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AN EXPERIMENTAL APPROACH FOR DETERMINING THE SPACE RADIATION HAZARD TO MANNED SPACE FLIGHT

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Summary

The discovery of the earth’s radiation belts and the presence of other space radiations coupled with the advent of manned space flight demanded that the biological hazards thus imposed be carefully and thoroughly studied.

A sound experimental program has been formulated and pursued by the U.S. Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico. This program uses a multidisciplinary approach to develop a sophisticated technique for the measurement, interpretation and evaluation of the space radiation environment and its potential danger. This many faceted program includes the use of both manned and unmanned earth satellites, particle accelerators, computer analyses, and sophisticated radiation measuring devices.

The end result of this work will be a radiation monitoring system, simple and economical, with adequate readout for the astronaut in the space vehicle, as well as, biologically meaningful dose, dose rate, and depth dose profile, rapidly available to the ground control facilities.

Introduction

The advent of manned space flight and the discovery of the biologically hazardous ionizing radiations which may be encountered during such flights have necessitated research efforts to determine the exact danger of the space radiation environment to manned space systems.

The space radiation environment can be subdivided for convenience into the following categories:

1. The natural radiations which are relatively stable in space and time (i.e., galactic cosmic rays and magnetically trapped electrons and protons in the inner Van Allen Belt out to 3,000 miles).

2. The natural radiations which are variable with space and time, primarily solar flares, and soft trapped radiations in the outer Van Allen Belt.

3. Particulate radiation injected by nuclear weapons which are mainly fission debris electrons.

4. Incident radiation from nuclear power devices, primarily leakage neutrons and gamma radiation.

A Statement of the Problem

After early experimental efforts in the late 1950s and early 1960s established the physical parameters of space radiation, it became apparent that a sophisticated experimental program must be designed to provide simultaneous measurements of both the physical environment and the biological dose inherent from exposure to that environment. This needed to be done in such a manner that an end product was information presented as biologically significant parameters which could be easily interpreted by medical personnel and radiobiologists in order for them to provide safety of flight guidelines in support of manned space systems.

An additional end product should be the development of a space radiation monitoring system which is simple in design, low in cost, easy to maintain, capable of instantaneous readout by the astronaut in the space vehicle and capable of providing mission control facilities with the biologically meaningful dose, dose rate, and depth dose profiles being encountered by the astronaut.

To accomplish this ambitious and complex program, it was apparent that a broad based multidisciplinary team of scientists would be needed. This team had to include individuals trained in medicine, biology, radiobiology, physics, nuclear physics, chemistry, mathematics, cybernetics, astrophysics, and mechanical and electrical engineering.

Approach to the Problem

The Biophysics Branch of the Air Force Weapons Laboratory at Kirtland AFB, New Mexico, has originated a unique experimental approach which simultaneously measures the radiation environment, both inside and outside of a space vehicle, as well as measurements of dose, dose rate, and depth dose profile for the biological system exposed.

The past few years have seen this approach develop into a scientifically sound multifaceted program utilizing all available research tools to accomplish the goals stated earlier.

There are three main areas of this approach and they are interrelated and interdependent. The first of these is the use of space research vehicles including both manned and unmanned satellites. The second is instrumentation design, development, fabrication, and procurement. The third is use of accelerators and computers to provide support and data analysis.

The entire program is based on two U.S. Air Force projects. Project 8803 entitled "Personnel Hazards Associated with Ambient Space Radiations"
is sponsored by the Office of Aerospace Research and is a basic research project. It includes the accelerator, computer, theoretical, calculational and data analysis and evaluation portions of the program. The second project in the program, 5677, entitled "Biophysical Parameters of Ionizing Space Radiations" is sponsored by the Aerospace Medical Division and is an exploratory development project. It includes the remainder of the program, i.e., research satellites and instrumentation.

A cornerstone of any research endeavor is adequate instrumentation, sufficiently sophisticated to provide data which can be readily reduced, analyzed, and evaluated. During the early phases of this program, instrumentation which would measure all of the necessary parameters was not available; therefore, it was necessary to design and develop the needed instruments. The most appropriate dosimetric devices are those which measure tissue equivalent dose. Early development led to ionization chambers which had walls composed of tissue equivalent material (i.e., plexiglas/polystyrene) and were filled with tissue equivalent gasses. By tissue equivalent, is meant materials which interact with the radiation environment in the same way as human muscle tissue. These chambers are known as tissue equivalent ionization chambers or TEICs and are designed for use in many ways which become apparent later on.

The occurrence of different types of ionizing radiation and their different energy ranges requires the consideration of a quality factor when discussing their biological hazard. RBE or Relative Biological Effectiveness was a unit originated to take the quality of radiation into account. Because of the many variables associated with this term, it is a very difficult parameter to handle. Therefore, in this program, the factor LET or Linear Energy Transfer was adopted in correlating dose measurements with biological effect. A linear energy transfer spectrometer utilizing a tissue equivalent sensor was designed and developed.

The LET and TEIC development progressed rapidly and units were fabricated for use in the program. Since that time, they have been continually improved as the state-of-the-art permitted and are presently the foundation of the program.

In order to pursue the philosophy of simultaneous measurements, it was necessary to obtain physical spectrometers which would measure the various physical parameters of ionizing space radiations. Some proton and electron spectrometers and various other detectors were available and fulfilled some of the requirements. These are used routinely and cooperatively with other agencies. However, the possibility of building a single unidirectional charged particle spectrometer capable of detecting protons, electrons, alpha particles, and heavy nuclei was investigated. Design and development proved to be complex and required advances in the state-of-the-art. Several technological advances were made and now a flight-qualified spectrometer has been added to the growing number of sophisticated tools available. This particular device has been dubbed a Solid State Space Radiation Monitoring System or the SS3MRS.

It is important, both in terms of economy and scientific soundness to support space research efforts with appropriate ground-based programs. This program leans very heavily on the use of various high energy particle accelerators capable of simulating portions of the space radiation environment.

These accelerator experiments have made it possible to provide properly calibrated instrumentation prior to flight and to determine the interaction of unidirectional homogeneous radiation with these instruments and other radiobiological equipment including a tissue equivalent plastic manikin.

The manikin, called MAX (Manikin Astronaut Experiment), can be fitted with up to eleven (11) TEICs and placed in an accelerator beam. Shields of different materials and thicknesses can be introduced between the source and the manikin and by proper dosimetry and beam mapping, very accurate data can be obtained on the dose, dose rate, and depth dose profile received by the manikin. This can then, in turn, be correlated with other radiobiological studies, experimental data and theoretical analyses.

A theoretical and calculational program is oriented toward establishing data handling procedures, designing satellite experiments, and toward developing and utilizing a computer code capable of predicting an astronaut's dose, dose rate, and depth dose pattern when the capsule shielding configuration and orbital parameters are known.

With the preceding base from which to work, the next obvious step was to develop the in-space aspects of the program. As instrumentation became available and was flight qualified, it was packaged for use on appropriate probes and satellites, as well as one X-15 aircraft and a high-altitude balloon experiment.

The Starfish radiation belt, the result of a U.S. high-altitude nuclear detonation, precipitated participation in experiments to determine the biological hazard produced. Thus began the establishment of a program, which led directly to concern with all types of ionizing space radiation.

Both manned and unmanned vehicles have been used to obtain the greatest amount of useful data by exploring as many different environmental parameters as possible.

**Progress**

The measure of success of any scientific program is its achievements. This program has had its share of disappointments and failures but has also made tremendous progress toward its goals in a relatively short time period.

The area of instrumentation has developed to the point where only improvements need be made as new advances in the state-of-the-art occur. Third and fourth generation TEICs are currently the work horses of the radiation monitoring systems. They have been space flight qualified and
space flight proven. The LET system is flight qualified and will shortly be launched aboard a research satellite. The S³RMS has the same status. Passive dosimetry units (PDUs) have also been used on space flights.

The ground-based portion of the program has seen the successful completion of accelerator experiments at several proton and electron accelerator facilities. A computer code has been developed and is presently available from the Defense Documentation Center (DDC) to anyone interested. It is called the AFWL/Boeing Code and has been used to support NASA programs such as Gemini, Apollo, and Bios as well as others; industry in their space research programs; and of course, the planned military manned space systems including orbiting research laboratories and other vehicles.

The probe and satellite portions of this program have been continuous and have provided a great deal of experimental data which are invaluable for supporting the nation's space effort.

A USAF satellite carrying TEICs measured the radiation environment from both the U.S. and Soviet high-altitude nuclear tests. This was a very successful attempt at gathering information from the Starfish radiation belt.

TEICs, spectrometers, and various dosimeters have been incorporated in payloads flown on a series of Atlas and Scout boosters. Some have been probes and some satellites. One X-15 aircraft was equipped with TEICs and other dosimeters in order to assess the radiation in the aircraft's flight profile. Several balloon packages were also flown from the high latitude of Bemidji, Minnesota in order to assess the biological consequences of cosmic radiation.

With this background and experience to build on, it was possible to design more sophisticated and complete radiation monitoring packages for use on future probes and satellites. A short period between mid-1962 and mid-1964 was utilized to plan for the present space satellite research endeavor. During this time, a great deal of theoretical and calculational work was performed, instrumentation refined and experimental payloads built, tested, and delivered for launch.

The next intensive phase of the program began in the spring of 1965. This was accomplished in cooperation with NASA, SSD/Aerospace Corporation, Air Force Cambridge Research Laboratories and various other support and administrative agencies. In April and June of 1965, payloads were launched on Blue Scout vehicles. These probes penetrated the inner Van Allen belt to an altitude of 15,000 nautical miles. The earlier shot was only partially successful because of intermittent telemetry problems. The second shot was successful even though the fourth stage did not perform normally. Data from both shots have been analyzed and reports will be published shortly.

OV-1-3 (WL-412) was a SATAR (Satellite for Aerospace Research) launched on an Atlas booster from Vandenberg AFB in May 1965. This satellite carried 6 advanced TEICs, one complete LET system, electron and proton spectrometry and a tissue equivalent phantom. The flight was planned to cut through the inner Van Allen belt at an apogee of 1850 nautical miles, a perigee of 400 nautical miles, and an inclination of 30°. This flight was unsuccessful when the Atlas booster exploded a few minutes after launch.

Gemini Flight GT-4 in June 1965 accomplished two "firsts" in the space program. This flight carried a fixed and a portable TEIC as well as 5 passive dosimetry units. It was the first time that active tissue equivalent radiation dose measurements were made on a manned space flight and it was also the first time these measurements had been made in free space on a manned mission. The latter occurred during Astronaut White's space walk with the portable TEIC on the opened hatch. Data from the TEICs was telemetered to the ground continually. The fixed chamber remained on the hatch near Astronaut McDivitt. However, the sensor head on the portable chamber was removed by Astronaut White during five passes through the South Atlantic Anomaly. During these passes, Col. White placed the sensor at various locations within the spacecraft and noted the mission time. This data was analyzed and compared with predicted doses made before the flight. The passive dosimeters were returned to the Weapons Laboratory for analysis immediately after splashdown. NASA provided the proton-electron spectrometer. This experiment was a complete success and proved the practicality of active space radiation monitoring systems.

OV-1-2 (FESS - Flight Experiment Shielding Study) satellite was designed to measure the ambient space radiation environment in the lower Van Allen belt and to determine radiation attenuation by various types and thickness of shielding materials. This satellite, also a SATAR, was launched by an Atlas booster in September 1965 from Vandenberg AFB. The first satellite to obtain a retrograde orbit, its apogee is 1865 nautical miles and its perigee is 223 nautical miles with a 35° inclination. This satellite has been extremely successful. All systems worked flawlessly the first 2 months. Some trouble was then experienced in the satellite clock and was remedied. After 3 1/2 months, the on-board tape recorder failed necessitating that all data be collected in real time. Data analysis is being performed as rapidly as possible and should be available later this year.

OV-2-1 (WL-512) was a tri-laboratory cooperative satellite riding on a Titan III booster. The Weapons Laboratory, Air Force Cambridge Research Laboratory and Aerospace Corporation were the experimenters. The AFWL provided the dosimetry system composed of TEICs and LETs imbedded in a tissue equivalent phantom and a proton spectrometer. AFRL and Aerospace provided the flux and spectral measurements as well as other related information. The vehicle was launched from Cape Kennedy in early October 1965.
but met a prenatal death when the Titan transtage exploded shortly after successfully completing its initial parking orbit and first transfer orbit. The really unfortunate aspect of this launch was that it was the second unsuccessful attempt in 5 months to orbit a LET device.

Gemini flight, GT-6, was launched in December 1965 and repeated the experiments performed on GT-4. Identical TEICs, one fixed and one portable, and 5 passive dosimetry units were flown. A brass shield was used to cover the fixed TEIC sensor to shield out any electrons present and to attenuate penetrating protons. The portable sensor experiment was performed during passages through the Anomaly; NASA again provided the physical spectrometry.

The past year has been very productive. A large step has been taken in developing and maintaining an unmatched capability in space radiation monitoring, as well as determining space radiations potential danger to manned space flight. There are many problems remaining to be solved and riddles yet to be answered. Therefore, a continuing long range program has been planned and is progressing smoothly.

Future Plans

The ground-based support activities are continuing with emphasis placed on cooperative experiments with other agencies. The accelerator program is currently being coordinated with the School of Aerospace Medicine at San Antonio, Texas. Experiments performed at various particle accelerators will include biophysical dosimetry and spectrometry in conjunction with radiobiological studies. These data can then be used to accurately correlate space radiation dose measurements with actual biological effect. LET and biological effect can hopefully be related over a wide spectrum of environments.

Computer routines are continually being simplified and made less time consuming. The AFWL/Boeing code is presently the most sophisticated and flexible code available. It has continually proven itself reliable and will become more accurate as more experimental data is correlated with its theoretical portions. Computer programming is an in-house capability and the recent addition of a CDC 6600 computer to the Weapons Laboratory inventory is a major reason for the present outstanding capability in data analysis and computer support.

Theoretical and calculational efforts will continue to be used in evaluation and interpretation of data from the various experiments and vice versa. From these efforts will come future experiments which will be soundly based and directed to filling the remaining knowledge gap. The satellite research program is planned to provide required data and to quickly and efficiently flight prove newer additions to the instrumentation list.

OV-1-4 is an AMD biological experiment satellite. The Weapons Laboratory is providing dosimetry support with TEICs. This vehicle is planned for launch in February 1966 aboard an Atlas booster. It will achieve approximately a 460 nautical mile circular orbit at a retrograde inclination of 30° - 39°.

OV-3-4 (WL-413) utilizes the OAR Standard module concept on a Blue Scout booster. This satellite will carry TEICs, LETs, the newly developed S'KOS, as well as omnidirectional proton and electron spectrometers. It will give us flux, spectral, and depth dose measurements in the Van Allen belt and will provide information on any residual radiation from STARFISH. The planned orbit is 370 nautical mile perigee, 2600 nautical mile apogee at 42° inclination. Present plans call for a Summer 1966 launch.

OV-1-9 (WL-702) satellite is planned for launch in the fall of 1966. It will have aboard TEICs and LETs in a tissue equivalent phantom. Physical spectrometry will be provided by AFCDL. The loss of the OV-1-3 and OV-2-1 spacecraft created a serious gap in the space radiation monitoring program. In order to obtain data required to support various space missions, OAR and AFCDL consented to including dosimetry on the OV-1-9. It will have an orbital configuration similar to that planned for OV-1-3.

FARO (WL-701) is an acronym for Flare Activated Radiobiological Observatory. This will be the first in a series of satellites designed to monitor the biophysical aspects of solar flare radiation. It will have a lifetime of one year and contain solar flare detectors which will activate the on-board monitoring system. FARO will provide data on the many parameters of solar flares which are necessary to assess the hazard of these phenomena to men in space. Hopefully, one by-product will be the discovery of some parameter which will allow the prediction of solar flares well in advance to their occurrence. This program has been coordinated with every agency concerned with solar radiation and solar flare prediction. The first launch is scheduled for calendar year 1967 in order to take advantage of the approaching solar maximum and to allow sufficient time for data analysis detailed enough to provide support to NASA's Apollo program and any military manned space systems.

Maintaining the capability to provide radiation monitoring support to many different systems, the Air Force Weapons Laboratory will provide dosimetry for at least one NASA Apollo mission. A recently modified TEIC will be placed aboard a manned Apollo vehicle scheduled for launch in early 1967. Apollo lunar missions should contain a TEIC and LET package in conjunction with NASA's physical spectrometry in order to provide complete radiation monitoring. Proposals have also been made to provide a radiation monitoring experiment on the Voyager missions to Mars in the 1970s.
Several agencies have taken advantage of the Weapons Laboratory capability in this area of radiation monitoring. Recently, the FAA has requested USAF to provide support in several areas for the proposed Supersonic Transport (SST). Presently, a program is underway to equip Air Force RB-57 aircraft with appropriate dosimetry and spectrometry to assess the radiation hazard for the anticipated flight profile of the SST. This is presently an FAA, USAF, NASA cooperative effort and is operating on schedule.

Concluding Remarks

All of the aforesaid efforts have led to an Air Force in-house capability to provide a radiation-monitoring system capable of supporting any US manned space venture. The instrumentation is mostly space-flight proven and all space-flight qualified. It is capable of providing biologically significant data in a rapid and economical manner so that mission control decisions can be based on accurate and timely information.

Bibliography

The following documents are listed as sources of background information for the reader's more technical and detailed study.


