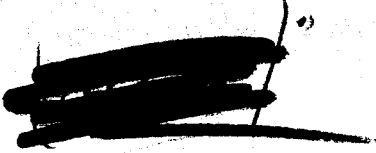


445883



MEASUREMENTS OF THE ASTRONAUTS' RADIATION EXPOSURE WITH  
NUCLEAR EMULSION ON MERCURY MISSIONS MA-8 AND MA-9

Hermann J. Schaefer and Jeremiah J. Sullivan

FACILITY FORM 802

9349

(ACCESSION NUMBER)	(THRU)
17	
(PAGES)	(CODE)
CB-82574	04
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)



JOINT REPORT



DDC  
 RECEIVED  
 SEP 7 1964  
 DDC-IRA B

UNITED STATES NAVAL SCHOOL OF AVIATION MEDICINE  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

589-55063

# Research Report

3 MEASUREMENTS OF THE ASTRONAUTS' RADIATION EXPOSURE WITH  
NUCLEAR EMULSION ON MERCURY MISSIONS MA-8 AND MA-9\* 6

6 Hermann J. Schaefer and Jeremiah J. Sullivan 9

Bureau of Medicine and Surgery

Project MR005.13-1002

Subtask 1

218 Report No. 27 END

Approved by

Captain Ashton Graybiel, MC USN  
Director of Research

Released by

Captain Clifford P. Phoebus, MC USN  
Commanding Officer

9 25 May 1964 10

\*This work was conducted under contract with the Manned Spacecraft Center,  
National Aeronautics and Space Administration, Houston, Texas.

**U. S. NAVAL SCHOOL OF AVIATION MEDICINE**

**U. S. NAVAL AVIATION MEDICAL CENTER**

7 PENSACOLA, FLORIDA 3

## SUMMARY PAGE

### THE PROBLEM

For the limited altitudes and times in orbit of the Mercury Missions, no objectionable radiation exposure of the astronaut was likely to occur. The objective of radiation monitoring, therefore, was limited to obtaining a post-flight record of the exposure during the mission. Since ionizing radiation outside the atmosphere consists predominantly of nucleons with only a negligible addition of gamma rays and electrons, a small nuclear emulsion pack seemed the most appropriate radiation sensor for the indicated purpose.

On Missions MA-8 and MA-9 two special circumstances called for closer attention to radiation exposure. These were the artificial radiation belt of electrons created in the high altitude nuclear explosion of July, 1962 (Starfish Test) and the residual proton flux of the Inner Van Allen Belt reaching down to satellite altitudes in the South Atlantic Anomaly. Earlier missions had not encountered either hazard because they were completed prior to the Starfish Test, consisted only of three orbits, and therefore stayed clear of the South Atlantic Anomaly.

### FINDINGS

Ilford G-5 emulsions flown on MA-8 and MA-9 showed a background from electrons and gamma rays not significantly different from that of the sea level controls, indicating that the inherent shielding of the capsule was sufficient for complete absorption of electrons from the artificial radiation belt. The emulsions did show large populations of low energy protons picked up in the South Atlantic Anomaly. Evaluation by track and grain count furnished the differential energy spectrum of these protons and lead to an absorbed dose of 27 millirads, an RBE dose of 31 millirems, and a QF dose of 41 millirems. The additional exposure from all other sources, i.e., from heavy nuclei, disintegration stars, and meson events, is estimated at 2 millirads.

The most significant result of the measurements is the absence of electrons and gamma rays as contributors to the additional dose in the flown emulsions as compared to the sea level controls. It indicates that the primary cosmic ray beam produces, in one and a half tons of compact material of the Mercury capsule, only an insignificant amount of electrons and gamma rays.

### ACKNOWLEDGMENTS

The authors are greatly indebted to F. C. Maienschein and R. T. Santoro of Oak Ridge National Laboratory for exposing test plates to 450 Mev protons at the Chicago Synchrocyclotron. The large workload of scanning the emulsions was aptly handled by M. G. Basha, D. A. Cormier, C. N. Coulter, E. T. Nelson, S. A. Sweeney, and R. C. Symington. The excellent microphotographic evaluation of the material was done by M. G. Basha.

## INTRODUCTION

When the question of a suitable method for recording the radiation exposure of the astronaut on Project Mercury arose, it was quite obvious from the beginning that, for the limited duration and the limited orbital altitude of the Mercury Missions, the radiation dose would remain far below any objectionable level. In-flight measurement of dose rate or in-flight reading of accumulated dose, therefore, seemed definitely dispensable. On the other hand, monitoring the radiation exposure of the astronaut on each mission seemed desirable for a complete record of all environmental parameters.

For Missions MA-8 and MA-9, closer attention to the radiation exposure was called for inasmuch as these two missions took place within one year after the high altitude nuclear explosion known as the Starfish Test. Beta rays from this explosion had created a strong artificial radiation belt of electrons reaching down to normal satellite altitudes. Uncertainties and discrepancies in the prediction of experts concerning flux values, energy levels, and decay times of the artificial radiation belt left those responsible for the safety of the astronaut essentially without reliable information on which to base a decision whether an in-flight follow-up of accumulated exposure would be necessary. Such instrumentation actually was provided for Mission MA-8; however, it turned out that the exposure from electrons remained entirely on the level of the ionization dosage from the ordinary cosmic ray beam.

Another problem concerned the additional exposure on MA-8 and MA-9 in the so-called South Atlantic Anomaly, a region over the South Atlantic where the Inner Van Allen Belt dips down more deeply than at any other longitude due to certain irregularities in the structure of the earth's magnetic field (1). The three orbits of Glenn (MA-6) and Carpenter (MA-7) stayed clear of this region. However, since the longitude of the nodes changes by about  $25^\circ$  per orbit due to the rotation of the earth, the last three of the six orbits of MA-8 and some ten of the twenty-two orbits of MA-9 scanned through the central or peripheral regions of the Anomaly. The added proton flux from this exposure showed up quite clearly in the emulsions of Missions MA-8 and MA-9.

The composition of the primary cosmic ray beam outside the atmosphere and its dependence on geomagnetic latitude are fairly well-known. It would appear basically an easy task, then, to establish a close estimate of the exposure per orbit by theoretical computation. The shortcoming of this approach rests in the fact that the astronaut's body is surrounded by one and a half tons of compact material made up of the vehicle frame and equipment. In this material the primary cosmic ray particles undergo complex transition processes partly resulting in attenuation, i. e., in a decrease of exposure, but also resulting in particle multiplication through production of secondaries in nuclear collisions, thereby increasing exposure. To be sure, in terms of millirem dose, this exposure will still remain far below any objectionable level even if a factor of 2 or 3 would be used for estimating the additional exposure from secondaries.

Considering the just-mentioned circumstances and the general conditions of the Mercury Missions, the most suitable choice of a radiation sensor appeared to be nuclear emulsion. Its extremely high sensitivity and its ability to identify ionizing particles individually, in combination with the fact that it works truly "automatically" without any power supply or electronic or mechanical device, gave it a clear preference for missions on which weight economy was a particularly pressing demand and no compelling reason for in-flight information on the exposure status existed.

## DOSE DETERMINATION IN RADS WITH NUCLEAR EMULSION—THE STANDARD EMULSION PACK

Since the ultimate purpose of the radiation monitoring was determination of absorbed dose in the astronaut's body, the objection might be raised that photographic emulsion, because its sensitive substances silver and bromine are elements of high  $Z$ -numbers, is not a tissue-equivalent sensor. Concerning this argument, it must be pointed out that the primary cosmic ray beam outside the atmosphere is composed exclusively of protons, alpha particles, and heavy nuclei and does not contain electrons,  $x$ -, or gamma rays. The principle of tissue equivalence, however, is based on the concept of an equilibrium exchange of secondary electrons between the sensing substance of the dosimeter and surrounding tissue or a surrounding tissue-equivalent wall material. It is obvious that this principle is not applicable to particle beams. To be sure, electrons do appear in the cosmic ray beam as soon as it starts interacting with absorbing material such as the earth's atmosphere or the hardware of a Mercury capsule; however, these electrons constitute just one of several agents contributing to the total energy dissipation. Moreover, the cosmic ray beam never reaches a state of equilibrium with its secondary electrons or, for that matter, with any other of its many types of secondaries. A continuous complex transition in number, type, and energy of secondaries occurs all through the atmosphere as well as in any compact absorber such as a space capsule and a human target in it. The situation is similar for high intensity proton radiations in space such as flare produced particle beams or trapped protons in the Van Allen Belt. Energy spectrum and Linear Energy Transfer (LET) distribution change continuously as these beams travel through absorbing material.

For all these reasons, indirect determination of absorbed dose from measurements of local flux and local LET spectrum would seem to be more accurate than direct measurement with a tissue-equivalent ion chamber. Admittedly, the heavy elements silver and bromine in nuclear emulsion will produce a contribution to scattering basically dissimilar to that from the light elements in tissue. As far as star production is concerned, this component can be identified and the star count can be excluded easily from the computation of dose. For other secondaries resulting from nuclear interactions with silver and bromine atoms, identification is more difficult. However, if the total emulsion volume is small enough to ensure that the bulk of the particle flux recorded in the emulsion enters from the outside, the contribution from nuclear interactions will also be small.

The foregoing proposition becomes invalid if a significant fraction of the radiation incident upon the emulsion consists of x-, beta, or gamma rays. These ionizing agents do not produce, in emulsion, distinct straight tracks but cause merely a general increase of background density which does not allow quantitative inferences on the incident flux and which, particularly for x-rays, depends very strongly upon the Z-number of the absorbing material. Photographic density, for these ionizing agents, is not related directly to absorbed dose in tissue. The criterion, then, whether an exposure of nuclear emulsion can be evaluated in terms of tissue ionization dosage would be whether it consists predominantly of particle tracks on a low background or of an enhanced background with few dense tracks. Fortunately, the nuclear emulsions on all Mercury flights retained a very low background which never differed significantly from that of the sea level controls.

The so-called standard emulsion pack used on all Mercury flights consisted of 8 nuclear plates of 1 by 3 inches of Ilford G-5 and K-2 emulsions of 50, 100, and 200 micra thickness in varying combinations. The plates were wrapped in black paper, aluminum foil, cardboard, and epoxy resin representing a maximum of almost 1.0 gram per centimeter material for particles entering at right angle to the emulsion plane and of about  $0.3 \text{ g/cm}^2$  at the 1-inch edge of the plates. These different equivalent thicknesses at different sides of the pack in connection with the glass support of the emulsions provided a wide range of different prefiltration values for individual emulsion areas which would have allowed identification of any soft radiation component. Electrons in particular, entering at the minimum prefiltration side of the pack, would have produced a gradient of the background density in the emulsions from the edge toward the inside. In no instance has such a gradient, which would indicate a soft radiation component, been found. One might say that this was to be expected since any radiation entering the capsule undergoes heavy prefiltration in the vehicle wall and equipment.

## EVALUATION METHOD

The problem of evaluating a population of particle tracks recorded in a nuclear emulsion might be explained with the aid of Figure 1. It shows a composite photomicrograph of a sectional area of an Ilford G-5 plate flown on Mission MA-9. Two very heavy tracks from nuclei of an estimated  $Z = 14$  and  $18$  stand out clearly on a background of a large population of light tracks, most of them protons. The micrograph also shows clearly the low general background of single grains and of tortuous tracks and grain clusters from electrons. As mentioned before, this low general background indicates that the ionization dosage is to be attributed mainly to the nucleonic component with a beta-gamma background not significantly different from that at sea level.

If a population of tracks is to be evaluated in terms of absorbed tissue dose in rads, it is necessary merely to know the total track length per unit volume and the

LET distribution. Identification of Z-numbers of tracks is not necessary. This distinguishes the task of the radiobiologist, who is interested in absorbed dose in tissue, from that of the physicist, who is interested in complete information on type of particle, number, and energy spectrum of a flux.

The range within which LET can be directly determined by grain counting depends greatly upon the type of emulsion and the degree of development. For fully developed G-5 emulsion it extends up to about 6 keV/micron emulsion with good accuracy and further up to about 10 keV/micron with substantially lower accuracy. Beyond 10 keV/micron the individual grains coalesce to a coherent track, and grain counting is no longer possible. If we assume a stopping power ratio of 2.33 for emulsion to tissue, the just-quoted LET values for emulsion correspond to about 2.6 and 4.3 keV/micron tissue.

Estimates of LET values of heavy nuclei are possible by comparing the diameter of the solid silver core and the delta ray aura of an unknown track with tracks of relativistic nuclei of known Z-number. A calibration scale of this kind covering the Z-numbers from  $Z = 1$  to  $Z = 26$  (Fe) for Ilford G-5 emulsion has been published by Powell, Fowler, and Perkins (2). This indirect method seems acceptable as a rough estimate, especially for exposures to the primary cosmic ray beam at low latitudes where the magnetic field of the earth admits only high energy nuclei.

More difficult is the determination of LET for tracks of low Z nuclei, especially of protons, at low energies. As mentioned above, such nuclei produce coherent tracks of essentially one grain diameter which look alike for different Z-numbers and for a wide range of different LET values. Accurate information on the local LET of such tracks can be established only by indirect methods such as measuring nuclear scattering or total range, methods which require a considerable length of the individual tracks (several thousand micra emulsion). For the sizes and emulsion thicknesses used in the standard emulsion pack of this investigation, only a very small percentage of all recorded tracks fulfill this condition. For the proton populations recorded on MA-8 and MA-9, we have tried to overcome this difficulty by utilizing the count of so-called "enders," i.e., of protons ending in the emulsion. If the assumption is made that the large populations of thin tracks recorded on these flights are predominantly from protons, the enders represent protons of zero kinetic energy, and the enders count defines the particle number in the differential energy spectrum at zero energy. In this way the left end of the differential energy spectrum is accurately defined, and the gap in the spectrum between this point and the region of higher energies where grain counting becomes possible can be bridged by interpolation, distributing the coherent tracks of unknown energies in such a way that a smooth curve is obtained for the energy spectrum. The differential energy spectrum for the proton population of MA-9 (shown in Figure 6 in the following section) has been established in the just-described manner. It is reassuring that the basic configuration of this spectrum with the differential particle number rising steeply from zero energy and curving over to a flat maximum at medium high energy is exactly the one

which would be expected in a compact absorber irradiated by protons with an incident spectrum of monotonic negative slope. The details of the transition mechanism, which causes this change in spectral configuration, have been analyzed in earlier studies (3, 4).

More sophisticated methods such as the blob or gap count are preferred to the direct grain count in modern techniques of track analysis in nuclear emulsions. While these methods achieve substantially higher accuracies in the determination of Z-number and LET, they are also considerably more time consuming. For exposure estimates in radiation safety a certain margin of error in the assessment of absorbed dose is acceptable. Direct grain counting, therefore, is entirely adequate and greatly preferable for its simplicity and greater speed. The data presented here are based exclusively on the grain count method.

Figure 2 shows eight photomicrographs of proton tracks taken from various G-5 plates flown on Mission MA-8 with grain densities varying from 23 to 240 grains per 100 micra emulsion. We consider this the useful range of grain densities in which grain counting can be conducted with reasonable working speed, acceptable reproducibility, and agreement among several observers. Below 23 grains/100 micra the number of tracks missed increases rapidly unless the scanning speed is greatly reduced. It should be mentioned, however, that tracks of this grain density contribute, in the particular track populations of MA-8 and MA-9, only a negligible fraction to absorbed dose. This particular point is discussed in more detail below.

The calibration curve relating grain count to LET for Ilford G-5 emulsion used in the present investigation is shown in Figure 3. For the region of low grain densities up to about 160 grains/100 micra, the curve has been established by test exposures of G-5 emulsion to 450 Mev Synchrotron protons and by grain count of protons ending in the emulsion. Since this section was found to coincide closely with the mean of corresponding curves established by Voyvodic and by Fowler as reported in a review by Voyvodic (5), this mean curve was used to complete the calibration curve beyond 160 grains/100 micra, in which region, due to the smallness of our emulsion volume, direct identification of protons was not possible.

Figure 4 shows a proton "ender," i.e., a proton ending in the emulsion. The same visual field is shown at three different adjustments of the depth of focus with the center micrograph showing the end of the ender sharply in focus. By following such enders up backwards through the emulsion stack to a residual range at which grain counting becomes possible, energy and grain count can be related since the range/energy relationship for protons in G-5 emulsion is well-known. As mentioned before, the smallness of our emulsion volume and alignment problems allowed using this method in the present investigation only up to about 160 grains/100 micra corresponding to 37 Mev. However, the excellent agreement of our calibration points with those of Voyvodic and Fowler furnishes directly the additional section of the calibration curve from 160 grains/100 micra to the upper end, i.e., from 37 Mev on to lower energies.



## RESULTS

In presenting the results of the evaluation method described in the preceding section, the data on the proton population recorded on the last Mercury flight (MA-9, 22 orbits, Cooper) will be reported first since these protons account for by far the largest exposure that occurred on any one of the missions. By converting track counts in the various grain density classes and the enders count into classes of kinetic energy as explained above, the circled dots in Figure 5 are obtained. The smooth graph in the same figure represents the curve of best fit on which the computation of millirad and millirem doses was based.

The apparent disregard of the point at 44 Mev in drawing the curve of best fit needs explanation. The energy interval for this point corresponds to rather high grain densities for which the accuracy of grain counting is substantially reduced. Quite differently, the two points to the left of the one at 44 Mev, i.e., at zero and at 18 Mev, are established with a much smaller margin of error by counting the enders (zero energy) and by redistributing the total count of black tracks (18 Mev). A further argument in favor of basing the curve of best fit essentially on the points at 18 Mev and at 62 Mev and drawing it well above the experimental value for 44 Mev rests in the fact that in this way the fractional absorbed dose in this particular energy interval will be rendered too high, which constitutes a safety margin for the assessment of the astronaut's exposure.

Numerical integration of Figure 5 furnishes the integral energy spectrum shown in Figure 6. For determination of dose, the integral energy spectrum is not very useful in describing a heterogeneous radiation in quantitative terms. However, since proton radiations in space are described frequently in terms of the integral energy spectrum, Figure 6 might be useful for the reader who would want to compare such spectra communicated in the literature with the one in Figure 6.

The differential energy spectrum in Figure 5 is representative of the local flux in the capsule; therefore, it can be evaluated directly in terms of absorbed tissue dose by assuming that nuclear emulsion is replaced by tissue. Since LET depends strongly upon energy, this evaluation has to be carried out in steps by breaking down the energy spectrum into narrow intervals. Adding up the contributions from these sections beginning at zero energy, one obtains the graph of cumulative dose of Figure 7 which shows not only the total dose, but conveys also information on the size of the individual contributions. It is seen that the steepest build-up of cumulative dose occurs at low energies, indicating that in this region the fractional dose per Mev is largest. At the other end, beyond 200 Mev, the contributions per Mev become very small. In fact, the cumulative dose quite closely approaches the total dose at 200 Mev. This indicates that even major errors in the track count at this energy and beyond, i.e., at low and very low grain densities, would produce only minor changes in the total proton dose of 27 millirads.

For a full appraisal of the exposure hazard, the absorbed dose in millirads has to be converted into the dose equivalent in millirems. For this conversion, Relative Biological Effectiveness (RBE) and Quality Factor (QF) have to be determined. For a heterogeneous radiation containing particles of different energies, i.e., of different LET values, this requires a breakdown of the differential energy spectrum into small energy intervals, separate determination of the dose equivalent for each interval, and reintegration for establishing the mean RBE and QF. For continuous proton spectra as they are encountered in space, the details of this analysis have been presented in earlier studies (3, 4). In the latest recommendations of the RBE Committee to the ICRP and the ICRU (6), formulae are set forth directly relating RBE and QF to LET. Using these formulae, we obtain, for the differential energy spectrum of Figure 5, a mean RBE of 1.15 and a mean QF of 1.52. Applied to the absorbed dose of 27 millirads, this leads to an RBE dose equivalent of 31.1 millirems and to a QF dose equivalent of 41.3 millirems.

A particular problem exists concerning the interpretation of the heavy nuclei count in terms of radiation damage. On the one hand, the total ionization dosage from heavy nuclei expressed in the usual way in millirads, i.e., in absorbed energy per unit tissue mass, is extremely small. On the other hand, it seems quite questionable whether this expression is realistic and meaningful since the absorbed energy is concentrated, in the micro-structure of tissue, in a cylindrical volume of about two cells diameter, in which the dose from a single traversal amounts to hundreds and thousands of rads. Several investigators (7, 8) have produced experimental evidence that such cells in the direct pathway of a heavy nucleus are indeed severely damaged. No data are available, however, on how acute or long-term damage would develop in multicellular organisms from total body exposure to such "microbeam" irradiation.

All that seems left to do under these circumstances is to identify the heavy tracks in the flown emulsions and to compare their count with the theoretical value. If one uses the energy spectrum for heavy nuclei suggested by Singer (9) as the best representation of all existing experimental data, the integral heavy flux per orbit can be computed by numerical integration, taking into consideration the dependence of the minimum energy of arrival on varying geomagnetic latitudes for the trajectory of a Mercury orbit. For the 22 orbits of Mission MA-9 this computation leads to a grand total of 27 traversals of a target area of  $1 \text{ cm}^2$  by nuclei of a  $Z \geq 10$  assuming isotropic hemispherical incidence. Classifying the heavy tracks in the MA-9 emulsions according to the standard tracks of Powell, *et al.* (2) mentioned above, we obtain a slightly smaller track count of  $Z \geq 10$ . In view of the large margin of error inherent in this method, we cannot state with certainty that this smaller flux inside the ship is real and indicative of a narrowing of the solid angle of particle acceptance due to local attenuation effects.

For the lower part of the heavy spectrum comprising the Z-numbers from 3 to 9, track identification by visual comparison is still less reliable. We are, therefore, unable to differentiate the track population in the flown emulsions and can only estimate in general that the track count is of the order of magnitude of the flux of the

incident beam. Summarizing the emulsion findings of the entire heavy component, one could say, then, that the dose contribution can be assessed on the basis of the flux values for the incident beam. This dose of the incident beam, computed under consideration of the latitude scan of a Mercury orbit, amounts for the thirty-five hour exposure on Mission MA-9 to slightly less than one millirad. The smallness of this dose demonstrates that an accurate Z differentiation of the heavy spectrum, which would require quite large emulsion volumes, is of no importance for the assessment of dose from heavy nuclei on Mercury type missions.

In addition to heavy nuclei, the flown emulsions show other nuclear interaction events characteristic of the extremely high energies of cosmic ray primaries. The population of multipronged evaporation stars has been evaluated thoroughly with regard to prong number distribution and number of stars per unit emulsion volume. This reaction is typical for the heavy elements Ag and Br of which nuclear emulsion contains about 85 per cent by weight. In organic matter and living tissue, which are practically devoid of heavy elements, star formation accounts for only a negligible contribution to total dose. A detailed account of the data on the star population, therefore, is omitted here.

Nuclear interactions at extremely high energies beyond the meson production threshold are still, by an order of magnitude, less frequent than star disintegrations. Moreover, most of their singly charged secondaries are counted with the proton component. That means their contribution to absorbed dose is correctly accounted for. The most spectacular event of this type, recorded on MA-7, identified in two adjacent emulsion layers, is shown in Figure 8.

## DISCUSSION

The most interesting finding in the emulsion monitoring of the Mercury Missions is the fact that, in all cases, even in the thirty-five hour exposure of MA-9, the G-5 emulsions retained a beta-gamma background essentially equal to that of the sea level controls. This proves that, in the space ship, the exposure in excess of the sea level background is mainly due to the nucleonic component. This, in turn, allows the conclusion that the close vicinity of almost one and a half tons of scattering material about the emulsion pack and the astronaut does not produce a significant contribution of beta or gamma rays. There are good reasons to assume that local scattering does produce a substantial contribution to the nucleonic component in the form of neutrons and protons. In this respect it might be emphasized again that there is no possibility of identifying this contribution, i. e., of distinguishing the primaries from the secondaries in the total proton population. However, as pointed out before, for the determination of dose this uncertainty is entirely irrelevant as long as the ionization dose of the particles is correctly assessed.

How far this characteristic feature of a very low beta-gamma background would be preserved in exposures of very large ships to solar particle beams cannot

be concluded from the Mercury data. Emulsion recordings of solar proton beams with high altitude balloons (10) indicate consistently that the bulk of the ionization dose is, in very much the same way as in the emulsions of MA-8 and MA-9, predominantly due to protons.

Except for this reservation concerning very large ships in solar particle beams, the radiation monitoring with nuclear emulsions on the Mercury flights has proven that the astronaut's exposure can be assessed reliably in terms of absorbed dose in millirads and of dose equivalent in millirems with very small emulsion volumes. It should pose no problem to design an even smaller unit than the standard emulsion pack by discarding a large part of the wrapping and casing material and by changing from plates to pellicles. Such packs could be inserted at several locations inside the astronaut's space suit and would provide essentially the same information as the standard emulsion pack did on the Mercury Missions.

## REFERENCES

1. Freden, S. C., and Paulikas, G. A., Trapped protons at low altitudes in the South Atlantic Magnetic Anomaly. J. Geophys. Res., 69:1259-1269, 1964.
2. Powell, C. F., Fowler, P. H., and Perkins, D. H., The Study of Elementary Particles by the Photographic Method. New York: Pergamon Press, 1959.
3. Schaefer, H. J., Dosimetry of proton radiation in space. BuMed Project MR005. 13-1002 Subtask 1, Report No. 19. Pensacola, Fla.: Naval School of Aviation Medicine, 1961.
4. Schaefer, H. J., The December 1962 report of the RBE Committee to the ICRP and ICRU in its implications for the assessment of proton radiation exposure in space. BuMed Project MR005.13-1002 Subtask 1, Report No. 26 and NASA Order No. R-75. Pensacola, Fla.: Naval School of Aviation Medicine, 1963.
5. Voyvodic, L., Particle identification with photographic emulsions, and related problems. In Wilson, J. G. (Ed.), Progress in Cosmic Ray Physics. Vol. II. New York: Interscience Publishers, 1954. Pp 219-238.
6. Report of the RBE Committee to the International Commissions on Radiological Protection and on Radiological Units and Measurements. Health Physics, 9:357-384, 1963.
7. Eugster, J., Method for demonstrating the biological effectiveness of cosmic radiation at high altitudes. J. Aviat. Med., 24:222-223, 1953.
8. Hutchinson, F., and Easter, S. S., Jr., A difference between biological effects of gamma rays and heavy ions. Science, 132:1311-1312, 1960.
9. Singer, S. F., The primary cosmic radiation and its time variations. In Wilson, J. G., and Wouthuysen, S. A. (Eds.), Progress in Cosmic Ray Physics. Vol. IV. New York: Interscience Publishers, 1958. Pp 205-335.
10. Freier, P., and Webber, W. R., Radiation hazard in space from solar particles. Science, 142:1587-1592, 1963.

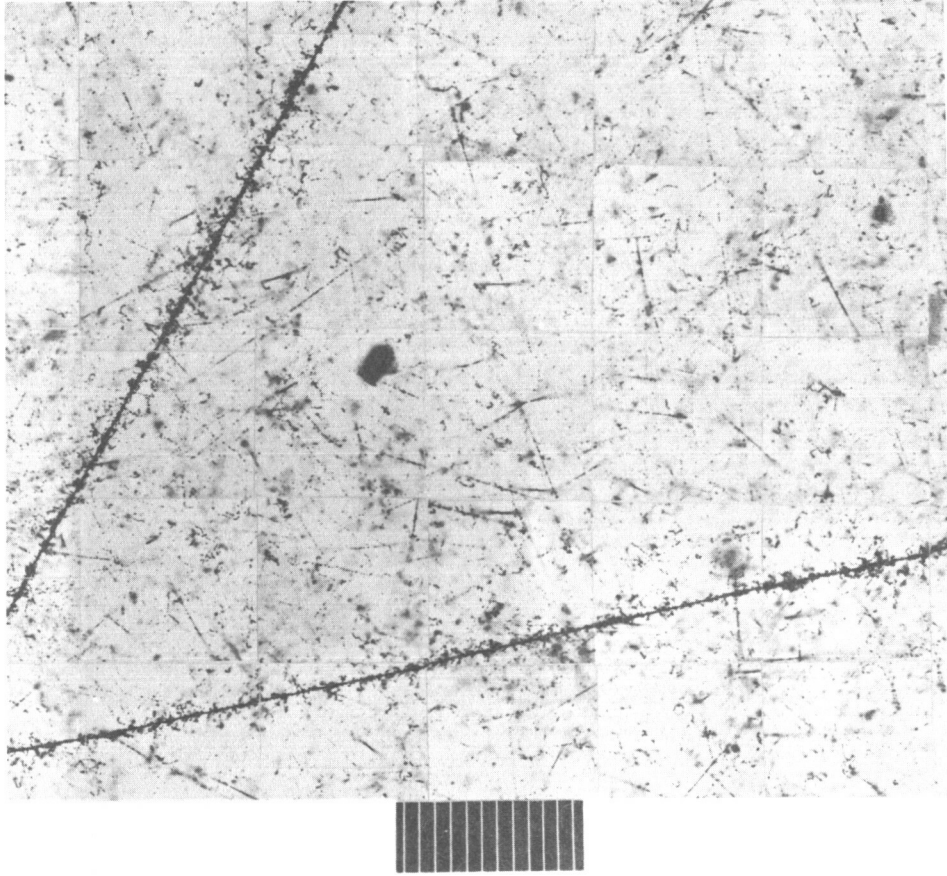


Figure 1

Composite Photomicrograph of Ilford G-5 Emulsion  
Flown on Mission MA-9

Picture shows two heavy nuclei tracks of estimated  $Z = 14$  (lower) and  $18$  (upper left) and many tracks of protons of different grain densities. Picture is typical for proton population, but is atypical with regard to heavy tracks since their flux is low and a combination of two of  $Z > 10$  in close vicinity quite seldom occurs. Note low background of beta and gamma rays.

1 scale division = 10 micra.

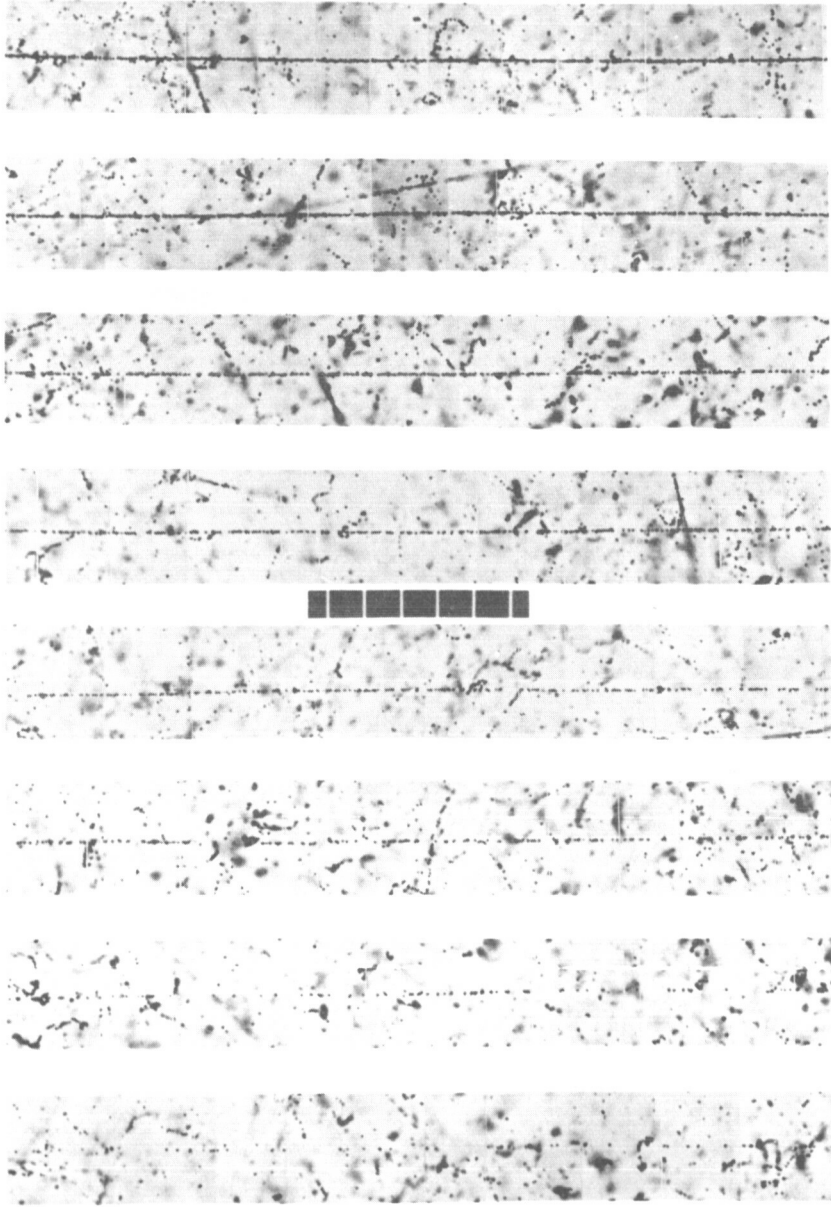


Figure 2

Selected Proton Tracks from Ilford G-5 Emulsions Flown on Mission MA-8

Grain density from left to right is: 23, 52, 77, 108, 120, 155, 203, 240 grains per 100 micra.  
1 scale division = 10 micra.

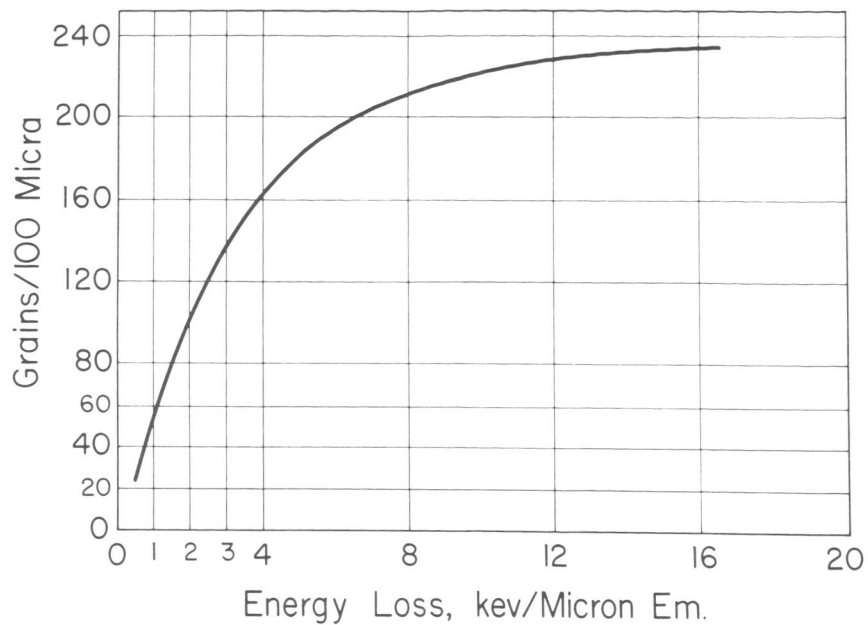


Figure 3

Grain Density as a Function of Energy Loss for Ilford G-5 Emulsion

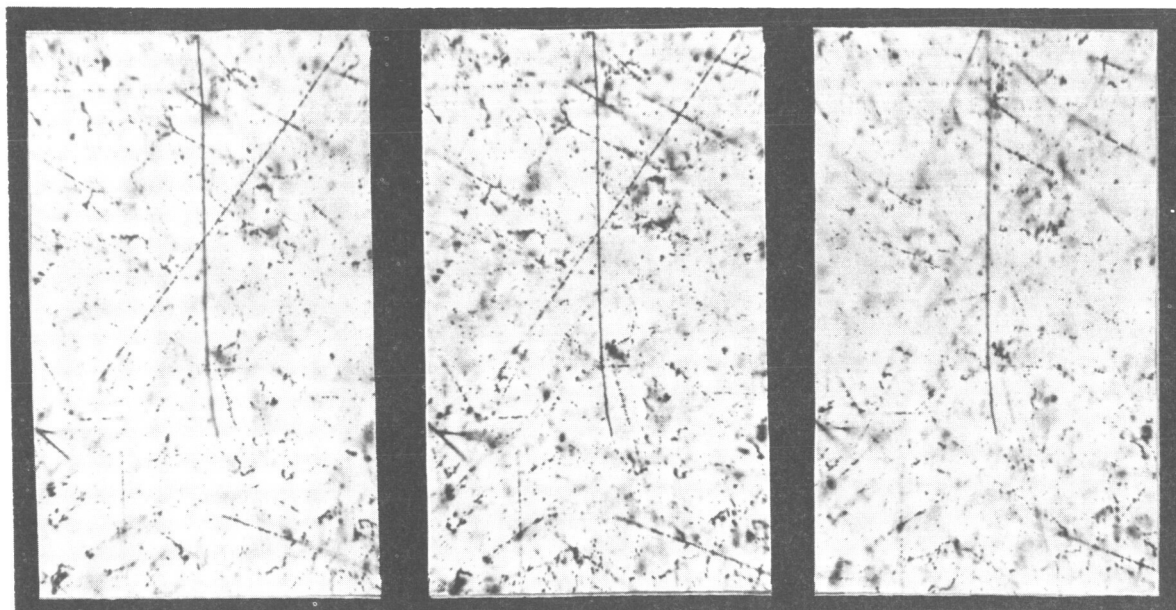


Figure 4

Photomicrograph of "Ender," i.e., of Proton Ending in the Emulsion

Same visual field is shown for three different depths of focus. Center graph is focused on end of ender. Note nuclear scattering toward end of track. Vertical length of visual field: 260 micra.



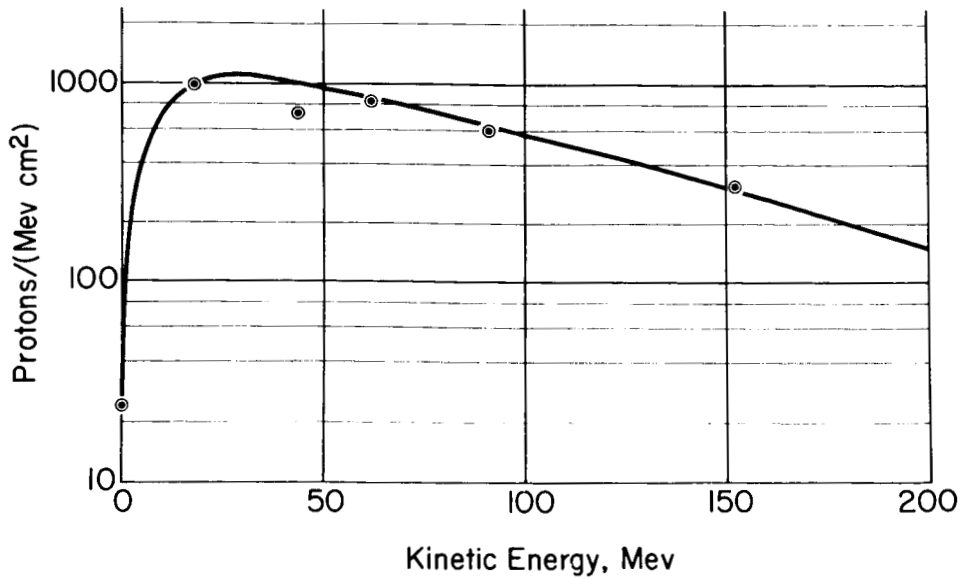


Figure 5

Differential Energy Spectrum of Proton Exposure on Mission MA-9

Shown is local spectrum directly as it corresponds to track and grain count in the emulsions. Ordinate gives total flux for entire mission: 22 orbits, 35 hours.

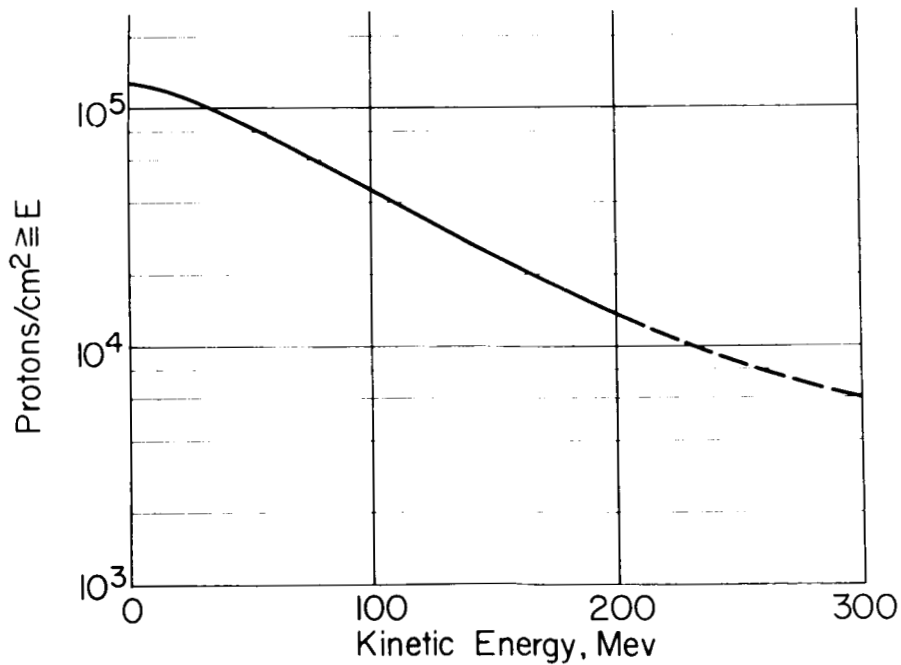


Figure 6

Integral Energy Spectrum of Proton Exposure on Mission MA-9

Spectrum is obtained by numerical integration of curve in Figure 5.

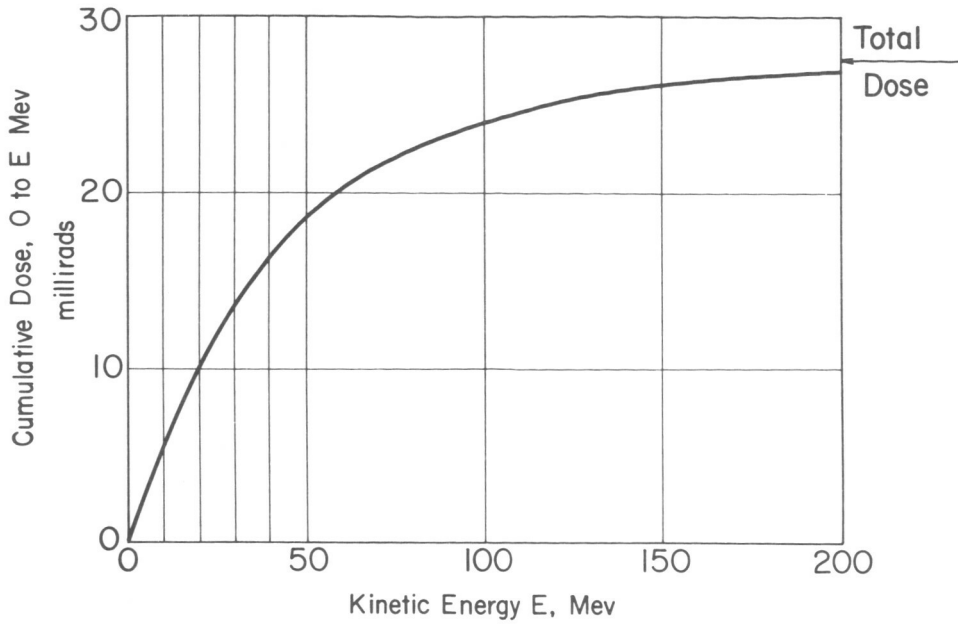


Figure 7

Cumulative Dose versus Proton Energy on Mission MA-9

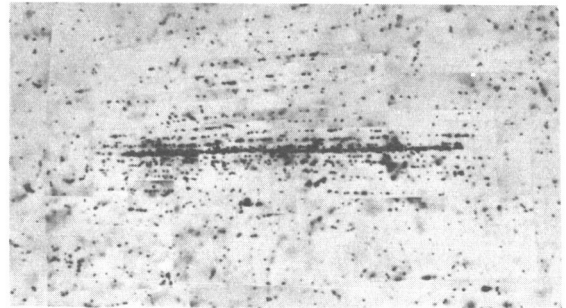
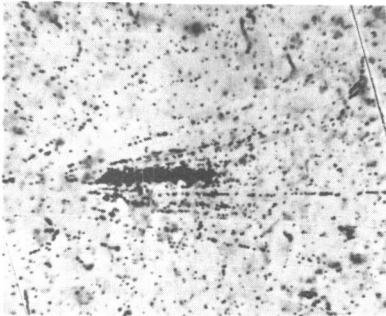


Figure 8

High Energy Nuclear Disintegration Showing Narrow and Wide Angle Meson Cones in Two Adjacent Ilford G-5 Emulsions Flown on Mission MA-7

1 scale division = 10 micra.