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# NUCLEAR EMULSION STUDIES


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Heavy primary cosmic rays were first detected by Freier (1) in 1948. The potential of these particles, ranging in size from carbon to iron nuclei, for causing pathologic damage, has been pointed out by Schaefer (2). Because the particles occur infrequently in cosmic radiation, a nuclear track-plate system has been devised to determine the direction of individual tracks and to predict the point at which an adjacent biologic sample was hit (3). This differs from the usual radiobiologic experiments employing accelerators in that, with the accelerators, the biologic damage is produced by a flux of particles rather than by a single particle.

Nuclear track plates flown on Discoverer XVII were observed to be completely blackened. They were, therefore, useless for monitoring heavy primary traversals. The most probable cause of the blackening was the radiation from a solar flare which occurred shortly before launch. There was still some doubt, however, about whether the track plates could be used on polar orbital flights, even if no flare occurred.

There are two approaches to monitoring heavy primaries when the plates are overexposed: One is to underdevelop the emulsions, and the other is to use less sensitive emulsions. We chose to study the second method.

The purposes of this study were threefold:

1. To determine whether the proton flux occurring during a nonflare flight would permit the use of the nuclear track plates to be used for heavy particle measurements.

2. To determine whether Ilford G-0 nuclear emulsion, an emulsion insensitive to protons, could be used to detect and identify the heavy primaries in the presence of a large flux of smaller particles. This required calibrating the G-0 emulsion in terms of the standard sensitive emulsion, Ilford G-5.

3. To determine the heavy particle flux within the satellite.

It should be emphasized that the nuclear track-plate technic using thin layers of emulsion on both sides of a glass plate does not permit a highly accurate determination of the charge of the heavies. Our interest was in comparing the measurements made in G-0 and G-5, using the track-plate technic as it is presently employed. To secure measurements that are more accurate would require large blocks of emulsions.

## METHODS AND MATERIALS

Three glass plates, 2 in. x 2 in. x 1 mm., were used. Ilford G-5 nuclear emulsion was poured on one side of plates 572 and 573, and Ilford G-0 was poured on the reverse side. The thickness of the emulsion layer when dry was 100 $\mu$. Ilford G-5 was poured on only one side of plate 574, giving a layer 50 $\mu$ thick when dried.

After flight, the plates were developed by using the "temperature cycle" method of Dilworth et al. (4).

The plate analysis was done with a standard research microscope under oil. The proton flux was found by counting the number of small broken tracks which passed through the upper surface of the emulsion. A small solid track was counted as a proton if it showed no delta rays.

To correlate the tracks caused by the same particle in sensitive and insensitive emulsions, delta ray counts in the G-5 emulsion were compared to grain counts made in the G-0 emulsion. The passage of the heavy particle through G-5 emulsion results in a heavy central track surrounded by an aura of short tracks caused by the ejection of secondary electrons. These short tracks are the delta rays whose numbers are proportional to the square nuclear charge ($Z^2$) of the heavy particle. In G-0 emulsion, no delta rays are created and the passage of the same particle leaves a series of developed grains whose numbers are also proportional to the $Z^2$ value. In this experiment, a heavy track was located in the G-5 emulsion, and the delta rays were counted. The plate was then turned over and a grain count was made on the corresponding track in the G-0 emulsion. Similar measurements were made for 9 heavy particles.

## RESULTS

The intense blackening found in the plates of Discoverer XVII did not occur on the track plates sent on this flight. It was concluded that the major cause of blackening during Discoverer XVII could be attributed to the solar flare which occurred during that flight. In addition, it was concluded that the three plates had received no appreciable flux of lower energy of electromagnetic radiation. Ground experiments before the flight had indicated that the Ilford G-5 nuclear emulsion blackens completely with a dose of 0.10 r of 60 kv. x-rays.

The plates were examined microscopically for heavy particle flux. It was found that, while the heavy particles could be located easily, the large flux of smaller particles which had passed through the plates interfered seriously with the determination of nuclear charge (Z) of the heavies. This was particularly true for the plates coated with the thicker emulsions. Plate 574 which had a single coating of only 50 $\mu$ of emulsion was much easier to read.

In order to determine the flux of small particles which produced this much interference with the measurements on the heavies, a count was made of the number of small particle tracks (presumably protons) in 40 fields chosen randomly on plate 574. The results are given in table I.

A similar count made on a track plate exposed on a balloon flight at 140,000 feet gave $1.8 \times 10^4$ protons per square centimeter. At this 10-fold smaller proton flux, no serious interference with heavy-particle track measurements occurred.

Plates 572 and 573 were intended to be used to correlate the delta ray count produced in G-5 emulsion to the grain counts produced in G-0 emulsion by the same heavy primary. No tracks were found, however, in the G-0 emulsion of plate 573. This is an unexplained phenomenon that has occurred infrequently in G-0 on balloon flights. Only plate 572 was useful for the correlation. The results are given for nine tracks in table II. The tracks are arranged in order of descending delta count values.

Although a linear positive correlation might be expected as a first approximation, it was not obtained. The large flux of small particles interfered in two ways with the accuracy of the measurements. In addition to creating an uncertainty in the delta ray measurements in the G-5 emulsion, it made the determination of the exact direction of the track difficult. Since the G-0 emulsion was on the opposite side of the glass plate, a large distance compared to

TABLE I

*Proton flux measurements (plate 574)*

| Number of fields scanned | Average proton count | Range | Area of field | Protons/cm.$^2$ |
|---|---|---|---|---|
| 40 | 4.18 | (1-9) | $2.2 \times 10^{-5}$ cm. | $1.9 \times 10^5$ |

TABLE II

*Comparison of ionization measurements for the same particle in different nuclear emulsions (plate 572)*

| Track No. | G-5 Delta counts/ 100 μ | G-0 Grain counts/ 100 μ |
|---|---|---|
| 1 | 52 | 125 |
| 2 | 48 | 118 |
| 3 | 48 | 102 |
| 4 | 44 | 77 |
| 5 | 40 | 77 |
| 6 | 36 | 107 |
| 7 | 36 | 115 |
| 8 | 29 | 69 |
| 9 | 13 | 82 |

the thickness of the emulsion layers, it was difficult to determine which track in the G-0 emulsion corresponded to a given track in the G-5 emulsion. A much better method for future use would be to pour the G-0 emulsion directly on top of the G-5 emulsion so that there would be no gap between the layers.

Two different readers scanned the entire area of plate 574 to measure the flux of heavy primary cosmic particles inside the satellite. Plate 574 was chosen because it permitted a more accurate particle identification. Only heavies of $Z \geqq 26$ were counted. This cutoff was chosen because it reduced the number of particles to be counted and because this group is potentially the most dangerous from a biologic standpoint. The results for each reader are given in table III.

TABLE III

*Heavy particle ($Z \geqq 26$) flux (plate 574)*

| Counts | Area cm.$^2$ | Counts/cm.$^2$ |
|---|---|---|
| 11 | 20 | — |
| 9 | 20 | — |
| 20 | 40 | 0.5 |

## CONCLUSIONS

1. The flux of small particles encountered in this flight did not prevent the identification of heavy primary particles in G-5 emulsion. The identification was more positive in a thinner emulsion layer.

2. Heavy primary tracks were readily located in G-0 emulsion. The correlation between particle identification measurements made in G-5 and G-0 emulsions for the same particle was poor. Placing the G-0 and G-5 layers in direct contact with each other, however, should improve the correlation.

3. A good calibration of Ilford G-0 nuclear emulsion will become increasingly important for measuring heavy primaries in flights where large proton fluxes are anticipated.

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