5

PARTICLE POPULATIONS IN SPACE

CARL E. FICHTEL
Head, Nuclear Emulsions Section
and
FRANK B. McDONALD
Head, Fields and Particles Branch
Space Sciences Division
Goddard Space Flight Center
National Aeronautics and Space Administration

INTRODUCTION

The development of spacecraft and the study of the properties of the primary particles in space have naturally gone together because each depends on the other. On the one hand, satellites and sounding rockets have provided two powerful new means of examining these fundamental particles outside of the earth's atmosphere and even beyond the magnetosphere. On the other, information is needed to ascertain the degree of structural damage radiation will produce and to determine the radiation hazard for manned space flight. This paper will summarize briefly present information on the particle populations in space with the aim of giving a picture of the flux, composition, and energy spectra of the various types of radiation, and at the same time indicating how well the properties of the radiation can be explained theoretically. We shall begin with a discussion of galactic cosmic rays, which were discovered first, and then proceed to solar cosmic rays and the Van Allen belt particles.

GALACTIC COSMIC RAYS

In this section, the cosmic-ray component which is accelerated outside of our solar system and which arrives with a kinetic energy > 10 mev/nuc will be discussed. The copious acceleration of moderate- to high-energy particles on the sun makes it necessary to designate energetic particles as being either of solar or of galactic origin.

The principal features of the galactic cosmic ray are its energy and charge spectra and its modulation with time.

ENERGY AND CHARGE SPECTRA

The composition and energy spectra of the primary cosmic radiation striking the top of the earth's atmosphere are reasonably well known at the present time.[1–3] Briefly, 85% are hydrogen, 12% are helium, approximately 1% are in the carbon, nitrogen, oxygen group, and 0.25% are in the group neon and heavier. In this heavier group, nuclei of all charges up to and including iron ($Z = 26$) have been identified. There is a small but significant flux of lithium, beryllium, and boron which is approximately 0.25% of the total flux. High-energy electrons constitute 1–3% of the total flux.[4, 5] Whether these electrons are of galactic or solar origin is not fully understood at the present time. From the recent results[6] of Explorer XI an upper limit of 0.1% can be placed on the flux of high-energy gamma rays.

A detailed summary of the charge spectrum is given in Table 1. There are two features of this charge spectrum which should be mentioned. First, the flux of lithium, beryllium, and boron is surprisingly high. If we assume that these elements are extremely rare in the source region, as the table of stellar abundance would have us believe, then these nuclei must be produced by fragmentation of heavier nuclei colliding with interstellar hydrogen nuclei. This, then, gives a measure of the average distance traversed by the galactic cosmic radiation before striking the earth. Using currently available fragmentation parameters,[3] we find that this corresponds to a value of 3 g/cm^2 or implies an average age of the order of 10^7 years. The other salient feature is the large flux of CNO and $Z \geqq 10$. The observed values are ten times greater than those expected from known stellar abundance. This is not understood at present, but perhaps it can be understood in terms of supernovae origin.[7]

In the high-energy region ($E > 3$ bev) it has been observed that all charged components have energy spectra of the form

$$J(E) = \frac{K_Z}{(1 + E)}\gamma$$

Table 1. RELATIVE ABUNDANCES OF MULTIPLY-CHARGED NUCLEI WITH A BASE OF 10 FOR OXYGEN

	He	Li, Be, B	C	N	O	F	Ne	$11 \leq Z \leq 18$
Solar cosmic rays*	1250	<0.2	6	$\lesssim 2$	10	<0.3	1.3	1.4
Sun†	?	<0.01	6	1	10	<0.01	?	1
Ordinary cosmic rays*	360	11	18	$\lesssim 8$	10	$\lesssim 1$	3	9

* The uncertainty in the values in this line varies from 15% to 40%.

† The uncertainty in the values in this line are of the order of a factor of 2.

where $J(E)$ = flux in particles/m^2-sr-sec with kinetic energy $> E$, γ = a constant independent of Z, and K_Z = a function of A. $J(E > 1$ bev) is typically 1,800 particles/m^2-sr-sec at solar maximum. In the region 0.3–5 bev, it is observed that all components appear to display the same form of spectra when expressed in terms of rigidity ($R = PA/Z$), where P = momentum/nucleon, A = mass number, and Z = atomic number of the primary.

Expressed in these terms, the differential spectrum displays a maximum in the region of 3 bev and is either constant or decreases down to 0.3 bev. In the region 0.4–0.7 bev, Vogt[8] has found large increases. Whether these are due to solar or galactic cosmic rays is not known.

MODULATION OF GALACTIC COSMIC RADIATION

It appears reasonable to assume that the flux of cosmic rays incident on the solar system is constant. However, in the vicinity of the earth, large modulations are observed which appear to be controlled by solar activity.

The two most important types of modulation appear to be the 11-year variation and the Forbush or storm-type decrease. It was first noted by Forbush that the cosmic-ray intensity varied inversely with solar activity over an 11-year cycle.[9] Also, Forbush first observed the rapid worldwide decreases in cosmic-ray intensity which are associated with some magnetic storms,[10] generally following large solar flares. At present the best evidence indicates that the modulation is heliocentric and controlled by solar activity. The effects on cosmic rays[11] can be summarized thus:

1. The protons and alphas have the same form of differential rigidity spectrum at solar minimum, and maintain the same relative form of rigidity spectrum during the solar cycle ($R > 1.0$ bev).
2. The total intensity is decreased by a factor of 2 from solar minimum to solar maximum, and the lower-energy particles are affected most—but the low-energy component is never completely removed.
3. At low energies or rigidities the form of the spectrum changes appears to be the same for the 11-year cycle as for the Forbush decreases that have been observed.

SOLAR COSMIC RAYS

It is now well established that solar cosmic rays arrive at the earth following some major flares of intensities which are orders of magnitude greater than ordinary cosmic rays. The first evidence for these particles came from sea-level ion chambers[12, 13]; however, these detectors and the neutron monitors developed after them are able to see only those events which have a large high-energy component. The development of the riometer[14] in 1956 provided an instrument which is sensitive to the effects of incoming particles in the low-energy region, 10–100 mev, and can detect a flux of the order of ten particles/cm^2-sr-sec or greater in this range. The riometer records showed that, during this last solar maximum, there were at least a dozen of these events per year.[15]

The most detailed data have come from particle detectors flown on balloons, sounding rockets, and satellites. Balloon-borne equipment has provided much valuable information on the intermediate-energy interval[16] (from approximately

80 to 500 mev) for protons, and also has yielded the first evidence of helium nuclei among the energetic solar particles.[17] Sounding rockets with recoverable payloads provide a means of studying these events above the earth's atmosphere with both electronic counters and nuclear emulsion techniques. Proton energy spectra down to a fraction of one mev[18] and detailed charge composition measurements[19] have been obtained in this manner. Finally, electronic experiments in satellites outside of the Van Allen belts can give a detailed history of the energy spectrum of an event down to very low energies. However, not until Explorer XII was launched on August 15, 1961, did such a system exist. Previous satellite experiments provided integral fluxes above some energy, and these results have aided in the study of several events.[20]

One of the most striking features of these solar cosmic-ray events has been the variation from one event to another. On the one hand, in some events the flux of protons above 20 mev has exceeded 10^3 particles/cm^2-sr-sec for more than a day[18, 21, 22] and the total energy arriving at the top of the earth's atmosphere for the whole event has been 10^4 ergs/cm^2-sr, about the same order of magnitude as that for cosmic rays for a year. On the other hand, events which are more than a hundred times smaller than this have been seen,[23, 24] and even smaller ones probably occur frequently and are not detected. The energy spectrum and its time variation have also shown marked differences from one event to another. For example, at comparable times in the November 12, 1960, and the July 12, 1961, events[22, 25] the integral fluxes above 10 mev were nearly the same, but above 100 mev they differed by more than a factor of 300. In some events, the maximum low-energy intensity occurred as early as 4 hours after the flare; whereas in others, it occurred as late as 30 or 40 hours after the flare.

Some of the general characteristics of these events may be observed in the time variation of the integral flux above 20, 100, and 500 mev shown for three events[26] (Figs. 1a, 1b, and 1c). An imaginary event which is just large enough to include any event ever observed is also shown (Fig. 1d). Particularly complete data exist for the September 28, 1961, events from the work of McDonald and coworkers[27] on Explorer XII. A detailed energy spectrum as a function of time exists for a large portion of the event including the important first hours. Their results show that the flux in any velocity interval rises smoothly to a broad maximum and then decays regularly, the rate of rise being greater for particles of higher energy. Further, this study revealed that, although the energy spectrum changed shape throughout the event, it did so smoothly with the result that the energy spectrum was always a smoothly varying function of energy with no very sharp discontinuities at any time.

Another interesting result obtained from Explorer XII was the direct detection of a large low-energy component[27, 28] below about 30 mev around the time of the sudden commencement of a magnetic storm (Fig. 1c). This large low-energy flux had previously been expected on the basis of sea-level riometer data and the predicted association of a plasma wave in space with a sudden commencement, but this was the first direct evidence.

Having briefly considered the characteristics of the primary component—namely, the protons—we may now give our attention to the charge composition of the particles in these events. On the basis of the detailed study of three events, there seems to be good evidence that the relative abundances of the various nuclei are nearly the same in each event when compared in the same velocity intervals for energies in the tens of mev region.[19, 22] The proton component is by far the most abundant, with helium nuclei being less abundant by more than an order of magnitude, and the heavier nuclei by at least three orders of magnitude relative to the proton component.

Among the multiply-charged components, the helium and medium nuclei (carbon, nitrogen, oxygen, and fluorine) have the same energy spectrum. The energy spectra of the other multiply-charged nuclei have not yet been determined because they are extremely rare; however, it is reasonable to assume that their energy spectra would also be the same, at least up to nuclei with a charge of about 16. The relative abundances of these elements in solar cosmic rays is then

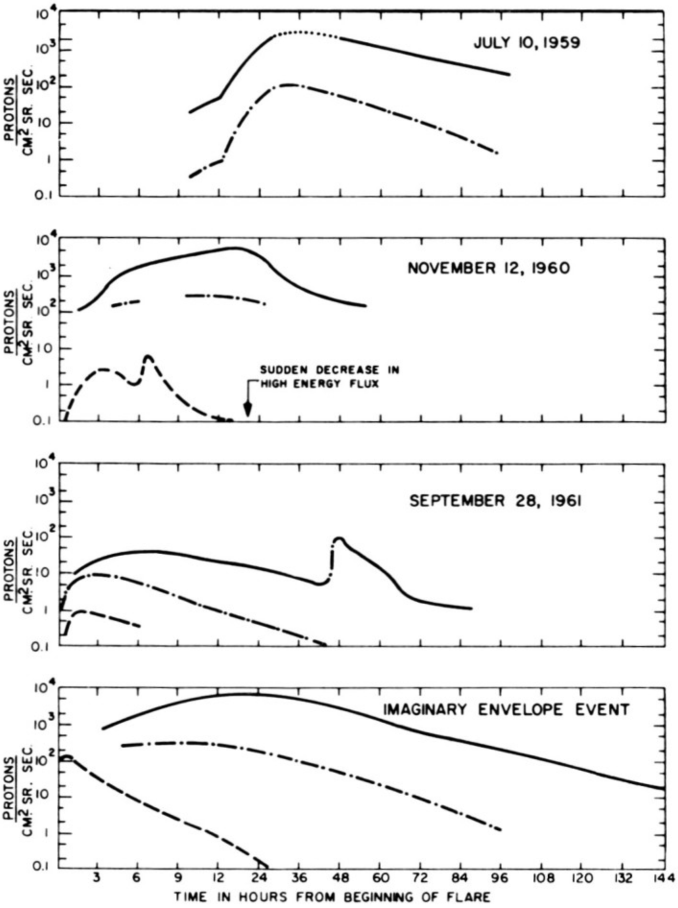

Fig. 1. Time variation of the integral flux above 20 mev (solid curve), 100 mev (dot and dash curve), and 500 mev (dashed curve) for three events and an imaginary envelope event which is just large enough to include any event ever observed.

independent of energy. They are shown in Table 1, along with those of the sun deduced from spectroscopic evidence for those elements where data exist. Note that the two sets of numbers are the same within uncertainties. Although the helium abundance in the sun cannot be determined by spectroscopic means, the relative abundance given here for helium in solar cosmic rays is within the rather wide limits set by theoretical models of the sun.

The proton component has been observed to have a very different energy spectrum from the others, probably because of its different charge-to-mass ratio. Therefore, the relative abundance of the proton component varies with velocity. For example, in one event the proton-to-helium ratio varied from about 20 at 40 mev/nucleon to about 300 at 120 mev/nucleon.

The information obtained on energetic solar particles can now be compared with the composition of galactic cosmic rays. There are at least five important differences between solar and ordinary cosmic rays. Two of these—the different carbon-to-oxygen ratios and the different light-to-medium ratios—can be attributed to the fact that ordinary cosmic rays have gone through several g/cm^2 of material wherein the light nuclei are formed by fragmentation, and there is at least an increase in the carbon-to-oxygen ratio. The other three—the different helium-to-medium nuclei ratios, the different ratios between the medium nuclei and those in the charge group, $11 \leq$ nuclear charge ≤ 18, and the different proton-to-medium nuclei ratios—are only enhanced by fragmentation. The helium-to-medium ratio is five times larger for the accelerated solar particles; the ratio of the medium nuclei to those in the charge group $11 \leq$ nuclear charge ≤ 18 is four times larger for the energetic solar particles; and the proton-to-medium ratio at galactic cosmic-ray injection energies is at least four times larger for solar cosmic rays.

The solar particles that are seen at the earth have already been acted upon by both the acceleration phase at their source and the transit phase, in which they are modulated by interplanetary conditions. In the modulation process, the particles are acted upon by the magnetic fields which are believed to have many irregularities that scatter the particles. The interplanetary conditions during an event are further complicated by one or more shock waves, or magnetic bottles, moving outward from the active regions of the sun. At this time, no explanation exists which will quantitatively predict the development of an event in any particular case; however, some general features of these events do seem to be becoming evident. The fact that the radiation observed near the earth is essentially isotropic, except for early times in some events, indicates that scattering of the particles must be very effective. Further, the rate of increase of the particle flux early in an event is much greater for high-energy particles than for low-energy ones, in agreement with the general predictions of diffusion theory. Finally, since solar particles are seen for many days after a solar event, the trapping in the inner region of the solar system must be relatively strong

Turning to the acceleration phase, Parker[29] has shown that, within the framework of the present understanding of plasma dynamics, all particle acceleration mechanisms occurring outside of the laboratory are reducible to the Fermi mechanism[30–32] which is based on random-particle collision with magnetic inhomogeneities. Insofar as comparisons can be made, the experimental results seem consistent with a Fermi-type acceleration mechanism.

VAN ALLEN BELTS

The Van Allen belt radiation, unlike cosmic rays, consists of particles trapped in the earth's magnetosphere. These charged particles spiral back and forth along the lines of force of the earth's magnetic field. Present evidence indicates that these particles are predominantly, and perhaps essentially exclusively, protons and electrons. The intensity and energy spectra of these particles vary greatly with their position in the trapped region, and even with their angle in relation to the magnetic field at any given point. Further, at least at large distances from the earth (several earth radii), rather large fluctuations in intensity are observed. For these reasons, a description of the particle properties would have to be long and detailed, and, in many respects, would remain incomplete because of lack of information. Therefore, only the more fundamental known characteristics will be reviewed here. Data on the proton component will be reviewed first, and then that of the electrons.

Several satellite experiments,[33–37] including the original work of Van Allen, have shown that the protons with energies greater than about 30 mev are contained in a roughly doughnut-shaped region centered over the geomagnetic equator and extending from approximately 500 km above the earth to about 6,000 km. The maximum intensity approaches approximately 2×10^3 protons/cm^2-sr-sec in the heart of this region. Detailed energy spectra are available at several points from the experiments of Freden and White[38, 39] and others[40] in one region and Naugle and Kniffen[41] in another. The energy spectra deduced from their work are shown in Fig. 2. In addition to these studies, there is additional information on the very low-energy proton component. Bame et al.[42] saw integral fluxes above 1 mev of from 0.3×10^5 particles/cm^2-sr-sec, depending upon the position but within two earth radii, and an energy spectrum from 2.7 to 7 mev that has approximately the same slope as that observed by Naugle and Kniffen at high energies. Davis et al.[43] see integral fluxes above 0.1 mev in excess of 10^6 protons/cm^2-sr-sec at about six earth radii. The spectrum is, again, very steep and the flux is below 10^4 protons/cm^2-sr-sec above 0.5 mev at this great distance from the earth. These spectra are also shown in Fig. 2. Finally, Freeman[44] has detected a very intense flux of particles at altitudes from 900 to 1,000 km. If these particles are assumed to be protons and reasonable assumptions are made about their energies, the results would indicate a proton flux above 0.1 mev in excess of 10^8 protons/cm^2-sr-sec.

Much of the existing knowledge on the electron population of the Van Allen belts comes from the same satellite experiments referred to earlier.[33-38,45,46] The flux of electrons with energies greater than 200 mev is known to reach a maximum at about four earth radii, and the electron component is observed to extend out to about 15 earth radii at the equator. There is considerable controversy over the absolute flux values and the shape of the energy spectrum because of the difficulty of interpreting the experimental data; however, the most recent estimates[47] give a flux of 5×10^6 electrons/cm^2-sr-sec above 600 kev in the region of highest intensity and 5×10^8 electrons/cm^2-sr-sec above about 40 kev.

There has been considerable speculation concerning the origin and history of the particles in the Van Allen belts. Hess,[47] Kellogg,[48] Lenchek,[49] Singer,[50] Vernov et al.,[51] and others have considered the possibility of albedo neutron decay, where the neutrons are secondaries from the interactions of galactic and solar cosmic rays in the atmosphere. There is reasonably good agreement between the flux and energy spectra of the proton component in the inner part of the belt above about 10 mev, but there are apparently many serious disagreements—the most serious involving the flux and energy spectrum of the electrons. In order to explain the properties of the electron component, several theories that relate to either direct injection or local acceleration by high-frequency electromagnetic fields[52] have been suggested. However, as yet, a detailed quantitative explanation has not been obtained.

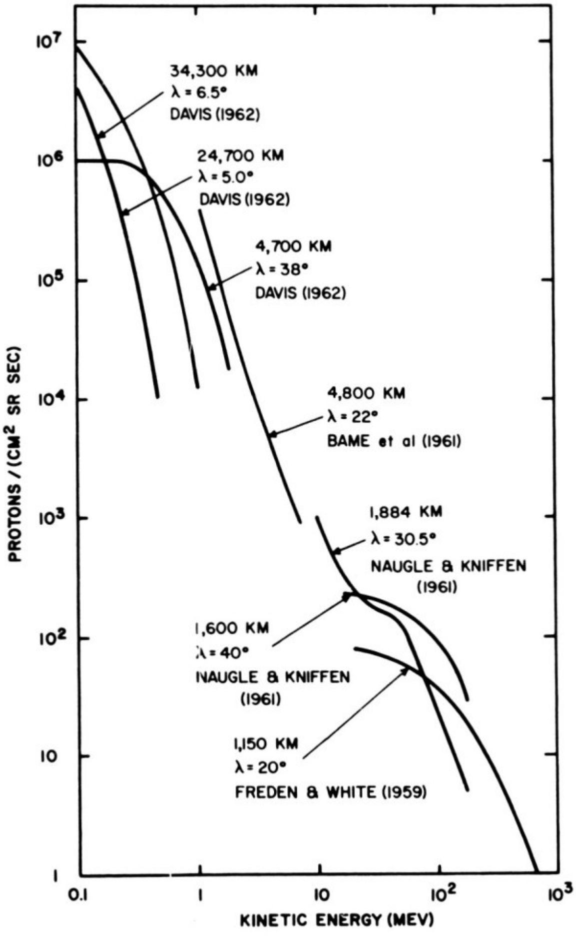

Fig. 2. Proton energy spectra at different points in the Van Allen belts as measured by several experimentalists.

REFERENCES

1. McDonald, F. B., and W. R. Webber, *Phys. Rev.*, vol. 115, 1959, p. 194.
2. Fichtel, C., Ph.D. thesis, Washington Univ., St. Louis, Mo., 1959.
3. Waddington, C. J., *Progress in Nuclear Progress*, vol. 8; New York, Pergamon, 1961.
4. Earl, J., *Phys. Rev. Letters*, vol. 6, 1961, p. 125.
5. Meyer, P., and R. Vogt, *Phys. Rev. Letters*, vol. 6, 1961, p. 193.
6. Kraushaar, W. L., and G. W. Clark, *J. Phys. Soc. Japan*, vol. 17, suppl. A-3, 1962, p. 1.
7. Ginzburg, V. L., and S. I. Syrovatsky, *Prog. Theor. Phys.*, suppl. 20, 1961, p. 1.
8. Vogt, R., *J. Phys. Soc. Japan*, vol. 17, suppl. A-2, 1962, p. 436.
9. Forbush, S. E., *J. Geophys. Res.*, vol. 59, 1954, p. 525.
10. Forbush, S. E., *Terr. Magn. Atmos. Elec.*, vol. 43, 1938, p. 207.
11. McDonald, F. B., and W. R. Webber, *J. Phys. Soc. Japan*, vol. 17, suppl. A-2, 1962, p. 428.
12. Lange, I., and S. Forbush, *Terr. Magn. Atmos. Elect.*, vol. 47, 1952, p. 331.
13. Elliot, H., *Progress in Cosmic Ray Physics*; North Holland Publishing Co., Amsterdam, 1957.
14. Little, G. C., and H. Leinback, *Proc. IRE*, vol. 46, 1958, p. 334.
15. Reid, G. C., and H. Leinback, *J. Geophys. Res.*, vol. 64, 1959, p. 1801.
16. Winckler, J. R., *J. Phys. Soc. Japan*, vol. 17, suppl. A-2, 1962, p. 353.
17. Biswas, S., P. S. Freier, and E. P. Ney, private communication.
18. Ogilvie, K. W., D. A. Bryant, and L. R. Davis, *J. Geophys. Res.*, vol. 67, 1962, p. 929.
19. Fichtel, C. E., and D. E. Guss, *J. Phys. Soc. Japan*, vol. 17, suppl. A-2, 1962, p. 321.
20. Lin, W. C., and J. A. Van Allen, private communication.
21. Webber, W. R., *Progress in Cosmic Ray Physics*, vol. VI; North Holland Publishing Co., Amsterdam, 1961.
22. Biswas, S., C. E. Fichtel, and D. E. Guss, to be published.
23. Davis, L. R., C. E. Fichtel, D. E. Guss, and K. W. Ogilvie, *Phys. Rev. Letters*, vol. 6, 1961, p. 492.
24. Bryant, D. A., T. L. Cline, U. D. Desai, and F. B. McDonald, *Bull. Amer. Phys. Soc.* II, vol. 7, 1962, p. 312.
25. Guss, D. E., and C. J. Waddington, *Bull. Amer. Phys. Soc.* II, vol. 7, 1962, p. 312.
26. Fichtel, C. E., Guss, D. E., and K. W. Ogilvie, *Radiation Manual*, to be published.
27. Bryant, D. A., T. L. Cline, U. D. Desai, and F. B. McDonald, Program of 43rd Annual Meeting of Amer. Geophys. Union, p. 109.
28. O'Brien, B. J., and J. A. Van Allen, private communication.
29. Parker, E. N., *Phys. Rev.*, vol. 109, 1958, p. 1328.
30. Fermi, E., *Phys. Rev.*, vol. 75, 1949, p. 1169.
31. Fermi, E., *Astrophys. J.*, vol. 119, 1954, p. 1.
32. Parker, E. N., *Phys. Rev. Letters*, vol. 107, 1957, p. 830.
33. Van Allen, J. A., G. H. Ludwig, E. C. Ray, and C. E. McIlwain, IGY Satellite Series, No. 3, 1958, p. 73.
34. Van Allen, J. A., C. E. McIlwain, and G. H. Ludwig, *J. Geophys. Res.*, vol. 64, 1959, p. 271.
35. Van Allen, J. A., and L. A. Frank, *Nature*, vol. 183, 1959, p. 430.
36. Vernov, S. N., A. Y. Chudakov, P. V. Vakulov, and Y. I. Logachev, Doklady Akademii *Nauk. SSSR*, vol. 125, 1959, p. 304.
37. Krassovsky, V. I., I. S. Schlovsky, G. I. Galperin, and E. M. Svetlitsky, *Proc. of Moscow Cosmic Ray Conf.* III, 1960, p. 59.
38. Freden, S. C., and R. S. White, *Phys. Rev. Letters*, vol. 3, 1959, p. 9.
39. Freden, S. C., and R. S. White, *J. Geophys. Res.*, vol. 65, 1960, p. 1377.
40. Armstrong, A. H., F. B. Harrison, H. H. Heckman, and L. Rosen, *J. Geophys. Res.*, vol. 66, 1961, p. 351.
41. Naugle, J. E., and D. A. Kniffen, *Phys. Rev. Letters*, vol. 7, 1961, p. 3.
42. Bame, S. J., J. P. Conner, H. H. Hill, and F. E. Holly, article IV (5) of Program, 1st Western National Meeting of Amer. Geophys. Union, p. 20.
43. Davis, L. R., *Bull. Amer. Phys. Soc.* II, vol. 7, p. 354.

44. Freeman, J. W., *Detection of an Intense Flux of Low-Energy Protons or Ions Trapped in the Inner Radiation Zone*, SUI, 1961, pp. 61–24.
45. Holly, F. E., L. Allen, Jr., and R. G. Johnson, *J. Geophys. Res.*, vol. 66, 1961, p. 1627.
46. O'Brien, B. J., J. A. Van Allen, C. D. Laughlin, and L. A. Frank, *Absolute Electron Intensities in the Heart of the Earth's Inner Zone*, SUI, 1961, pp. 61–23.
47. Hess, W. N., *Phys. Rev. Letters*, vol. 4, 1959, p. 11.
48. Kellogg, P. J., *Nature*, vol. 183, 1959, p. 1295.
49. Lenchek, private communication.
50. Singer, S. F., *Phys. Rev. Letters*, vol. 1, 1958, p. 171.
51. Vernov, *et al.*, 5th ESAGI Meeting, Moscow, 1958.
52. Kellogg, P. J., *Nature*, vol. 183, 1959, p. 1295.

DISCUSSION

Authors: Fichtel and McDonald
Discussor: W. Dieminger, Max-Planck-Institut fuer Aeronomie

I should like to ask the author about the effect of the last nuclear explosion over Johnston Island. There is a big discrepancy between the effects discussed in the newspapers before the experiment, namely that the natural radiation belt would have been blown out, and the informations leaking out after the explosion that a new artificial belt with rather high intensity has been formed.

Author's reply to discussion:

Primarily on the basis of a news release of Dr. Van Allen, it seems that the electron fluxes are much higher than expected roughly in the region of the old inner belt and at lower altitudes. I do not have exact figures at this time, but they should be forthcoming from the Injun, Telstar, Traac, Discoverer, and Cosmos VII satellites.* To my knowledge, there is as yet no definite data on the natural protons in the inner belt since the explosion to indicate whether the higher energy proton flux has increased, decreased, or remained about the same.

---

*Subsequently in a colloquium given by Dr. Hess at Goddard Space Flight Center on October 5, 1962, he explained that the data from the first three of these satellites indicated that the electron fluxes exceeded 10^8 particles/cm^2 sec in the heart of the new radiation belt and that the lifetimes would be large.

Authors: Fichtel and McDonald

What are the chances of a spaceship being hit and damaged by meteorites?

Author's reply to discussion:

> The flux of meteorites which are big enough to cause serious physical damage to a spaceship is thought to be sufficiently small so that the probability of an impact during a mission is extremely unlikely. Further, a hit would not necessarily cause the mission to be a failure since the damage could very likely be repaired. Perhaps Dr. Dieminger would like to comment on this question and say something about micrometeorites.

Authors: Fichtel and McDonald
Discussor: W. Dieminger, Max-Planck-Institut fuer Aeronomie

I completely agree with Mr. Fichtel's comments on the hazards caused by meteorites. The big ones are by far too rare to be a real danger. A full hit of a big meteorite is very unlikely even for a long mission. In addition, a mere puncture where no vital part of the vehicle has been damaged may be fixed up by a plaster. As far as micrometeorites are concerned the actual number seems to be much higher than assumed from an extrapolation of visual observations. They are, however, harmless since they cannot penetrate the walls of the vehicle. There may be, however, a blinding of windows or an ablation of polished surfaces during very long missions. Generally speaking, the hazards from meteorites seem to be much less than those from energetic particles or from failure of vital parts of the equipment of the vehicle.