Reports

Extra-Atmospheric Cosmic Ray Dosage during the Large Solar Flare of 23 February 1956

During the large solar flare of 23 February 1956 cosmic ray measurements were carried out on a world-wide scale. Though most of the measurements were collected at sea level and mountain altitudes, synoptic evaluation of observations made at different geomagnetic latitudes permits inferences to be drawn about the extra-atmospheric intensity of the primary cosmic ray beam during the flare. This intensity was so large that it seems of interest to investigate what ionization dosage might be encountered if human beings should be caught by a large solar flare in extra-atmospheric flight.

The neutron intensity of cosmic radiation, at sea level, as recorded among others by Lockwood and collaborators (*1*) in Durham, N.H., showed on the critical day a steep increase to 36 times its normal value 21 minutes after the onset of visible activity on the sun and then slowly returned to normal in about 20 hours. Specifically, at 20:30 Universal Time, somewhat over 16 hours after the maximum, the intensity had declined to a value about 15 percent above normal. At exactly the same time, the balloon flight of the University of Minnesota, as reported by Winckler (*2*), had reached an altitude of 80,000 feet and recorded a 4-times normal total ionization. From these data two conclusions can be drawn: (i) If a 300-percent increase of the total ionization at 80,000 feet is reflected in a 15 percent increase of neutron intensity at sea level, the increase of the total ionization at extreme altitude at the time of the cosmic ray maximum when the sea-level neutron intensity was 36 times normal must have been tremendous. (ii) The disproportionately smaller intensity change at sea level indicates that the flare-produced radiation is of low penetrating power—that is, it mainly affects low-energy particles.

More detailed estimates of the additional intensity produced by the flare at the top of the atmosphere have been made by Meyer, Parker, and Simpson (*3*). From their data on the neutron intensity at sea level and at mountain altitudes in different geomagnetic locations, they were able to analyze the energy spectrum of the flare-produced primary protons in the cosmic ray beam. This spectrum exhibits a very strong dependence of particle intensity on geomagnetic latitude, approximately following a N^{-7} power law (N = magnetic rigidity). It is interesting to align the flare-produced and the normal spectrum in one graph (Fig. 1). The normal spectrum shown is that suggested by Winckler (*4*). The flare spectrum is derived by Meyer, Parker, and Simpson from observations at the geomagnetic latitudes 29°, 42°, 48°, and 52° marked by arrows on the abscissa. In trying to extrapolate these data to lower magnetic rigidities—that is, to higher latitudes—the phenomenon of the so-called geomagnetic cutoff has to be considered. The low-rigidity end of the normal integral spectrum is known to shift to smaller rigidities with increasing latitude, in full agreement with geomagnetic theory, up to a certain medium-high latitude. From there on it remains constant, contrary to expectation. In the normal spectrum in Fig. 1, this minimum cutoff latitude is assumed to be 54°, corresponding to a minimum rigidity of 1.78 Bv. However, the observations of different experimenters do not agree well with regard to the exact value of this critical latitude. Meyer, Parker, and Simpson draw the conclusion from their flare observations that "the primary spectrum was strongly peaked at particle rigidities just above the geomagnetic cutoff rigidity at Chicago" (*3*, p. 773). This would set the latitude knee of the flare spectrum just below 52°, as indicated in Fig. 1. Of particular interest in this connection is the fact that the cutoff phenomenon shows a strong correlation to solar activity in the sense that it is very weak or nonexistent at solar minimum during the 11-year cycle. This relationship would represent a protective mechanism inasmuch as large solar flares occur only at times of high solar activity—that is, at times when the cutoff is fully developed, preventing low-energy particles from reaching the earth.

For a radiobiological assessment of the flare-produced radiation, the total extra-atmospheric dosage should be expressed in rad units. This conversion can easily be carried out and is indicated in the right-hand ordinate index of Fig. 1. The extremely strong dependence of this dosage on geomagnetic latitude suggests that any indirect way of assessing the exposure hazard in quantitative terms must be subjected to a large margin of error. Direct measurements seem indispensable for the flare-produced radiation more than for any parameter of the ordinary cosmic ray beam. If the flare-produced intensity levels off at 52°, the dosage for the polar region would stop growing just below the danger mark. However, it remains an open question whether or not, outside magnetically shielded regions, the flare spectrum follows the straight-line extrapolation shown in Fig. 1. The implications of this possibility for the exposure hazard in interplanetary space during a large flare are ominous.

Entirely missing are clues on the participation of heavy nuclei in the flare-produced transitory radiation. This is particularly unfortunate since the biological effects of the ordinary cosmic ray beam center strongly on low-energy heavy nuclei of maximum ionization (so-called "thindown hits"). The complementary probabilities of a thindown hit or a nuclear collision for heavy nuclei are plotted in the upper graph of Fig. 1. When the speculative assumption is introduced that heavy nuclei in a solar flare are accelerated in a manner similar

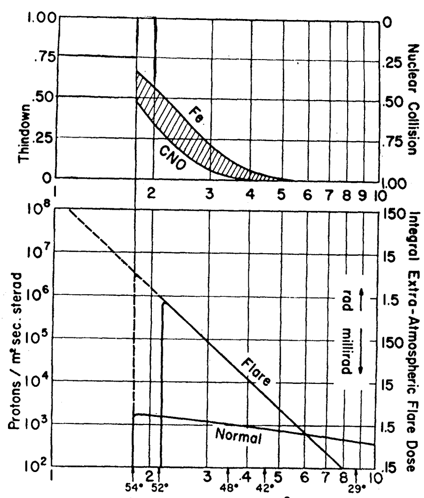

Fig. 1. (Bottom) Normal and flare-produced integral rigidity spectrum of primary protons. (Top) Probability of termination in thindown or nuclear collision for heavy nuclei as a function of magnetic rigidity.

All technical papers and comments on them are published in this section. Manuscripts should be typed double-spaced and be submitted in duplicate. In length, they should be limited to the equivalent of 1200 words; this includes the space occupied by illustrative or tabular material, references and notes, and the author(s)' name(s) and affiliation(s). Illustrative material should be limited to one table *or* one figure. All explanatory notes, including acknowledgments and authorization for publication, and literature references are to be numbered consecutively, keyed into the text proper, and placed at the end of the article under the heading "References and Notes." For fuller details see "Suggestions to Contributors" in *Science* 125, 16 (4 Jan. 1957).

to that in which protons are accelerated, it is seen that, in this case, the biologically most important fraction of the heavy beam which produces the thin-down hits would be subjected to an especially large increase of intensity. It might be mentioned in this connection that the optical emission lines of all heavy components, particularly those of calcium and iron, have been identified in the flare spectrum.

Other parameters on which no data are available are the intensities of flare-produced beta, x-, and gamma rays. It thus appears that, while the extra-atmospheric ionization dosages plotted in Fig. 1 certainly represent the lower limit, they might possibly do so by a large margin. On the other hand, flares of the size under discussion are rare events that occur only a few times during the entire peak of one 11-year cycle.

HERMANN J. SCHAEFER
Department of Biophysics,
U.S. Naval School of Aviation Medicine,
Pensacola, Florida

References and Notes

1. J. A. Lockwood *et al., Phys. Rev.* 103, 247 (1956).
2. J. R. Winckler, *ibid.* 104, 220 (1956).
3. P. Meyer, N. Parker, J. A. Simpson, *ibid.* 104, 768 (1956).
4. J. R. Winckler *et al., ibid* 79, 656 (1950).

26 August 1957

Concentration of Cesium-137 by Algae

The ab-adsorption of Cs^{137} by algae is of interest because Cs^{137} is one of the critical fission products in power reactor wastes and atomic weapon fallout, because it has an estimated half-life of 26.6 years, because it is water-soluble, and because it may be expected to increase in the environment as more and more use is made of nuclear energy as a source of electric power. It is well known that plankton take up radioactivity in fairly high concentrations (*1*). The purpose of this investigation was to study the accumulation of Cs^{137} by fresh-water algae (*2*).

Unialgal cultures of nine species, collected from the vicinity of Oak Ridge National Laboratory, were dosed with Cs^{137} chloride so that the initial activity of the nutrient media ranged from 1556 to 4056 disintegrations per minute, per milliliter. Results from these nine species are given in Table 1. The concentrations (in parts per million) of potassium present in the nutrient media were determined by flame photometry. The concentration factor given in Table 1 is the ratio of the activity of wet weight of washed algal cells (disintegrations per minute, per gram) to the activity of the nutrient medium (disintegrations per minute, per milliliter). The remainder of this report deals with the accumulation of cesium by *Euglena intermedia* and *Chlorella pyrenoidosa*. Dense populations were produced repeatedly in a putrified "Euglena" nutrient medium (*3*); white fluorescent lamps, delivering about 380 ft-ca, controlled by automatic clocks to give a 20-hour day and a 4-hour night, were used. The extent to which these algae decontaminate their nutrient medium was investigated. In 6 days *Euglena* decontaminated the medium by 69 percent; in 11 days, by 82 percent; in 18 days, by 86 percent; and in 34 days, by 96 percent. *Chlorella* decontaminated the medium by about 47 percent at each concentration of Cs^{137} in 13 days. The rate of decontamination appeared to vary directly with the number of cells in *Chlorella,* but in *Euglena* there was an increase in uptake per cell from the time cells ceased dividing, as the population became maximum.

Unialgal cultures of *Euglena* and *Chlorella,* grown in three concentrations of Cs^{137}, demonstrated repeatedly that the uptake of this radionuclide is linear with concentrations of 1, 5, and 10 μc/lit or of 1, 5, and 10×10^{-7} mmole/lit. Knauss and Porter (*4*) have found this to be true for calcium, iron, manganese, zinc, copper, and strontium at varied concentrations in *Chlorella.* However, at concentrations of 0.04 mmole/lit or more, in the present study, the concentration factor for cesium was reduced.

Morgan and Myers (*5*) have reported that uptake of cesium by *Chlorella* is significantly depressed by traces of potassium ion in the exchange solution. Also, cesium has been reported by MacLeod and Snell (*6*) to behave similarly to sodium, potassium, and rubidium in the nutrition of lactic acid bacteria. The relative influence of potassium and stable cesium on the uptake of tracer cesium by *Euglena* was determined experimentally, and the results are shown in Fig. 1. In the range of concentrations from 0.5 to 4.0 mmole/lit, potassium had a slight depressant effect on the uptake of Cs^{137} at tracer levels. When 1 mmole of potassium was present, increasing the concentrations of cesium carrier from 0 to 0.15 mmole/lit depressed the uptake of tracer cesium. The further increase of cesium content to 0.75 mmole/lit caused little additional depression of Cs^{137} uptake. It should be noted that an addition of an equimolar amount of potassium resulted in very little additional depression of the cesium uptake. The effect of potassium in the medium is presumed to be slight, because a concentration factor of 100 was found for *Chlorella* grown in media with potassium concentration as high as 1 mmole/lit.

In experiments during which *Chlorella* was grown in varying concentrations of stable cesium, the concentration factor for Cs^{137} was 46 to 59 in the absence of cesium, 15 to 18 with 0.5 mmole of stable cesium per liter, and 8 to 12 for other concentrations of stable cesium up to 2.5 mmoles per liter.

Table 1. Uptake of cesium-137 by species of algae.

Species	Potassium (parts per million)	Days after dosing	Concentration factor
Rhizoclonium hieroglyphicum	1	5	1530
Oedogonium vulgare	1	3	790
Spirogyra ellipsospora	1	2	341
Spirogyra communis	13	5	220
Gonium pectorale	10	2	138
Oocystis elliptica	10	10	670
Chlamydomonas sp.	8	5	52
Euglena intermedia	8	14	706
Chlorella pyrenoidosa	8	11	154

Since it has been shown that dead organic material can have a high affinity for cesium (*7*), *Chlorella* and *Euglena* cells which had been grown in a medium containing 15 parts of potassium per million were washed, killed in formalin, and dosed with Cs^{137}. After 8 days the concentration factor was 16 for *Euglena* and 418 for *Chlorella.* Because dead *Chlorella* showed a high concentration factor for cesium, an experiment was performed to test the uptake of cesium from varying levels of cesium, potassium, and cesium-potassium by these dead cells. Healthy living cells of *Chlorella* were washed and centrifuged in demineralized water. These cells were then killed with formalin, equally distributed into 33 large centrifuge tubes, and resuspended in demineralized water. To the 33 tubes were added stable salts to make three classes of 11 each, as follows: (i) 0 to 5 mmoles of potassium per liter; (ii) 0 to 5 mmoles of cesium per liter; and (iii) potassium and cesium in varying ratios but always totaling 2.5 mmole/lit. Each tube was dosed to give an activity of about 1 μc of Cs^{137} per liter and left standing for 72 hours. Thereupon, the cells in each tube were

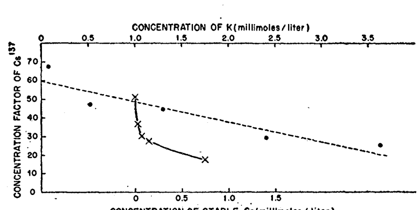

Fig. 1. Influence of potassium and cesium ions in the nutrient medium on the concentration of Cs^{137} by *Euglena intermedia.* The broken line represents the influence of potassium (regression line determined by least squares). The solid line represents the influence of cesium (curve fitted by eye), with potassium constant at 1.0 mmole/lit.