CHAPTER 3
RADIATION PROTECTION AND INSTRUMENTATION

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Introduction

The solar and cosmic radiation found in space has long been recognized as a possible danger in space travel. Exposure to such radiation has the potential of causing serious medical problems. For example, radiation exposure can produce a number of significant changes in various elements of the blood, making an individual more susceptible to disease; also, ionizing radiations of the type found in space can produce significant damage to the lens of the eye. Radiation exposure can also cause temporary or lasting damage to the reproductive system ranging from reduced fertility to permanent sterility. The extent of damage depends upon the tissue involved, the duration of exposure, the dose received, and other factors.

Apollo missions placed men for the first time outside the Earth's geomagnetic shield, subjecting them to potentially hazardous particulate radiation of an intensity and frequency not encountered in the Earth's environment. In addition, various aspects of ground-based operations in support of Apollo missions involved some exposure to radioactive materials, for example during manufacture, testing, and installation of radioluminescent panels in the spacecraft. In flight, astronauts were exposed to both manmade radiations and those occurring naturally in space. Of the two, space radiations posed the larger hazard and were largely uncontrollable. Manmade radiation sources, while of appreciable strength, could be controlled.

The Apollo radiation protection program focused on both the natural radiations encountered in space and manmade radiations encountered on the ground and in the space environment. In both areas, the basic philosophy remained the same: to avoid harmful radiation effects by limiting the radiation dose to the lowest level judged consistent with the achievement of beneficial goals.

Radiation from Space

During a complete Apollo mission, astronauts were exposed to widely varying radiation sources. These included the Van Allen belts, cosmic rays, neutrons, and other subatomic particles created in high-energy collisions of primary particles with spacecraft materials. Spacecraft transfer from low Earth orbit to translunar coast necessitated traverse of the regions of geomagnetically trapped electrons and protons known as the Van Allen belts. When beyond these belts, the spacecraft and crewmen were continuously subjected to high-energy cosmic rays and to varying probabilities of particle bursts from the sun. In addition, the individual responsibilities of the crewmen differed, and with these, their radiation exposure. Free-space extravehicular activity, lunar surface activity, and intravehicular Command and Lunar Module activity imposed varying radiation doses.

Van Allen Belts

The problem of protecting astronauts against the radiation found within the Van Allen belts was recognized before the advent of manned space flight. These two bands of trapped radiation, discovered during the Explorer I flight in 1958, consist principally of protons and high-energy electrons, a significant part of which were, at that time, debris from high-altitude tests of nuclear weapons. The simple solution to protection is to remain under the belts [below an altitude of approximately 556 km (≈300 nautical miles)] when in Earth orbit, and to traverse the belts rapidly on the way to outer space. In reality, the problem is somewhat more complex. The radiation belts vary in altitude over various parts of the Earth and are absent over the north and south magnetic poles. A particularly significant portion of the Van Allen belts is a region known as the South Atlantic anomaly (figure 1). Over the South Atlantic region, the geomagnetic field draws particles closer to the Earth than in other regions of the globe. The orbit inclination of a spacecraft determines the number of passes made per day through this region and, thus, the radiation dose.

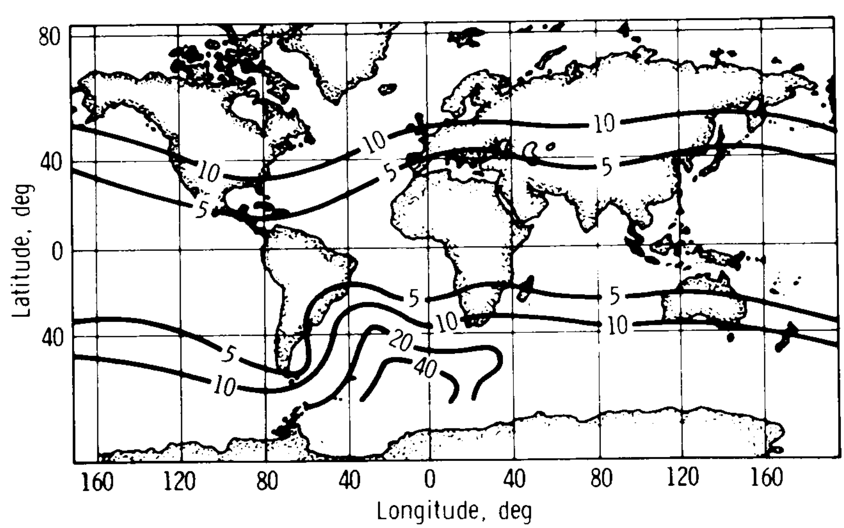

Figure 1. Isodose profile showing high-dose region over South Atlantic.

Particles within the Van Allen belts, in spiraling around the Earth's magnetic lines of force, display directionality. This directionality varies continuously in angular relationship to the trajectory of the spacecraft. Therefore, dosimetry instrumentation for use in the Van Allen belts had relatively omnidirectional radiation sensors so that the radiation flux would be measured accurately. The Van Allen belt dosimeter (figure 2) was designed specifically for Apollo dosimetry within these radiation belts.

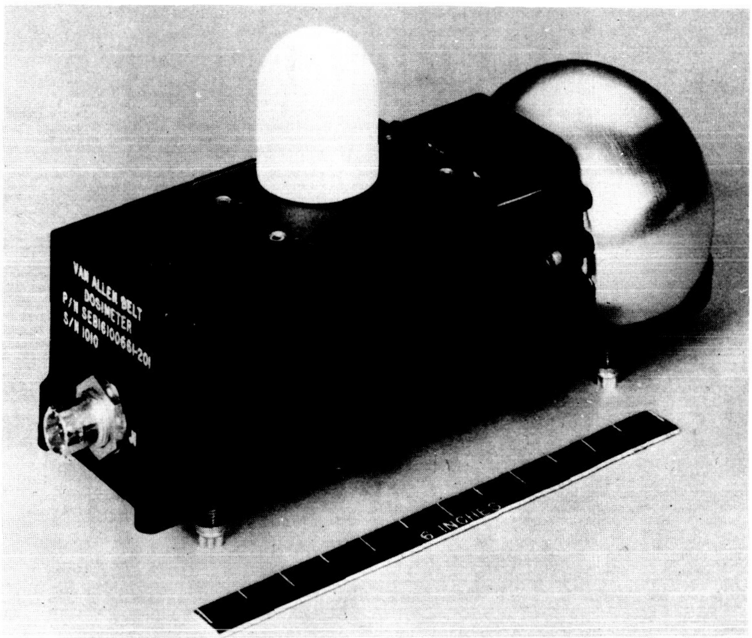

Figure 2. Van Allen Belt dosimeter.

Solar-Particle Radiation

No major solar-particle events occurred during an Apollo mission. Although much effort has been expended in the field of solar-event forecasting, individual eruptions from the solar surface have proved impossible to forecast. The best that can be provided is an estimate of particle dose, given visual or radio-frequency (RF) confirmation that an eruption has occurred. A system of solar-monitoring stations, the Solar Particle Alert Network (SPAN), provides a NASA-sponsored network of continuous data on solar-flare activity. SPAN consists of three multiple-frequency radio telescopes and seven optical telescopes. The network gives data for determining the severity of solar-particle events and the resultant possible radiation hazards to crewmen. After the appearance of particles is confirmed onboard a spacecraft, protective action can be taken.

In terms of hazard to crewmen in the heavy, well shielded Command Module, even one of the largest solar-particle event series on record (August 4-9, 1972) would not have caused any impairment of crewmember functions or ability of the crewmen to complete their mission safely. It is estimated that within the Command Module during this event, the crewmen would have received a dose of 360 rads* to their skin and 35 rads to their blood-forming organs (bone and spleen). Radiation doses to crewmen while inside the thinly shielded Lunar Module or during an extravehicular activity (EVA) would be extremely serious for such a particle event. To monitor particle activity, a nuclear-particle-detection system (figure 3) was designed to have a relatively narrow acceptance angle. It measured the isotropic proton and alpha particles derived from solar-particle events.

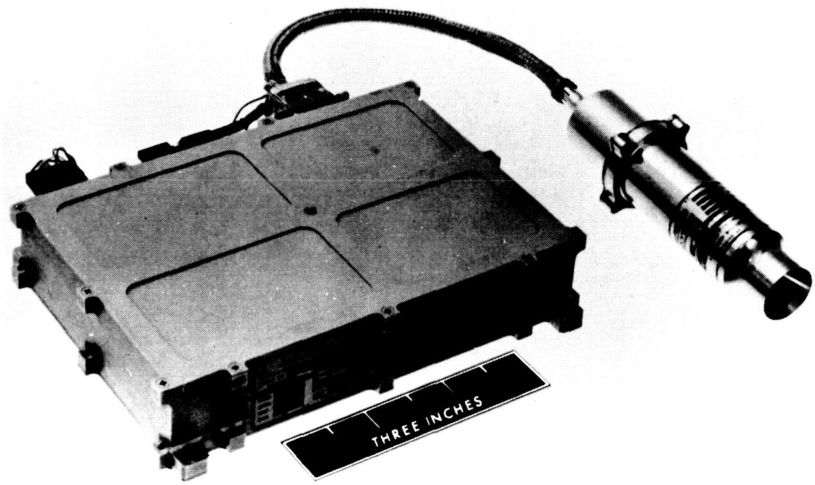

Figure 3. Nuclear-particle-detection system.

Cosmic Rays

Cosmic ray fluxes, consisting of completely ionized atomic nuclei originating outside the solar system and accelerated to very high energies, provided average dose rates of 1.0 millirads per hour in cislunar space** and 0.6 millirads per hour on the lunar surface. These values are expected to double at the low point in the 11-year cycle of solar-flare activity (solar minimum) because of decreased solar magnetic shielding of the central planets. The effect of high-energy cosmic rays on humans is unknown but is considered by most authorities not to be of serious concern for exposures of less than a few years. Experimental evidence of the effects of these radiations is dependent on the development of highly advanced particle accelerators or the advent of long-term manned missions outside the Earth's geomagnetic influence.

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*Radiation absorbed dose. Corresponds to absorption of watts (100 ergs) per gram of any medicine.

**That region of space between the Earth and the moon or the moon's orbit.

Neutrons

Neutrons created by cosmic rays in collision with lunar materials were postulated to be a potential hazard to Apollo crewmen (Kastner et al., 1969). Two methods for neutron-dose assessment were used. These techniques of whole-body counting and neutron-resonant foil were initiated on the Apollo 11 mission. Later analyses indicated that neutron doses were significantly lower than had been anticipated. Both methods were retained because of the remaining potential for neutron production by solar-event particles and because of possible crewman exposure to neutrons from the SNAP-27 radioisotope thermal generator used to power the Apollo lunar surface experiments packages.

Detection Devices

To allow accurate determination of overall radiation exposure of the crewmen, each carried a personal radiation dosimeter (PRD) (figure 4) and three passive dosimeters (figure 5). The PRD provided visual readout of accumulated radiation dose to each crewman as the mission progressed. It is approximately the size of a cigarette pack, and pockets were provided in the flight coveralls as well as in the space suit for storage. The passive dosimeters were placed in the garments worn throughout the mission. By placing these detectors at various locations (ankle, thigh, and chest) within the garments, accurate radiation doses for body portions were determined.

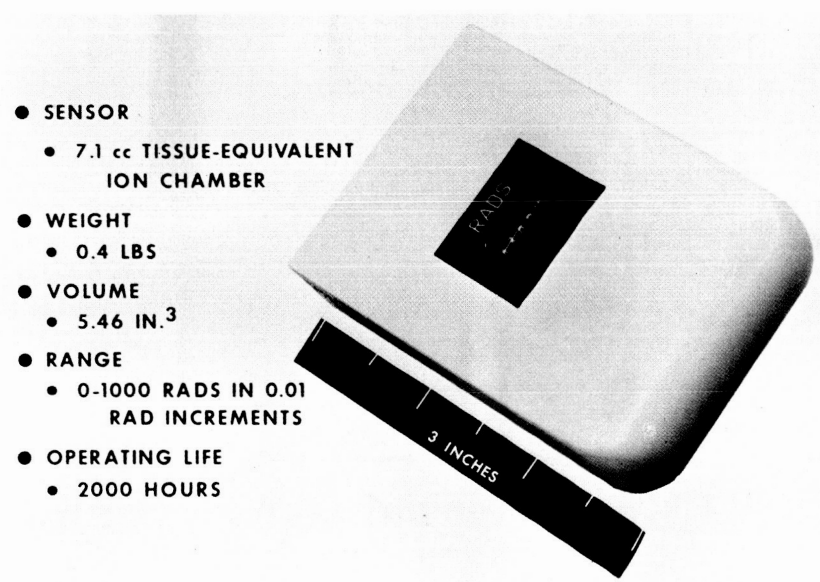

Figure 4. Personal radiation dosimeter.

A radiation-survey meter (RSM) (figure 6) allowed crewmen to determine radiation levels in any desired location in their compartment. Crewmen could use the RSM, a direct-reading dose-rate instrument, to find a habitable low-dose region within the spacecraft in the event of a radiation emergency.

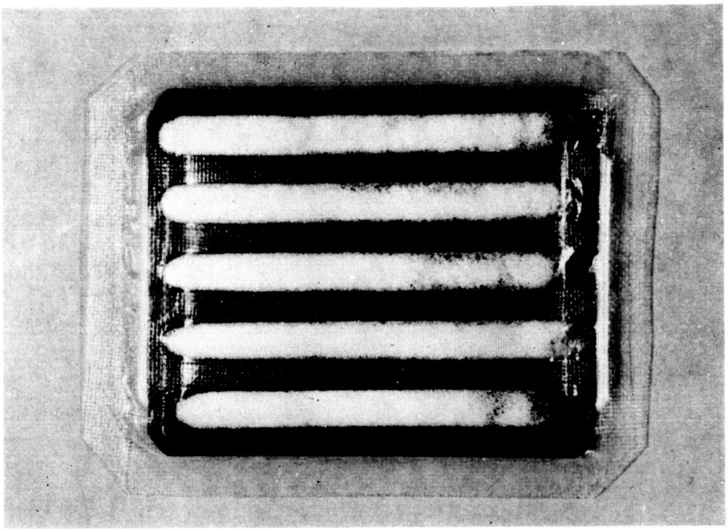

Figure 5. Passive dosimeter with component parts.

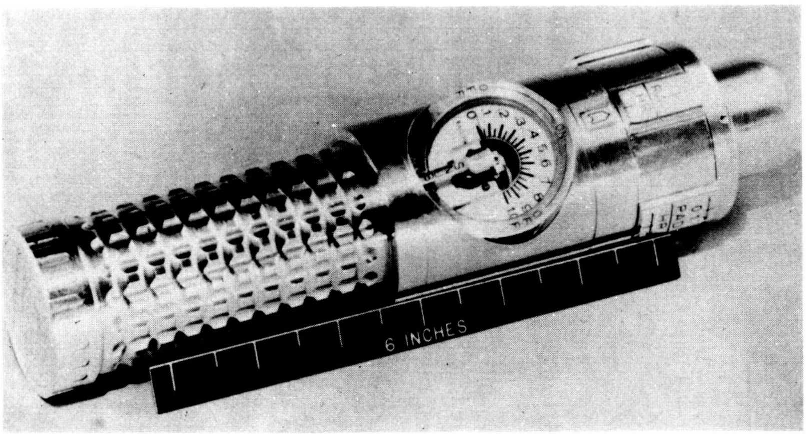

Figure 6. Radiation-survey meter.

Problems Involving Radiations of Manmade Origin

Protection against manmade sources of radiation is a ground support function concerned mainly with the protection of the ground personnel, the general public, and the environment against detrimental effects of radiation. Much of this effort involved routine health-physics procedures governed by U.S. Atomic Energy Commission regulations (Title 10, Code of Federal Regulations, 1971) and U.S. Department of Labor Standards (Title 29, Code of Federal Regulations, 1971). However, certain problems concerning spacecraft radioluminescent sources were peculiar to the Apollo Program. The chief problems were leakage of radioactive material from radioluminescent switch tips, and emission of excess soft X-ray radiation from radioluminescent panels. Both of these problems were solved.

A summary of all of the onboard instrumentation used during Apollo missions to assess radiation exposure is presented in table 1.

Table 1

Onboard Radiation Instrumentation

Instrument	Measurement	Location
Nuclear particle detection system	Alpha-proton spectrometer (4 channels proton, 15 to 150 MeV; 3 channels alpha, 40 to 300 MeV); telemetered	Service Module
Van Allen belt dosimeter	Skin and depth dose rates; telemetered	CM
Radiation survey meter	Portable, hand-held ratemeter: 4 linear ranges, 0 to 0.1 to 0 to 100 rad/hr; visual readout	CM (portable)
Personal radiation dosimeter	1/crewman; accumulated radiation dose; 0.01 to 1000 rad; visual readout	Suit
Passive radiation dosimeter	3/crewmen; emulsion/thermoluminescent dosimeters; postflight analysis	Constant-wear garment

Results and Discussion

Average radiation doses were computed for each mission (table 2). Individual readings varied approximately 20 percent from the average because of differences in the shielding effectiveness of various parts of the Apollo spacecraft as well as differences in duties, movements, and locations of crewmen. Doses to blood-forming organs were approximately 40 percent lower than the values measured at the body surface. In comparison with the doses actually received, the maximum operational dose (MOD) limit for each of the Apollo missions was set at 400 rads (X-ray equivalent) to skin and 50 rads to the blood-forming organs.

Radiation doses measured during Apollo were significantly lower than the yearly average of 5 rem* set by the U.S. Atomic Energy Commission for workers who use

*Roentgen Equivalent, Man refers to the absorbed dose of any ionizing radiation which produces the same biological effects in man as those resulting from the absorption of 1 roentgen of X-rays.

radioactive materials in factories and institutions across the United States. Thus, radiation was not an operational problem during the Apollo Program. Doses received by the crewmen of Apollo missions 7 through 17 were small because no major solar-particle events occurred during those missions. One small event was detected by a radiation sensor outside the Apollo 12 spacecraft, but no increase in radiation dose to the crewmen inside the spacecraft was detected.

Table 2

Average Radiation Doses of the Flight Crews for the Apollo Missions

Apollo Mission	Skin Dose, rads
7	0.16
8	.16
9	.20
10	.48
11	.18
12	.58
13	.24
14	1.14
15	.30
16	.51
17	.55

One particular effect possibly related to cosmic rays was the light-flash phenomenon reported on the Apollo 11 and subsequent missions. Although it is well known that ionizing radiations can produce visual phosphenes (subjective sensations best described as flashes of light) of the types reported, a definite correlation was not established between cosmic rays and the observation of flashes during the Apollo Program. The light flashes were described as starlike flashes or streaks of light that apparently occur within the eye. The flashes were observed only when the spacecraft cabin was dark or when blindfolds were provided and the crewmen were concentrating on detection of the flashes.

There is a possibility that visual flashes might indicate the occurrence of damage to the brain or eye; however, no damage has been observed among crewmen who experienced the light-flash phenomenon. During the Apollo 16 and 17 missions, a device known as the Apollo Light Flash Moving Emulsion Detector (ALFMED) was employed for the purpose of establishing if the flashes were indeed being caused by heavy cosmic rays. Further information regarding the light-flash phenomenon is contained in Section IV, Chapter 2 of this book.

Although Apollo missions did not undergo any major space radiation contingency, procedures for handling radiation problems were ready. The development of spacecraft dosimetry systems, the use of a space radiation surveillance network, and the availability of individuals with a thorough knowledge of space radiation assured that any contingency would be recognized immediately and would be coped with in a manner most expedient for both crewmember safety and mission objectives. The possible deterrent to manned space flight by large radiation doses was successfully avoided in the Apollo missions. More significantly, Apollo astronaut doses were negligible in terms of any medical or biological effects that could have impaired the function of man in the space environment.

The two key problems affecting safe operations with manmade radiation were resolved by design modifications. Leakage of radioactive materials from radioluminescent switch tips was eliminated by a change in encapsulating material. The problem of extensive emission of soft X-ray radiation from radioluminescent panels was resolved by applying a layer of plastic to the panels.

Summary and Conclusions

Radiation was not an operational problem during the Apollo Program. Doses received by the crewmen of Apollo missions 7 through 17 were small because no major solar-particle events occurred during those missions. One small event was detected by a radiation sensor outside the Apollo 12 spacecraft, but no increase in radiation dose to the crewmen inside the spacecraft was detected. Solar-particle releases are random events, and it is possible that flares, with the accompanying energetic nuclear particles, might hinder future flights beyond the magnetosphere of the Earth.

Radiation protection for the Apollo Program was focused on both the peculiarities of the natural space radiation environment and the increased prevalence of manmade radiation sources on the ground and onboard the spacecraft. Radiation-exposure risks to crewmen were assessed and balanced against mission gain to determine mission constraints. Operational radiation evaluation required specially designed radiation-detection systems onboard the spacecraft in addition to the use of satellite data, solar observatory support, and other liaison. Control and management of radioactive sources and radiation-generating equipment was important in minimizing radiation exposure of ground-support personnel, researchers, and the Apollo flight and backup crewmen.

References

Anon.: Occupational Safety and Health Standards. Title 29, Code of Federal Regulations, part 1910, May 1971.

Anon.: Standards for Protection Against Radiation. Title 10, Code of Federal Regulations, part 20, rev. July 15, 1971.

Kastner, Jacob; Oltman, B.G.; Feige, Yehuda; and Gold, Raymond: Neutron Exposure to Lunar Astronauts. Health Phys., vol. 17, no. 5, Nov. 1969, pp. 732-733.