large, some small, and generally gathered together in great clusters in the major "sunspot regions." Christmas Day of 1957 reached the highest sunspot number of any date since telescopic observations were commenced, back at the time of Galileo, around 1612. The peak of average solar activity was reached in 1957, during the International Geophysical Year; the 1957 average sunspot number was the largest since 1778.

Sunspots not only vary in number and size from day to day but can also be detected drifting from east to west as the sun rotates on its own internal axis. A rotation at the equator takes something like 26 days, judged by the sunspot motion, but takes a bit longer near the sun's rotation axes at the north and south poles. Sunspots are rarely found, however, at solar latitudes higher than about forty degrees, and the rotation period at higher latitudes must be determined by other means. Large sunspot groups are obviously symptoms of great activity.

Outside the sunspot areas the solar surface possesses a distinctive mottling, the "granulation", with individual cells possessing extremely small sizes of the order of a few hundred kilometers in largest dimension. These cells show clearly polygonal outline of their bright areas, which appear relatively large in size compared to the darker interstices between.