A SUMMARY OF THE BERKELEY CONFERENCE ON BIOLOGICAL EFFECTS OF COSMIC RAYS AND ACCELERATED HEAVY IONS

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A SUMMARY OF THE BERKELEY CONFERENCE ON BIOLOGICAL EFFECTS OF COSMIC RAYS AND ACCELERATED HEAVY IONS

held at

Donner Laboratory
University of California
Berkeley, California

Abstract

On January 21-22, 1958 an informal conference was arranged through the cooperation of the Space Biology Branch of the Aero Medical Field Laboratory, Air Force Missile Development Center at Holloman Air Force Base, New Mexico, and the Donner Laboratory of the University of California, to discuss the present status of knowledge of biological hazards of primary cosmic rays in space flying and to plan avenues of research that should lead to more definite knowledge. Attached is the program of the meeting and a summary of the recommendations resulting therefrom. A more detailed report may be prepared at a later date.

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March 10, 1958

I. Introduction

The rapidly approaching age of space and space travel calls attention to a number of unanswered questions concerning biological compatibility with such an environment. Some of the problems involved are effects of low or zero gravity high accelerations, oxygen and CO_2 metabolism studies, stress and fatigue, and effects of cosmic, x- and ultraviolet irradiation. For many or most of these problems the possibility exists, at least in principle, of overcoming or avoiding their deleterious effects by proper engineering of a controlled environment. With high-energy primary cosmic rays, however, we are faced with a phenomenon that in large measure cannot be avoided or shielded against and which, consequently, we must learn to live with.

In this report, then, we are primarily concerned with cosmic rays as a potential hazard to space travel. The emphasis is directed especially toward the more fundamental scientific questions involved and possible experimental approaches leading to a better understanding of these radiation phenomena. Because of the complexity of the biological and physical problems and the elaborate instrumentation involved, this can be considered only as a large and long-term research effort.

II. Physical Nature and Biological Effects of Primary Cosmic Rays

Primary cosmic radiation consists of high-velocity atomic nuclei bombarding the earth from all directions in space. Most of the particles are protons and helium nuclei, but a significant fraction of the cosmic-ray flux is due to nuclei of carbon, oxygen, and occasionally calcium, iron, or even heavier nuclei.

During the past few years a body of knowledge has accumulated on the biological effects of cosmic rays, based on balloon experiments and work with accelerators. We have some knowledge of the distribution of different ionizing particles, of the occurrence of nuclear-collision events, and of the physical structure of tracks. We know that a single, heavy primary particle may kill a sea urchin egg or yeast cell. On the average, however, only 1 out of 10 (carbon) particles traversing a yeast cell proves lethal. We also know that a single heavy primary can cause reverse mutations. Some heavy primaries can even affect an entire group of cells located near one another, as evidenced by production of grey hairs on black mice when several hair-follicle pigment cells are knocked out.

Microscopic observations in brain-tissue and nerve-tissue cultures indicate the possibility of occurrence of tissue damage in many cells along a single cosmic ray track.

The feasibility of using balloons for studies of longevity and carcinogenesis has been indicated.

Most of these studies point to the fact that radiation damage from cosmic-ray primaries may be of most consequence (a) in regions where damage to a few cells may be biologically amplified to affect many cells, as with germ plasm or when homeostasis is upset (from hypothalamic damage, for example); or (b) when the cells affected do not have the ability to regenerate (as for various parts of the central nervous system); or (c) where a single particle may inactivate a whole group of cells necessary for a biological function (as for the pigment-cell example, above, or possibly also for disruptive effects on biological membranes). Cosmic-ray effects may well differ from more commonly observed radiation effects in another respect: partial-cell irradiation may lead to an increased incidence of nonkilling but deleterious effects, such as carcinogenesis.

Because of the variability in occurrence and nature of solar and perhaps stellar events, the intensity of primary cosmic radiations exhibits great spatial and temporal variation. A human in a spaceship removed from the earth's magnetic field might be exposed to a mean dose of around 140 millirads per week. The Relative Biological Effectiveness is not known for some of these particles, but since they have dense tracks, one might find the primary rays many times as effective as low-energy x-rays, for at least some effects.

III. Cosmic-Ray Hazards to Space Travelers

In space flight and in colonization of the moon and planets, where long-time exposures are involved, the biological effect of cosmic-ray primaries might be a limiting factor. Short flights not lasting more than a few weeks probably will not involve a great health hazard unless regions are found in space with radiations of unusually high intensity or effectiveness. (In this respect, radiation associated with giant flares needs more thorough investigation to determine whether dangerously high intensities prevail.) The use of nuclear-powered craft might introduce, however, a significant new factor of exposure.

IV. Future Work: General

A. Principles

1. More studies are necessary, both at ground level and in flight, on the physical properties, dosimetry, and biological effects of cosmic rays.

2. Fundamental studies--for example, determining appropriate dose-response relationships--should as a rule be carried out at ground level prior to the corresponding flight experiment.

3. It is particularly important to have compatibly designed and simultaneously taken physical and biological measurements.

4. Both acute and chronic biological effects should be considered, the latter perhaps being the more important.

5. As an alternative to the usual more or less random examination of animals for biological damage, experiments could be set up to measure an effect in a specific area (e.g., by exposure until coincidence crystals on the head should give a response).

6. Biological studies should be conducted on the unicellular, tissue, and animal, and eventually human levels.

B. Techniques

1. Vertical sounding rocket flights are of interest particularly for physical measurements on primary cosmic rays (charge and energy distribution and variations) in regions beyond the earth's magnetic field. At present, however, they appear unattractive for biological experiments.

2. Similar physical measurements should be made utilizing balloons and satellites. When it is desired to avoid the earth's magnetic field, balloons may be flown near the north magnetic pole, and satellites may be employed, orbiting at distances of several earth diameters or in polar orbits.

3. Accelerator work on dose response and RBE for various biological materials should be continued and expanded, using nuclei identical to or closely analogous to those occurring in cosmic rays. At present it appears theoretically possible to accelerate artificially the very heaviest of such nuclei, and the long view may eventually require this. To this end, some of our very largest acceleraters

could be adapted to biological experimentation or new accelerators could be built if the prospective workload for biological and physical experimentation required it.

4. The continuation of balloon flights is also desirable both for measuring the actual effects on special biological materials near the top of the atmosphere and as for gaining experience in handling techniques and in problems of closed environment.

5. Satellite flights carrying biological material have their place in the program and will become increasingly valuable as more information and experience become available from the multifold approach outlined above, and when satellite recovery becomes feasible.

V. Detailed Program of Investigations

The following experiments were recommended for the near future.

A. Ground-Level Experiments Using Accelerators, Etc.

1. Existing accelerators should be used to full capacity for duplicating, at high intensity if possible, primary cosmic-ray components. Exploration should continue for determining which biological systems exhibit greatest sensitivity. (See also Sections II and V, D.)

2. With these same heavy-ion radiations, fundamental physicochemical studies should be carried out in water and in other basic materials. This would include study of behavior along tracks: distribution of primary events, exact delta-ray effects, H_2O_2 production, etc.

3. The Radiation Laboratory of the University of California has a new heavy-ion linear accelerator capable of producing intense beams of carbon, nitrogen, oxygen, and neon ions at 10 Mev per nucleon. Acceleration of argon may also be feasible in the near future. These beams can serve as a tool for studies on exact dose-effect relationships in a number of biological systems. Yale University will soon have a similar accelerator in operation which may also be used for physical track-structure studies. These heavy-ion beams have a range of a few cell diameters, limiting investigations to the surface layers of animal tissues.

Investigation of the heavy-ion effects on dried enzymes, phage, and bacterial spores is in progress. Work has also been started with wet yeast cells.

The following heavy-ion accelerator studies are being planned:

(a) Effects of heavy ions on skin and hair of mice.

(b) Radiation effects on nerve and brain tissue (exposures to be done with bone flap removed over brain area to be exposed).

(c) Action of heavy ions on nerve-cell cultures.

(d) Effects of heavy ions on reverse mutations of neurospora.

(e) Lysogenic action of heavy ions.

(f) Action of heavy particles on developing larvae of drosophila and on other systems, e.g., frog embryo.

(g) Effects on an animal or human cell culture (as nerve).
It is hoped that the above studies, to be carried out by various groups of investigators, will get under way within a few months. They should yield valuable information, of use in later flight tests.

4. Ion beams of the 184-inch cyclotron in Berkeley include 720-Mev protons and 900-Mev alpha particles; the primary cosmic rays are mostly composed of protons and alpha particles. For long-term purposes, an attempt may be made to obtain a carbon beam of 350 Mev per nucleon (4.2 Bev). Such a beam would allow experiments irradiating deeper parts of the mouse central nervous system, for example, and perhaps whole-body exposures in small animals as well.

5. The present program of the 184-inch cyclotron includes studies of local irradiation damage by penetrating particles. Of special interest is brain tissue. It is already known that large areas of brain tissue may be removed or injured without very serious consequence. Injury to the hypothalamic centers of homeostatic control appear to have much more serious consequences, however; permanent damage to some of the hypothalamic nuclei may result in chronic metabolic imbalance.

6. We already have in this country machines delivering 3.2- and 6.5-Bev protons (and in Russia a synchrocyclotron operates at 10 Bev). For the long term it may be worth while to adapt large accelerators of this type for biological experimentation, and it may be desirable or necessary to build machines accelerating ions heavier than argon to energies of several hundred Mev per nucleon. Work on existing accelerators is expected to furnish clues to the need for such developments, which can involve huge and expensive efforts.

7. Although some of the ground-level irradiations might be carried out by use of pulsed x-ray microbeam techniques, for most purposes more realistic studies can presumably be made using machines that accelerate particles more closely analogous to the cosmic radiations themselves.

8. Past hematological studies of binucleated lymphocytes (in humans) have indicated their possible utility as indicators of low radiation dosages. More ground-level study is needed on their relation to the over-all stress problem as well as to radiation. Work is also necessary to establish the dose-response relationship and to extend it to higher doses.

9. The possible utility of electroencephelogram measurements to indicate radiation damage to parts of the brain has been indicated, and more work along these lines may be worth while.

B. Dosimetry and Other Physical Problems for Flights

1. Our present knowledge of the physics of primary cosmic rays has come principally from flights sponsored by the U.S. Navy.

2. Contact with the International Geophysical Year cosmic-ray program will be increased with a view toward obtaining better data on the frequency of occurrence of primary nuclei as a function of atomic number. The energy dependence near the low-energy end of the spectrum is of special interest; particular attention is to be given to cosmic-ray increases caused by solar flares, and to measurements at great distances and away from the influence of the earth's magnetic field.

3. Improved physical methods and instrumentation are needed for biologically significant in-flight dosimetry; it is necessary to have better information concerning identification and location of heavy-particle tracks with respect to experimental animals (e.g., the exact angle and depth of tissue penetration). In long flights the photographic emulsions currently in use fog over completely; improved methods are needed.

C. Biological Experiments for Flights

1. Balloon flights

(a) Most of our biological information has come from U.S. Air Force flights under the direction of the Aero Medical Field Laboratory, Air Force Missile Development Center, Holloman Air Force Base, New Mexico.

(b) Flights of 36-hour duration have already been made at altitudes exceeding 100,000 feet in a pressurized cabin of controlled internal environment. It should soon be possible to arrange flights with a 100-lb payload going to 150,000 feet or with a 1500-lb payload to 120,000 feet, with a relatively high probability of success. To date most of these flights have originated at the geomagnetic latitude of Minnesota.

(c) Flights up to a week in duration would be of substantially greater interest for studying radiation effects, in view of the low intensities involved. Flights exceeding one week must probably be made in satellites.

(d) Balloon experiments should be continued on systems for which definite evidence has been obtained that single heavy primary hits can give rise to easily observable discrete injuries by damaging small groups of cells (hair morphology and pigmentation, skin effects, etc.).

(e) Animal-longevity and carcinogenesis experiments should be continued, though they will be even more interesting when larger groups of animals can be flown for longer periods of time (i.e., in recoverable satellites). For the nearer future the consensus was that it would be worth while to look for these effects in groups of a few hundred mice exposed for a week in high-altitude balloons.

(f) Human balloon flights are useful for the total experience of preparing man for space flight, and they will be continued.

2. Flights, general.

(a) Satellite testing of biological material will become particularly interesting when recovery becomes feasible. Longer-term carcinogenesis and aging studies should be included at that time.

(b) Hematological indicators should be examined for information on radiation exposure (see remarks on binucleated lymphocytes in Section V, A-8).

(c) Most of the flight experiments should be run on biological material for which some indication already exists of the presence of some definite effect, and for which ground-level measurements have given an idea of the magnitude of the expected injury.

D. Additional Biological Objects of Study

Discussion brought forth the following suggestions for biological materials for eventual study.

1. Cells suspended and frozen in gelatin.

2. Other dried spores.

3. Other eggs: hatchability studies.

4. Continuous living matter -- as slime molds.

5. Embryonic systems in which single cells determine specific parts of the adult organisms (as with certain marine snails).

6. Physical organ systems: visual, hearing, other sensations.

7. Animal reproduction.

VI. Conclusion

It is hoped that the conference, and the above summary, will serve as a helpful guide to some of those interested in biological effects of cosmic-ray primaries. Progress in this field must be based on cooperation and free exchange of information between scientists of several disciplines and various service groups. With regard to planning for satellite flights the group was somewhat hampered by insufficient availability of data on expected satellite performance, recovery, and other capabilities. Several participants expressed their interest in being kept up-to-date with respect to progress in this field and to have the opportunity for additional exchanges of ideas with this and related groups.

List of Participants

Adams, Gail	University of California Medical School
Allen, Ralph G.	School of Aviation Medicine, USAF, Randolph Air Force Base, Texas
Birge, Ann C.	Donner Laboratory
Clemente, Carmine D.	Anatomy Dept., UCLA
Cooper, Irwin	RAND Corp., Santa Monica, Calif.
Chase, Herman B.	Brown University, Providence, R.I.
Flanders, Paul Howard	Donner Laboratory
Fox, Robert	Radiation Laboratory, Livermore (Tuesday evening only)
Goodpasture, Ernest	Armed Forces Institute of Pathology, Washington, D.C.
Haymaker, Webb	Armed Forces Institute of Pathology, Washington, D.C.
Hild, Walther	University of Texas Medical School, Galveston, Texas
Hubbard, Edward L.	Radiation Laboratory, Berkeley
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Secretaries:	Mrs. Polly Thomas Mrs. Blanche Burns

Program of the Berkeley Conference on Biological Effects of Cosmic Rays and Accelerated Heavy Ions

January 21-22, 1958

Donner Laboratory
University of California
Berkeley, California

Tuesday, January 21

201 Donner Laboratory

Session I. Physical nature, intensity, variations of primary cosmic rays and experimental methods available for biological studies.

Discussion leaders: C. Tobias (general properties of cosmic rays and biological effects of accelerated particle)

H. Schaefer (dosimetry of primary rays)

D. Simons (balloon techniques)

I. Cooper (rocket techniques)

E. Hubbard (heavy-ion linear accelerators)

Session II. Effects of cosmic rays and low-level radiation on unicellular organisms (lethal, metabolic, developmental, genetic).

Discussion leaders: W. Hild (cytology)

W. Stone (genetics)

Session III. Effects of cosmic rays and low-level radiation on animals (acute and delayed physiological effects; carcinogenesis and longevity).

Discussion leaders: H. Chase (skin)

M. Chupp (hemopoiesis)

H. Jones (longevity and carcinogenesis)

Tuesday evening. Nuclear rockets; R. Fox

Wednesday, January 22

201 Donner Laboratory

Session IV. Effects of radiation on nerve and brain tissue.

Discussion leader: W. Haymaker

Session V. Informal discussion of future investigations with heavy ions, and visit to the 184-inch cyclotron and heavy-ion linear accelerator.

Session VI. Informal discussion.