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APPENDIX A

RADIATION DOSIMETRY STUDIES FOR MA-8

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SUMMARY

The creation of an artificial belt of trapped electrons resulting from the nuclear test of July 9, 1962, necessitated that an analysis be made of the expected radiation level for the MA-8 flight. The results of the supporting studies did not justify postponement of the launch date, but the MA-8 pilot was instrumented to determine in-flight radiation exposure. The types of dosimeters carried aboard the spacecraft for the MA-8 mission were ionization chambers, thermoluminescent detectors, and film badges. It was determined that although Astronaut Schirra received a radiation dose of approximately 160 millirad at his eyes and 13 millirad on the skin of his upper torso, this dose level is well below that required to produce significant biological damage. A comparison of the measured values with those calculated prior to flight indicates that the flux from the electron belt at the time of flight was lower by a factor of 3 or 4 than was measured immediately after the nuclear test.

INTRODUCTION

On July 9, 1962, an international message was disseminated as a result of information obtained from a U. S. government warning system. The message is quoted as follows: "A megaton yield range device was detonated in the ionosphere at an altitude of hundreds of kilometers in the vicinity of Johnston Island in the Pacific at 0900 U.T. on 9 July 1962." Several hours thereafter, geiger counters on the Injun I satellite recorded an increase of up to a hundred times the normal count rate of radiation as the satellite passed through the lower Van Allen belt.

This increase in the radiation level at altitudes below the Van Allen belt prompted Manned Spacecraft Center personnel to investigate the implications with respect to the upcoming MA-8 flight of Astronaut Schirra. Although detailed radiation studies conducted on a continuing basis had shown that damage resulting from high energy particles at Mercury orbital altitudes was practically nonexistent, an analysis concerning the nature of the artificial belt and the expected dose levels was begun. Because of the brief period available in which to complete this investigation, the assignment was given a high priority. This analysis was based on satellite data supplied by B. J. O'Brien, C. D. Laughlin, and J. A. Van Allen of the Iowa State University. Further investigation was conducted by Dr. W. N. Hess of the NASA Goddard Space Flight Center, and, after close collaboration with him, it was concluded by MSC that the expected radiation level did not present a significant hazard to the mission as scheduled.

Once the decision was made to proceed with the flight, it was concluded that the astronaut and spacecraft should be instrumented with radiation counters. The purpose of this instrumentation was to verify the conclusions from the sources previously mentioned, as well as to provide some means of real-time radiation monitoring during the flight. The optimum configuration for the proposed instrumentation was three self-indicating ionization chambers with different ranges of sensitivity and five thermoluminescent dosimeters to be placed near the pilot and analyzed following the flight. This dosimetry served to complement the film emulsion packages already included in the spacecraft. The purpose of this paper is to describe the dosimeters used and to discuss the in-flight and postflight results.

DISCUSSION OF THE ARTIFICIAL BELT

The increase in the radiation level was attributed to energetic electrons emitted by the radioactive decay of fission nuclei. These electrons presumably have a differential number energy spectrum $N(E)$ which can be approximated by

$$N(E) = K \exp(-0.575E - 0.055E^2) \text{ for } 1 \leq E \leq 7 \text{ Mev} \qquad (1)$$

where E is the electron energy in Mev and K is a constant (ref.1). Some of the electrons emitted were injected at such pitch angles to the geomagnetic field vector that they were trapped, executing oscillatory motion along magnetic lines in latitude and drifting eastward in longitude. The net effect was the formation of an artificial electron belt surrounding the earth.

Although the main portion of the belt was well above the altitude of the Mercury orbit, Dr. Hess verified that an anomaly centered in the region of 5° West longitude and 45° South latitude, permitted the trapped electrons to dip as low as 100 km. Since the MA-8 orbital trajectory passed through this region on the fourth, fifth, and sixth orbital passes, detectors were installed within the spacecraft to assess the dose accumulated by Astronaut Schirra.

DOSIMETER DESCRIPTION

The primary dosimeter used was the self-indicating ionization chamber shown in figure A-1. The chamber was wrapped in Velcro, and, once in orbit, was placed on the interior of the spacecraft hatch by the pilot. Three dosimeters of this type having operating ranges of 0 to 1 rad, 0 to 10 rad, and 0 to 50 rad were carried inside the spacecraft. The pilot read the low-range dosimeter after each orbital pass through the region of interest and this verbal reading was recorded on the voice tape. Also shown in figure A-1 are five thermoluminescent dosimeters (TLD) which were placed on the pilot. Figures A-2 and A-3 show the locations of the thermoluminescent dosimeters over the eyes, on the chest, and on the interior thigh. These detectors were supplied, calibrated, and analyzed by the Los Alamos Scientific Laboratory in New Mexico.

The ionization chamber, designed to monitor primarily X and gamma radiation, is calibrated at the factory and is guaranteed to an accuracy of ± 10 percent full scale for dose rates up to 6×10^5 roentgen per hour, independent of incident gamma spectra. However, it was not expected that the instrument would display the same efficiency with incident electrons, mainly because the spacecraft skin thickness (~ 250 mg/cm^2) attenuates electrons having energies less than 5 to 7 Mev.

The dosimeters had the advantage of being readily obtainable, inherently rugged, and completely self-contained, since, once they are charged, they require no power supply or electronic indicator. They have the capability of withstanding the reduced atmospheric pressure of 5 psi within the spacecraft cabin without leaking. The time between the first published reports of the Injun I satellite count-rate increase and the MA-8 flight precluded the use of any dosimeter except one having these characteristics.

RESULTS AND ANALYSIS

Astronaut Schirra, during the sixth orbital pass, reported that the dose reading from the low-level ionization chamber was approximately 60 millirad, most of which was accumulated during the final three passes.

In an effort to relate the ambient free-space electron flux encountered on the MA-8 flight to readings of the ionization chamber and, therefore, the resulting doses to the astronaut's eyes and the surface of his upper body, experimental data were obtained on energetic electrons and detailed calculations were subsequently performed. A monodirectional, monoenergetic electron source was used to measure the response of the ionization chamber. The geometry of the chamber (fig. A-4) was identical to that employed for the MA-8 spacecraft. Three levels of electron energy at 3.0, 5.5, and 10.0 Mev were directed at the mock-up of the spacecraft hatch, and a curve was constructed from the experimental results showing detector response as a function of incident electron energy.

A convolution of the experimental data with the fission electron spectrum indicates that the reading in rad of the ionization chamber R_{IC} when oriented as it was during the MA-8 flight, satisfies the relationship

$$R_{IC} = (3.2 \times 10^{-10})\ J \tag{2}$$

where J is the number of electrons e per square centimeter normally incident on the exterior surface of the spacecraft. Therefore, since R_{IC} was reported as having been 0.06 rad, equation (1) yields

$$J = 1.9 \times 10^{8} e/cm^{2} \tag{3}$$

The relationship between J and the ambient free-space flux ϕ_0 has also been investigated in detail. If the pitch angles of the electrons are so great that the overall effect is essentially that of an isotropic flux, then

$$J = \phi_{0_i}/4 \tag{4}$$

Van Allen has stated, however, that at Mercury orbital altitudes the electron pitch angles are within ±15° of being in a plane, in which case

$$J = \phi_{0_p}/\pi \tag{5}$$

is more applicable. Equations (4) and (5) represent the two limiting cases. Substituting the value for J derived from equation (3), it is found that the ambient free-space flux encountered on the MA-8 flight falls between

$$\phi_{0_p} = 5.9 \, (10^8) \ e/cm^2 \qquad (6)$$

and

$$\phi_{0_i} = 7.5 \, (10^8) \ e/cm^2 \qquad (7)$$

where ϕ_{0_p} is the flux for electron pitch angles in a plane and ϕ_{0_i} represents the isotropic flux. Both of these values are from $\frac{1}{3}$ to $\frac{1}{4}$ the value of the flux measured the first or second day after the nuclear test of July 9.

In addition to the measurement expressed by equation (2), dosimeter readings were taken behind several other thicknesses of the spacecraft hatch. These data indicate that the response of the ion chamber as a function of hatch thickness in gm/cm^2 of titanium may be approximately expressed by

$$R_{IC} = K_1 e^{-1.9 \, t} \qquad (8)$$

where K_1 is a constant and t is the hatch thickness. This equation yields results which compare with independent calculations using the data of reference 2. These calculations were used to express the tissue dose behind a given thickness X of aluminum in gm/cm^2 as

$$D = D_0 \exp(-2.5X) \tag{9}$$

where D_0 is the incident dose on the shield material. Expressed in terms of flux

$$\phi = K_2 \phi_0 \exp(-2.5X) \tag{10}$$

where K_2 is a constant.

Since the responses indicated by equations (8) and (10) are not markedly different, particularly if the shield material is relatively thin, the theoretical calculations can now be combined with the measured response of the ionization chamber.

From these calculations, the relationships between the dose at two points of interest and normally incident electrons were derived. These are presented for the body and the eyes in the assumed geometry as

$$D_{body} = 6.8 \times 10^{-11} J \tag{11}$$

and

$$D_{eyes} = 8.4 \times 10^{-10} J \tag{12}$$

Table A-I presents a comparison between the dose measurements made on MA-8 and those calculated by using the source term information supplied by Dr. Hess.

REFERENCES

1. Carter, R. E., Reines, F., Wagner, J. J., and Wyman, M. E.: Free Antineutrino Absorption Cross Section. II. Expected Cross Section from Measurements of Fission Fragment Electron Spectrum. The Physical Review, vol. 113, 1959, pp. 280-286.

2. Smedal, Magnus I., Johnston, David O., et al.: Ten Year Experience with Low Megavolt Electron Therapy. The American Jour. of Roentgenology, vol. 88, no. 2, Aug. 1962, pp. 215-228.

TABLE A-I. - DOSE MEASUREMENTS FOR MA-8

Dose point	Calculations by Hess, rad	Calculations from in-flight data,[a] rad	Dose measured by dosimeters, rad
Free ambient space	77	19 (Plane pitch angles) 24 (Isotropic)	...
Hatch interior	1.5	0.47	0.47
Eyes	.50	.160	< .030 (TLD)[b]
Centerline of upper torso surface	.040	.013	< .030 (TLD) < .002 (FB)[c]

[a] $R_{IC} = 0.060$ rad

[b] By reference to figure 3, it can be seen that the placement of the thermolumiscent dosimeter (TLD) under the helmet overhang added shielding to the solid angle from which the dose is received. It is estimated that the dosimeters read approximately 25 to 50 percent of the true eye dose. Since the detection limit of the TLD is 30 millirad, the reading is not inconsistent with calculated values. The dosimeter placement was originally on the earphone covers, which should have given a reading closer to the true eye dose.

[c] Film badge (FB) measurement by Dr. Hermann J. Schaefer, U.S. Naval School of Aviation Medicine. These radiation films were located on the instrument console behind at least 2 gm/cm^2 of additional shielding.