# A SURVEY OF THE PHYSICS AND BIOLOGICAL ACTION OF COSMIC RAYS WITH SPECIAL REFERENCE TO THE EFFECTS OF SECONDARY COSMIC RAY SHOWERS UPON CHICK EMBRYOS

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## ABSTRACT

A review of the incidents which led to the discovery of cosmic rays is presented. The corpuscular nature of the radiation is discussed briefly, and the two major components are reviewed with special emphasis being placed upon the soft component. Secondary shower radiation and the frequency of these showers are reviewed.

The biological action of cosmic radiation is summarized briefly, and some of the basic research with bacteria, plants and plant seeds, and animals is reported. A report of an investigation into the effects of secondary cosmic ray showers upon chick embryos is included.

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# INTRODUCTION

Following World War I, scientists became increasingly interested in the nature and effects of cosmic rays. Although they had been noted and investigated for a decade prior to the war, experimentation was slow and tedious and results were meager. The outbreak of the war postponed practically all work which was in progress, and it was not until 1922 that inquiries into the origin and composition of the phenomenon were again proceeding with any regularity.

Because of the nature of cosmic radiation, it was first investigated by those in the physical sciences, but as more information and data were amassed, workers in the field of biology became interested. Here was a source of radiant energy which was constant, or nearly so, for any given area; could it possibly have any effects upon living organisms and if so what were these effects? These were questions that needed investigation. Again, because of the nature of the radiation, investigations were difficult and had to be continued over extremely long periods of time. With respect to the facility and results of these investigations, Lewis (1951) stated that:

> In contrast to the great body of information available on the biological effects of radiant energy of most frequencies, very little it known of the possible action of the components of cosmic radiation on living tissues. The relatively few published studies taken as a whole are inconclu-

> sive, largely theoretical in approach, and in some instances contradictory....
>
> Experimental work has been discouraged physically by the difficulty of access to the upper atmosphere at levels of the primary component, and theoretically, by the known low intensity of the total radiation. One does not expect detectable effects from 15 milliroentgens/day (70,000 ft.) when doses in hundreds or thousands of roentgen units are commonly used in similar laboratory assays. The discovery of tremendously energetic heavy nuclei in the radiation incident to our atmospheric shell capable of great penetration and high specific ionization makes new investigation possible. Since absorption of these particles and dissipation of their energy is accomplished very rapidly by air molecules, little may be learned by shielding experiments or by exposures on mountain tops or in aircraft. Further, roentgen units may not express with accuracy the tissue ionization by absorption of quanta from extremely heterogeneous radiation.

Lewis mentioned only investigations of the primary components of cosmic rays. Although the radiation incident upon the earth is of low intensity, increased intensity can be produced by placing layers of dense metals above the experimental subject. Lead is most commonly used in this manner, because its great density allows the use of thinner sheets or bars. The discovery of this method of intensification has overcome many of the limitations which were first encountered. Even so, the results of the experiments to date have been varied, and their interpretation difficult.

This paper will present a review of some of the basic experiments in both the physical and the biological effects of cosmic radiation. An investigation by the writer into the effects of secondary cosmic showers upon chick embryos is reported.

# CHAPTER I

## DISCOVERY OF COSMIC RAYS

For many years following the discovery of X-rays, which have the ability to ionize air and render it electrically conductive, a residual discharge of electroscopes was noticed even when they were surrounded by thick shields of radiation absorbing materials. This discharge was thought by most workers to be the result of ionization of the air within the electroscope by radioactive materials in the earth in the vicinity of the instrument (Leprince-Ringuet, 1950). Tests were made to determine the amount of ionization necessary to cause this discharge, and it was calculated that the production of ten to twenty ion pairs per cubic centimeter per second would be sufficient (Hess and Eugster, 1949). In carefully cleaned instruments the ionization was found not to exceed ten ion pairs per cubic centimeter per second.

In 1906, Richardson made the observation that this discharge was probably due to influences of the sun (Millikan, 1935). He had evidently overlooked the fact that the discharge occurred as rapidly at night as during the day. In 1909, Kurz studied the three existing explanations, that the discharge had its origin in effects of

(1) the earth, (2) the atmosphere, and (3) those regions beyond the atmosphere. He immediately discounted the last two possibilities and proposed that the discharge had its origin in effects of the radioactive substances in the soil, air, and water surrounding the instruments (Millikan, 1935, Hess and Eugster, 1949).

Between 1909 and 1914, Bergwitz, Wulf, Gockel, Hess, Kolhoerster, and others carried electroscopes to ever increasing altitudes by means of balloons. They established that there was an initial decrease in the ionization up to an altitude of 1800 meters. They found also that between 1800 and 9000 meters, instead of decreasing further, the ionization increased until it reached a value of about eighty ion pairs higher than at sea level (Hess and Eugster, 1949). The balloon ascents were made at night as well as during the day, and Hess made one ascent during a solar eclipse in 1912. No change in the ionization was noticed. This led the investigators to postulate that the ionization had its origin in effects of those regions above atmosphere.

Little or no work was done between 1914 and 1922 because of World War I. However, in about 1922 investigations were resumed with renewed interest, and results were accumulated at an exceedingly rapid rate. Compton proposed the theory of the extragalactic origin of these ionizing radiations and in 1926, Millikan first used the name "cosmic rays".

## CORPUSCULAR NATURE OF COSMIC RAYS

The corpuscular nature of cosmic rays was established by two major observations. The first was the so-called "latitude effect", observed by Millikan and Cameron in 1926 (Millikan, 1935), and Clay in 1927-1929 (Lemon, 1936). Hess (Hess and Eugster, 1949) adequately explains the latitude effect:

> It was now evident that at least a great part of the primary cosmic rays consist of electrically charged particles which are deflected in the magnetic field of the earth. The particles of greatest energy reach the surface of the earth in all latitudes: particles of lesser energy cannot reach the zones near the geomagnetic equator where the deflecting force (horizontal component of the magnetic field intensity) is stronger.

The second was observed by Bothe and Kolhoerster in 1929, (Lemon, 1936) and showed that cosmic rays produced simultaneous discharge pulses in two Geiger-Muller tubes placed one above the other. This placement is termed the coincidence method, and discharge of two counter tubes so placed is produced by a charged particle passing through both tubes almost simultaneously. The angle of incidence is easily determined by varying the position of the tubes with respect to one another. By means of specific wiring systems, this method insures that only cosmic rays will discharge the tubes.

## COMPONENTS OF COSMIC RAYS

Cosmic rays have been separated into two major components on the basis of their penetrating power. These are termed the "soft" and "hard" components, and there is adequate evidence that each component may consist of more than one type of particle.

The soft component is defined as those rays which cannot penetrate a layer of lead fifteen centimeters thick (Leprince-Ringuet, 1950). It is found in small proportion at sea level but increases rapidly in intensity as altitude is increased until it is more intense than the hard component. "At the Jungfraujoch laboratory (altitude 3,500 meters), the soft component is three times more abundant than the penetrating components" (Leprince-Ringuet, 1950). The hard or penetrating component is defined as that group which will penetrate a layer of lead greater than fifteen centimeters thick. Leprince stated of this hard component that:

> Its properties are very different from those of the soft component. First of all, its intensity increases only slightly with an increase in altitude, and in such a way that the increase of the two groups as a function of altitude does not follow the same law. Its penetrating power is such

that a thickness of 1 meter of lead stops only half of its particles.

## CASCADE OR SECONDARY SHOWER EFFECTS

Between 1925 and 1930, Hoffman, Steinke, and Schindler established that if cosmic rays pass through a layer of metal such as lead, secondary showers of rays are produced in the metal (Hess and Eugster, 1949). These secondary or cascade showers have been observed and studied by use of the Wilson-Chamber. A shower is defined as two or more associated tracks, and these tracks are considered to be associated if they are produced by rays that pass through the chamber at the same time, as indicated by the identity in the sharpness or diffuseness of the tracks they leave (Millikan, 1935).

The major portion of the showers is produced by the soft component of the cosmic rays. Millikan (1935) reported that the secondary showers were composed of three types of particles. There were:

> (1) rays consisting of electrons (+ and -) directly emerging as a result of the encounter; (2) photons of the same nature as the general X-radiation emitted from the point of impact of the cathode ray beam on the anticathode; and (3) annihilation-ray photons of half-million-volt energy as first measured by Chao. The existence of all three of these radiations has been directly brought to light in the Norman Bridge Laboratory.

SHOWER FREQUENCY

The frequency of shower production has been found to increase when metals of sufficient density and thickness are interposed in the path of the cosmic rays. Millikan (1935) stated that with expansions and exposures (of Wilson Chambers) made at random, twelve per cent of the tracks registered are showers. This twelve per cent is calculated for air showers; that is, showers occurring from the effects of cosmic rays upon atoms of the air. The showers can "almost be produced at will by placing dense screens above the chamber. The showers are relatively compact and a large shower can produce more than one hundred thousand rays" (Leprince-Ringuet, 1950).

A thorough investigation of shower production was made by Rossi (Hess and Eugster, 1949). He found that shower production increased in frequency with an increase in thickness of lead above the chamber. This increase reached a maximum for thicknesses of lead between sixteen and eighteen millimeters and dropped off rapidly as the thickness was increased to five centimeters.

We can understand this behavior since it is shown in cloud-chamber pictures that multiplication of particles takes place when a cosmic-ray particle is penetrating through heavy materials like lead; the greater the thickness, the more secondary electrons are produced. However, as these particles travel through lead, some of them are stopped.

> Within the first 17 mm. the rate of multiplication is greater than the rate of absorption. Beyond that thickness, absorption gains the upper hand (Hess and Eugster, 1949).

As interest in the physical aspects of cosmic rays increased, many biologists began to look at this newly found source of energy as a possible mechanism for many unexplained biological phenomena. Among the first to become interested were the geneticists, looking for a mechanism for natural mutations. Workers in other divisions of biological research soon followed the lead of the geneticists and began investigating the effects of both components of cosmic rays upon varied biological materials.

# CHAPTER II

## BIOLOGICAL EFFECTS OF COSMIC RADIATION

Many of the investigations into the biological effects of cosmic radiation have been inconclusive, and many conflicting reports have been made. Test subjects ranging from bacteria to small mammals such as mice and rabbits have been used, and most of the positive results have been reported when the tests organisms were exposed to intensified secondary cosmic showers under optimal thicknesses of lead.

### EXPERIMENTS WITH BACTERIA

The tests using bacteria as subjects have been reported on with respect to the mutagenic effects and culture growth stimulatory or inhibitory effects of cosmic rays. In 1936, Rajewsky, Krebs, and Zickler found that optimal screening of cultures of the fungus *Bombardia lunata Zickler* caused a definite increase in the number of cultures showing mutations. Cultures which were exposed under lead showed an increase in mutation which amounted to 3.1%, whereas control cultures showed only 0.71% mutations. Rajewsky and his co-workers reported that "the rate of mutated cultures is relatively large. Even granting that the actual number of mutations may be smaller than the number of mutated cultures, there is nevertheless an excess of mutations under the optimally screened cultures compared with the rest."

Working with two non-pathogenic forms, Bacterium violaceum and Bacterium fluorescens non-liquef., Eugster (1949) found that growth of the organisms was stimulated when they were placed in an environment which shielded them from the greater part of the cosmic rays. An inhibition of growth in bacterial spores exposed under lead for eight months was also reported by Eugster.

EXPERIMENTS WITH PLANT SEEDS

Germination and growth tests of the seeds of Linum usitatissimum exposed under lead indicated that germination proceeded more quickly than in the controls, but that subsequent development was greatly retarded. More plants were obtained from the exposed seed of Antirrhinum majus; these plants were stronger and had a tendency to be more bushy than the plants grown from the control seeds (Hess and Eugster, 1949). Using germinating seeds of L. usitatissimum, Rivera found that initial growth was stimulated. In addition, roots and stems appeared some ten to fifteen hours earlier in those seeds maintained under lead than in those of the control group. Lead covering the test groups was varied in thickness from 1 mm. to 18 mm. with an optimal effect noticed using 18 mm., and no change noticed using

1 mm. (Hess and Eugster, 1949).

Stroman and Lewis (1948) placed dormant seeds from three cotton plants in a V-2 rocket launched for test purposes at the White Sands Proving Grounds, Las Cruces, New Mexico. During its flight which lasted 9.9 minutes, the rocket reached an altitude of 90.5 miles, exposing the seeds to increased intensities of secondary cosmic showers, up to 70,000 feet. Above 70,000 feet the intensity of the secondary showers drops off noticeably, and any effects registered would be from the primary particles of the radiation. Germination and growth tests were reported for these seeds through the second generation and plants grown from the exposed seeds showed an increase in height over plants grown from control seeds. Some evidence of increased germination and seedling vigor was noticed but was not reported because of a doubt as to the reliability of the information (Lewis, 1951). "Changes noticed in the radiated material", stated Stroman, "remain to be fully evaluated, and cannot as yet be designated as cosmic radiation effects" (Stroman & Lewis, 1948).

## EXPERIMENTS WITH ANIMALS

Many investigators have used animal subjects to test the effect of cosmic rays upon two primary factors: (1) its effect upon carcinogensis, both spontaneous and induced, and (2) its effect upon the fertility of the animals and upon the viability of their offspring. The material reported in this paper seems to indicate a correlation between tumour growth and intensity of secondary cosmic showers.

Barnothy and Forro (1948), working with white mice, found that when the animals were maintained under lead there was a definite statistical increase in the number of young which were born dead, or which died within the first week after delivery. Following tests in which they used Angora rabbits, they reported that all females kept under lead dropped dead offspring; most of these died on the last day of gestation. When one of the females was placed under lead on the last day of gestation only, all of the young were born dead. In a similar series of experiments, Eugster (Hess and Eugster, 1949), found a high percentage of sterility occurring in the females along with an increased number of still-births. This conflicts with the results of Barnothy and Forro because they noticed only a very low incidence of sterility, and this only when copulations were accomplished under lead. The resulting sterility was temporary, whereas Eugster presented evidence of permanent sterility after varying periods of exposure. His conclusions were based upon definite degenerative changes which he observed in the ovaries of the animals.

Following a series of experiments designed to test the effects of secondary showers on mice injected with a carcinogenic agent, Figge (1947) reported a marked decrease in the latent period for the appearance of palpable tumors in the test groups. The highest incidence of tumors was noted in a cage which has been kept under one-half inch (12.7 mm.) of lead. Over the other test cages only one-fourth inch (6.35 mm.) of lead was placed; one-half inch more nearly approaches the optimum thickness for shower production. In a similar series, George, George, Booth, and Horning (1949) reported that with the exception of one test group which was under five centimeters of lead, "the latent period between inoculation and the appearance of tumours followed a random variation. In this respect our results differ from those of Figge".

Hoping to avoid some of the difficulties inherent in investigations on induced carcinogenesis, Eugster (Hess and Eugster, 1949) carried out experiments designed to test the effects of secondary showers upon spontaneous carcinogenesis in mice. Using a strain which had been inbred for the carcinogenic principle, he reported that 91% of those that died of cancer were from the exposed groups. Although only preliminary work had been completed, Eugster stated that:

> Taking into consideration all the mice involved in these experiments, we calculated the incidence of carcinoma to be four times higher among those animals exposed to showers than among the controls. Should these observations be confirmed with a wider

> range of experimental material, then we could accept the view that in local radiation, and particularly cosmic radiation, we have a regulating mechanism for the balance of normal and pathological development of cells.

The literature on the biological effects of secondary cosmic showers has become quite extensive as more individuals have become interested. However, no reference to tests using chick embryos as radiation subjects could be found. Since the most promising line of investigation seemed to be centered upon tests using actively growing cells as experimental material, an investigation of the effects of secondary cosmic showers upon chick embryos was made.

## CHAPTER III

### EFFECTS OF SECONDARY COSMIC RAY SHOWERS UPON CHICK EMBRYOS

The objective of this investigation was to determine what effects secondary cosmic ray showers might have on chick embryos. It was thought desirable to determine whether or not embryos of Gallus domesticus would be suitable material for further investigations with cosmic radiation since they are in such widespread use as reasearch material.

### MATERIALS AND METHODS

At the time the investigation was made the hatcheries in the Houston area had ceased operations for the summer season and some difficulty was encountered in procuring fertile eggs. The ultimate source was a flock of White Wyandottes located South of Sealy, Texas. The eggs used in the experiment were gathered each morning and delivered twice a week so that they were a maximum of four days old at the time of delivery.

Upon receipt, the eggs were divided into equal groups by random choice. The test groups were placed horizontally so that the centers of the eggs were three to three and one-half inches below a lead plate 18 mm. in thickness, and were located on top of a metal cabinet on the first floor of a two story structure. The elevation above mean sea level was approximately 130 feet. The control groups were located on the same level but about forty feet distant from the rest groups with two walls intervening.

Test group E-A was exposed to secondary cosmic showers under the lead plate for a period of seventy-four hours; test group E-B was exposed for sixty-eight hours; and test group E-C was exposed for seventy-two hours. Immediately following exposure the test groups, along with the respective control groups, were placed in an incubator in which a temperature of 105 degrees F, optimum for maximum development within a seventy-two hour period (Romanoff, 1949), was maintained. Upon removal from the incubator the eggs were opened, and the embryos were harvested and numbered consecutively for each group. The maximum elapsed time during the harvesting of any one group was two and one-half hours; a range of developmental stages was therefore probable. The embryos were examined superficially as they were harvested, and further examinations were made after they had been stained and mounted.

## RESULTS

The results of this investigation were inconclusive. There were seven position abnormalities noted in the exposed groups whereas only four were noted in the control groups.

The position of an embryo was considered to be abnormal if there was any deviation from the normal position relative to the yolk. This increase, in the number of exposed embryos showing abnormalities of position, was small. There was an increase in the number of embryos viable to seventy-four in the exposed groups, but it was so slight that it was disregarded. Table I gives a summary of the results of the experiment, and Table II reviews the variation in per cent for the differences noted above.

## DISCUSSION

It is probable that since the work reported in this paper was done under a relatively low intensity of cosmic radiation, the number of secondary showers produced in the lead was too small to exert any effects. The work must be considered as being preliminary, and it is thought that with certain modifications of experimental procedure more definite results could be obtained. One method, which seems to be indicated, would be to expose the embryos to varying periods of shower radiation during the incubation period, not prior to it.

## SUMMARY

As research continues in the field of cosmic radiation, an understanding of some of the fundamental physical concepts is necessary for those interested in the biological action of the radiation. This paper presents a short review of some of these basic concepts. A review of some of the research into the biological action of cosmic rays is also presented.

This paper has presented a report of an investigation into the effects of secondary cosmic ray showers upon chick embryos. Although the results of this investigation were inconclusive, a need for further work is indicated.

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TABLE I

REVIEW OF THE EFFECTS OF SECONDARY COSMIC SHOWERS UPON CHICK EMBRYOS

| | Group A | | Group B | | Group C | |
|---|---|---|---|---|---|---|
| | exp | con | exp | con | exp | con |
| Number of eggs | 12 | 11 | 12 | 11 | 16 | 16 |
| Number of fertile eggs | 11 | 9 | 10 | 11* | 12 | 13 |
| Time under lead (hours) | 74 | 0 | 68 | 0 | 72 | 0 |
| Incubation time (hours) | 74 | 74 | 74 | 74 | 74 | 74 |
| Number of embryos viable to 74 hrs. | 10 | 6 | 10 | 12 | 12 | 13 |
| No. of position abnormalities | 3 | 2 | 2 | 2 | 2 | 0 |

*One egg was double-yolked, each yolk having a viable embryo.

TABLE II

COMPARISON OF PERCENTAGE VARIATIONS

| | Group A | | Group B | | Group C | | Total | |
|---|---|---|---|---|---|---|---|---|
| | exp | con | exp | con | exp | con | exp | con |
| Percent fertility | 91.6 | 81.8 | 83.3 | 91.7 | 75.0 | 81.3 | 82.5 | 84.6 |
| Percent viable to 74 hours | 90.9 | 66.7 | 100 | 109 | 100 | 100 | 97.3 | 93.9 |
| Percent position abnormalities based upon number of fertile eggs | 27.2 | 22.2 | 20.0 | 18.2 | 16.7 | 0.0 | 21.2 | 12.1 |
| Percent position abnormalities based upon embryo viability | 30.0 | 33.3 | 20.0 | 16.7 | 16.7 | 0.0 | 21.9 | 12.9 |