Possibility of Biological Effects of Cosmic Rays in High Altitudes, Stratosphere and Space

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RECENT DISCUSSIONS on aero medical problems of space travel (Armstrong, Haber and Strughold[4]) have called attention to the possibility that cosmic rays in the stratosphere and in space may influence stratosphere planes, rockets, space ships and their freight (humans, animals and plants).

There is no doubt—as shown by Hess and Eugster[28] in their report, "Cosmic Radiation and Its Biological Effects"—that cosmic radiation under special conditions, especially by shower-formation, can produce biological effects. It is not the primary radiation and the ionization alone that concern us but we encounter secondary effects connected with nuclear evaporation processes and nuclear break-up events which, in turn, influence biological material.

Recently, cosmic ray research has produced new discoveries in this field, concerning heavy nuclei in the primary component of cosmic radiation, the creation of high energy cosmic ray stars, the production of mesons and the origin of the radiation. A review of our present knowledge as to the possibility of biological effects caused by cosmic radiation at high altitudes and in space seems, therefore, justified and, in light of the seriousness of aero medical problems of space travel, necessary.

MODERN COSMIC RAY PHYSICS*

The Heavy Nuclei in the Primary Component of Cosmic Radiation.—Until a few months ago, the primary component of cosmic radiation was thought to consist mainly of protons. There was no evidence for the existence of heavier particles as postulated by several workers.

However, recent applications of new emulsions highly sensitive to electrons have changed the situation completely.[10,19,20,50,71] These new photo plates (Eastman NTB-3, Ilford G-5 Kodak NT-4), flown for several hours high in the stratosphere—in the experiment of Bradt and Peters,[10] in four flights for three to six hours to 95,000 feet (equivalent to 16 gm./cm.^{2} of residual atmosphere)—have shown the first direct proof for the existence of energetic heavy nuclei in cosmic ray primaries.

The heavy nuclei enter the atmosphere from the upper hemisphere of space with energies up to 0.8 x 10^{13} eV and atomic numbers up to 26 $\pm$ 2. At a geomagnetic latitude of $\lambda = 30°$, of a measured 450 incident particles, 356 were protons, 90 were helium nu-

*This review concerns only the recent data. For more detailed discussions see: D. J. X. Montgomery, "Cosmic Ray Physics, based on lectures given by Marcel Schein," Princeton, 1949; C. F. Powell and G. P. S. Occhialini, "Nuclear Physics in Photographs," Oxford, Clarendon Press, 1947.

See also Medical Department Field Research Laboratory Report 6-24-12-08-(7), April 28, 1950.

TABLE I. FLUX OF HEAVY PRIMARIES AT GEOMAGNETIC LATITUDES $\lambda = 55°$, $\lambda = 51°$, $\lambda = 30°$

Geomagnetic Latitude	Flight No.	Exposure Time in Hours	Altitude in gm./cm.^{2} air	At the Top of the Atmosphere $10^3 \cdot I_0$ (10^3 nuclei)/cm.^{2} sec.^{1} sterad^1		
				$Z = 2$	$6 < Z < 10$	$Z > 10$
55°	4	6	16	—	1.1 ± 0.2	0.30 ± 0.1
51°	3	3	10	38 ± 13	1.2 ± 0.3	0.25 ± 0.07
30°	2	6	16	9 ± 3	0.35 ± 0.06	0.10 ± 0.03

clei, 3.5 belonged to the C, N, O-group, and one had an atomic number $Z > 10$. Three flights at the top of the atmosphere gave, in the experiments of Bradt and Peters, the data shown in Table I.

Similar results are reported by Lord and Schein,[41] who, studying 550 events obtained at an altitude of 95,000 feet, estimate the incident particles to consist of about 90 per cent of single charged particles of minimum ionization probably all primary protons, and about 10 per cent of particles at least as heavy as alpha particles.

In the earlier work by Freier, Lofgren, Ney, Oppenheimer, Bradt and Peters,[19] it was estimated that the number of incident heavy nuclei with $Z > 10$ is at least about one for every 500 primary protons.

If the incident nuclei are stripped of electrons, then the results at a geomagnetic latitude of $\lambda = 30°$ show their energy per nucleon to be at least 3.5 x 10^9 eV (the geomagnetic cut-off energy at this latitude). For the heavier nuclei with $Z > 10$, the total energies are up to $10^{11} - 10^{13}$ eV.

According to Bradt and Peters, no particles were found with atomic numbers higher than 26 ± 2, corresponding to elements in the neighborhood of iron. About ¾ of the nuclei with charges $\geqq 6$ belong to the C, N, O group ($6 < Z < 10$); about 60 per cent of the heavier nuclei with $Z > 10$ belong to the Mg, Si group ($11 < Z < 15$), and about 10 per cent to the iron group ($Z = 26 \pm 2$).

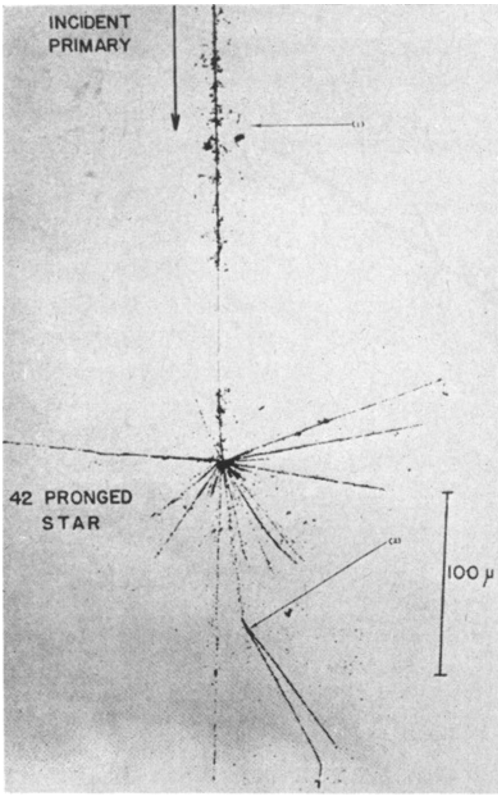
THE COSMIC RAY STARS

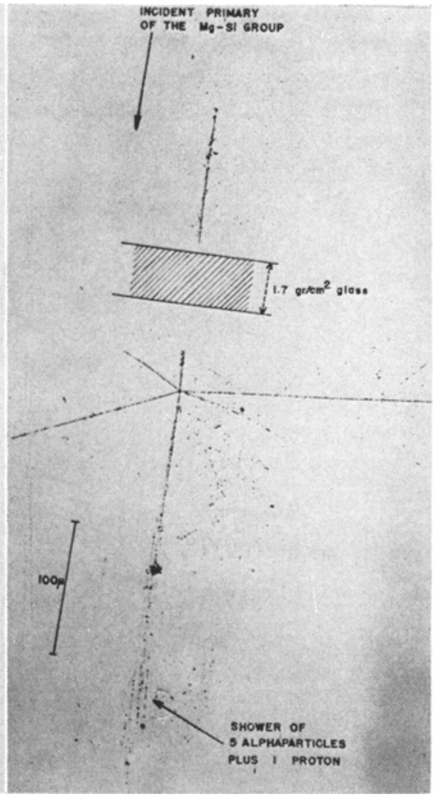
1. *The Explosion-Stars.*—The heavy nuclei coming from outside the atmosphere with energies up to about 10^{13} eV are able to produce specific, hitherto unknown effects as shown by the photographic emulsions flown to the top of the atmosphere. They create, in general, stars of different kinds,[1,27,40] with more or less numerous prongs. A few typical stars are shown in Figures 1-4.

The star events occur relatively often at the top of the atmosphere; according to Bradt and Peters, at $\lambda = 30°$ with a frequency of 450 stars per square meter, per second, per steradian.

The prongs (secondaries), produced in these violent nuclear explosions consist of all kinds of particles and respective rays: electrons, mesons, protons, heavy nuclei, neutrons, neutrinos, neutrettos and gamma rays.

The explosions happen, so far as is known, at the top of the atmosphere and are nuclear events of a special nature. Their importance and novelty lies—as pointed out by Leprince-Ringuet[40]—in the demonstration of the pro-





Courtesy Physical Review, 1950

Fig. 1. Collision of a primary Ca-nucleus ($Z=20\pm1$), with an energy of the order of at least 100 BeV and an Ag or Br nucleus in the emulsion of a Kodak NTB3, flown at $\lambda=30°$N., at an altitude of about 100,000 feet.

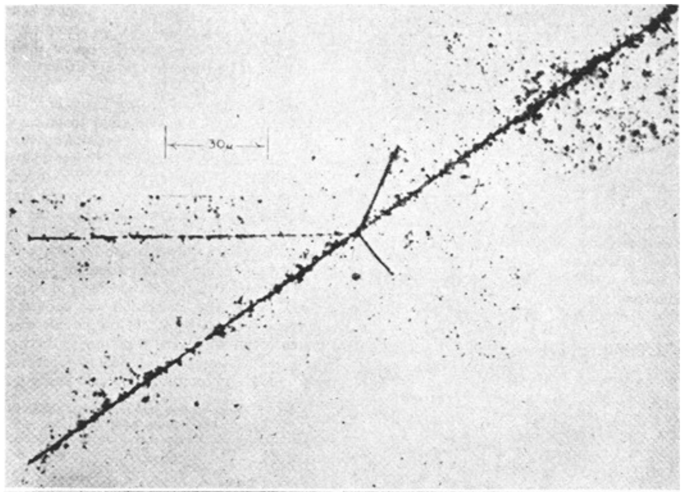
Forty-two charged particles are emitted in this violent explosion. Ten prongs are minimum ionization tracks, collimated in the forward direction (they are hardly visible in the figure); most of them probably are tracks of a meson shower. One fast, single charged particle causes a second nuclear event.[2] (From Bradt and Peters: Phys. Rev., 77:55, 1950.)

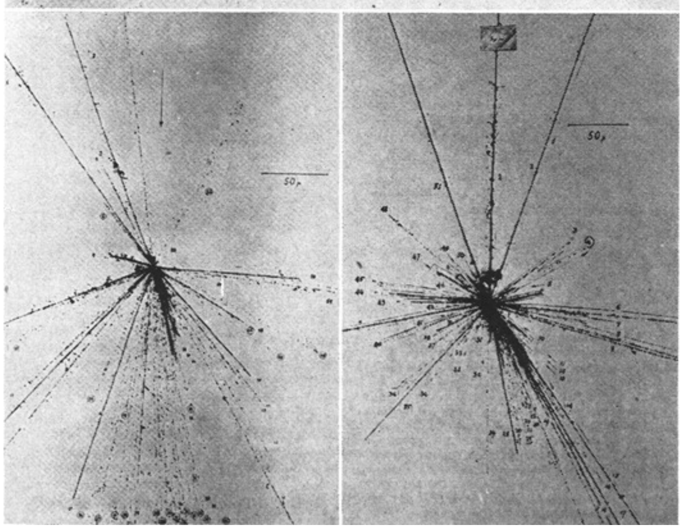
Fig. 2. Collision of a nucleus of Mg-Si group ($Z \sim 12-14$), resulting in a narrow shower of five doubly charged relativistic particles (α-particles) and one singly charged relativistic particle (proton).

The particles of the shower, carrying 11 units of charge, are considered to be the products of the dissociation of the incident nucleus. A second minimum ionization track emerges with an angle of 30° with respect to the shower axis. Four low energy particles ejected from the star at large angles with respect to the direction of the primary are considered to be fragments of the target nucleus. (From Bradt and Peters: Phys. Rev., 77:56, 1950.)

duction of multiple charged particles (electrons and gamma), as well as in the fact that multiple neutral particles are created in these high energy nucleon-nucleon collisions. The mechanism of the process is unknown, and different phenomena are probably involved in these nuclear break-ups.

An interesting and important result may be mentioned here. Addario and Tamburino[1] examined Ilford C-2 plates, which had been exposed at $\lambda=55°$ N.g.L. at 29,000 meters for several hours; the balloons spending 2.2 hours between sea level and 27,500 meters and 5.3 hours above 27,500 meters. Superimposed was only the aluminum of the sphere (1 mm. in thickness), in which the plates were carried.





Courtesy Physical Review, 1950

Fig. 3 *(above)*. A nucleus with charge Z ~ 20 causes ejection of three charged particles from a target nucleus without suffering any noticeable deflection or loss of charge.

This event, which was observed by Dr. E. O. Salant and Dr. J. Hornbostel, may be the result of a rather distant collision. (Courtesy of Dr. E. O. Salant and Dr. J. Hornbostel, Brookhaven National Laboratory.) (From Bradt and Peters: Phys. Rev., 77:60, 1950.)

Fig. 4 *(below)*. Two characteristic nuclear cosmic ray stars obtained at high altitude of about 100,000 feet with Ilford G-5 emulsions. Energy involved in the process is more than 12 BeV.

Star No. 1 *(left)* contains: 27 ionizing prongs, corresponding to the usual type of nuclear fragments (protons, α-particles, etc.); 27 relativistic prongs, all well collimated. No incident primary particle has been observed.

Star No. 2 *(right)* contains: 51 prongs, 17 of which are relativistic. Produced by a heavy primary with Z between 14 and 20. (From Leprince-Ringuet, Bousser, Hoang-Tchang-Fong, Jauneau and Morellet: Phys. Rev., 76:1273, 1949.)

In 1.120 $cm.^3$ of emulsion, Addario and Tamburino found 488 stars with three or more prongs, which indicates a star frequency of 1950 stars per cubic centimeter, per day in the relatively insensitive Ilford C-2 emulsion. The frequency of stars with four or more prongs was 1450 stars $cm.^{-3}$ $day,^{-1}$ while Hornbostel and Saltan[30,31] give for the same kind of stars at 30,000 meters altitude, a frequency of about 2000 stars $cm.^{-3}$ $day.^{-1}$

2. *Evaporation-S t a r s.*—Somewhat more is known as to the evaporation-stars which were observed for the first time in 1936 by Anderson and Neddermeyer[3] in cloud chamber experiments and in 1937 by Blau and Wambacher[8] in photographic emulsions. They are low-energy events—the energies involved in the process being 89 MeV at 200 meters above sea level, about 144 MeV at 3450 meters above sea level (E. Bägge[5]) and a few hundred MeV in special cases.

Their frequency is relatively well known. Bernardini, Cortini and Manfredini[7] give, for the frequency of stars with three or more prongs, at an altitude of 3500 meters above sea level (equivalent to 685 $gm./cm.^3$ of air) without superimposed absorbers, the value of about fifteen stars per $cm.^3$ per day, and for stars with three prongs and less, the value 39 to 60 stars per $cm.^3$ per day.

3. *The Nature of the Star-Exciting Radiation.*—The explanation of the stars is very complicated and controversial. In the case of the high-energy explosion-stars, the incident heavy nuclei are one group of the exciting agents; in the case of the low-energy evaporation-stars, different suggestions and hypothesis have been proposed. Bägge argues that high-energy gamma rays may produce the stars. Perkins,[48] and Occhialini and Powell[47] have gotten stars at the end of a slow meson track. Powell[51] concludes that high-energy neutrons may be the producers of stars and Rossi[57] with his co-workers, could show that most of the stars and bursts are due to nuclear disintegrations and not to air showers. These theories are of interest in that they show how complicated the situation is and how many events are involved when cosmic rays produce secondary effects. The importance of these events in connection with biological effects cannot be over-emphasized.

MESONS

Closely connected with the reported events are the mesotrons or mesons. They are produced in nuclear processes (nuclear disintegrations and collisions) and play an important role in the production of cosmic ray showers as well as in the reverse processes. Their lifetime is very short, depending on the kind of meson, between 10^{-6} seconds and 10^{-13} seconds.

Today, several kinds of mesons are known and relatively well investigated; the best known are the μ-meson, the π-meson and the τ-meson. They are distinguished by their mass, their charge, their lifetime and their fate.[13,16,24,37,39,49,61,64,73,74]

The μ-meson, the "ordinary" meson, predicted by Yukawa, 1935-36, and discovered by Neddermeyer and Anderson, 1938, has a mass of 217 $\pm$ 4 electron masses.[39] It exists with a negative or with a positive charge. Its lifetime is about 2 x 10^{-6} seconds and it disintegrates into an electron and 2 neutrinos.

The π-meson is a heavier meson, its mass being about 285 $\pm$ 1 electron masses.[16] It also exists with a negative or a positive charge and disintegrates probably into a μ-meson and a neutrino, perhaps also an electron and a neutrino. The latter process is believed to be 100 times slower than the μ-meson-neutrino process. The π-μ-decay involves delays of about 10^{-8} seconds.

The τ-meson is a very heavy meson with a mass of about 725 $\pm$ 40 electron masses.[74] It carries a single positive or negative charge and its lifetime is, according to Forster,[24] about 10^{-12} seconds.

Reported is also the existence of a neutral meson with a mass of about 300 electron masses.[13,24] It may decay into two photons with an upper lifetime limit of $\leqq 10^{-13}$ seconds.

THE ORIGIN OF COSMIC RAYS

The origin of cosmic rays is still unknown and is a highly discussed subject at the moment. While, in the past, the fact that the radiation incidents from all directions favored the theories, which believe interstellar space to be the source of cosmic rays, recent observations[2,23] as to the correlation between sun-activity and cosmic-ray intensity as well as the theories by Alfvén, Spitzer,[66] Richtmyer and Teller[56] and Fermi[17] make it possible that the sun may be the source of cosmic radiation.

Important for the discussion are a few thoughts connected with the existence of heavy nuclei in the primaries of cosmic radiation. These heavy nuclei come from the outside and they must originate somewhere in the hemisphere. Spitzer and Bradt and Peters point out that these nuclei may arrive as parts of still larger structures. Extending the supernovate theory of Zwicky, they propose, as possible mechanisms:

1. Supernovae produce cosmic radiations with expulsion of high speed atoms from the stellar surface. They assume these heavy nuclei to be small, solid particles or dust grains, which are accelerated by the radiation pressure in the neighborhood of supernovae. The velocities reached in this process are close to that of light. These high speed grains do not last long, if they, as postulated, by Fermi, are retained in the galactic plane by strong magnetic fields. They will collide with low speed grains in an interstellar cloud and/or encounter H-atoms. Thus, the grains will gradually disintegrate into cosmic-ray particles of the heavier elements, primarily O, Mg and Fe. The computed density of these particles in space is consistent with the observed flux of heavy nuclei at the top of the atmosphere. Each of these grains or dust particles has a radius of 10^{-6} cm. and contains about 10^6 atoms. In the galaxy, the density of these high speed atoms is about 5 x 10^{-14} per cm.,[3] while the density of interstellar matter may be (0.2 – 1) H-atoms per cm.,[3] equivalent to a density of about 10^{-24} gm./cm.[3] This yields a particle flux of about 10^{-4} atoms per cm.[2] per second per sterad, in accordance with the observed experimental data for cosmic

TABLE II. RELATIVE ABUNDANCE OF ELEMENTS IN INTERSTELLAR SPACE

	$Z > 10$	C, N, O	$Z = 2$	H
Unsöld	1	~ 6	~ 500	~ 5000
Bradt and Peters	1	~ 3.5	~ 100	~ 400-600
Bradt and Peters (Table VIII)	1	~ 14	~ 400	~ 1600

radiation at $\lambda = 30°$: 1×10^{-4} nuclei with $10 < Z < 28$; 4.3×10^{-4} nuclei for C, O, N-group and 90×10^{-4} nuclei for helium.

2. The heavy nuclei observed may be the products of sudden break-ups of fast dust grains due to collisions in interstellar space or an appreciable number of such dust particles, not broken up in interstellar space, succeeds in penetrating the earth's magnetic field at the top of the atmosphere.

Bradt and Peters also discuss the possibility that cosmic rays, according to Alfvén, Richtmyer and Teller, are accelerated in the neighborhood of the sun. These particles then will circle in complicated curves in the planetary system, until they hit, coming from all directions, the earth.

Another hint as to the origin of cosmic radiation may be gained by studying the relative abundance of the observed heavy nuclei. Conclusions as to this question can be drawn from the experiments of Bradt and Peters[10] and the data on the relative abundance of nuclei in the atmosphere of the sun and of τ-scorpii given by Russell and Unsöld.[10,17,46] The latest data on stellar atmosphere indicate that for each atom of any metallic element, there are about six atoms for the group C, N, O and about 500 atoms of helium with about 5000 atoms of H (Table II).

Important may be, in this connection, the considerations of Teller.[68] He emphasizes that photographic plates of high sensitivity were flown by balloons up to 100,000 feet; by using V-2 rockets, however, distances five times greater could be reached. At these altitudes, the effects which give evidence for the existence of heavy nuclei become greater, so that these heavy particles which quickly dissipate their energy when traversing the highest atmosphere could be detected. To find them, "The apparatus had to be taken closer to heaven than," according to Teller, "any living physicist can ascend." He emphasizes too that these particles carry far more energy than necessary to tear them up into their constituent parts—energies which suddenly are set free in the observed nuclei collisions.

BIOLOGICAL EFFECTS OF COSMIC RAYS

The question as to biological effects of the cosmic radiation arose after the pioneer work of H. J. Muller[43] in 1927 on genetic effects of x-rays. It has been taken up by numerous investigators at different times and with different methods.

While in the earlier days, only the primary cosmic radiation was investigated and the ionization was taken as a basis for the discussion, later experiment made use of the secondary effects of cosmic radiation, especially of the "shower" radiation. In nearly all these cases, where secondaries were applied, positive effects were obtained, while in the earlier kind of experiments with primary radiation alone, in agreement with ionization calculation, clear-cut effects could be gained only in a few cases.[28]

In the past, it was the tendency to answer the question as to biological effects of cosmic radiation, by protecting the material from the irradiation. The biological material was placed in deep mines or protected with thick iron shields, while the control material was exposed under normal conditions (Sievert[63]).

In 1935-36, however, Rajewsky, Krebs and Zickler[54] systematically made use of the fact that cosmic radiation produces, in proper absorbing material, "showers" which easily can be demonstrated and studied with cloud chambers. In such a shower case, the energy of a single incoming cosmic ray is split up into numerous secondaries—there are showers with up to several thousand secondaries—so that not only the hit probability but also—by producing a softer radiation—the absorbing probability is increased.

To get the most pronounced effects, Rajewsky, Krebs and Zickler shielded their samples (protein-solutions, fungi Bombardia Lunata, and drosophila) with lead shields, the thickness of which was varied according to the Rossi curve[57] and the shower experiments of Schwegler.[62] The details of the experimental setup are given in Figures 5 and 6.

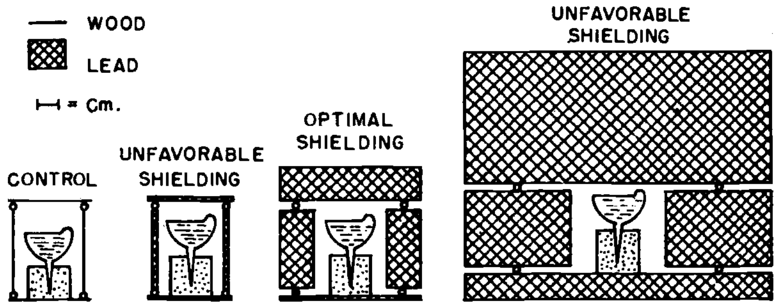


Fig. 5. Cosmic ray shower experiment, with solution of proteins. (After Rajewsky, Krebs and Kasten.)

After an exposure of four to six weeks at nearly sea level (Frankfurt am Main), the Bombardia experiments gave the results shown in Table III.

TABLE III.

Shielding	Total Number of Secondary Cultures	No. of Mutated Cultures	% of Mutated Cultures
Controls and Unfavorable Shielding	3095	22	0.71
Optimal Shielding	2721	85	3.1

The effect on the protein solutions was studied by counting the floculated particles with the ultramicroscope. The results, obtained by counting of about 30,000 particles, were in close agreement with the Rossi curve. While the controls and unfavorable shielded samples (1 mm. of lead and 60 mm. of lead) gave a low number of particles in the volume unit, the optimal shielded samples (15 mm. of lead) gave, in several independent experiments, a number three to four times as high as the control (controls and unfavorable shielded samples) values. The exposure times in these experiments were six to eight weeks, and the series—this may be emphasized here—were set up with distances of several yards between the samples.

These shower shielding experiments were varied and repeated, from different sides, especially by Eugster, at high mountains where the shower effect is greatly increased. The first high mountain experiments were done at the Hafelekar (2340 m.), in Austria, and later at the Jungfrau-Joch (3400 m.), in Switzerland. The striking results obtained by Eugster and his co-workers are described in the book of Hess and Eugster[28] together with a critical view of all other investigations done in this field.

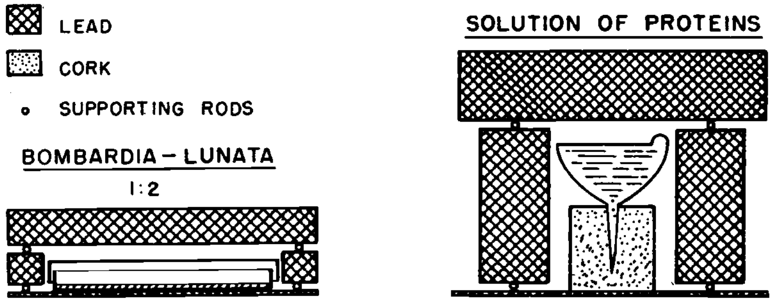


Fig. 6. Cosmic ray shower experiment. Optimal lead shielding 15 mm. (After Rajewsky, Krebs and Zickler, and Rajewsky, Krebs and Kasten.)

Working at high mountains and high altitudes, no biological effects of the primary radiation could be found by Stubbe[67] and Friesen.[21,22] Stubbe exposed plants at the Jungfrau-Joch and Friesen flew drosophila flies for two hours at 15,900 meters. No clear-cut effect could be gotten with "shower" radiation in the drosophila experiments of Rajewsky, Krebs and Timoféeff. Unfortunately, these experiments were interrupted by the war, and as reported by Rajewsky and Timoféeff,[53] the number of the exposed flies has not been great enough to make final decisions.

Positive effects as to the influence of cosmic radiation on carcinogenesis in mice were obtained recently by George, George, Booth and Horning[26] and by F. H. Figge.[18] In both cases, shielded radiation was used and a part of the experiments was done in deep mines.

DISCUSSION

Nearly all outstanding biological effects of cosmic rays have been obtained so far with secondaries. In these events physical processes are involved known as extensive-showers, penetrating-showers, and air-showers characterized by the fact that in all these cases the incident particle is split up into a "shower," into a bundle of particles and rays. The number of the produced secondaries depends on the material in which the showers are produced, on its thickness and on the kind of exciting radiation. There are very small showers with two or three prongs only, but also very large showers with several thousand prongs. It is assumed that biological effects are obtained with these secondaries because, by the multiplication of the incident particle, the probability for a "hit-event" is enlarged and by the softening of the radiation the absorption-probability is increased.

If this is true, then the newly discovered effects produced by cosmic radiation in matter by nucleon-nucleon collisions can be expected to have at least similar, if not stronger, effects. These nuclear break-ups going on in the high atmosphere have been unknown hitherto and the conclusions to be drawn from their existence as to stratosphere and space travel are obvious.

To date, little is known about biological effects at high altitudes. The experiment of Friesen, with drosophila flown for two hours up to 15,900 meters, is the only research in this field. It shows by well-intentioned interpretation, that there may be within two hours no genetic effects, if one considers the number of the investigated flies (300 drosophila males) to be great enough for drawing such a conclusion. No individual will be killed, so far as we can conclude at present, by cosmic radiation, but we believe that, in this field, recent considerations of Muller[44,45] should be taken seriously. He emphasized that nobody—even if a dose of 50 r received by germ cells induces gene mutations with a frequency only about equal to the spontaneous one and even if it takes generations before the effect becomes manifest—has the right to take these risks without the necessary responsibility and care.

Such a single or an accumulated exposure—Stern, Spencer, Caspari and Uphoff could, as Muller emphasizes, show that the rule of proportionality between effect and dose holds down to doses of less than 0.001 r per minute—carries a 5 per cent risk of future genetic death for some descendant of each offspring, produced after such an exposure, and a concomitant risk of the subtle handicapping of several descendants.

For stratosphere flights, there may be a minimum of danger for the passengers because the exposure-times in general will be short. If, however, once rockets and space ships really go to the moon and to mars, the question as to possible biological effects of cosmic radiation have to be considered and discussed as seriously as the questions of encounters with meteorites, gravity questions, et cetera. According to Armstrong, Haber and Strughold,[4] the trip to the moon will take five to six days, and a one-way trip to Mars ten weeks, a round trip twenty to twenty-two weeks. In these times, there is no doubt the cosmic radiation with their newly discovered properties will become biologically effective.

How important the environment during the travel in high and highest altitudes may become can be concluded from the experiments by L. C. L. Yuan.[75] In a flight with a B-29, measuring the cosmic ray neutron intensities at medium high altitudes (30,000 feet), he found a considerable number of slow neutrons, which had been produced by the slowing down of fast neutrons in the rubber tire of the nose wheel of the plane. Since the biological effectiveness depends very much on the kind and energy of the particles, this example shows how by the environment under certain conditions radiation can be changed from

TABLE IV. RADIUM CONTENT OF HUMAN TISSUE

Tissue	Investigation	No. of Cases	Activity In 10^{-12} Gram Radium Equivalent per Gram Tissue
Lung	Behóunek	21	9 cases with 0.2 - 0.8 12 cases with 1.0 - 5.4
	Krebs	38	8 cases with 0.01 - 0.1 23 cases with 0.1 - 0.6 7 cases with 1.0 - 9.0
Muscle	Krebs	6	4 cases with 0.01 - 0.09 2 cases with 0.2 - 0.3
Vertebral Column	Behóunek	10	1 case with 0.48 8 cases with 1.0 -10.0 1 case with 19.5
	Krebs	5	2 cases with 0.7 - 0.9 3 cases with 1.3 - 4.6
Tissue	**Investigation**	**No. of Cases**	**Activity In 10^{-8} Gram Radium Equivalent per Body**
Total Body	Krebs	17	3 cases with less than 0.1 4 cases with less than 1.0 10 cases with 1.0 - 2.5

an ineffective one into an effective one and vice versa.

No details, concerning the main question, can be given today. There are only extrapolations of a few well-known data. One of these extrapolations is the fact that besides the primary cosmic radiation with its ionization effects the secondary and tertiary events in their turn play important parts in the production of biological effects. A first rough idea of the magnitude of the effects to be expected at the top of the atmosphere can be obtained by comparing the star events (all the other cosmic ray events are neglected in the following calculations), with data known from radium-poisoning cases and the measurements as to the normal radium-content of human beings.

The frequency of stars with four and more prongs at an altitude of 95,000 feet is, according to Hornbostel and Salant,[31] about 2000 stars $cm.^{-3}$ $day.^{-1}$ There are stars with up to fifty to seventy prongs. If we assume every star to have, on the average, ten prongs and that the particles produced in these nucleon-nucleon collisions are preferably α-particles (observed are protons, neutrons, α-particles, heavier nuclei, mesons, et cetera), then, $1 cm^3$ gets per day about 2×10^4 α-particles. This is:

$$\frac{2 \times 10^4}{8.6 \times 10^4} = 0.23 \ \alpha\text{-particles per cm.,}^3 \text{ per second.}$$

Since 1 g of Radium without decay products emits 3.72×10^{10} α-particles per second, these 0.23 "cosmic-ray-α-particles" per $cm,^3$ per sec. are equivalent to:

$$\frac{0.23}{3.72 \times 10^{10}} = 6.2 \times 10^{-12} \text{ gm. radium element/cm.}^3 \text{ without decay products.}$$

A comparison of this amount with the radium content of different human tissues gives a first idea of the effects to be expected.

According to the investigations and measurements of Behóunek and Fort,[6] of Hoffmann,[29] and of Krebs,[35] the radium content of 1 gram of fresh tissue is as shown in Table IV.

Recent investigations of Hursh and Gates[32,33] and measurements under way by Evans[15] make it probable that in

TABLE V. ACTIVITY-RANGE FOR HUMAN TISSUE

Tissue	10^{-12} g Radium Equivalent per g Tissue
Muscle	0.01 - 0.3
Lung	0.01 - 9.0
Vertebrae	0.48 - 19.5
	10^{-8} g Radium Equivalent per Body
Total Body	less than 0.1 - 2.5

certain cases and under special conditions even smaller amounts (one to two magnitudes smaller), are in tissue.

Thus, the radiation delivered by the cosmic-ray stars at the top of the atmosphere comes close to the amounts of radioactive energies, which today are considered to be in no way harmless to tissue. If one takes into account, too, the energies delivered additive to these calculated ones in form of "normal" cosmic radiation (see Forssberg[25]), then the possibility for biological effects of cosmic radiation becomes, to a certain degree, reality. This, so much more so as the properties of the particles, produced in the star explosions differ from normal laboratory particles, as to energy, specific ionization and energy dissipation.

SUMMARY

Recent discussions on aero medical problems of space travel by Armstrong, Haber and Strughold have brought up the question as to biological effects of cosmic radiation encountered in the stratosphere and in space travel. The possibility of such effects is discussed in detail.

Using recent discoveries in cosmic ray physics (heavy nuclei in the primary radiation, explosion stars at high altitudes, meson production, origin) and the report of Hess and Eugster on cosmic radiation and its biological effects, it is shown that at these altitudes biological effects of cosmic radiation have to be expected.

By comparing the cosmic ray events in high altitudes with data obtained in recent radium-poisoning investigations, a first rough estimation of the magnitude of cosmic ray effects is made.

For further investigations it is proposed to study:

1. Biological effects of star events, fission processes and meson processes.
2. General biological effects and specific biological effects (genetic effects), on drosophila, seeds, fungi and protein solutions exposed, several times if necessary, at high altitudes.
3. Correlated with 1 and 2, the effects in deep mines.

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Twenty-Second Annual Meeting

The Aero Medical Association

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