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RADIATION DOSIMETRY FOR THE GEMINI PROGRAM

by Robert G. Richmond

Manned Spacecraft Center

Houston, Texas 77058

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16. ABSTRACT

The principal source of radiation for low-earth-orbit, low-inclination space flights is in the area of the South Atlantic magnetic anomaly. None of the Gemini dose measurements reported in this paper are of high enough intensity to be considered hazardous. There is a trend toward larger doses as missions are flown higher and longer. Extended orbital operations between 1400 and 4400 kilometers would encounter high interior radiation levels. Pronounced spacecraft geometry effects have been measured in manned spacecraft. Radiation dose is already a criterion used in mission planning. Instrumentation for radiation measurements on Gemini spacecraft is described.

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RADIATION DOSIMETRY FOR THE GEMINI PROGRAM

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SUMMARY

Radiation dose, a current criterion in mission planning, is affected by the shape of the spacecraft orbit. As missions are flown higher and are of longer durations, radiation doses tend to be greater.

During Project Mercury, the region of the South Atlantic magnetic anomaly was confirmed as the principal source of radiation for low-altitude nonpolar orbits. Several Gemini missions, flown higher and of longer duration than the Mercury flights, passed through the South Atlantic magnetic anomaly; one mission, Gemini XI, was specifically programed to miss the anomaly in order to protect a nuclear-emulsion cosmic-ray experiment. However, the radiation doses on the Gemini missions were not large enough to be considered hazardous.

Instrumentation for radiation measurements on Gemini missions included a passive dosimeter and the Gemini radiation-monitoring system. Pronounced spacecraft geometry effects have been measured in manned spacecraft.

INTRODUCTION

Space-radiation-dose measurements during Project Mercury clearly established the region of the South Atlantic magnetic anomaly as the principal source of ionizing radiation in low-altitude nonpolar orbits. This fact was shown by comparing the proton flux in the nuclear emulsions from the three-orbit Mercury-Atlas (MA) 7 mission (which did not traverse the South Atlantic magnetic anomaly) with the higher proton flux recorded on the six-orbit MA-8 mission.

Like the Mercury missions, all manned Gemini missions were instrumented to record the radiation dose. Since the radiation dose encountered in low-altitude (100 to 200 nautical miles) earth orbit was not sufficient to warrant real-time measurement for radiological-safety purposes, a passive-dosimeter system was devised for the Gemini Program.

The Gemini V mission lasted 8 days and reached an apogee of 189 nautical miles. The Gemini VII mission was a 177-nautical-mile-apogee orbital mission that lasted 14 days. These two flights were of much longer duration than any of the other Mercury and Gemini missions. The Gemini X mission, although of shorter duration, reached a higher altitude in the South Atlantic magnetic anomaly than was reached by any previous flight, and the spacecraft stayed almost 13 hours in a 161- by 412-nautical-mile orbit. Four of the high-altitude orbits cut through the South Atlantic magnetic anomaly region. Gemini XI, which reached a higher altitude than Gemini X, was programed to attain an apogee of approximately 750 nautical miles over Australia, deliberately away from the South Atlantic magnetic anomaly, to protect a nuclear-emulsion cosmic-ray experiment.

The photodosimeter package was assembled and analyzed by Dr. Herman J. Schaefer of the U. S. Naval Aerospace Medical Institute. The author wishes to acknowledge the assistance of John B. Nelson and C. Varren Parker, both of the Texas Nuclear Corporation, Austin, Texas, and John C. Mitchell and Stuart J. Allen, both of the Brooks School of Aerospace Medicine.

PASSIVE-DOSIMETRY DESIGN

Passive-Dosimeter Components

The Gemini radiation dosimeter was a logical evolution from the Mercury measuring devices. Mercury missions were equipped with a stack of eight Ilford G. 5 nuclear emulsions. The stack was packaged in a thin aluminum-foil wrapper and was cast in epoxy to form a rigid block 1. 0 by 3. 0 by 1. 0 inches. The stacks were affixed to the right and left instrument consoles of all the Mercury spacecraft.

In addition to these emulsion stacks, MA-8 Astronaut Walter Schirra wore five 1-inch-long 1/8-inch-diameter polyethylene tubes of lithium fluoride thermoluminescent powder inside his pressure suit so that the accumulated radiation exposure could be read out soon after the flight. The radiation doses recorded in the MA-8 mission are discussed in reference 1.

After the MA-8 mission, a Gemini dosimeter was designed that would combine the attributes of the nuclear emulsion and the thermoluminescent dosimeter (TLD) in a small, soft, flexible package that could be worn with comfort and safety inside the astronaut's constant-wear garment. The TLD was included because it can be read immediately after flight. The Ilford G. 5 and K. 2 emulsions were included so that the charged-particle flux incident on the crewmember's body could be analyzed in detail. (That is, estimates of radiation dose due to protons, alpha particles, and primary cosmic rays could be considered separately and their energy spectra used to estimate tissue depth dose.) The emulsions also provide a permanent historical photographic record of the radiation environment. Standard film badges (one Kodak type 2 double-component pair and one Kodak NTA neutron-monitoring-type badge) were added to provide a densitometric read-out capability to be used in the event of an overexposure of the Ilford nuclear emulsions (refs. 2 to 5).

The TLD, provided by the Radiation and Fields Branch of the NASA Manned Spacecraft Center (MSC) and combined with the photodosimeter package, was heat sealed in a polyvinylchloride plastic package (fig. 1). The combined packages were installed in pockets in the Gemini constant-wear garment: one each on the right and left sides of the chest, one on the right thigh, and one in the helmet over the right front portion of the forehead between the helmet liner and the helmet shell. Upon recovery, the packages were returned to MSC, where they were separated. The photodosimeters were sent to the Naval Aerospace Medical Institute, and the thermoluminescent dosimeters were kept at MSC for analysis. The TLD data are tabulated in table I. Some of the more pertinent mission parameters are given in table II.

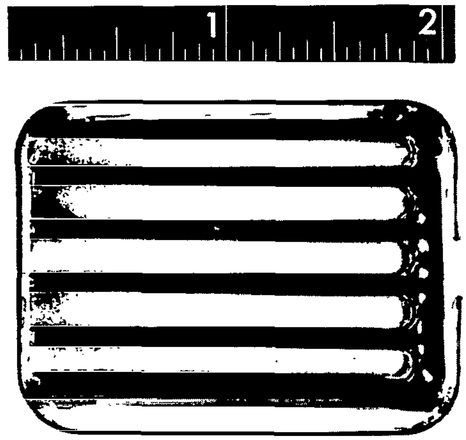

Figure 1. - The NASA Gemini passive dosimetry package (actual size).

TABLE I. - RADIATION DOSE MEASURED WITH THE

THERMOLUMINESCENT DOSIMETER

Location	Command pilot dose, millirads	Pilot dose, millirads
	Gemini III	
Helmet	20	45 ± 20
Right chest	20	20
Left chest	20	39 ± 15
Thigh	20	20
	Gemini IV	
Helmet	45 ± 4.5	69 ± 3.8
Right chest	40 ± 4.2	46 ± 4.6
Left chest	39 ± 4.5	43 ± 4.7
Thigh	43 ± 4.5	43 ± 4.5
	Gemini V	
Helmet	195 ± 19.5	172 ± 17.2
Right chest	173 ± 17.3	172 ± 17.2
Left chest	190 ± 19.0	140 ± 14.8
Thigh	183 ± 18.3	186 ± 18.8

TABLE I. - RADIATION DOSE MEASURED WITH THE THERMOLUMINESCENT DOSIMETER - Continued

Location	Command pilot dose, millirads	Pilot dose, millirads
	Gemini VI-A	
Helmet	25 ± 2.8	31 ± 7.4
Right chest	26 ± 1.5	20 ± 1.5
Left chest	25 ± 2.1	24 ± 1.4
Thigh	24 ± 1.7	22 ± 0.2
	Gemini VII	
Helmet	Not used	Not used
Right chest	113 ± 13.6	231 ± 9.0
Left chest	192 ± 10.8	105 ± 10.5
Thigh	178 ± 4.5	163 ± 8.2
	Gemini VIII	
Helmet	<10	10
Right chest	<10	10
Left chest	<10	10
Thigh	<10	10
	Gemini IX-A	
Helmet	15 ± 1	27 ± 1
Right chest	14 ± 1	22 ± 3
Left chest	18 ± 1	17 ± 1
Thigh	20 ± 3	22 ± 1
	Gemini X	
Helmet	618 ± 6	763 ± 6
Right chest	725 ± 6	763 ± 7
Left chest	[a]769 ± 7	[a]779 ± 13
Thigh	626 ± 6	Not used

[a]Gemini radiation monitoring system — 910 millirads.

TABLE I. - RADIATION DOSE MEASURED WITH THE THERMOLUMINESCENT DOSIMETER - Concluded

Location	Command pilot dose, millirads	Pilot dose, millirads
	Gemini XI	
Helmet	39 ± 1	34 ± 2
Right chest	26 ± 3	25 ± 1
Left chest	27 ± 1	[b]23 ± 1
Thigh	28 ± 3	25 ± 1
	Gemini XII	
Helmet	<20	20
Right chest	<20	20
Left chest	<20	20
Thigh	<20	20

[b]Gemini radiation monitoring system — 30 millirads.

TABLE II. - GEMINI ORBITAL PARAMETERS

Gemini mission	Launch date	Apogee, n. mi.	Perigee, n. mi.	Number of revolutions	Inclination, deg	Crew
III	Mar. 23, 1965	121	87	3	32.5	Grissom and Young
IV	June 3, 1965	152	88	62	32.5	McDivitt and White
V	Aug. 21, 1965	189	87	120	32.5	Cooper and Conrad
VII	Dec. 4, 1965	177	87	206	29	Borman and Lovell
VI-A	Dec. 15, 1965	140 177	87 87	16 --	29 --	Schirra and Stafford
VIII	Mar. 16, 1966	161	86	7	29	Armstrong and Scott
IX-A	June 3, 1966	168	86	45	29	Stafford and Cernan
X	July 18, 1966	412 161	161 86	8 35	NA[a] 29	Young and Collins
XI	Sept. 12, 1966	739 161	161 87	2 42	NA 29	Conrad and Gordon
XII	Nov. 11, 1966	163	87	59	29	Lovell and Aldrin

[a]Not applicable.

Thermoluminescent Dosimetry Calibration

A vigorous program to determine the response of various TLD phosphors as a function of incident energy and geometry was undertaken jointly by the School of Aerospace Medicine at Brooks Air Force Base, Texas; a U.S. Air Force contractor; and the Radiation and Fields Branch of MSC (ref. 6). Lithium fluoride in the form of rods, minirods, ribbon, disks, and powders was exposed to cobalt-60 gamma radiation and to protons from a threshold response of a few million electron volts to 137 MeV. The proton exposures were made at the Harvard University and Oak Ridge National Laboratory cyclotrons. The radiation-dose-rate responses of both lithium fluoride and calcium fluoride dosimeters were shown to change little up to a rate of approximately 4000 rads/min. (A rad is 100 ergs/g of energy deposited in any material.) All dose-rate response data were taken with an incident proton energy of approximately 32 MeV.

It is seen from figure 2 that the relative response of the TLD varies little as a function of radiation dose, whether the source of ionizing radiation is cobalt-60 gamma rays or intermediate-energy protons. Protons of 32- and 100-MeV incident energy were used for the calibration. Thirty-five-milligram samples, all of which were read out at MSC, were used instead of the usual 50-milligram samples. Eight to 10 readings were made at each measurement, and the typical scatter of the individual measurements was approximately 2 to 3 percent.

Figure 3 shows the relative response and theoretical radiation dose as a function of proton energy for the standard NASA Gemini passive dosimeter. Proton energies of 5 to 137 MeV from three cyclotron were used, with all data normalized to 137 MeV for the comparison. The data included dE/dx in lithium fluoride

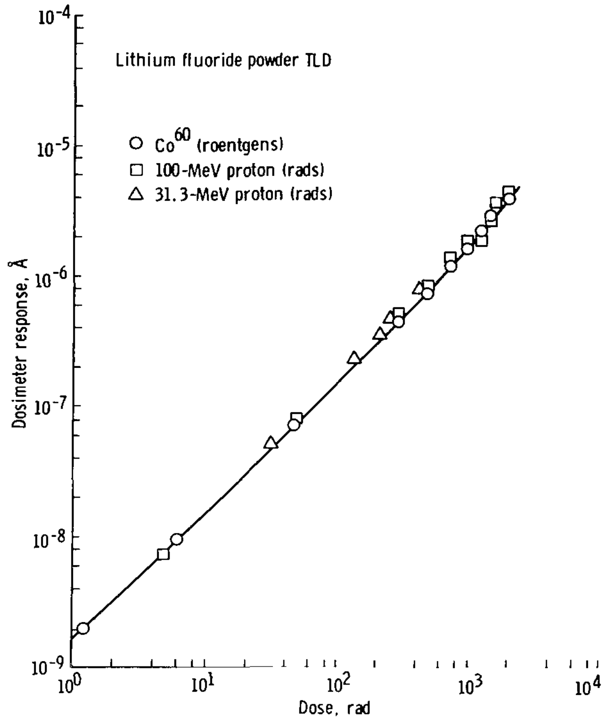

Figure 2. - Relative response of lithium fluoride powder for proton and gamma radiation.

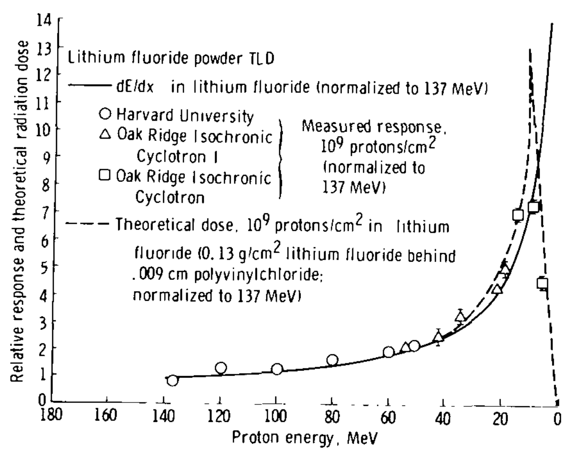

Figure 3. - Relative response and theoretical radiation dose as a function of proton energy for the standard NASA Gemini passive dosimeter.

(where dE = differential particle energy and dx = differential path length). A similar program to evaluate lithium fluoride response for electrons is being initiated.

Thermoluminescent Dosimetry Read-Out Technique

The read-out system for the lithium fluoride TLD is described in detail in references 7 to 9. Fifty-milligram samples of the exposed lithium fluoride were heated to 240° C on a small planchet. The resulting luminescence was viewed by means of a carbon dioxide-cooled photomultiplier (PM) tube. The PM-tube output is indicative of the radiation dose. During the process of evaluating the TLD exposure, the following variables and possible sources of error are controlled.

1. The TLD powder is selected for grain size (between 100 and 150 mesh Tyler).

2. The PM tube is cooled to near 0° C to stabilize and reduce the tube noise level (dark current) to a value less than that equivalent to 1 millirad.

3. The planchet temperature is raised to 240° C in a 30-second interval by using a programed power cycle.

4. A fixed-level light source is used intermittently to monitor any gain changes in the reader.

5. The reader is calibrated to read radiation dose rates by irradiating samples of the control badges which were kept with the flight badges until installation.

The procedure eliminates most of the background radiation dose by superimposing the calibration data on any background. The calibration irradiation is accomplished with a 1-curie cobalt-60 source; the dose is determined by using a Victoreen R-meter with appropriate corrections applied. The flight badges are read immediately after calibration of the reader. From five to 10 readings are taken from each dosimeter by dividing the powder into small samples.

DISCUSSION OF THE MEASUREMENTS

The Gemini III mission, flown by Astronauts Virgil I. Grissom and John Young, was so short that the space radiation dose was below the threshold of the TLD system at that time. The relatively higher doses of approximately 45 millirads to the head and chest of the pilot are attributed to the spacecraft geometry as determined in Gemini Experiment S-3. The experiment, entitled "Radiation Effects on the Blood in Zero Gravity," contained a 25-millicurie phosphorus-32 beta source. According to an Oak Ridge National Laboratory survey, the measured dose rate at 15 centimeters was 11 millirads/hr of mixed beta and bremsstrahlung radiation. The Gemini Experiment S-3 package was installed on the right hatch behind and 15 centimeters away from the pilot's head.

Figure 4 illustrates typical radiation-dose profiles across the spacecraft cabin. The data are from the chest badges for Gemini IV, V, and VII. The curves are drawn through the four points in a continuous interpolation. The flight data in figure 4 for the 8-day, 189-nautical-mile-apogee Gemini V mission show the effect of the spacecraft geometry.

The highest radiation doses occur on the outboard sides of the spacecraft. The lower readings, nearer the center of the cabin, are attributed to the shielding provided by the structural bridge between the egress hatches and to the complicated arrangement of center-line storage compartments. The storage compartments contain the various supplies required for a 2-week space flight.

Like the Gemini V flight profile, the 14-day, 177-nautical-mile-apogee flight profile for the Gemini VII mission bears a marked impression of the spacecraft geometry. However, the Gemini VII profile is different in that the inside chest dosimeters registered considerably lower radiation doses than the corresponding Gemini V dosimeters. It was suspected that the difference was a result of the contents and their arrangement in the center-line storage compartments which separated the two astronauts. The launch-storage-configuration drawings for Gemini V and VII are also compared. The Gemini VII center-line storage compartments contained 54 separate items of significant bulk. The Gemini V center-line storage compartment contained 20 comparable items.

Figure 5 shows a vertical skin-radiation-dose profile for Gemini IV, V, and VII. The data on the profile were obtained from three data points down the astronaut's body: (1) the top right side of the forehead, (2) the interpolated midpoint of the chest, and (3) the inside of the right thigh. The result of this configuration of data points was an approximate profile

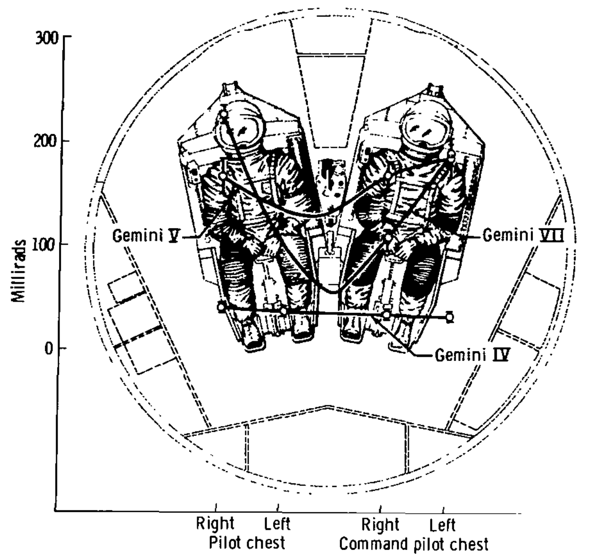

Figure 4. - Gemini IV, V, and VII horizontal radiation-dose profile.

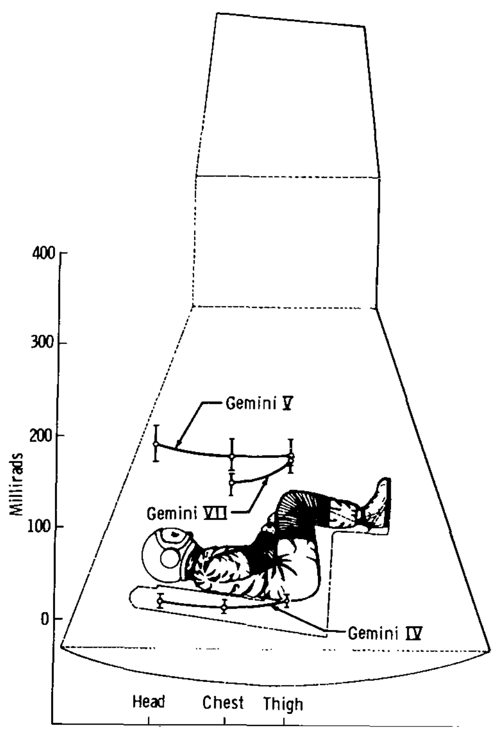

Figure 5. - Gemini IV, V, and VII vertical radiation-dose profile.

down the center of the body. The passive-dosimetry measurements on Gemini IV and VI compare favorably with passive-dosimetry measurements reported by the Air Force Systems Command Weapons Laboratory (ref. 10).

THE GEMINI RADIATION-MONITORING SYSTEM

Because the Gemini X and XI missions went higher into the Van Allen belt than man had ever been before, flight controllers at MSC thought it desirable to have a real-time dose read-out capability throughout the missions. By using prototype dosimeters developed for the Apollo Spacecraft Program, a hybrid package was built at MSC. This package (the Gemini radiation monitoring system (GRMS)) incorporated ionization chambers to read radiation-dose rate and integrated radiation dose. The GRMS (fig. 6) was stowed for launch and placed on the spacecraft wall, where it remained until reentry. Although the radiation-dose rate was negligible throughout the mission, the integrated dose recorded for Gemini X was 910 millirads (table I). The difference between this reading and the TLD reading was attributed to differences in local shielding by the spacecraft. The GRMS was carried on Gemini XI, but the resulting low reading of 30 millirads was expected.

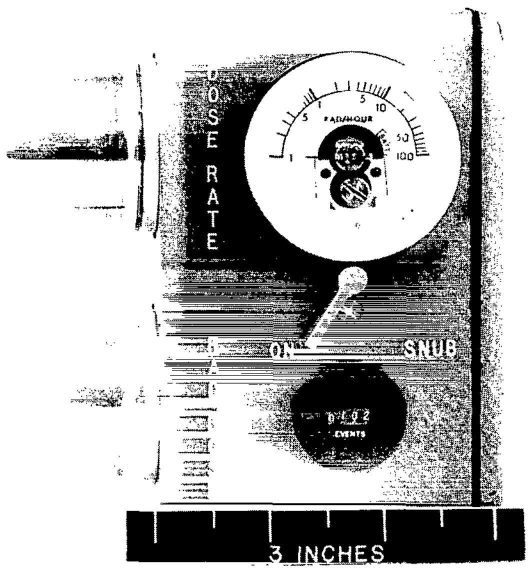

Figure 6. - The GRMS flown aboard Gemini X and XI.

In the GRMS, two 10-cubic-centimeter tissue-equivalent ionization chambers were used, with field-effect transistors as the input element from the ion chambers to the electronics. In the rate-meter section, a 3-decade logarithmic amplifier was used to cover a radiation-dose-rate range of 0.1 to 100 rads/hr. The integrating section of the dosimeter integrated the current from the ion chamber to an equivalent of 10 millirads, at which point an electromechanical register was used to accumulate the total dose in 10-millirad increments. The system operated from its own internal batteries and had an operating lifetime of approximately 250 hours.

COMPARISON OF CALCULATED AND MEASURED RADIATION DOSES

Previous attempts to calculate the radiation dose inside the spacecraft, using spectra that were extrapolated from high-altitude unmanned satellites, produced electron doses that did not compare well with measured electron doses. To obtain a better source description, a proton-electron spectrometer was installed on Gemini IV and

VII, together with a magnetometer to describe the directionality of the trapped particles. Proton and electron spectra (ref. 11) measured on these missions were used to calculate the radiation dose inside the Gemini spacecraft. The resulting calculated doses and corresponding measured radiation doses are presented in table III. The TLD is not capable of discriminating between components. However, the Ilford G. 5 and K. 2 nuclear emulsions provide a means of measuring the components of the total proton dose separately (ref. 5).

Those emulsion tracks evaluated by microscopic track- and grain-counting techniques were unambiguously determined to be protons. Searching of the emulsions for electrons has revealed that the observable electron background in the flown emulsions is about the same as the sea-level control-emulsion electron background. The electrons shown in the emulsions are all of low energy. Electrons with energies greater than 0.5 MeV are relativistic and leave, at best, thin minimum ionizing tracks in an

TABLE III. - CALCULATED AND MEASURED RADIATION DOSES AT THE PILOT'S CHEST FOR TWO GEMINI MISSIONS, USING GEMINI SPECTROMETER RESULTS

Particle type	Calculated dose, millirads	Measured dose, millirads
	Gemini IV	
Electrons	29.3	--
Protons	22.4	--
Total	51.7	46
	Gemini VII	
Electrons	77.7	--
Protons	78.4	--
Total	156.1	[a]168

[a]Average pilot chest reading.

emulsion. The tracks are difficult to detect anywhere but in the plane of the emulsion. In this plane, the shielding is thick enough to stop the electrons. The Gemini V radiation-dose nuclear-emulsion read-outs indicated a proton dose of 105 millirads (ref. 5). This dose is compared with a TLD measurement of 190 millirads. Both radiation measurements were taken on the left side of the Gemini V command pilot's chest. The difference in the two readings is assumed to be from electrons, bremsstrahlung, and other components.

Calculated radiation-dose predictions were employed in mission planning in both Gemini X and Gemini XI. The results showed that the radiation dose received for the four passes through the South Atlantic magnetic anomaly were not biologically significant.

The dose-prediction technique was used to a great extent in the selection of a trajectory for the Gemini XI mission. On this mission, it was necessary to minimize the integrated proton flux to protect a radiation-sensitive nuclear-emulsion cosmic-ray experiment. Because the spacecraft trajectory was programed so that the 750-nautical-mile apogee would be reached over Australia and away from the South Atlantic magnetic anomaly, the total proton flux was not significantly higher than for the nominal 160-nautical-mile-apogee missions.

GEMINI NUCLEAR-EMULSION RESULTS

As was pointed out earlier, the nuclear-emulsion component of the NASA Gemini passive dosimeter was a logical evolution from the Mercury measuring devices (refs. 2 to 5 and 12). A quantitative analysis of the energy spectrum required a resolution from a few million electron volts to several hundred million electron volts. Because of the time-consuming aspect of the nuclear emulsion technique, only a 200-micron Ilford G. 5 and K. 2 emulsion pair from Gemini V, VII, and X were selected for detailed analysis. To keep the total passive dosimeter flexible, plastic-backed emulsions were used rather than the conventional glass-backed emulsions. In addition, the photodosimeter package contained one Kodak type 2 double-component pair (for electrons) and one Kodak NTA emulsion (for nucleonic components) (ref. 5).

The K. 2 nuclear emulsion has a significantly lower sensitivity, with respect to grain count, than the G. 5 emulsion. Therefore, the K. 2 emulsion gives good resolution (i. e., low grain count for proton tracks of low energies which would heavily saturate the more sensitive G. 5 emulsion). Typically, a grain count of approximately 160 grains/μ can be readily resolved. For the K. 2 emulsion, this grain count corresponds to a linear energy transfer (LET) of approximately 50 keV/μ and a proton energy of slightly less than 1. 0 MeV. The K. 2 emulsion was usable to approximately 50 MeV, where the G. 5 emulsion could be grain counted with satisfactory resolution.

An accurate determination of the proton energy spectrum hinges on the grain-count/ LET calibration. Because of the variables involved, a grain-count/ LET relationship must be individually determined for each observer or film or both.

A typical proton integral energy spectrum is shown in figure 7 (ref. 5). The measurement was taken from the left side of the chest of the command pilot on Gemini V. The smooth line represents the "best fit" through the actual data points. Numerical differentiation of the data shown in figure 7 gives the differential energy spectrum shown in figure 8 (ref. 5). Within the relatively limited proton energy interval (up to 300 MeV), the differential radiation-dose contribution varies significantly. The largest value has the lowest energies and drops slowly and continuously to an insignificant level of approximately 300 MeV.

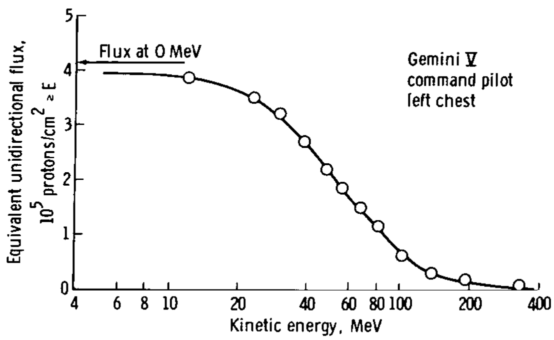

Figure 7. - Typical proton integral energy spectrum obtained from the left chest location of the Gemini V command pilot.

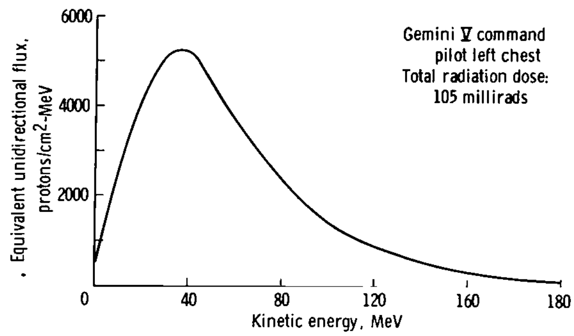

Figure 8. - Typical proton differential energy spectrum on Gemini V.

For conversion of the spectra to radiation absorbed dose, the population of tracks in the emulsion was assumed to be the same as the population of tracks in a tissue sample of the same volume. The validity of this assumption rests upon two requirements: (1) that a negligible percentage of tracks originate in the emulsion and (2) that the energy change along a track segment be small compared to the absolute energy of the particle. The first criterion is easily met; the second, however, becomes less valid with increasing graze angle. The proton energy spectrum is changed rapidly by additional absorption to such an extent that local radiation dose can vary as much as 20 percent within the same sheet of emulsion. As expected, analysis of proton ender tracks shows that low-energy protons were incident upon the emulsions in a complex distribution pattern. The radiation doses contributed by heavy nuclei were usually shown to be approximately 0.5 millirad/day.

One emulsion, taken from the Gemini VII command pilot thigh location, was selected for detailed grain-count analysis. The remaining emulsions were evaluated by counting the ender tracks. The integral LET spectra in the Ilford G.5 and the K.2 emulsions are presented in figure 9, which shows the effect of applying a constant normalizing factor between the two types of emulsions and demonstrates that, in the region of high LET values (above 2-keV/μ tissue), the emulsions have essentially the same sensitivity (ref. 12).

The typical LET is shown in figure 10 as functions of flux and percent cumulative radiation doses. The ordinate gives the differential proton flux for a constant abscissa interval of log LET = 0.1. The total dose for this location (command pilot thigh) was 190 millirads (ref. 12). Table IV lists the available radiation-emulsion-dose data at the time of this printing.

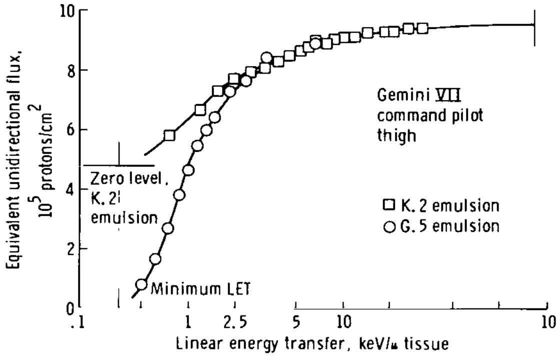

Figure 9. - Integral LET spectra obtained from the track and grain count of an Ilford G. 5 and K. 2 emulsion pair on Gemini VII.

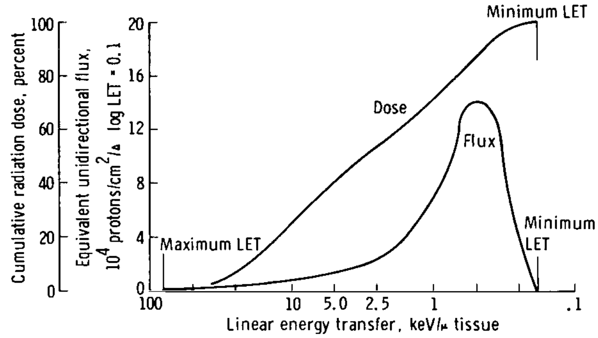

Figure 10. - Typical LET spectrum as a function of equivalent unidirectional flux and percent cumulative radiation dose.

TABLE IV. - RADIATION DOSES FROM NUCLEAR EMULSIONS[a]

Position	Gemini V dose, millirads	Gemini VII dose, millirads	Gemini X dose, millirads
Command pilot			
Helmet	--	--	634
Right chest	--	177	729
Left chest	105	218	756
Thigh	--	190	612
Pilot			
Helmet	--	--	801
Right chest	--	233	774
Left chest	--	159	770
Thigh	--	205	--

[a]Data derived from reference 12.

CONCLUSIONS

Gemini radiation-skin-dose-measurement magnitudes were not high enough to be considered hazardous. Radiation doses tend to be greater as missions are flown higher and longer.

Pronounced spacecraft-geometry effects have been measured in manned spacecraft. The effects may be useful in large space stations and in long space-flight operations where, during periods of high radiation intensity, the crews may seek shelter in protected areas and thus eliminate the requirement for bulk shielding and weight.

Radiation dose is already a criterion used in mission planning. The actual shape of the orbit (i.e., the location and the number of revolutions at high altitude) is the limiting criterion for some missions. Instrumentation for radiation measurements is being tailored to suit individual mission environments as determined by mission objectives.

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National Aeronautics and Space Administration
Houston, Texas, April 9, 1970
914-14-40-02-72

REFERENCES

1. Warren, Carlos S.; and Gill, William L.: Radiation Dosimetry Aboard the Spacecraft of the Eighth Mercury-Atlas Mission (MA-8). NASA TN D-1862, 1964.

2. Schaefer, H. J.; and Sullivan, J. J.: Measurements of the Astronaut's Radiation Exposure with Nuclear Emulsion on Mercury Missions MA-8 and MA-9. NASA CR-82574, 1967.

3. Schaefer, H. J.: Linear Energy Transfer Spectrum of Proton Exposure on Mercury Mission MA-9. NASA CR-58948, 1964.

4. Schaefer, H. J.; and Sullivan, J. J.: Radiation Monitoring with Nuclear Emulsions on Project Gemini. Vol. 1. Experimental Design and Evaluation Procedures: Partial Results on Missions 4 and 5. NASA CR-75036, 1966.

5. Schaefer, H. J.; and Sullivan, J. J.: Radiation Monitoring with Nuclear Emulsions on Missions Gemini IV and V. Aerospace Med., vol. 38, no. 1, Jan. 1967, pp. 1-5.

6. Nelson, John B.; Parker, C. Varren; Boles, Larry A.; and Burton, Ben F.: Report on Physical Dosimetry Measurements for Superficial Dose Exposures. Final rept. to USAF School of Aerospace Medicine, AF contract F-41609-68-C-0029, 1968.

7. Richmond, Robert G.; Davis, William G.; and Lill, Joseph C.: Gemini Dosimetry Results. Paper presented at 11th Annual Meeting of the Health Physics Society (Houston, Texas), 1966.

8. Richmond, Robert G.; and Lill, Joseph C.: Apollo Operational Dosimetry. Paper presented at the 11th Annual Meeting of the Health Physics Society (Houston, Texas), 1966.

9. Richmond, Robert G.; Davis, William G.; Lill, Joseph C.; and Warren, Carlos S.: Radiation Dosimetry for Manned Space Flight. NASA SP-169, 1967, pp. 555-580.

10. Janni, Joseph F.: Measurement of Spacecraft Cabin Radiation Distributions for the Fourth and Sixth Gemini Flights. AFWL-TR-65-149, Air Force Systems Command Weapons Laboratory, Kirtland Air Force Base, New Mexico, 1967.

11. Reagan, J. B.; Heinemann, M. A.; Bakke, J. C.; Imhof, W. L.; and Smith, R. V.: Detailed Analysis of Radiation Data from the Gemini IV and Gemini VII Proton-Electron Spectrometer Experiments. LMSC 682411, Lockheed Palo Alto Research Laboratory, Palo Alto, Calif., Dec. 30, 1968.

12. Schaefer, H. J.; and Sullivan, J. J.: Radiation Monitoring with Nuclear Emulsions on Project Gemini. Vol. II. Results on the 14-Day Mission Gemini VII. NASA CR-83543, 1967.

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