THE DISCOVERY OF THE EARTH'S RADIATION BELTS. NEW HISTORICAL DOCUMENTS

I.V. Zavidonov [1]

Institute for the History of Science and Technology, Moscow, Russia

The full text of S. N. Vernov's report to the Fifth Assembly of the International Geophysical Year Special Committee is published for the first time along with two letters from James Van Allen to Vernov. It is clear from Vernov's report that his group was not only the first to find and identify the charged particles of the outer radiation belt, but also the first to give a correct explanation of the new phenomenon. They were the first to establish that orbiting satellites were registering high-energy charged particles that originated near the Earth and formed permanent fluxes.

The documents presented here deal with the discovery made by the physicists S. N. Vernov (Lebedev Physics Institute of the Soviet Academy of Sciences; INP Moscow State University) (in the photo) and James Van Allen (Iowa State University, USA) between January 1958 and April 1959. The discovery of the Earth's radiation belts is one of the greatest discoveries of the space age. The international scientific community traditionally gives priority in this discovery to James Van Allen and his research group. Even if Vernov's research group first discovered the charged particles of the outer radiation belt, Soviet scientists are generally regarded as having interpreted the phenomenon not quite correctly [1].

The letter [2] from J.A. Van Allen to S.N. Vernov (January 13, 1958) deals with the data from the second artificial Earth's satellite and demonstrates the American researcher's interest concerning the charged particle scientific data obtained by the Soviet scientists.

**STATE UNIVERSITY
OF IOWA
IOWA CITY DEPARTMENT OF PHYSICS**

13 January 1958

Academician S. N. Vernov[2]
Soviet Academy of Science
Moscow, Russia

Dear Dr. Vernov:

According to information available in the United States, you have conducted observation in Sputnik II on the total cosmic ray intensity. I should be very grateful for an account of your work and of the preliminary results.

We have prepared a similar experiment in one of our forthcoming satellites and I shall be pleased to advise you of the outcome. See following references and enclosed reprints:

(I) J.A. Van Allen, "Cosmic Ray Observations in Earth Satellites", pp. I7I-I87 in "Scientific Uses of Earth Satellites" (University of Michigan Press, Ann Arbor, and Chapman and Hall, London) (I956).
(2) G.H. Ludwig and J.A. Van Allen, "Instrumentation for a Cosmic Ray Experiment for the Minimal Earth Satellite", Journal of Astronautics, 3, 59-61 (1956).
(3) J. A. Van Allen, "The Artificial Satellite as a Research Instrument", Scientific American, Vol. 195, 41-47, (1956).
(4) W. Matthews and G. H. Ludwig, "Scientific Telemetry for U. S. N. C. - I. G. Y." Q. S. T. January 1958, pp. 41-46.

Sincerely yours,
J.A. Van Allen

1 E-mail: iv@history.ihst.ru.
2 S.N. Vernov became the member of Soviet Academy of Science in 1968.

S.N. Vernov (1950?). (*Archive of Russian Academy of Science*, collection 1809, list 1, folder 154, P. 1.)

The other presented document [3] is the report by Vernov and Chudakov at the V Assembly of International Geophysical Year Special Committee (Moscow, July - August, 1958). By that time, Van Allen had already made his report about the first registration of charged particles at the low latitudes[3]. In July - August, 1958, Van Allen interpreted his results as fluxes of electrons of interplanetary plasma, which come from the Sun and encounter the Earth's environment [4].

Vernov and Chudakov reported quite different conclusions. First, they proved that the radiation zone includes electrons. The equipment of the third Soviet satellite not only allowed to determine the number of particles but also to estimate their energy. So soviet scientists first could identify particles. (Van Allen's Geiger tubes could not yet exactly determine the type of charged particles.)

Secondly, the Soviet researchers realized that the polar fluxes of particles[4] were arising near the Earth and moving around it rather then coming from the Sun as it was supposed by Van Allen's group for the similar phenomenon registered at low latitudes. (The fluxes of charged particles from the Sun - "the solar wind" were directly discovered at the of 1960 by K.I. Gringauz and his colleagues.)

ON THE RESULTS OF COSMIC RAY INVESTIGATIONS WITH THE HELP OF THE ROCKETS AND SATELLITES IN THE USSR[5]

S.N. VERNOV, A.E. CHUDAKOV

The invention of rockets and in particular satellites opened up broad perspectives for the development of many branches of science. In this fashion it became possible to carry out investigations with the help of a measuring device located beyond the Earth's surface. Cosmic rays arriving from space interact strongly with atomic nuclei in the atmosphere. Even comparatively small quantities of matter are sufficient for cosmic ray particles passing through atmospheric layers to create large numbers of secondary particles.

The investigations of cosmic rays with the help of rockets began in the USSR in 1947.

Initially the number of charged particles was measured with the help of a Geiger tube and the formation of the electron-photon component was investigated during the interaction of primary cosmic ray particles with atomic nuclei of the light elements. It was shown that in 1947, 1949, and 1951 the intensity of the cosmic rays at altitudes less than 75 km was the same and did not change by more than 5%.

In 1949 data were obtained on the intensity of photons outside the atmosphere. A method of measuring the number of high-energy photons in the presence of a strong background of charged particles was proposed by one of us (A.E. Chudakov).

This method consists of the following: The lead block was surrounded on all sides by counters connected in parallel. Such a system must register:

1) All charged particles incident upon the apparatus which are capable of penetrating through at least one envelope of counters.

2) Photons absorbed in the lead block and yielding an electron capable of exiting the lead and hitting one of the counters.

It is essential that absorption and multiplication of the incident charged particles in the block of lead does not lead to a change in the number of registered pulses. Indeed, if the incident charged particle falls on the lead, it has already been counted by one of the counters and its further fate does not change the result.

If the lead is removed from the indicated system of counters without changing their mutual disposition, the number of pulses will be decreased by the number of pulses in the device from the conversion of photons in the lead. The difference in the number of pulses registered by such a device with the lead and without it is determined only by neutral particles absorbed in the lead. The thickness of the lead was chosen equal to 1 cm so that the device was sensitive namely for the photons.

With the help of this device it was found that at the latitude above 50 km the flux of photons with energy around 10^7 eV was approximately 0,25 photon/(cm^{2}s). With a similar device measurements of the photons in the stratosphere at different altitudes were carried out, and it had been shown, that the number of these photons had the maximal value 0,7 photon/(cm^{2}s) at altitudes of 15-20 km.

---

3 Later turned out that the particles at low latitudes are the inner radiation belt.

4 Later this phenomenon was called "the outer radiation belt".

5 The report at the meeting of IGY Assembly on 31-th of July 1958. (The foot-note was made by S.N. Vernov.)

In order to ascertain the number of photons of significantly lesser energies in the device without lead, the number of counters in which discharges occurred simultaneously was measured. The device was scaled at sea level with the help of cosmic ray mesons. With the help of this scaling it was measured how frequently the firing of only one counter was possible when the charged particles are incident upon the device.

It turned out that outside the atmosphere the number of triggering only one counter is significantly higher. This is caused by the presence of photons with energies of the order 10^6 eV. Such photons are absorbed in the counter walls and create the secondary electrons, which can not pass through the walls of other counters. Processing of the obtained data showed that the number of photons with energy of the order of 10^6 eV was about 200% of the number of primary charged particles.

When determining the number of these photons an assumption was made about their energy, and the probability of their registration by the counters was accounted for in accordance with this assumption. The final value is inversely proportional to the energy of the photon. Thus it is possible to determine the energy flux carried by these photons without tying ourselves to a definite assumption about the photon energy. This value turns out to be approximately equal to the high energy photon flux, namely equal to about 2 10^6 $cm^{-2}s^{-1}$.

In 1951 the ionization created by cosmic rays up to an altitude of 100 km was measured. The following method was proposed and elaborated for that purpose. The collecting electrode of ionization chamber was completely isolated. The charge accumulated on this electrode was periodically removed with the help of an electromagnetic relay. This was when the accumulated charged shot threw the resistor. The voltage pulse obtained on the resistor served as a measurement of the accumulated charge. The sensitivity of this method was determined by the "parasitic" phenomena during the relay contact closing. As the experiment showed, it was not difficult to obtain a charge measurement error of 10^{-14} coulombs, quite sufficient for these purposes. The chamber was filled by argon at a pressure of about 5 atm. The measurements were carried out with absorber thicknesses of 1 g/cm^2 of steel, 15 g/cm^2 of aluminium, 1 g/cm^2 of lead and 15 g/cm^2 of aluminium + 1 g/cm^2 of lead. Surrounding the ionization chamber with 1 cm^2 of lead results in a 2,06±0,03 ionization increase, 15 cm^2 of aluminum yields a 1,92±0,02 increase, and 15 of aluminum + 1 cm^2 of lead yields a 3,26±0,03 increase. The difference in the ionization values measured during 3 rocket flights was not more than 2-3%. The comparison of ionization and particle number in stratosphere and outside the atmosphere shows that the average specific ionization of cosmic radiation particles is significantly more than the relativistic particle ionization. The ratio of average specific ionization to the ionization of the relativistic particle takes on the following values:

```
20 km - 1,59±0,06
                                                        without an absorber
at the altitude more than 50 km - 2,16±0,07
at an altitude of more than 50 km - 1,68±0,06 - under a layer from 15 cm2 of
aluminium.
```

More intensive ionization in the stratosphere is explained by the presence of the secondary heavy and rather slow particles. Beyond the atmosphere the number of these secondary particles is rather small. As may be seen from the data introduced above, when the ionization chamber is placed under an aluminum layer with a thickness of 15 cm the average specific ionization approximately corresponded to that which was expected on the basis of experiments at an altitude of 20 km. The large value /2,16/ of average ionizing capacity resulted from the presence of alpha particles and heavier nuclei along with photons in the composition of the primary radiation. This conclusion about the large average specific ionization of the primary cosmic particles was obtained also by means of measuring of impulses in pulse ionization chambers on rockets. One of us (A.E. Chudakov) carried out this series of cosmic ray studies on rockets. P.V. Vakulov and V.A. Khvoles took part in developing the special electronics and radio-transmission system needed for this purpose. M.I. Fradkin took part in the impulses measurements and V.I. Solovyova took part in the photon measurements.

On the basis of rocket experiments carried out to study cosmic rays, new measurements have been prepared, some of which were achieved during the 2-nd and 3-nd[6] flights of artificial satellites around the Earth. The opportunities opened up by satellite launchings make it possible to find a new approach to the solution of the following problems.

[6] The third Soviet satellite launched on 15 of May 1958 is haven in mind here and after.

First of all it is possible to plot the map of cosmic ray distribution for the entire terrestrial globe and by the same token to carry out investigations of the Earth's magnetic field.

The extended presence of the device on board the satellite lets us hope to find new components in the composition of cosmic radiation. The search for photons in the composition of cosmic radiation takes on particular significance in connection with this. If a photon component is found in the composition of cosmic rays, then a new opportunity for the investigation of processes taking place in outer space will emerge.

The study of the composition of primary cosmic rays and the determination of the presence of nuclei of various elements among the particles also has considerable significance.

Sufficiently long-term changes of cosmic rays on satellites allows us to compare the changes of intensity of these rays with those processes on the Earth and in space which determine the variation of cosmic radiation.

Two identical devices were placed on the 2-nd artificial satellite of the Earth for cosmic ray measurement. Both devices were quite independent, which is why the coincidence of both device readings makes us confident in the correct performance of the equipment in flight. Each device consisted of a charged-particle counter with effective length 100 mm and diameter 18 mm. The counters were surrounded by 10 g/cm^2 of material on average. The working voltage of the counter /400 V/ was provided with the help of the semi-conductor converter fed from the battery with the voltage of 6,5 V.

Both devices contained scaling mechanisms constructed on semiconductor triodes and consuming 0,1 W each. The entire device consumed 0.15 W. The reserve power supply provided continuous work of the device for 200 hours.

The weight of one of the devices together with power supplies totaled 2.5 kg. Elements of the device design were described in the article published in "Uspekhi fizicheskikh nauk" /1/. The measurements were carried out by the authors together with N.L. Grigorov and Yu.I. Logachev.

Separate examples of cosmic ray measurements during the 2-nd satellite flight are shown in chart 1[7].

The geomagnetic latitude is marked on the abscissa axis. The number of pulses counted by counters is marked on the ordinate axis. Two curves according to two counters available in the apparatus are drawn at the figure. The statistical errors are shown on the left.

As is clear from the figures, the readings of both counters fall within the limits of the statistical errors. The rise in cosmic ray intensity with increase in latitude is distinctly clear from the figures.

During the flight of satellite moving from south to north in circuits over the territory of the Soviet Union its flight altitude over the Earth's surface remained practically constant. Satellite's altitude rose monotonically from 350 to 700 km during moving in direction from north to south.

The ratio of cosmic ray intensity in this direction moving to the intensity at moving from south to north at the same geographical points gives the relative increase of intensity because of the difference in altitude.

The altitude dependence of cosmic ray intensity obtained in this way is shown in chart 2.

The abscissa is the altitude.

The ordinate axis is the intensity.

If the dependence of cosmic radiation intensity on altitude is the same at the different latitudes, chart 2 must show this altitude dependence. This dependence of cosmic radiation on altitude in any case must be conditioned by the following effects:

I. Intensity increase due to decrease in screening by the Earth.

II. Intensity increase due to decrease of the Earth's magnetic field, which results in a decrease in the threshold energy of particles capable of penetrating the Earth's magnetic field.

The altitude dependence found here can only be explained by taking into account only these two effects.

Measurements of cosmic ray intensity carried out during the satellite's flight on many circuits allow us to construct lines of equal radiation intensity /isocosms/.

The isocosms for three counting rates (18, 27, and 36 impulses/sec) are shown on chart 3.

Horizontal lines are the geographical parallels.

Vertical lines are the meridians.

As is evident from chart 3, the experimental points lay down on geographical parallels best of all.

[7] The figures are absented in the found text. The presented figure 1 is taken from [5] and figures 2-4 are taken from [6].

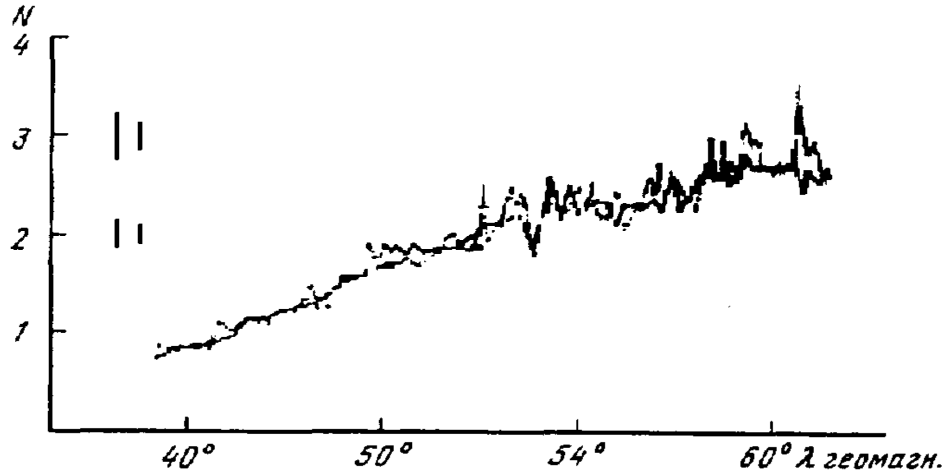

Chart 1. The typical record of the count rate for 1-st and 2-nd devices during the satellite flight in geomagnetic atitude range 40 - 60^0. The geomagnetic latitude is marked on the abscissa. The number of pulses counted by counters is marked on ordinate. N is the particle numbers/cm^2s.

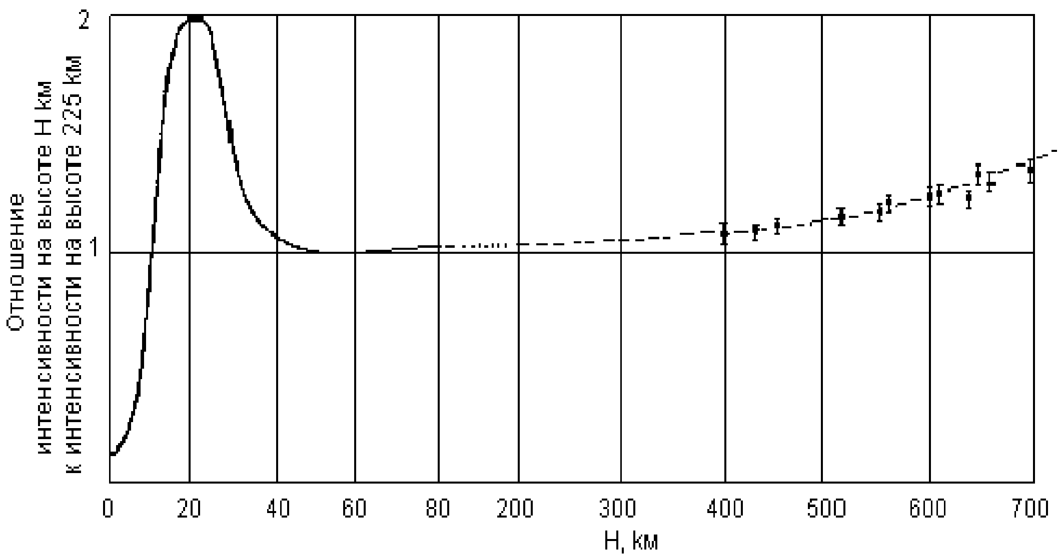

Chart 2. The dependence of cosmic rays intensity from altitude. The abscissa is the altitude. The ordinate is the ratio of an intensity to an intensity at the altitude 225 km.

In the equatorial region it was observed by Simpson /2/[8] that the line of minimal intensity of the cosmic rays ("cosmic equator") does not coincide with the geomagnetic equator. Obtaining data on the cosmic ray intensity distribution for the entire globe presents great interest in that regard.

---

8 J.A. Simpson is the famous American physicist working in field of cosmic ray investigation. Apparently, the report at Varena by J.A. Simpson and J. Katzman was had in mind. See also Simpson J.A., Fenton K.B., Rose D.C. "Effective geomagnetic equator for cosmic radiation" // Phys. Rev. 1956, V. 102, ser. 2, N 6, p. 1648.

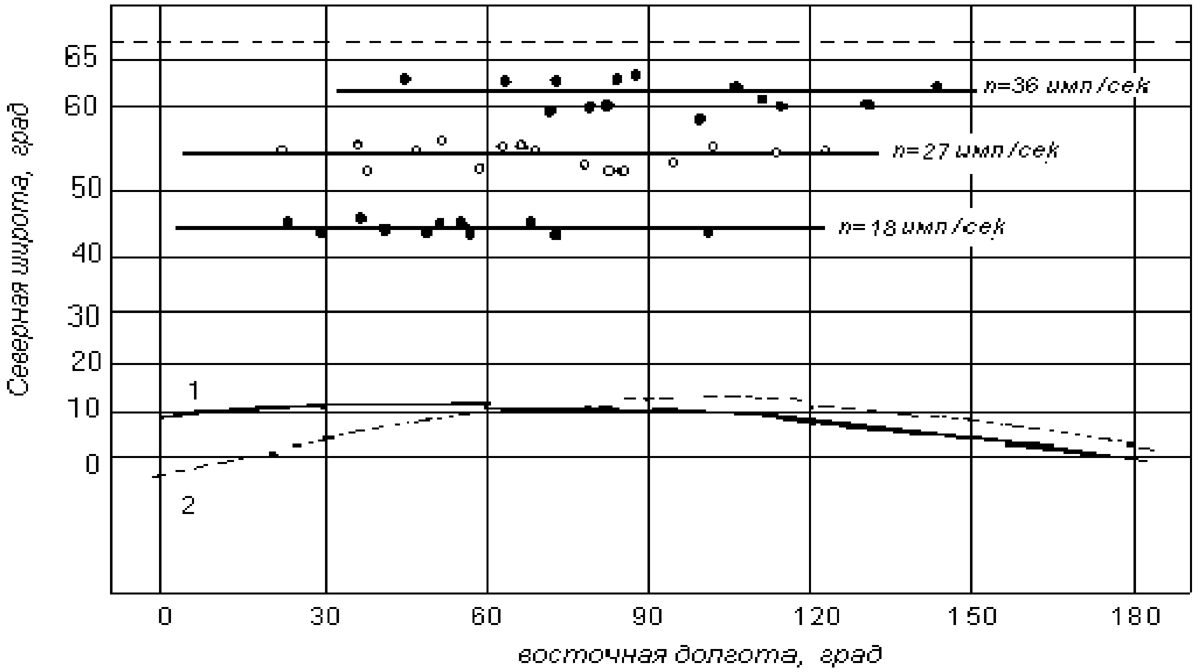

Chart 3. The lines of cosmic ray equal intensity (18, 27, 36 pulses per sec). 1 is the cosmic ray equator according to Simpson. 2 is the geomagnetic dipole equator. The abscissa is east longitude; the ordinate is the north latitude.

The scattering of data points exceeds by 2-3 times the scattering that one would expect from statistical errors alone. This may be connected to cosmic ray intensity variations. Analysis of the data obtained shows that considerable increases of cosmic ray intensity were sometimes observed. Thus on 7 November 1957 an increase in cosmic ray intensity of about 50% was registered from 4:36 am to 4:49 am (Moscow time) at latitudes greater than 58^0. This increase was recorded simultaneously by two devices. The change of cosmic ray intensity during this "flash" according to the data of both devices is shown in chart 4 /the crosses are the data of one device, dots are the data of another/.

In the same figure the change in cosmic ray intensity as a function of time is shown by a dashed curve, which one would expect taking into account the average data obtained on all circuits except the circuit on which the "flash" was observed.

One's attention is drawn to the fact that large fluctuations in intensity are observed during the "flash."

The given flash was not registered by terrestrial stations. It is difficult at present to determine what caused the observed increase in intensity. One cannot exclude the possibility that the reason is not the rise in intensity of the primary cosmic ray, but the increased electron current density at relatively low energy – on the order of several hundred KeV, which can be registered by a Geiger counter (albeit with quite low efficiency) due to the bremsstrahlung emitted during the absorption of the electron in the satellite envelope.

The possibility of such an interpretation suggests itself on the basis of data analysis from the third satellite, on which a luminescent counter possessing high efficiency for photon registration was installed. In this case rather significant photon intensity was observed, and furthermore, in the region of those latitudes in which the flash was observed. The photon intensity was increasing and was undergoing strong fluctuations.

It is natural to explain the origin of those photons by bremsstrahlung of electrons with energy 10^5 eV.

Increases in the photon intensity in a distinct geographical zone (around 60^0 north latitude) have been observed over the course of many days. Therefore, **it is possible to make a conclusion about the presence of stationary electron fluxes at the high latitudes**[9]**.**

[9] The bold type in the whole Vernov's - Chudakov's report belong to I.Zavidonov.

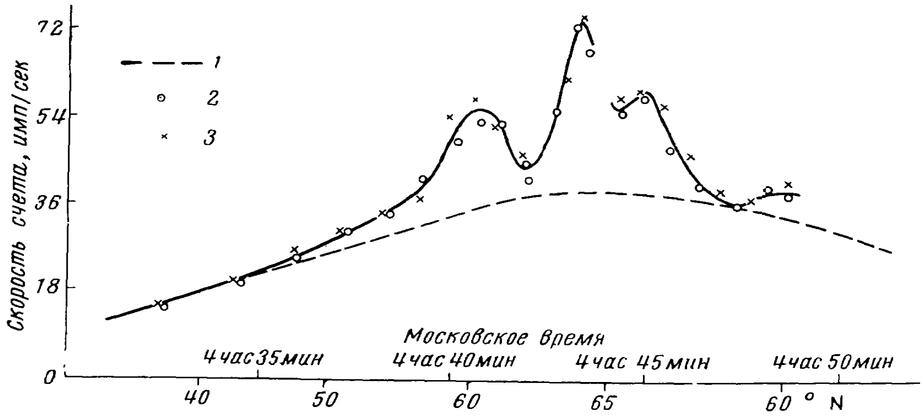

Chart 4. Change of intensity of cosmic rays in time of "the flash". The latitude is marked on abscissa. The count rate (pulses per second) is marked on the ordinate.

The observed cosmic ray intensity variations on satellites differ from the variations observed at sea level and in the stratosphere (at altitudes of 20-30 km) at the same period of time. There are apparently two types of variations. Part of the variations is caused by cosmic rays and thus must correspond to the change of primary cosmic particle number. The other part of the variations do not refer to cosmic rays, and is only registered on the satellites with the help of equipment designed previously for the study of cosmic rays. **The new radiation and number of charged particle and photon variations caused by it are registered. These variations are caused by radiation which can be called "terrestrial radiation", i.e., high-energy particles arising near the Earth and moving around the Earth.**

REFERENCE

(I) Vernov S.N., Logachev Yu.I., Shafer Yu.T. Uspekhi Fizicheskih Nauk, v. LXIII, vypusk I, c. I49-I62, 1957.
(2) Simpson and others /I955/ and report at the conference in Varena.

The last document [7] is also the Van Allen's letter to Vernov (15 April, l959). In spite of the fact that the exchange of information between two researchers was obviously restricted American scientist received the above-mentioned yet unpublished report by Vernov and Chudakov. By this way the report was presented at the special evening meeting of the Assembly at the 31 of July, 1958, where scientists from many countries were present [8]. Hence, the report was accessible for foreign researchers studying Earth's environment.

STATE UNIVERSITY OF IOWA

IOWA CITY

DEPARTMENT OF PHYSICS

15 April l959

Academician S. N. Vernov
U.S.S.R. Academy of Sciences
Molodeshnaya 3
Moscow B-296,
U.S.S.R.

Dear Dr. Vernov:

I am writing a review article on the trapped, corpuscular radiation in the geomagnetic field and should like to include a proper account of your work in this field.

Thus far, we have received in the United States only fragmentary accounts -- i.e. copies of preliminary papers at the 5th CSAGI Reunion in Moscow July-August l958 and miscellaneous newspaper accounts.

Therefore, I should be very grateful for:

(a) A comprehensive bibliography of the Soviet satellite work; and if convenient
(b) A comprehensive collection of reprints and other prepared accounts of the work.

Sincerely yours,

J.A. Van Allen

Enclosure

The complex process of the discovery took a rather long time. Several groups of researchers came to these studies. They started from different initial hypotheses and searched for different things in space. They also observed different things, because orbits of early Soviet and American satellites allowed researchers to explore different areas of space. In a nutshell, the process of discovery with the help of satellites included Van Allen's initial discovery of the inner belt in May 1958 and Vernov's registration of the outer belt in July 1958 and understanding that there were, in fact, two zones of radiation in latitudinal dimension by October 1958 [9].

In addition the polarized world of Cold War propaganda had little respect for real-life ambiguities and complexities of the process of scientific research. The public side of the scientific discovery reflected the interests of two rival superpowers – US and USSR – and developed primarily in mass media with the help of the states' propaganda machines. Priority claims in this dispute were made in newspapers such as “Washington Post”, “New York Times”, “Time” (Photo), and “Pravda”, rather than in scholarly publications. For example Van Allen's announcement of the existence of two belts and his chart of two belts was published by the New York Times on 1 January 1959, while scientific journal Nature received the corresponding paper only on February 14th.

Results obtained by Vernov's group initially did not receive any substantial coverage in the Soviet media, which paid more attention to the very fact of Sputnik I, II and III launches rather than to their scientific results. Thus the media coverage of the story had different patterns in the Soviet Union and in the United States.

Only belatedly did Vernov and Chudakov get an access to central media and published a claim for their part in the discovery in “Pravda”. Eventually, Vernov received in 1960 a Lenin Prize for his discovery of the outer radiation belt thus winning credit for his contribution to the discovery inside the Iron Curtain. Outside the Iron Curtain, Van Allen succeeded in his priority claim on the discovery of the inner radiation belt.

J.A. Van Allen ("Time" 1959, May 4).

REFERENCES

[1]. Van Allen J.A. Origins of Magnetospheric Physics, Smithsonian Institution Press. Wash. (DC), 1983.

[2]. Archive of Russian Academy of Science, collection 1809, list 1, folder 260, p. 1.

[3]. Archive of Russian Academy of Science, collection 1809, list 1, folder 8, PP. 6-16.

[4]. Van Allen J.A., Ludwig G.H., Ray E.C., McIlwain C.E., Preliminary reports: Satellites 1958 Alpha and 1958 Gamma // Transactions, American Geophysical Union, v. 39, N 4 (August, 1958), p. 768.

[5]. Vernov S.N., Chudakov A.E., 1959, Izuchenie kosmicheskih luchey s pomosch'yu raket i sputnikov v SSSR Vtoraya mejdunarodnaya konferentsiya po mirnomu ispol'zovaniyu atomnoy anergii, provodivshayasya s 1 po 13 sentyabrya 1958 g. po resheniyu OON, M.: Atomizdat, V. 1, p. 263.

[6]. Vernov S.N., Grigorov N.L., Logachev Yu.I., Chudakov A.E. Izmerenir kosmicheskogo izlucheniya na iskusstvennom sputnike Zemli, // DAN SSSR, 1958, V. 120, **6**, P. 1231.

[7]. Archive of Russian Academy of Ssience, collection 1809, list 1, folder 260, p. 3.

[8]. Kellog W.W., IGY Rockets and Satellites: A Report on Moscow Meeting, August 1958 // Planetary and Space Sciences, 1959, v. 1, N 1, p. 71.

[9]. Vernov S.N., Vakulov P.V., Gorchakov E.V., Logachev Y.I., Chudakov A.E., October 1958, "Izuchenie myagkoy komponenty kosmicheskih luchey za predelami atmosfery" Iskusstv. sputn. Zemli, vyp. 2. p. 61. (This has been translated by J.L. Zygielbaum by September 1959, under the title: Astronautic information translation 2, Artificially earth satellites, Jet Propulsion Laboratory, California Institute of Technology).