

APL

Library
Bulletin

TRANSLATIONS SERIES

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY

8621 Georgia Avenue • Silver Spring, Maryland

TG 230-T466 11 March 1966

PHYSICAL PICTURE OF THE FORMATION OF AN
ARTIFICIAL RADIATION BELT BY THE AMERICAN
HIGH-ALTITUDE THERMONUCLEAR BURST OF 9 JULY 1962

by

Yu. I. Gal'perin

translated from

Issledovaniya Kosmicheskogo Prostranstva
[Cosmic Space Research]

Special Issue, pp. 388-393 (1965)

by

C. R. Haave

Summary

Direct observations by Kosmos-5 and other satellite sources indicate that the final radius of the plasma cloud accompanying the American high-altitude burst of 9 July 1962 did not exceed 600 km. This is less than the final radius for a plasma cloud expanding in a vacuum, which indicates considerable dissipation of energy. Particle ejection beyond the plasma cloud is assumed to be the reason for this discrepancy and three mechanisms are proposed to explain the ejection: 1) diamagnetic ejection of plasma blobs due to instability at the interface between plasma and field; 2) free separation in the magnetosphere of fission fragments neutralized in the beginning stages of cloud expansion, i.e., before the stage of "inertial separation"; 3) free separation in the magnetosphere of fragments neutralized by charge exchange between ions in the plasma cloud and neutral particles in the atmosphere.

Distribution of this document is unlimited.

CLEARINGHOUSE FOR FEDERAL SCIENTIFIC AND TECHNICAL INFORMATION			
Hardcopy	Microfiche		
\$ 1.60	\$ 0.50	12 pp	as
ARCHIVE COPY			

Coole /

AD681025
TT66-61005

PHYSICAL PICTURE OF THE FORMATION OF AN
ARTIFICIAL RADIATION BELT BY THE AMERICAN
HIGH-ALTITUDE THERMONUCLEAR BURST OF 9 JULY 1962*

by

Yu. I. Gal'perin

As has already been reported [1,2], instruments aboard the Satellite "KOSMOS-5" intended for the measurement of soft corpuscular radiation in the upper atmosphere recorded a burst of γ -radiation far beyond the limits of direct visibility of the burst region. If the altitude of the screening layer δ for γ -radiation is taken into account, radius r_{\min} of a spherical cloud of plasma centered at a point with coordinates ϕ_0, λ_0, h_0 , whose boundary would be tangent to the lower limits of the zone of direct visibility from the satellite (with coordinates ϕ_c, λ_c, h_c), can be found from the formula

$$r_{\min} = -(R_3 + h_0) \cos(\theta_0 - \mu) + (R_2 + \delta), \quad (1)$$

$$\left. \begin{aligned} \cos \theta_0 &= \sin \varphi_0 \sin \varphi_c + \cos \varphi_0 \cos \varphi_c \cos(\lambda_c - \lambda_0) \\ \cos \mu &= \frac{R_3 + \delta}{R_3 + h_c}; \quad R_3 \text{ — radius of the Earth} \end{aligned} \right\} (2)$$

With the satellite coordinates given in [1], the burst point $h_0 = 400$ km above Johnston Island [3], and using the calculated value $\delta = 64$ km, we obtain $r_{\min} \approx 770$ km. It is very important in the interpretation of the γ -radiation burst whether the radius of the expanding plasma cloud formed by the burst exceeded or did not exceed the magnitude of r_{\min} ; i.e., whether the cloud penetrated into the zone of direct visibility. Let us consider the experimental data on the diameter of a cloud of plasma in the geomagnetic field. First of all, such data can be obtained from observations of the artificial aurorae that accompanied the burst.

Photometric observations of the luminosity of the aurora in the near-equatorial regions of the southern hemisphere [3] showed that

*Translated from Issledovaniya Kosmicheskogo Prostranstva [Cosmic Space Research]; Special Issue, p.388-393 (1965).

intense luminosity was created in a belt $\pm 5^\circ$ wide in longitude along the geomagnetic meridian of Johnston Island immediately after the explosion. This luminosity could have resulted from direct excitation by particles from the plasma cloud which were absorbed in the atmosphere at the conjugate point. The luminosity could also have originated from a number of other causes: as a consequence of excitation by energetic photo-electrons formed beyond the limits of the plasma cloud by the action of short-wavelength radiation from the burst; or as a result of a discharge in the conjugate region of the ionosphere under the action of the electric field originating in the tube of force containing the expanding plasma cloud and transmitted along the field to the conjugate point as a consequence of the high electrical conductivity of the upper atmosphere along the field, and the like. However, the diameter of the region of luminosity obtained with all mechanisms is not less than the cloud diameter, although a very interesting fine-structure, i.e. thin rays, reminiscent of the natural polar aurora, was also observed inside the aurora. From this it follows that the radius of the plasma cloud in the horizontal direction along an east-west line did not exceed ~ 600 km.

Most important is determination of the limits of expansion of the cloud along the L-shells of charged particles' motion. Such data were obtained from measurements on the satellites "TRAAC" and "ARIEL" [3,4] by analyzing the intensity distribution in the "second" artificial belt of relativistic electrons which were injected by fission fragments remaining in the upper atmosphere of the burst region after dispersion of the plasma cloud. Inasmuch as the lower limit of the artificial belt ($h_{\min} \sim 200$ km over Johnston Island) passed only at an altitude of ~ 1000 km, the lower-lying regions of space can be populated only by "fresh" β -decays [Ref. 3, p. 64]. This permits data to be obtained on the distribution of fission fragments in the first to second days after the burst. It was found that the intensity of the "secondary" artificial belt fell off sharply for $L > 1.18$, so that a deep intensity minimum was observed between the

secondary and main belts [Refs. 3,4]. These results agree with the measurements on "KOSMOS-5". The shell $L = 1.18$ passes over Johnston Island at an altitude of about 700 km. Since it is difficult to expect an appreciable drift of these particles due to the circulation of the upper atmosphere in the course of the first 24 hours, the data presented here indicate that the radius of the tube of force containing the main portion of the fission fragments did not exceed ~ 300 km over Johnston Island and the maximum L-value reached was $L \approx 1.18$ [4].

Finally, a photograph was published in Ref. 5 of the luminous region in the upper atmosphere taken in the 5777 Å hydrogen line over Johnston Island 3 minutes after the burst, at a distance of ~ 1000 km, and the disposition of the magnetic lines of force and of the burst point is indicated. The luminosity within this interval of time must have arisen principally from β -decay of the radioactive products of the burst, and consequently, the location of the region of luminosity reflected the dispersion of the fission products in the atmosphere. From the photograph it is evident that the luminosity extended only within a tube of force of radius less than 400 km near the burst point. These direct data, therefore, are in good agreement with the deductions given above, which were obtained from analysis of the measurements of the "secondary" artificial belt.

Thus, direct observations show that the final radius r_k of the plasma cloud did not exceed 600 km, and possibly it was even smaller. The maximum radius attained by the plasma cloud is less than the final radius R_k of the expansion of the cloud of plasma in a vacuum [Ref. 6], which indicates a significant dissipation of the energy of the plasma expanding in the ionosphere in the vicinity of the F-layer maximum. The indicated value $r_k < r_{\min}$ and, consequently, the cloud is located entirely below the horizon for the satellite "KOSMOS-5". (Precisely for this reason, the term " γ -shine" was proposed in Ref. 1 as a qualitative metaphor to designate the detected burst of γ -radiation).

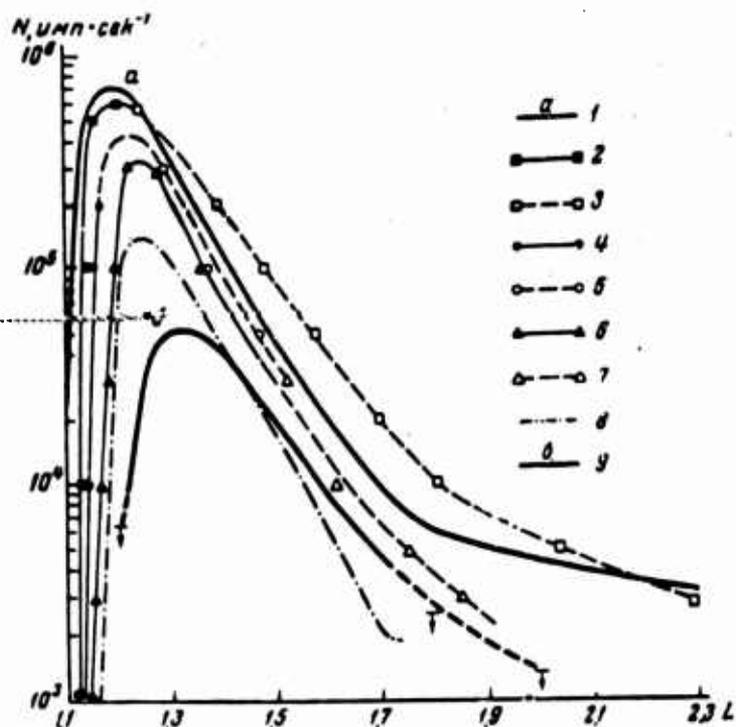


Figure 1. Distribution over L of the counting rate N (pulses/sec) of the Geiger counter on KOSMOS-5 in the equatorial plane. Measurements and model (see text) and the EXPLORER-15 and ELECTRON-1 measurements are normalized to the same intensity of the fission β -spectrum.

I. - From KOSMOS-5 data (1962): 1-measured ($L \lesssim 1.25$) and model ($L \gtrsim 1.25$), 9 July; 2 and 3- measurements and model, resp., 10 July; 4 and 5- measurements and model, 17 and 19 July, resp.; 6 and 7- measurements and model, 12 August and 16 Oct., resp.

II. - From EXPLORER-15 data: 8 - $E > 4.5$ Mev, 1 Jan. 1963.

III. - From ELEKTRON-1 data: 9 - $E > 1.1$ Mev, Feb. 1964.

Nonetheless, fission fragments undoubtedly penetrated to high altitudes (and high L-values), inasmuch as the radiation belt extended at least up to $L \sim 3.5$ (according to data from KOSMOS-5, Ref. 2) and up to at least $L \sim 6.5$ (according to data from ARIEL, Ref. 4). In Fig. 1 are given the results of the construction of model distributions of the counting rate of the KOSMOS-5 counter. In their lower portions they coincide with the values measured on the KOSMOS-5 and were extrapolated to the equatorial plane on the following basis: a) intensity measurements in the artificial belt during 1964 from the satellites ELEKTRON-1 and ELEKTRON-3, and b) measurements of the rate of decay of intensity (lifetime) by the satellites KOSMOS-5, and also INJUN-1 and INJUN-3 [Ref. 7], EXPLORER-15 and RELAY-1 [Ref. 8], ELEKTRON 1 and ELEKTRON-3

[Ref. 9] and calculations [Ref. 3, p. 98; Ref. 10]. In this same figure, for comparison, are shown the results of the measurement of hard electrons ($E \approx 4.5$ Mev) on the EXPLORER-15 [Ref. 8]. This is a lower estimate, since it was assumed that the particle concentration in the tube of force above about $h_{\min} = 500$ km was constant, i.e. the distribution was isotropic.

As can be shown, the volume $U(L)dL$ of a radiation belt of thickness dL above some h_{\min} is

$$U(L)dL = \left(4/3\pi R_3^3\right) \cdot \frac{3}{35} \cdot L \cdot \sqrt{\frac{l-1}{l}} \left(16 + \frac{8}{l} + \frac{6}{l^2} + \frac{5}{l^3}\right) dL, \quad (3)$$

where
$$l = L \cdot \frac{R_3}{R_3 + h_{\min}}$$

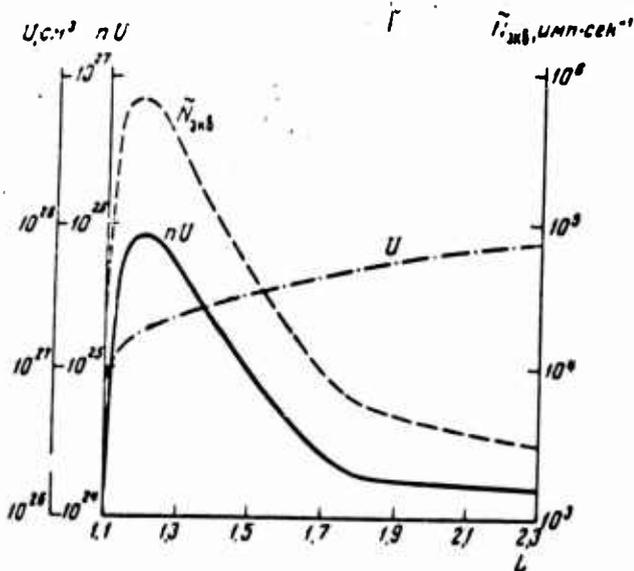


Figure 2. The function $U(L)$, and also the total number of electrons on the L-shell, $n(L) U(L)$. The first model of the intensity distribution \tilde{N}_{eq} in the equatorial plane is shown for comparison.

The plot of the function $U(L)$ is given on Fig. 2 together with the model distribution of counting rate \tilde{N}_{eq} for 9 July 1962. On Fig. 2 is also shown the total content of trapped electrons in the belt (nU), with $n = \tilde{N}_{eq} \times Kc$, where $1/K$ is the counting efficiency to β -spectrum fission fragments ($K = 2 \times 10^3$ particles \times cm^{-2} /pulse and c is the velocity of light):* Integrating the quantity nU over L gives the total number of electrons injected into the belt.

As a result of integration, it was found that after about one hour after the burst there were about 1.5×10^{25} electrons in

*We ignore the possible softening of the fission electron spectrum with increasing L [Ref. 3, p. 7], since measurements by ELEKTRON-1 and ELEKTRON-2 [Ref. 9] showed that in this region there existed a very intense electron component of natural origin, which was not excluded in the results [Ref. 3, p. 8].

the artificial belt with energies greater than 20 Kev. An estimate shows that such a quantity of electrons in the belt required the decay at corresponding altitudes (above about 1200 km over Johnston Island, i.e., in the limits of direct visibility from KOSMOS-5) of the fragments of about 10^{25} fissions [Ref. 2] whereas during the burst about 2×10^{26} fissions [Ref. 3, p. 25] had evidently taken place.

An upper estimate of the time during which these fission fragments penetrated far from the confines of the plasma cloud can be obtained from the measurements of the burst of γ -radiation. The most important factor is that the products of exactly 10^{25} fissions were found [Ref. 2] within the zone of direct visibility from KOSMOS-5 only 3 seconds after the burst. The quantitative agreement of data on the number of injected fission fragments from measurements of the radiation belt and from measurements of the " γ -shine" leads to the conclusion that both these effects, the " γ -shine" and the radiation belt have the same source - the decay of a small portion of the radioactive fission fragments in the geomagnetic field beyond the limits of the burst cloud. The particles may possibly be ejected beyond the limits of the cloud by the following mechanisms [Ref. 2] (Fig. 3).

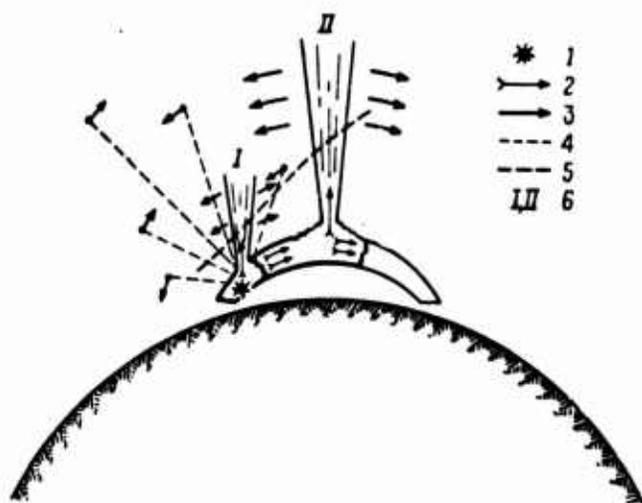


Fig. 3. Schematic illustration of the diffusion of fission fragments in the upper atmosphere following the explosion.

1- Burst point; 2- plasma motion; 3- motion of trapped particles; 4- motion of neutral particles; 5- horizon line for KOSMOS-5; 6- eruptive ejection of plasma.

A. Diamagnetic ejection of blobs of plasma owing to instability at the plasma-field boundary. Actually, this boundary is convex toward the field and thus cannot be stable [Ref. 11]. As a consequence of the significant times of relaxation and expansion,

blobs of plasma will also be expelled toward the side of decreasing geomagnetic field, i.e. upward, much like the process of diamagnetic ejection of blobs of plasma in the solar chromosphere [Ref. 12].

B. Free dispersion in the magnetosphere of fission fragments neutralized in the initial stages of the expansion of the burst cloud, i.e. even before the state of "inertial dispersion". Such a mechanism was proposed in Ref. 4 to explain the observation by "ARIEL" of the burst of rapid counting about 20 seconds after the burst.

C. Free dispersion in the magnetosphere of fission fragments neutralized as a consequence of charge exchange between plasma cloud ions and neutral particles of the atmosphere. Since the number of neutral particles along the path of a fission fragment, and also the degree of ionization in the atmosphere after the burst, depend strongly on the angle between the velocity vector of the ion and the vertical (zenith angle z), the main part of these ions must have traveled in the vicinity of the horizontal plane with respect to the burst point and must have had some distribution of velocity v_0 .

It must be considered that, on the average, β -decay of each of the two fission fragments occurs within 15 seconds, after which a fragment again becomes an ion and is "trapped" by the magnetic field. Some portion of the fragments is precipitated into the dense atmosphere and absorbed, which gives rise to an additional decrease in γ -radiation intensity after 10 to 20 seconds. On the other hand, owing to the approach of the satellite to the burst cloud and to the westward drift, toward the satellite, of the ionized fragments trapped after β -decay, some relative increase in γ -radiation intensity should take place in 1 to 2 minutes. However, during the course of the first ~ 200 seconds, neither of these effects is very significant. Figure 4 gives a comparison

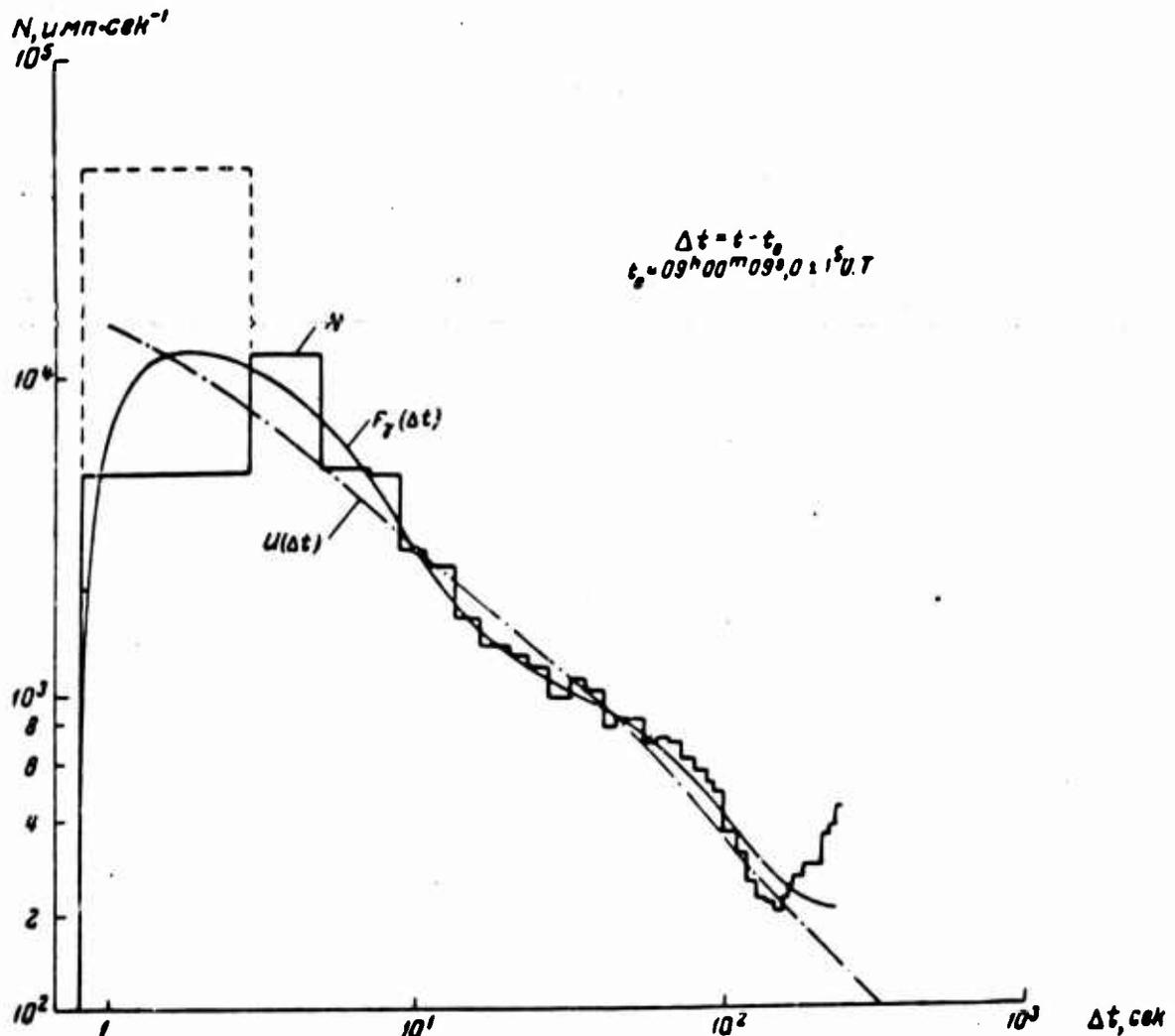


Figure 4. Comparison of the calculated time trend of γ -radiation intensity for fission fragments with velocity $v_0 = 1000 \text{ km sec}^{-1}$ and the observed "gamma-shine" 9 July 1962.

of the observed counting rate N of the counter aboard "KOSMOS-5" at the time of the "gamma-shine" and the computed trend $F_\gamma(\Delta t)$ of the intensity of γ -radiation from fission fragments ejected at the moment $t_0 = 9\text{h } 00\text{ m } 09.0 \text{ sec (UT)}$ [Ref. 3] with uniform velocity $v_0 = 1000 \text{ km sec}^{-1}$ and with a distribution over Z proportional to $B(z)$ - the Bemporad function, which is probably descriptive of charge-exchange particles. Taken into account were only the change in dilution coefficient due to expansion of the cloud (the first 15 seconds) and to the relative approach of the satellite (after 1 to 2 min); the departure of particles from the zone of direct visibility, the distribution of the particles with respect to v_0 and the effective scattering of γ -radiation in the atmosphere were neglected. Therefore, the agreement of final detail is in some respects fortuitous, although the qualitative character of the trend of γ -radiation intensity with time (proportionality $u(\Delta t)$ after the first few seconds [Ref. 2]) is very

weakly dependent on v_0 .

Some contribution to the observed intensity could also have been provided by fission fragments ejected by mechanisms A and B mentioned above. Auroral rays directed upward from the equatorial region of the tube of force of the burst, apparently connected with plasma outbursts, were in fact observed [Ref. 3].

In conclusion we express our gratitude to V. I. Krasovski, S. B. Pikel'ner, A. S. Strelkov and Yu. V. Kukushkin for their useful discussion of the results.

References

1. Yu. I. Gal'perin and A. D. Bolyunova. Cosmic Research; 2, No. 5, 669 (1964); Space Res.; 5, 446, (1965).
2. Yu. I. Gal'perin. Kosmicheskie Issledovaniya; 3, No. 3, 426 (1965).
3. Operation "Starfish". Atomizdat. 1964.
4. A. C. Durney, H. E. Elliot, R. J. Hynds, J. J. Quenby. Nature; 195, 1245 (1962); Preprint 1964.
5. U. S. National Report to V COSPAR, Florence, May 1964.
6. Yu. P. Raizer. PMTF; No. 6, 19 (1963).
7. W. Hess. Space Res.; 4, 60 (1964).
8. C. E. McIlwain. Science; 142, 355 (1963); Preprint March 1964.
9. A. D. Bolyunova, et al. This collection, p. 406; Space Res.; 6, (1965) (in press).
10. M. Walt, L. L. Newkirk. Space Res.; 5, 458 (1965); J. Geophys. Res.; 69, No. 19, 3947 (1964).
11. L. A. Artsimovich. Upravlyaemie Termoyadernie Reaktsii [Controlled Thermonuclear Reactions]; Fizmatgiz (1961).
12. M. A. Lifshitz, S. B. Pikel'ner. Soviet Astron.-AJ; 8(41), 368 (1964).

Distribution of this document has been made in accordance with a list on file in the Distribution Project of the APL/JHU Technical Reports Group. This distribution includes 20 copies to the Defense Documentation Center.

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) The Johns Hopkins University, Appl. Phys. Lab. 8621 Georgia Avenue Silver Spring, Maryland		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
		2b. GROUP	
3. REPORT TITLE APL LIBRARY BULLETION (TRANSLATIONS SERIES) - PHYSICAL PICTURE OF THE FORMATION OF AN ARTIFICIAL RADIATION BELT BY THE AMERICAN HIGH-ALTITUDE THERMONUCLEAR BURST OF 9 JULY 1962			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) ---			
5. AUTHOR(S) (Last name, first name, initial) Yu. I. Gal'perin			
6. REPORT DATE 11 March 1966		7a. TOTAL NO. OF PAGES 9	7b. NO. OF REFS 12
8a. CONTRACT OR GRANT NO. NOw 62-0604-c b. PROJECT NO. c. d.		9a. ORIGINATOR'S REPORT NUMBER(S) TG 230-T466 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) ---	
10. AVAILABILITY/LIMITATION NOTICES Distribution of this document is unlimited.			
11. SUPPLEMENTARY NOTES ---		12. SPONSORING MILITARY ACTIVITY Bureau of Naval Weapons Department of the Navy	
13. ABSTRACT Direct observations by Kosmos-5 and other satellite sources indicate that the final radius of the plasma cloud accompanying the American high-altitude burst of 9 July 1962 did not exceed 600 km. This is less than the final radius for a plasma cloud expanding in a vacuum, which indicates considerable dissipation of energy. Particle ejection beyond the plasma cloud is assumed to be the reason for this discrepancy and three mechanisms are proposed to explain the ejection: 1) diamagnetic ejection of plasma blobs due to instability at the interface between plasma and field; 2) free separation in the magnetosphere of fission fragments neutralized in the beginning stages of cloud expansion, i. e., before the stage of "inertial separation"; 3) free separation in the magnetosphere of fragments neutralized by charge exchange between ions in the plasma cloud and neutral particles in the atmosphere.			

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Geophysics Thermonuclear explosion Cosmos-5 (satellite) Artificial radiation belt						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.
- 2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.
- 2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.
3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.
4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.
5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.
6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.
- 7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.
- 7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.
- 8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.
- 8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.
- 9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.
- 9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).
10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.
12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.
13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U)

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.