Working Group on Radiation Problems Summary Report

Working Group on Radiation Problems, Man in Space Committee, Space Science Board, National Academy of Sciences, National Research Council

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SPACE SCIENCE BOARD

MAN IN SPACE COMMITTEE

WORKING GROUP ON
RADIATION PROBLEMS

FIRST SUMMARY REPORT

National Academy of Sciences—
National Research Council

National Academy of Sciences
Space Science Board
2101 Constitution Avenue, N. W.
Washington 25, D. C.

Introduction

The Space Science Board has undertaken through its Committee on Man in Space the study of a series of topics of importance to the practical realization of space flight. The enclosed documents, comprising a Summary Report and annotated accounts of two discussion meetings, contain the results of inquiries to date into the problems posed by the existence of strongly penetrating radiations in space.

The principal topics covered are the assessment of the radiation hazard; review of protection criteria proposed for the Apollo spacecraft; consideration of lacunae in the relevant physical and biological fields and some discussion of preferred approaches to the acquisition of required information.

The Working Group responsible for this report expects to continue study of these and other related subjects and will report its findings as new data become available.

In approving this report for distribution the Space Science Board and the Man in Space Committee acknowledge with gratitude the helpful and intimate participation of representatives of the Department of Defense, the Atomic Energy Commission and the National Aeronautics and Space Administration.

July 10, 1962

National Academy of Sciences
National Research Council
2101 Constitution Avenue, N.W.
Washington 25, D. C.

S P A C E S C I E N C E B O A R D

Man in Space Committee
Working Group on Radiation Problems

Summary Report

31 May 1962

In connection with its responsibilities to the Space Science Board and the NASA the Man in Space Committee has undertaken examination of the problems which may arise from exposure of spacecraft crews to penetrating radiations in lunar flight.

As a first step, an "ad hoc" discussion group was convened on 28 July 1961, under the chairmanship of Dr. Howard Curtis, to review the problems in general terms. The record of this discussion (Discussion of Radiation Problems Associated with the Manned Lunar Landing Program, 28 July 1961, attached) was subjected to extensive review with the participants in order to clarify divergent views and appropriate amplifying matter was incorporated.

In order to consolidate and carry on the work thus begun, a small Working Group, under the chairmanship of Dr. Wright Langham, was appointed by the Committee.

It is to be noted that, throughout, the terms of reference of these discussions have been strongly "mission-oriented" -- that is, the principal concern has been for the practical aspects of the radiation problem as they will affect the development of manned spaceflight. The broader and more fundamental aspects of radiation biology are treated under another committee of the Space Science Board and safeguarded by appropriate liaison representation on the Working Group. Also, in arriving at the composition of the Working Group, care was taken to include representation from the relevant government agencies, in order to make them parties to the deliberations and alleviate dependence on the written record.

The revised and annotated account of the first discussion served as a point of departure for the first meeting of this Working Group (12-13 January 1962), and its findings were generally ratified.

The record of the first Working Group meeting (Working Group on Radiation Problems in Spaceflight, First Meeting 12-13 January 1962) revised and annotated is also attached.

The following is a summary of the principal findings and recommendations emerging from both discussions. Details of these and other considerations will be found in the attachments.

1. Radiation Dose Considerations

   a. Trapped radiation: Dosage received is dependent on the manner in which the belts are traversed. It does not appear difficult to limit the dosage to less than 25 r. Use of the parking orbit technique, however, may cause problems in dose limitation.

   b. Solar flare protons: Events are not at present predictable over useful periods of time. Intensities and energy spectra are extremely variable. Most solar events do not produce, at earth distances, proton fluxes which would be of biological significance under 1 g/cm^2. More intense and energetic events, occurring at the rate of about 2 to 4 per year near solar maximum, are a serious hazard and may give doses of about 1,000 rad under 1 g/cm^2.

   c. Galactic cosmic rays: The accumulated effects are not thought to be serious enough to deter lunar flights of about 14 days duration.

   d. Radiation protection criteria: Industrial standards should not be rigidly applied to the cases of the astronauts. It seems reasonable to expect a dose of 25 r to be taken on a lunar mission and if a flare were encountered which raised the aggregate dose to 150 r the result would probably not be catastrophic. (Note, however, that more than a trivial amount of shielding would be needed to give this kind of protection in a large flare.)

   e. Apollo radiation protection design values: The lowest radiation dose design values specified for Apollo by the Manned Spacecraft Center were found to be essentially conservative, provided the RBE of trapped and solar flare radiation is not significantly greater than unity. The bone marrow dose limit for maximum single acute exposure may be too high and requires further study as a matter of urgency.

2. Physical Measurements of Energetic Radiations in Space

   a. Trapped radiation: Continued measurements of the variation of energy spectra with distance through the trapping region are required for calculation of radiation dosage.

   b. Solar flare radiation: Continued efforts are needed to obtain measurements of energy spectra and variations; time histories and frequency of flare occurrence for estimation of radiation dosage.

   c. Experimental programs: The NASA program in physics of energetic particles in space is strongly endorsed especially with respect to interplanetary and solar studies.

   Continuation and, where possible, extension of ionospheric scatter observation is supported because of its importance in the observation of solar proton events.

   d. Solar flare prediction: Continued study of this problem is important. The National Aeronautics and Space Administration is urged to obtain the services of a good solar physicist or astronomer for the Apollo program.

3. Shielding Studies

   a. Use of particle accelerators: First priority in the use of available particle accelerators should be devoted to experimental studies of shielding.

   b. Variable Energy Accelerator: Development of a proposed variable energy proton accelerator should be encouraged.

4. Radiobiology

   a. Depth dose distribution and RBE: Measurement of proton dose distribution and RBE are serious biological problems urgently requiring solution. Knowledge of the effects of partial body irradiation is also needed.

   b. Laboratory simulation: Efforts to simulate solar proton dose distribution in the laboratory with particle accelerators and particularly with other sources - e.g. x-rays - should be strongly encouraged.

   c. Biological experiments: For the present; the preferred emphasis in biological experiments on the effects of radiation seems to be on laboratory work with simulated sources. Check measurements of radiation dose in space will be required and, for this purpose, tissue equivalent chambers and experimental animals will probably be required, together with the absolute physical instruments. The design of suitable radiobiological experiments merits careful attention.

   d. Medical evidence: Clinical and other medical evidence on cases of intentional or accidental exposure to radiation should be sought whenever it may illuminate space radiation problems. Records of very high altitude pilots may be useful in connection with cosmic ray exposure.

5. Future Plans

The Working Group will take up the problems of the specific design, control and interpretation of biological experiments at its next meeting.

National Academy of Sciences
Space Science Board
2101 Constitution Avenue, N.W.
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Committee 16 Working Paper
Final Revision 31 May 1962

MAN IN SPACE COMMITTEE

Working Group on Radiation Problems
in Spaceflight

First Meeting 12-13 January 1962

School of Aerospace Medicine
San Antonio, Texas

Introduction

On 28 July 1961, the Man in Space Committee sponsored a discussion meeting for the purpose of examining the problems which may arise from exposure to penetrating radiations of the crews of spacecraft in lunar flights.

The topics discussed and conclusions reached at that meeting were given extensive review and, together with additional comments and amendments, are incorporated in the Account of Proceedings dated 27 October 1961 (Committee 16 Working Paper).

In order to consolidate and extend the work thus begun, the Man in Space Committee appointed a Working Group on Radiation Problems in Spaceflight under the chairmanship of Dr. Wright Langham. This group (Appendix A) held its first meeting on 12-13 January 1962 at the School of Aerospace Medicine, San Antonio, Texas. An account of this meeting follows, together with appropriate amplifying material.

Terms of Reference

In his opening remarks, the Chairman explained the circumstances which, in the view of the Man in Space Committee, made it desirable initially to center discussion of the radiation problems on those of particular concern in the Apollo program. The practical problems affecting the design of the spacecraft and its shielding must be solved well in advance of the date of first flight and, if the group's deliberations are to assist in the solution of these problems some concentration of effort is necessary.

This temporary preoccupation with the problems of the lunar missions is not, however, to be taken as indicating a lack of concern for the more fundamental aspects of radiobiology. In this connection, it is to be noted that Dr. J. J. Nickson as Chairman of the Subcommittee on Radiobiology of the Committee on Nuclear Science would be able to maintain a watching brief on the Working Group's discussions and help guard against any inadvertent disregard for the longer term interests of radiobiology.

Account of July 1961 Discussion

The Chairman expressed himself strongly in support of the findings of the Discussion of Radiation Problems as recorded in the Committee 16 Working Paper dated 27 October 1961 and hoped that the present meeting would be able to confirm or qualify them. The Group endorsed these findings subject to modification arising from the present discussion.

Attention was drawn to the importance of the problems attending (1) the role of biological experiments in the study of interplanetary radiation hazards and (2) the calculation of radiation dosages from physical data. A suggestion was made that it might be worthwhile to examine in some detail the assumptions used in the calculation of radiation dose with a view to ascertaining whether there might be some preferred method for application to biological problems. In any event, a strong plea was made for consistency in such calculations.

The Apollo Program

Noting the importance of the specific plans for the lunar flights in clarifying the problems facing the Group, the Chairman called on Mr. William Gill for a description of those aspects of the Apollo program affecting the radiation protection of the crew and a discussion of the criteria selected.

The following is a summary of the material presented. Appendix B, submitted by Mr. Gill after the meeting, contains a more detailed discussion.

a) Radiation protection is only one aspect of the Apollo spacecraft design problem; all other important risks will have to be taken into account in the final design.

b) Estimates have been made of the margin of safety which should be applied in calculating the shielding requirements for Apollo. These estimates are based in turn on estimated uncertainties in calculated or measured values of the principal physical factors (excluding biological effects).* Knowledge of the radiation environment was taken as uncertain to a factor of 3; calculated shielding effectiveness - a factor of 2; execution of shield design - a factor of 2. The root mean square of these factors - approximately 4 - was taken to represent the tolerance which should be applied in assessing the adequacy of the capsule design from the point of view of radiation protection.

c) The sequence of events in the Apollo flight program is expected to be:

	Begin	Apogee	Duration
Earth orbital flight	1963-4	400 m	< 2 weeks
Cislunar flight	1965	Between Earth and Moon	1 week
Translunar flight	1966	Beyond Moon	< 2 weeks
Lunar orbit	1968	--	"
Lunar landing	1968-9	--	"

* It should be emphasized that the exclusion of biological considerations from these estimates of uncertainty in the expected radiation environment within the capsule does not imply that they can or will be neglected. These estimates of uncertainty are merely preliminary to the estimation of bounds on the biological effects.

Opportunities exist in the early flights for terminating the mission prematurely in the event of an unexpected solar event but this would not be possible in the lunar landing flights. It was also noted that landings on the moon would be attempted during the next period of solar maximum when the probability of encountering a large solar event would be greatest.

Some additional weight (~100 lbs.) may be available for extra shielding after the capsule design has been "frozen." The total weight of the capsule is expected to be 8,500 lbs.

It was noted that the dates given above may be modified in the light of experience with the Gemini program in which a two-man capsule similar to that of Mercury will be flown in earth orbit.

d) Shielding design. Gill noted that the experimental verification of the shielding design was a most pressing practical problem; the final design would be calibrated by exposure of the whole spacecraft to the beam of a suitable proton accelerator.

Experimental shielding studies on a small scale would also be conducted with sounding rockets carrying shield specimens and nuclear emulsions. He described the general configuration of the Apollo capsule as at present conceived (See Appendix B); the minimum shield thickness is about 6 g/cm^2 in the region of the windows. Elsewhere the amount of shielding is appreciably greater. Additional shielding might be applied to increase the minimum value and some partial shields might be provided for the crew's sleeping positions.

e) Criteria for exposure dosage. A phantom model has been devised for calculation of radiation exposure dosage and is shown in Fig. 4, Appendix B.

In terms of this phantom the following doses have been specified by the Manned Spacecraft Center to North American Aviation for guidance in their task of developing the specifications for the Apollo spacecraft.

	Total permissible dose over active career* rem	Average annual dose rad	Max. single acute exposure rad	Design** value rad
Skin of whole body	1630	233	500	125
Skin, extremities	3910	559	700	175
Blood forming organs	271	54	200	50
Eyes	271	27	100	25

*Assuming for purposes of calculation, an active flying life of 5 years.
**Maximum single exposure reduced by "uncertainty factor" of 4.

In the application of these values to the design of shielding, the average annual dose is taken as determining the shielding needed for normal operations, including exposure to the relatively constant geomagnetically trapped radiation. For estimation of the shielding required for protection against large solar events the maximum single acute exposures are taken as limiting, but in this case arbitrarily reduced by the uncertainty factor of 4 discussed on page 2.

A model energy spectrum for a large solar event has been chosen and is patterned after that of May 1959. Solar events are assumed to be randomly distributed in time and the probability of occurrence as a function of integrated flux >100 Mev is given on the basis of events observed. Shielding for protection against solar proton fluxes is then to be designed so that the probability of exceeding the design value doses given in the last column above is not greater than 1%. This level of risk is to be compared with a planned probability of catastrophic mechanical failure of 0.1% and a probability of failure from all causes of not more than 10%. (These risk levels are working assumptions of the Manned Spacecraft Center.)

NASA Organization in Support of Apollo

Joseph Connor described some of the new organizational measures which had been adopted by the NASA in support of the spaceflight program. In particular, five (now four) "principal area scientists" had been selected to advise and assist the NASA in obtaining the support of appropriate medical facilities belonging to other agencies. The NASA intends to rely whenever feasible on the special competence and experience of other government departments in the subjects related to "space medicine" before acquiring its own facilities. Broad scientific advice would be forthcoming from the Man in Space Committee of the Space Science Board.

Dr. J. E. Pickering had been selected as principal area scientist with responsibility for advising on programs concerned with the radiation problem but confirmation of his appointment and authority to act on NASA's behalf was awaiting an exchange of correspondence between the National Aeronautics and Space Administration and the Department of Defense.

In connection with the exposure of Apollo crews to radiation, Connor noted that a total of 30 to 40 missions was anticipated for the combined Apollo and Gemini programs and that about 30 crews* would be trained. He expressed concern lest early exposure of crews to large radiation doses might interfere with the use of the more experienced crews for the later and more difficult flights. It is NASA's intention to design the radiation protection to permit survival of the flux from a class 3 event,** but the success of any flight will depend on the efficiency of the crew; automatic controls will not be sufficient to enable the flight to be completed otherwise.

* This question is still under review and fewer crews may, in fact, be trained.

** This point is better stated as follows: "NASA intends to design the radiation protection to permit survival of a solar event producing a total flux of the order of 10^8 protons/cm^2 with energies > 100 Mev." (W. Gill) See note on flare importance scale at the foot of page 11.

Discussion of Radiation Protection Criteria in the Apollo Program

In general discussion of the approach to the planning of radiation protection in Apollo, Haymaker asked why the brain had been omitted from the phantom model described and how large a dose to the brain had been considered reasonable to accept. It was argued in reply that the more stringent limitation imposed by the dosage to the eyes would automatically safeguard the brain. Haymaker did not believe that brain dosage would be a limiting factor in this case but thought that it might be wise to include it in the model because of the importance of protecting the central nervous system.

Grahn cited the case of a recent accident in which technicians working on a high powered klystron had unwittingly received doses up to 1000 r of 150 kv rays to the head. All had to cease work because of acute headache. The doses received in these cases were far greater than those which would be involved if the criteria cited for Apollo were applied.

Connor observed that detailed consideration of dose to organs of less sensitivity than those selected would not, in any event, change the outcome of the shielding calculations.

Pickering referred to clinical evidence of the ability to perform complex tasks after irradiation. He noted that design engineers must be given useful criteria and that the main problem here is to decide whether the dose prescribed for design purposes will produce effects of biological importance.

Questioned on the acceptability of the dose levels tabulated above, Nickson stated that, on the basis of clinical experience, the doses were quite acceptable and that the design figures given in the last column were probably conservative.

Grahn felt also that these figures were generally acceptable but that possible interaction effects on crew performance should be considered: e.g., the potentiation of radiation injury under actual flight conditions.

Curtis considered the design dosage figures conservative but added that it might not be feasible to allow repeated exposure (i.e., in successive missions) of a given crew to the anticipated radiation levels in space.

It was generally agreed that the design dosages expressed in the tabulated criteria were definitely on the conservative side* but it was also noted that as the design progresses toward finality, the tolerance may well decrease and

* This statement reflects the consensus at the time of the meeting concerning the last column of the table on p. 3. However, subsequent review has led some of the group to be seriously concerned over the maximum single acute exposure at 200 rads to the blood forming organs, from which the lower design value was derived. A recent paper (Measurement of Bone Marrow Dose in a Human Phantom for Co-60 Gamma rays and Low Energy X-rays, Health Phys. 7, 171-177 (1962)) supports the view that 200 rads to these organs may be lethal with high probability. It would therefore seem advisable to reduce this value, in principle, to about 100 rads. Experimental evidence on this point should be sought as a matter of urgency, especially in view of the depth dose distribution effects also involved. (See also Curtis, p. 10).

therefore cases which may result in the astronauts becoming very sick should also be considered. In this connection the contrast between the case of the astronaut and that of a patient in a hospital bed should be borne in mind. Nickson proposed that a search be made for experimental evidence which might support the selection of the calculated design dosages and proposed also that the depth for calculation of skin dosage should be modified from 0.07 to 0.10 and suggested that Chase should be consulted on this point. He noted also that his earlier comments on the calculated dosages were based on the assumption that the RBE of the radiation involved would be about the same as that of ordinary x-rays. A question was again raised concerning the importance of considering the doses to the gonads and again ruled out of consideration because of the small number of individuals involved and the consequently insignificant effect on the population.

Langham proposed that the group approve the radiation limits described by Gill as design criteria, recognizing there are complex interactions involved, and other factors, to clarify which other work may be required. The principal point emerging in discussion of this proposed resolution centered around (1) uncertainty in the RBE value of the radiations and (2) the effects of complex interactions and potentiations. Although there is considerable reason to believe that the RBE of energetic protons is likely to have a value near unity the group adopted the proposed resolution with the qualification that the numbers stated would need to be adjusted if it should turn out that the RBE was not approximately equal to 1.

Physical Measurements of Energetic Radiations in Space

Recent advances in the state of knowledge of the physics of energetic particles of biological significance in space were reviewed. The following summarizes the discussion.

a. Trapped radiation: inner region.
A good summary of recent work is to be found in the report of the Kyoto Conference on Cosmic Rays and the Earth Storm (copies to be obtained for the Working Group).

b. Trapped radiation: outer region.
Explorer XII preliminary results show the presence of protons of energies 0.1 to 10 Mev. No change in radiation dose under nominal shielding is implied. The intensity of electrons is revised downwards from 10^{11} to 10^{3} particles/cm^2/sec. Note that the radiation dose from this flux is not changed in the same ratio, but remains at about 10 r per hour.

c. Solar flare radiation.
Analysis of Explorer XII data is expected to provide new and more detailed information about the energy spectra and time history of the solar events which occurred during its lifetime. Re-examination by Van Allen of observations of the November 1960 event indicated little prospect of extracting any new information concerning its time history, as had been hoped. A graph showing the change in integrated proton flux intensity above 30 Mev as measured by Explorer VII during the event has been submitted.

Solar Flare Prediction

The Apollo program is not at present designed to be critically dependent on the ability to predict the occurrence of large solar proton events, although, since the lunar landing flights will occur at or near sunspot maximum it would clearly be advantageous to be able to do so. The long times required for launch preparation and the limitations imposed by celestial mechanics require flare warning times much greater than the 2-4 days which now appear feasible.

In this connection, Anderson strongly recommended, and the group agreed, that the NASA consider acquiring the full time services of a good solar astronomer or physicist for the Apollo staff. Such an individual would be able to provide up-to-date and authoritative advice on current and expected levels of solar activity and solar-terrestrial phenomena, and would thus be able to assist in the selection of launch dates and crews in relation to the anticipated levels of radiation.

In attempting to understand solar proton events it is necessary not only to measure flux intensities and energy spectra near the Earth but also to observe the appearance and changes in plage areas on the Sun. Although only short range prediction is now possible, useful identifications,in advance,of longer periods of time when flares will be either more or less likely can be made. Analysis of the increasing level of solar activity to be expected in 1965 should also make possible an estimate of the absolute magnitude of activity at the next solar maximum.

Physical Measurements Required in Radiobiology

Schaefer reviewed the kinds of measurements necessary for calculation of radiation dosage due to trapped particles and solar protons. For trapped particles it is necessary to know not only the particle intensities and energy spectra but also how these vary as the trapping region is penetrated, in order to be able to calculate dosage for a flight passing through the belts.*

In the case of solar protons it is necessary to know (1) the representative intensities and energy spectra for typical flares or the range of variation; (2) the time history of these quantities; (3) the frequency of occurrence of such events, and (4) interactions with shielding materials and tissue.

Physical Measurements in Prospect

Naugle reviewed the NASA programs in physics which would contribute information relevant to the assessment of radiation dosage levels. The payloads of interest in this connection are:

1. Payload S-3a is expected to be launched early in the current year. This is a replacement for Explorer XII which suffered a premature demise after functioning for about three months.

2. Some instruments will be flown as auxiliary experiments aboard the relay satellites A-15 and A-16 during the second half of the current year. These are expected to provide information on the energy spectra and pitch angle distribution of protons in the inner radiation belt to about 100 Mev.

* The importance of accurate knowledge of trapped radiation dosage is greatly increased if the parking orbit type of launch technique is used.

3. The first eccentric geophysical observatory is scheduled to be launched in 1963 into an earth orbit with apogee at about 100,000 km. This payload contains a comprehensive collection of instruments for the study of energetic particles. It is intended to have a lifetime of one year and the program calls for replacement at yearly intervals so that one of these observatories is always in orbit.

4. Two payloads S-64 and S-64a, similar in composition to S-3a, are planned to be launched into a synchronous earth orbit early in 1963. This program is dependent, however, on the success of the Centaur development.

5. The Mariner spacecraft which are intended as interplanetary probes to the vicinity of Mars and Venus will carry instruments for the study of energetic particles and magnetic fields. The earliest members of this group are known as Mariner R (the payload is adapted from the Ranger series) and two of these are due to be launched late in 1962. Mariner B, which like S-64 depends on Centaur for propulsion, will carry instruments comparable to those on EGO. Four of these are expected to be flown in 1964, two to Venus and two to Mars. A preliminary test launching on an interplanetary trajectory is also expected to take place in 1963.

6. Three interplanetary monitoring probes were under consideration in NASA at the time of the meeting to supplement the measurements of energetic particles and fields in the 1963-64 period (these have since been approved for inclusion in the program). The payloads are relatively simple but contain redundant instruments for the measurement of energy spectra and magnetic fields. They are to be launched into earth orbits of apogee about 50 earth radii at six monthly intervals starting early in 1963.

7. The orbiting solar observatories, the first of which is due to be launched this year (successfully launched 8 March 1962) may help to provide information and statistics of interest to the understanding of solar flare mechanisms.

8. Sounding rockets are to be launched from Fort Churchill for the study of particular solar proton events as opportunity permits.

The group strongly endorsed this program and particularly items 6 and 7.

Bailey described the experimental basis for his work on the occurrence and morphology of solar proton events. The data are obtained as a by-product of the operation of the Air Force's VHF ionospheric scatter communication links in the Arctic regions. Measurements of signal strength at the receiving terminals of this communications system have given virtually uninterrupted data on solar flukes striking the ionosphere since 1952. The continuity of operation was threatened by plans to replace these links with cables but troubles with the latter have caused the system to remain in use. As a detector of energetic particles the system has an advantage over riometers in that it functions day and night and responds only to protons. If the links should shut down at some time in the future it would be possible to modify the antennas and receivers to operate at low power for a relatively small cost. In addition, a staff of about 6 or 7 observers would be required. The observations are at present transmitted to NBS by mail but it is understood that it would be feasible to establish interpretation of the data on a real time basis with the aid of a few trained operators in the field. Bailey also mentioned that plans to install similar links in the Antarctic were under consideration.

He felt that the Air Force was to be commended for having made the efforts which had resulted in this unique source of data becoming available. The working group strongly endorsed the desirability of continuing such work and recommended that the SSB consider transmission of an appropriate letter to the Air Force authorities concerned.

Gill asked for information on plans to extend the neutron monitor network. Bailey reported that there are new proposals under consideration for the installation of monitors of greater sensitivity than those which had been in use during the IGY and with a better geographical distribution.

Shielding Investigations

Connor, Gill and Pickering reported that a beginning had been made in the quantitative study of shielding both by computational methods and experimentally with the aid of particle accelerators. It was reported that the preliminary design for a variable energy proton accelerator had been worked out at Berkeley. The beam size was uncertain, but Sondhaus felt that it would be quite feasible to vary the energy in a controllable fashion over the range of about 25 to 750 Mev. The Group felt that every encouragement should be given to the development and funding of such an accelerator.

The urgent need to obtain quantitative results from shielding studies was noted but it was agreed at the time that it would be premature to review results. It was also agreed that it would be advisable to give first priority in allocation of available accelerator time to shielding work.

Radiobiological Problems

The preferred experimental approach to the problem of establishing the biological effects of exposure to the penetrating radiations of space was again discussed. It was proposed by Naugle and generally agreed that the most systematic and satisfactory method would involve (1) measurements of the radiation environment with the best available physical instruments in appropriate spacecraft; (2) determination of biological effects in the laboratory with simulated sources; (3) check measurements through the radiation belts with tissue equivalent chambers (or perhaps experimental animals) aboard vehicles such as Apollo.

The group noted the usefulness of the tissue equivalent chamber for providing an empirical check on estimates or measurements of radiation dose obtained by other methods. It seemed important to note, however, that concurrent absolute measurements of particle intensities, spectra, etc. should always be made whenever tissue equivalent devices are flown.

It was agreed that the achievement of proper reproduction or simulation in the laboratory of the radiations of interest was extremely important to the solution of the radiobiological problems. Determination of the composition of radiation in the interior of a shielded spacecraft appeared to be more easily made by experimental methods. There was initially some support for the view that some biological experiments might be delayed until the results of the shielding work became available. However, later review has led to the conclusion that the study of biological effects should proceed concurrently with the shielding work, if at all possible.

It was also recognized that it would be difficult to obtain time on suitable accelerators for biological work unless the experiments were thoroughly well designed.

Curtis, commenting on the last point, said that the most pressing radiobiological problem was the study of dose distribution. He felt that it might not be necessary to repeat measurements of biological effects with protons if the LET for protons is properly determined. Sondhaus noted that evidence from work performed with proton accelerators is consistent with an average RBE near unity*. Schaefer remarked on the necessity of taking into account the modification of the incident proton spectrum by the non-linearity of the range of the particle as a function of energy and noted the contrast with protons produced from neutron recoil.

In discussion of the equivalence of protons and x-rays in biological effects, Curtis thought that it would be possible to find an energy level or range in x-radiation which would match the energy loss distribution of a given proton flux and Schaefer referred to work in progress on the comparison of LET spectra of x-rays and protons. Barr noted in this connection that 90% of the energy is transferred in processes involving particles of less than 1000 EV energy.

Concerning the design of biological experiments with accelerators or other sources, Nickson emphasized the great importance of using appropriately chosen biological indicators. He proposed also, and the group approved, that encouragement should be given to efforts to find a means to reproduce the depth dose distribution in animals and man to be expected from space radiations, not only by means of proton fluxes but also with other sources (e.g., x-rays). Such efforts should be related to the results emerging from studies of the shielding problem. If successful, the prospect of simplified biological experimentation would be most attractive.

On a motion from the chairman, the group generally endorsed the observations of the July 28, 1961 discussion on the heavy primary cosmic ray problem, Curtis noting that it would be necessary to make very drastic assumptions in order to support the expectation of very serious effects from exposure to galactic cosmic radiation. The availability of useful evidence concerning cosmic ray exposure (not previously considered) from the medical records of pilots of very high altitude aircraft and balloons was mentioned by Pickering, who undertook to obtain the data.

* Note by Grahn: The work referred to did not involve the high LET Bragg peak. The peak was deliberately calculated to occur on the exit side of the experimental animal; thus the RBE would have to be near unity.

Future Plans

The discussions reported here dwelt more heavily on the physical aspects of the radiation problem than the biological. This is not to be taken as indicating a bias on the part of the Working Group, although it does reflect in part a relative lack of specific and detailed proposals for biological studies. The Working Group proposes to take up the matter of the specific design of biological experiments at its next meeting.

Note on solar flare classification (see page 4)

The numerical scale of importance used by solar astronomers to classify flares on the sun is based on estimations of area and brightness. Although energetic proton events observed in the vicinity of the earth can almost always be correlated with observed flares, the converse is not true; also the scale and intensity of these solar proton fluxes observed near the earth is not well correlated with the importance class of the flare.

The flare importance classification is, therefore, not a very good index of the magnitude of the solar energetic particle events near the earth. (J.P.T.P.)

Working Group on Radiation Problems in Spaceflight

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Dr. Kinsey Anderson - University of California, Berkeley
Dr. Howard Curtis - Brookhaven National Laboratory
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Visitors - Meeting 12-13 January 1962

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J. P. T. Pearman

Appendix B

STATEMENT OF THE APPROACH TO THE RADIATION PROBLEM FOR APOLLO

Submitted to:

National Academy of Sciences, Space Science Board,
Working Group on Radiation Problems in Space Flight

January 12-13, 1962

and

Particle and Fields Committee

January 16, 1962

By W. L. Gill
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STATEMENT OF THE APPROACH TO THE RADIATION PROBLEM FOR APOLLO

By W. L. Gill

PREFACE

Much of the following material is excerpted or paraphrased from the Apollo statement of work, which is being submitted to the prime contractor.

OBJECTIVES

(a) The [illegible] objective of Project Apollo is the landing of men on the moon, limited observation and exploration of the moon and safe return to earth.

(b) The intermediate objectives of the project are scientific observation in the earth-moon space and lunar reconnaissance prior to lunar landing.

(c) An additional objective is that the Apollo space vehicle will be adaptable for use as an earth orbital vehicle for conducting a variety of scientific and technological services.

DESCRIPTION

Project Apollo is divided into the following three phases:

(a) Phase A - Low altitude earth orbital flights.- These flights, which may be up to 2 weeks duration, are for the purpose of verifying design approach, study of the physiological and psychological reactions of the crew, development of flight and ground operational techniques and equipment and experimental investigation to acquire information for lunar missions. Except for the possibility of a highly eccentric orbit, there is no radiation hazard during this phase and should some unforeseen radiation hazard arise, the crew has the capability of escaping the radiation field in a short period of time (90 minutes or less).

(b) Phase B - Circumlunar, lunar orbital.- These flights are for the further test and development of the spacecraft and operational procedures together with closeup reconnaissance of lunar surface for scientific and technological purposes. Radiation hazards begin to be significant in this phase. There may be some ability to escape the radiation zone, but this will be limited.

(c) Phase C - Manned lunar landing.- These flights include lunar landing, limited exploration in the landing area and return to earth. The radiation hazard for these flights is the largest, since the period in which exposure to a solar flare might occur is the longest of all the phases.

LAUNCH VEHICLES

Three types of launch vehicles are currently under consideration:

(a) Saturn C-1, which will have a thrust of 1.5×10^6 pounds, will be used for the earth orbital phase.

(b) Saturn C-5, which will have a thrust of 7.5×10^6 pounds, will be used for the lunar orbital phase, and may be used for the lunar landing by employing a rendezvous technique.

(c) Nova, which will have a thrust of 12×10^6 pounds, may be used if available for a direct ascent to the moon.

VEHICLE CONFIGURATION

The vehicle configuration changes to meet the requirements of the various missions. The general arrangement of the lunar landing configuration is shown in figure 1. The general arrangement for earth orbital missions which include the space laboratory is shown in figure 2. The purpose of this laboratory is to provide additional space for experiments in earth orbit. At the present time, this portion of the space vehicle is not funded, since its need has not been clearly established. The internal arrangement of the command module which the crew occupies is shown in figure 3.

RADIATION PROTECTION DESIGN APPROACH

In providing adequate radiation protection to the crew, the following three areas require consideration:

(a) The environment — which includes a quantitative understanding of solar proton events, and the trapped radiations.

(b) The interaction of the particles and photons in this environment with the materials of the spacecraft, and the nature of the change in these particles and photons as a result of this interaction.

(c) The levels of radiation dose to which crew members may be safely exposed.

Over-all design requirements of the spacecraft dictate that the weight of material to be used for shielding be established within fairly close limits by the time that the earth orbital phase commences. The requirement necessitates an early design freeze in radiation protection. In considering the three areas above which determine shielding, weight and characteristics, it was decided to take a conservative approach in the biological area so that biological experimentation required to establish design parameters could be minimized or eliminated. The radiation protection problem then is limited to those experiments and calculations required to determine the radiation incident on the crew member. The levels of radiation exposure which we believe meet these requirements are shown in figure 4 and table I. In arriving at these limits, only those radiation effects which influence the design of shielding have been considered. Thus, such organs as the brain, the gastrointestinal tract, lungs, and so forth, have been eliminated from the table. Genetic effects are not considered to influence exposure limits. The exposure limits are of two varieties: the total exposure which any astronaut will be permitted to receive in a given year together with the cumulative total permitted during his space flying career, and the maximum emergency level which will be permitted in a single exposure. The former of these limits is set at the same level recommended for occupational exposure in the atomic industry by the International Commission on Radiation Protection and the National Committee for Radiation Protection. Since the average period of exposure of the astronaut to space radiations is estimated at 5 years, the permissible yearly dose shown in column 2 of table I is higher than at atomic installations. These levels are considered acceptable in view of the other risks involved in space travel and provide criteria for crew selection for any particular mission. The maximum permissible acute exposure shown in the last column of table I is used to determine the radiation shielding requirements in the event of a solar flare. In assessing this problem, a probable exposure is determined. The probable exposure must be balanced against other mission risks.

MISSION RISKS

A discussion of mission risks at this point may assist in gaining some perspective on this problem, and the following definitions give the design approach to a balanced risk:

(a) Reliability and crew safety.- Mission reliability and crew safety goals, assuming a launch vehicle reliability of 0.95 and including the effect of the ground complex reliability, but excluding consideration of radiation and meteoroid impact, shall be as follows:

(1) The probability of accomplishing mission objectives shall be 0.90.

(2) The probability that none of the crewmen shall have been subjected to conditions greater than the nominal limits specified shall be 0.90

(3) The probability that none of the crewmen shall have been subjected to conditions greater than the emergency limits specified shall be 0.999.

(b) Crew requirements.-

(1) Nominal Limits are defined as the limits within which the envirorment of the crew shall be maintained during normal operations.

(2) Nonstressed Limits are defined as the environmental limits to which the crew may be subjected for extended periods of time such as orbit, lunar transit, and periods subsequent to normal landings.

(3) Emergency Limits are defined as the environmental limits beyond which there is a high probability of permanent injury, death, or incapacity to such an extent that the crew could not perform well enough to survive.

(c) Radiation.- The nominal limits of exposure (the exposure received in transiting the regions of trapped radiation or other known sources of radiation for which the probability of exposure is one) shall not exceed the average yearly exposure of table I. The emergency dose limits shall for initial design purposes be one-fourth of the maximum permissible exposure limits of table I. It is being considered that the probability of the emergency dose being equal to or less than these limits shall be 0.99. Dose calculations shall be based on the model shown in figure 4. For design purposes, the model event shown in figure 5 shall be used. The average frequency of events as a function of event size is shown in figure 6. In assessing the probability of encounter, events are assumed to be randomly distributed in time. The reliability assigned to radiation is lower than that assigned to all other sources of failure. This is justified for two reasons: (a) we have no actual experience under exposure conditions, i.e., reliability has not been demonstrated; (b) the increase in radiation reliability is accompanied by a marked increase in weight which results in a decrease in the reliability of other systems. This effect was illustrated in a recent study contract by the General Electric Co. For the study vehicle arrangement in question, 1,200 pounds of shielding over and above that provided by the vehicle structure and equipment was required to insure that a dose of 100 rem would not be exceeded with a reliability of 0.99. To increase the reliability to 0.999 required that the shielding weight be increased to 3,600 pounds. Note that each pound added to the spacecraft requires that the launch vehicle weight be increased by approximately 10^3 pounds. Thus, to increase the reliability from 0.99 to 0.999 requires the addition of approximately 2.4×10^6 pounds to the launch vehicle, and is accompanied by a decrease in launch and escape tower reliability.

IMPLEMENTATION OF DESIGN APPROACH

In implementing the design approach described above, the NASA Manned Spacecraft Center will rely heavily on the assistance of research centers, both private and government.

For a continuing refinement of the description of the environment, the NASA Manned Spacecraft Center is acquainting Goddard Space Flight Center with our needs. Since Goddard is the focus of experimental work in determining the space environment, their assistance and guidance in assessing the radiation environment are keystones in the successful design of the radiation protection of Apollo. Specifically, a quantitative description of the trapped radiations as a function of position and time, the perturbation of solar flare events by the magnetic fields of the earth and moon and refinement of the frequency of occurrence, number of particles and spectra relationships of solar proton events are required. Assistance and cooperation in the design of the scientific radiation payload is also considered desirable.

For particle interaction with material, we are negotiating a contract with the Neutron Physics Division of Oak Ridge National Laboratory (ORNL). This program accelerated several studies which that laboratory has been conducting in this area. The approach is both theoretical and experimental, working on the hypothesis that limited experiments in conjunction with a theoretical approach can indicate the mode of interaction of many materials and combination of materials. The experimental portion of this program requires that ORNL obtain experimental time at accelerators of various energy across the country. Here the close cooperation of the scientific community is required for the timely completion of radiation protection design. Dr. N. Barr of the Atomic Energy Commission Division of Biology and Medicine has been investigating the availability of these experimental facilities and is performing an invaluable service in obtaining these vital services. While the above fundamental data are being assembled, it is planned to have the prime contractor for Apollo prepare computer programs which apply the basic data to the specific problem of shielding the Apollo vehicle. A local body shielding arrangement using water may be employed to reduce the dose to tolerance levels.

The final successful design of radiation protection requires the cross comparisons by each of the above groups, and the role of the NASA Manned Spacecraft Center is to perform this function. At the writing of this paper, the following appear to be areas which involve cross comparison: intercalibration between Goddard experimental equipment, and ORNL equipment during accelerator experiments; and reexamination of Goddard emulsion packs for neutron yields. Close cooperation will be required between ORNL and the prime contractor to apply theoretical and experimental data to the shielding problem.

VERIFICATION OF THE DESIGN APPROACH

There are two major areas which will require experimental verification of the design approach:

(a) Verification of the spectrum and dose rate inside the Apollo vehicle.

(b) Verification that the macrodose distribution pattern at the design exposure levels do not produce any unanticipated effects.

To effect the first of these two experiments requires protons of several energies. The variable energy accelerator, on which the University of California, Lawrence Laboratory is currently making a feasibility study, would be ideal for this application. It is visualized that small sections of a complete spacecraft would be irradiated by several energies of protons, and that any defects in shielding which such tests revealed would be corrected prior to circumlunar and lunar landing shots. It is believed that this approach is best, both from good experimental control and an economics point of view.

The second of these experiments is simpler to carry out than the first. It appeared to the writer that the consensus of opinion of the biological group was that the depth dose patterns of space radiations could be simulated with gamma radiation. It similarly appeared to be the consensus of opinion of the biological group that the microdose deposition pattern will not profoundly influence the biological effect of space radiations.

CONCLUSIONS

The NASA Manned Spacecraft Center is the agency charged with the responsibility for the design of a spacecraft capable of carrying men to the moon. The goal directed research and development required for the success of the Apollo mission must be accomplished by employing the resources of many national agencies. The preceding paragraphs set forth a program which it is believed employs the talents of the laboratories and research centers which can best respond to the needs of the radiation protection problem; and it is believed the program outlined here is adequate for the safe and timely completion of the radiation portion of the Apollo design.

REMAINING AREAS WHICH REQUIRE EXPLORATION

In connection with the operational phase of Apollo, there are several areas which deserve exploration. The first of these is an investigation of the type of ground medical facilities required for treatment of the crew should they encounter a solar proton event greater than design values. Secondly, it would appear that warning of a flare in being should be incorporated into operation procedures. Finally, outer belt size should be estimated just before or after launch to assess the dose which will be received in transiting the outer belt.

Critical organ	Maximum permissible integrated dose (rem)	RBE (rem/rad)	Average yearly dose (rad)	Maximum permissible single acute emergency exposure (rad)	Location of dose point*
Skin of whole body	1,630	1.4	233	500[1]	0.07-mm depth from surface of cylinder 2 at highest dose rate point
Blood-forming organs	271	1.0	54	200	5-cm depth from surface of cylinder 2
Feet, ankles, and hands	3,910	1.4	559	700[2]	0.07-mm depth from surface of cylinder 3 at highest dose point
Eyes	271	2[3]	27	100	3-mm depth from surface on cylinder 1 along eyeline

*See figure 6.

[1]Based on skin erythema level

[2]Based on skin erythema level but these appendages believed to be less radiosensitive

[3]Slightly higher RBE assumed since eyes are believed more radiosensitive

Table I. - Radiation exposure dose limits.

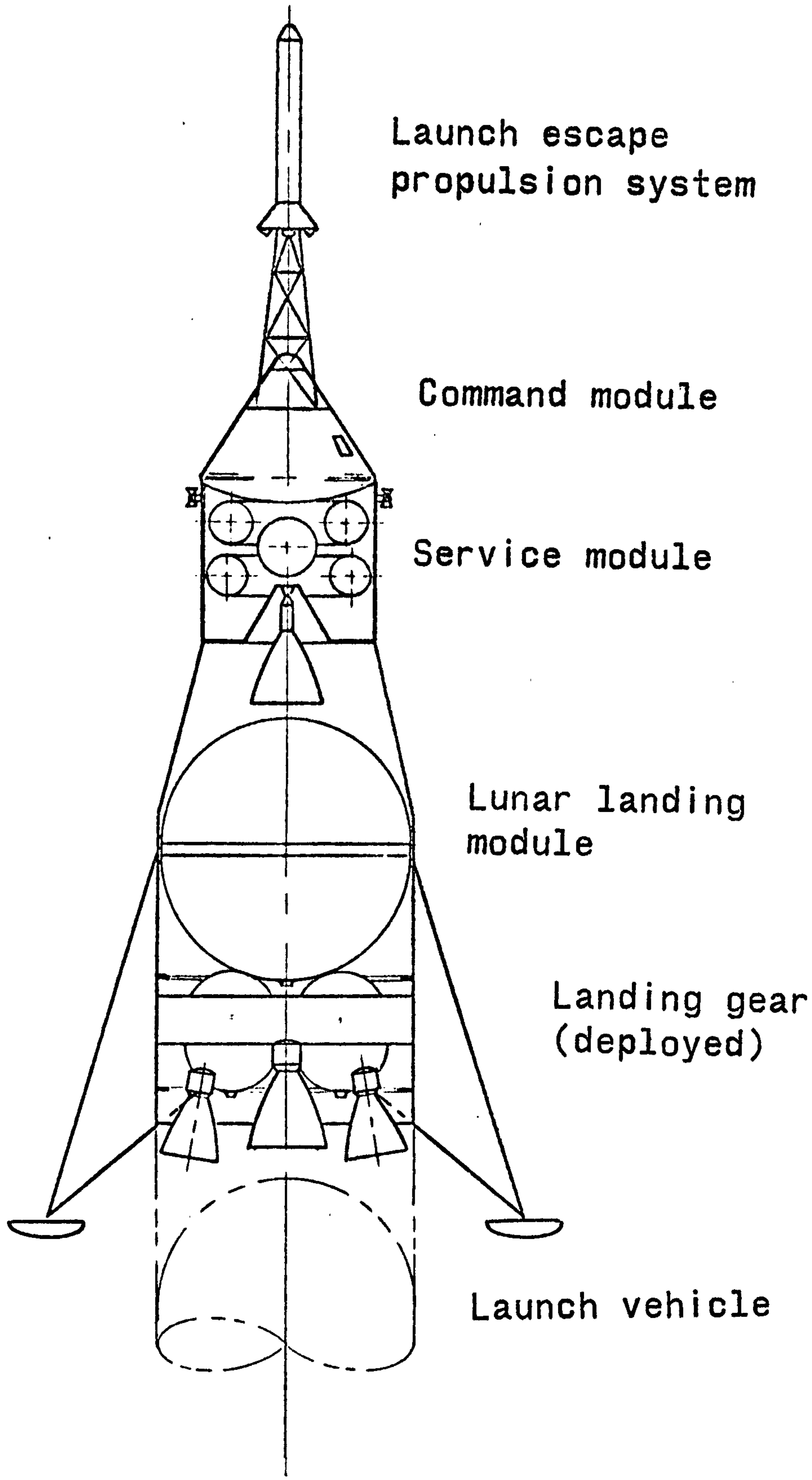

Figure 1.- General arrangement -
lunar landing configuration.

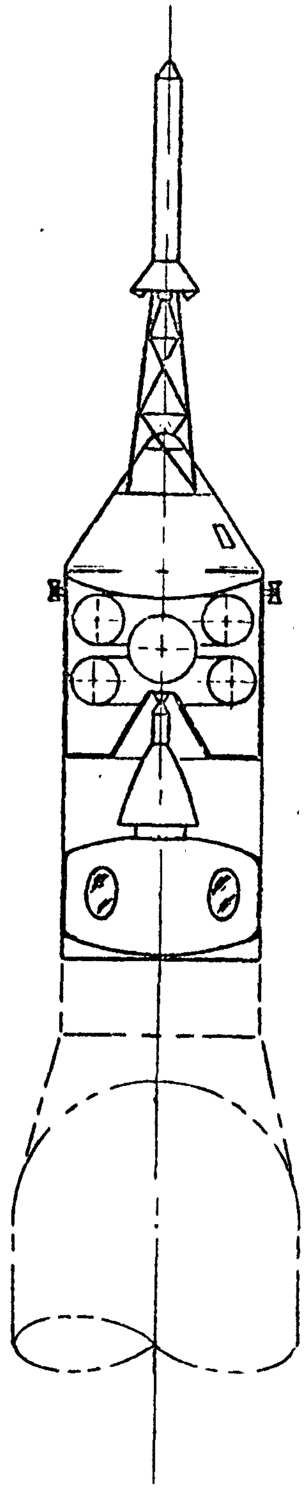

Figure 2.- General arrangement - earth orbital configuration with space laboratory.

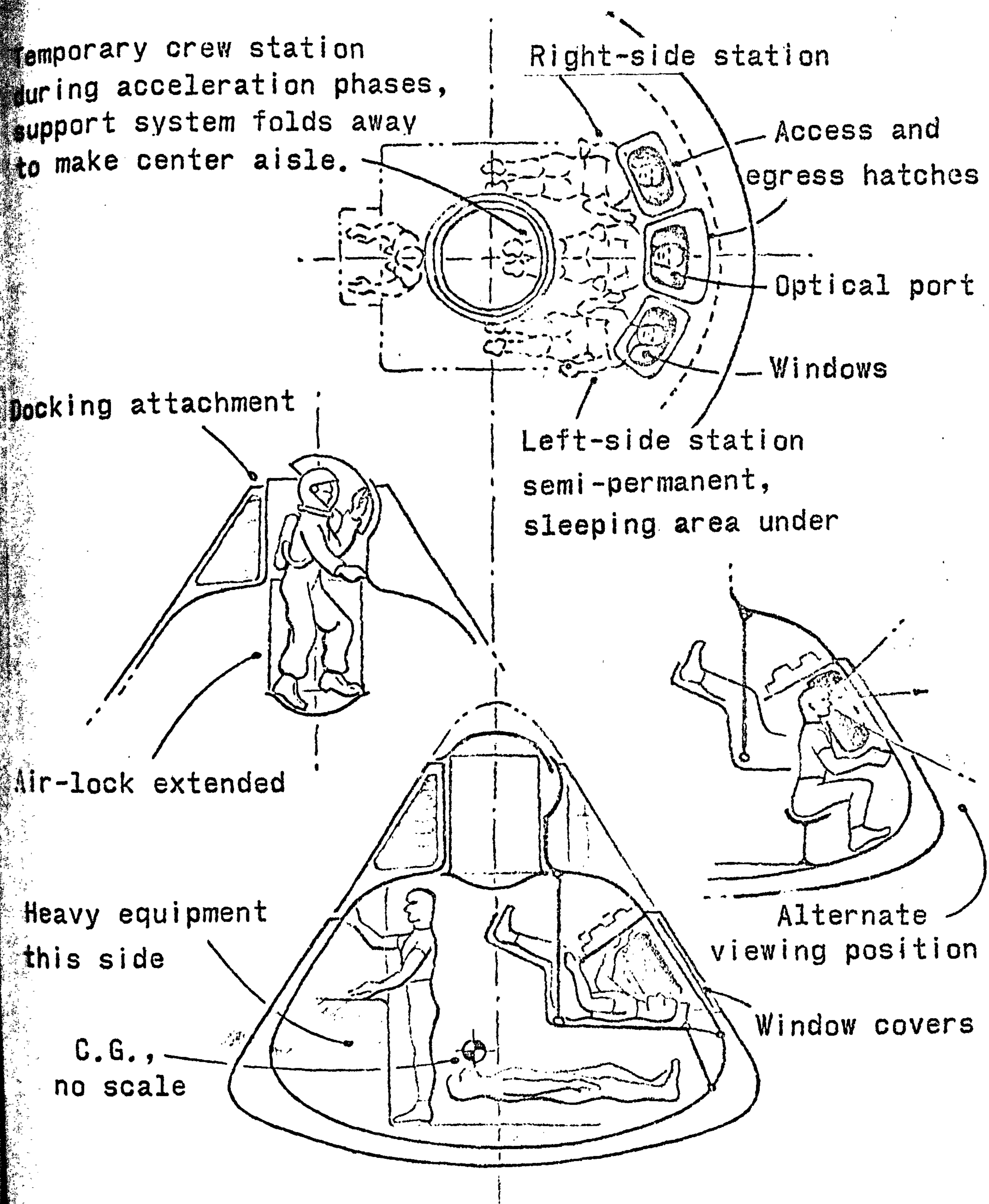

Figure 3.- Command module - Inboard profile, activity areas.

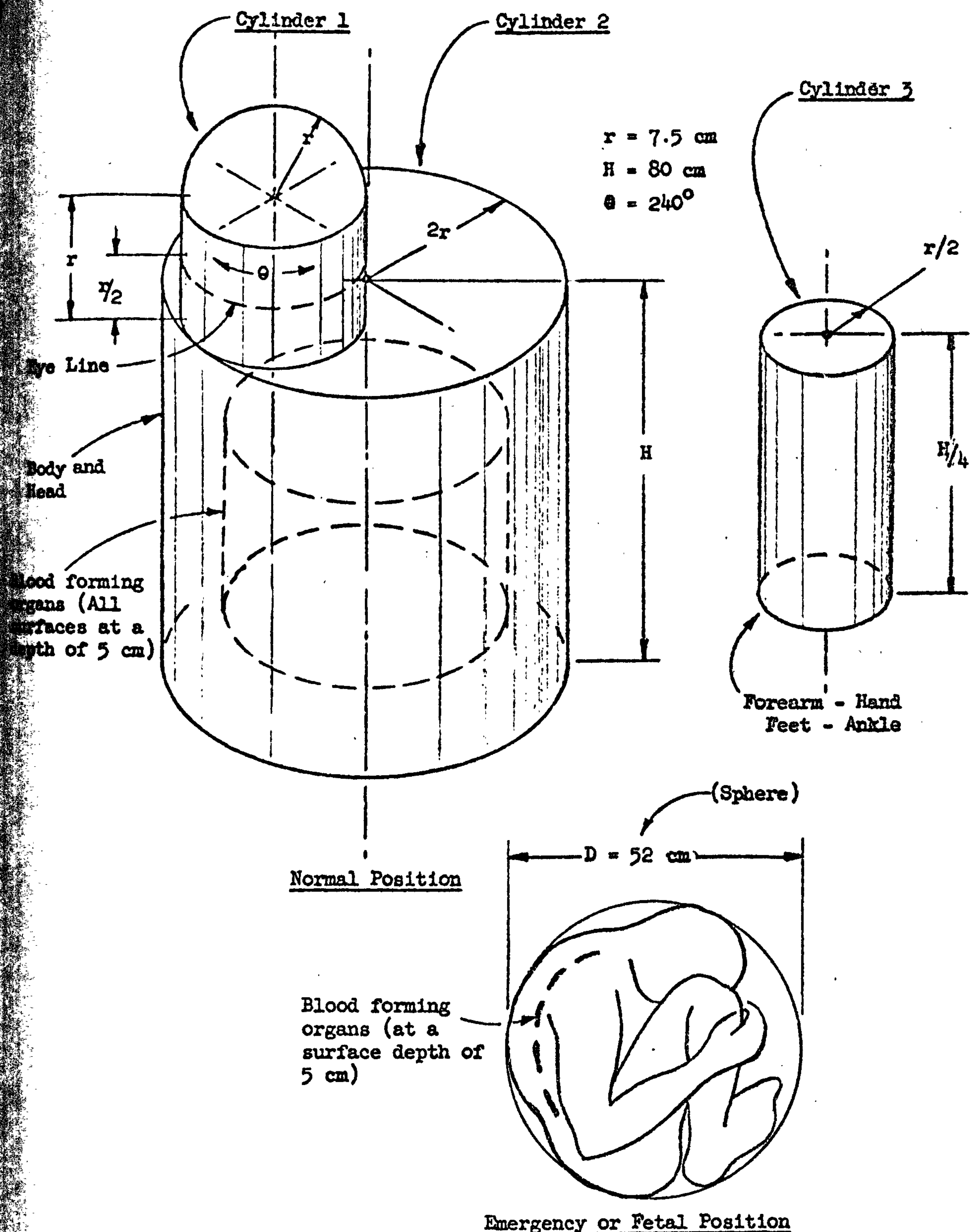

Figure 4.- Models of the radiation standard man.

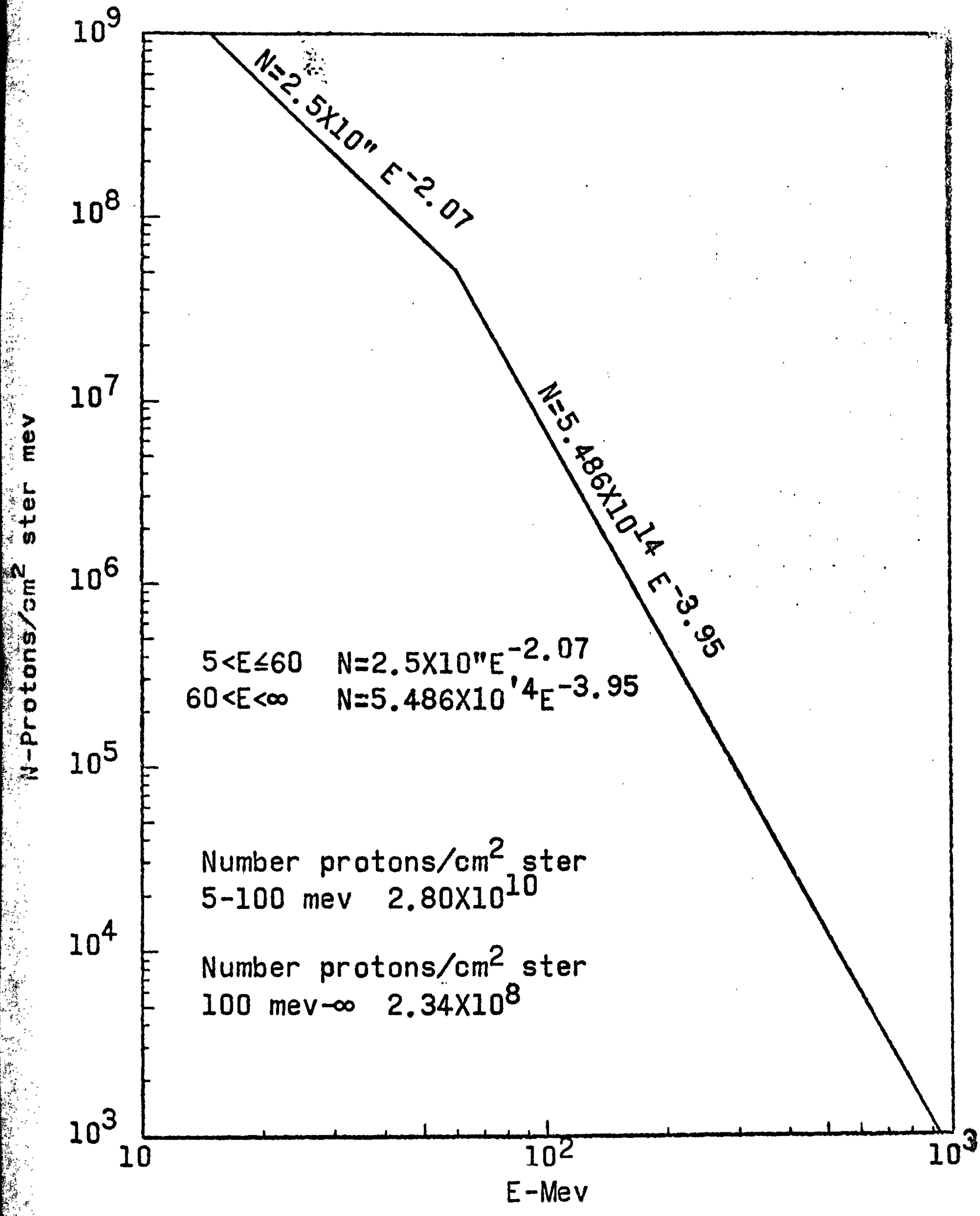

Figure 5.- Time integrated differential energy spectrum for May 10, 1959 event.

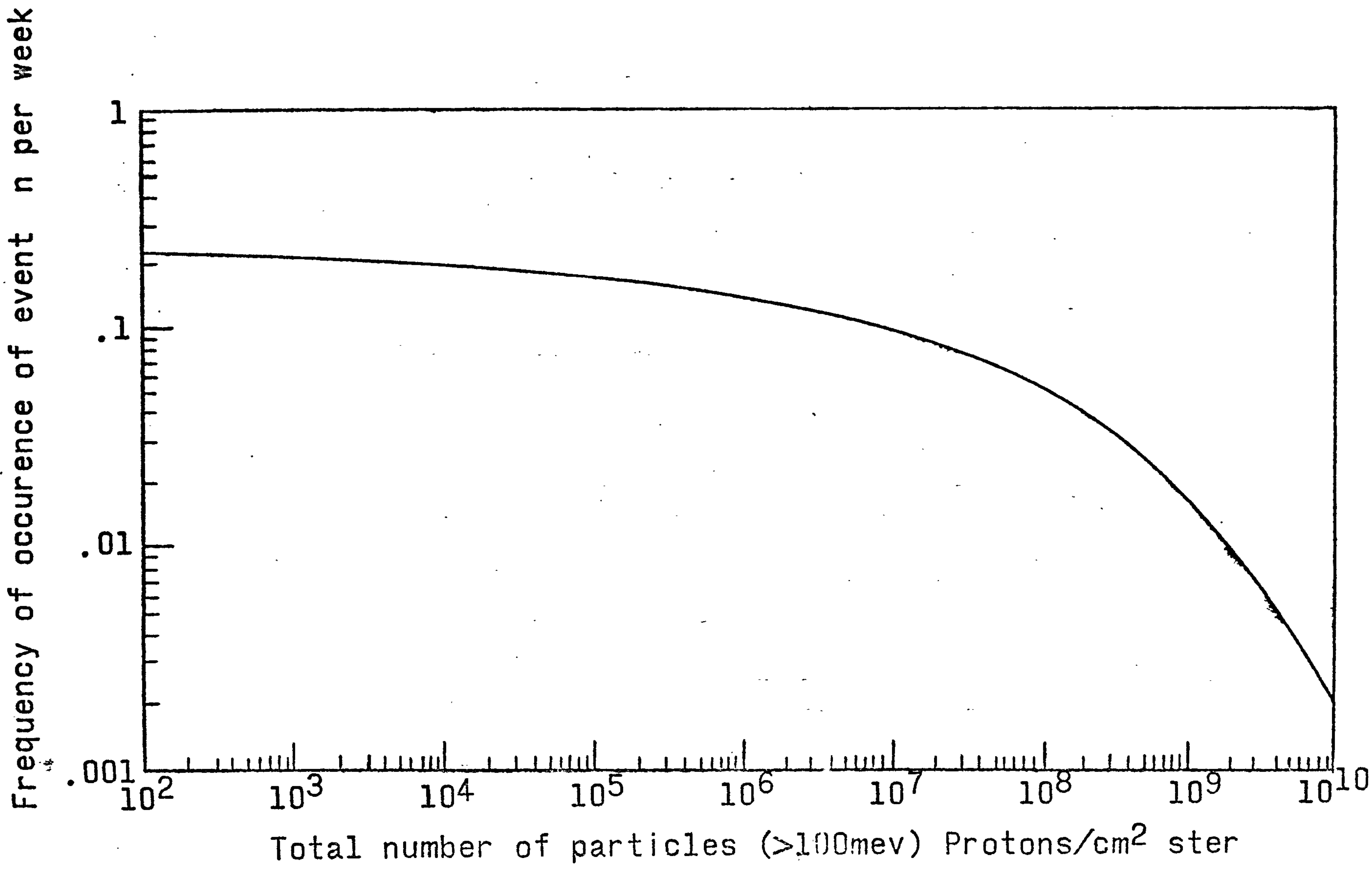

Figure 6.- Frequency dis bution of solar proton events.

National Academy of Sciences
Space Science Board
2101 Constitution Avenue, N.W.
Washington 25, D. C.

Committee 16 Working Paper
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27 October 1961

MAN IN SPACE COMMITTEE

Discussion of Radiation Problems Associated With The Manned Lunar Landing Program

28 July 1961

Account of Proceedings

1. INTRODUCTION

The Man in Space Committee of the Space Science Board has undertaken on the initiative of its Chairman and with the full collaboration of the Office of Life Sciences of the NASA a series of special investigations into particular problems with which the realization of space flight is inextricably concerned. The enunciation by the President of the intention to attempt landings on the Moon in the relatively near future gives urgency to the task of defining and solving several groups of problems.

The topic selected first for special treatment by the Committee was the assessment of the magnitude of the danger from radiation to which the crew of a spacecraft attempting the lunar flight would be exposed. This is not a new subject. Several studies of the problem have already been made and as recently as a year ago a conference was held by the NASA for this purpose. Nevertheless, it has been difficult to derive much in the way of practically useful results from these deliberations.

A disturbing amount of uncertainty has appeared on occasion concerning estimates of the magnitude of energetic corpuscular fluxes which may be expected in interplanetary space. Some of these estimates have been so large as to occasion the fear that in the design of the spacecraft a great deal of weight would need to be devoted simply to shielding the crew from harmful radiation. Discussions of the radiation problems have also tended to emphasize underlying differences of opinion among radiobiologists as to the significance or magnitude of the biological effects which might be experienced. These, coupled with uncertainties in the physical estimates of the interplanetary fluxes, have given little enough assistance in the solution of the practical problems attending spacecraft design and flight planning.

Terms of Reference

In an attempt to resolve some of these uncertainties, a special meeting* was convened on 28 July 1961 under the chairmanship of Dr. Howard Curtis, in his capacity as member for radiobiology of the Man in Space Committee of the Space Science Board. Recognizing the extent of earlier work** and discussions on the problems of radiation in space exploration, the scope of these deliberations was explicitly limited to a consideration of these aspects most intimately involved in planning for the lunar expeditions. It was not the intent, nor was it thought desirable, to consider, on this occasion, either the problems of radiobiology generally or of the physics of energetic particles in space -- except insofar as these subjects might be of fundamental or limiting significance in the planning of the lunar flights. The discussions at this meeting were therefore guided along the following lines.

* A list of those attending the meeting is given in Appendix A.

** Papers distributed to those attending the meeting and references to the records of discussions of the radiation problems in space flight are given in Appendix B.

1. To examine the available evidence with respect to the magnitude and spectral distribution of the fluxes of energetic particles in interplanetary space -- particularly with reference to the basis for estimates indicating very large and very dangerous fluxes;

2. On the basis of the evidence presented under 1, to make a first order assessment of the magnitude of the harmful biological effects which these fluxes might be expected to produce, and

3. To comment on existing plans for acquiring essential information bearing on solution of these problems and, if appropriate, to recommend new measures, both in physical and biological research; in the laboratory or in space.

The meeting reviewed the physical and biological aspects of radiations expected to be of significance -- trapped radiation; solar flare protons; and cosmic rays. Programs for further investigations of these subjects were presented in outline and a set of specific questions of particular relevance to the lunar flights were discussed in detail.

The account which follows constitutes a summary of the discussions and principal findings of the group within the terms of reference stated above. It has been prepared on the basis of verbatim records of the proceedings and additional comments solicited from the participants after the event.

Beyond this, efforts have been made to ascertain and incorporate into this report the views and comments of other authorities in the field who had been invited but were unable to attend the meeting. Among these, J. R. Winckler has provided comments; C. A. Tobias has also undertaken to do so but at the present writing (27 October 1961) these are not available.

In such a rapidly moving field it cannot be expected that the findings of any group will stand for long. Very recently, recalculations by J. A. Van Allen of the radiation dosage which would have been received under 1 g/cm^2 of shielding during the November 1960 solar events show that earlier estimates of about 100 r underestimate the dose by about a factor of 7. The latest estimates of 700 to 1000 r under 1 g/cm^2 place this event (and presumably others like it) in the lethal category. Although events of this magnitude are rare, if this latest estimate is confirmed*, some of the conclusions reached at the meeting described here and in the subsequent review will necessarily be modified. Attention has been called to such cases by footnotes to the text.

Nevertheless, this new result affects only those considerations which involve the magnitude of the estimated risk from radiation and do not affect conclusions about methods for quantitative experimental assessment of the radiation hazard. More particularly, it emphasizes most strongly the desirability for encouraging the widest possible attention to the methods of calculation of radiation dosage from the physical measurements which are now available and which may become available in the future.

2. PHYSICS

a. Trapped Radiation

Van Allen reported that there is little to add to the information already in the literature concerning the radiation belts. The inner zone, however,

* The earlier estimate of 100 r had received some confirmation from other observations.

is now found (on the basis of observations with 1959 ι, Explorer VII) to be subject to marked fluctuations. These fluctuations appear to be latitude dependent and correlated with solar activity.

b. Solar Protons

Observations with 1959 ι, Explorer VII, have given useful information about solar flare protons over a period of 16 months since October 1959 and for some 23 solar cosmic ray events. Peak intensities of protons with energies > 30 Mev reached values of the order of 10^4 particles/cm^2/sec* over the polar cap in two of these events but the majority gave far lower values.

Preliminary results from the Injun satellite (1961 o), which carries p-n junction detectors, indicated a flux of 9,000 protons/cm^2/sec/ster in the energy range 1.5 to 15 Mev over Southern Canada in July 1961. Other detectors aboard registered an integrated proton flux of 3 x 10^4/cm^2/sec/ster at energies > 0.5 Mev.

Van Allen referred also to estimates which have appeared in the literature suggesting enormously large values (~ 10^6) for solar proton fluxes in free space. These have been obtained by extrapolation down to fractional Mev energies from measurements made at much higher energies (50-100 Mev) and are perhaps representative of what would be measured with very thin walled detectors. He did not believe that proton fluxes greater than those observed in the November 1960 event by Explorer VII, namely ~ 2 x 10^4/cm^2/sec*, were at all likely to be found under about 1 g/cm^2 of shielding -- such as might be reasonable for the shell of a practical spacecraft. This would indicate an upper limit of some tens of roentgens per hour as the dose rate due to protons in large solar events.** (In this context Shaefer observed that it would

* Omnidirectional flux.

** See note on revised estimate of total dosage on p. 4.

be well to define the lower energy limit of interest, noting that he had been informed that space suits would be likely to have 0.2 g/cm^2 and spacecraft > 2 g/cm^2 of shielding, inherently).

Bailey discussed the energy spectra and rate of decay of proton fluxes occurring in conjunction with solar events as derived from observations by radio methods of the polar ionosphere.* He agreed generally with Van Allen's estimate of flux values and his remarks concerning the dangers of extrapolating a few measurements at high energies to obtain estimates at lower energies.

Experimental observations of solar proton flux intensities at different energy levels are, in general, best fitted by integral spectral curves having characteristically small negative exponents of the energy at the lower energies and large negative exponents at high energies; a power law with constant exponent is not a good representation.

Bailey also pointed out the difficulties in estimating the flux during the early stages of a flare by extrapolation from measurements made at later times. Extrapolations over time to obtain estimates of early flux values are very likely to yield impossibly large numbers if the common $T^{-1.5}$ to T^{-3} relationships are used. Radio observations of ionospheric behavior simply do not support intensities of the order of 10^5 particles/cm^2/sec/ster which such procedures are apt to give. In summary, he doubted whether the integrated solar proton flux is ever likely to exceed 10^3 particles/cm^2/ sec/ster for energies > 100 Mev in free space (or 10^4 at energies > 1 Mev).

* Bailey discusses the subject in a letter to the editor of JGR entitled "Time variations of the energy spectrum of solar cosmic rays in relation to the radiation hazard in space". Publication is expected early in 1962.

Naugle expressed himself in general agreement with Van Allen and Bailey on the proton flux intensities and spectra in solar events. He quoted measurements made during the first of the November 1960 events of $< 10^3$ particles/cm^2/sec/ster with energies > 100 Mev and estimates of about 100 r for the total dosage during that event (this agrees with Van Allen's estimate*).

Note: John R. Winckler, whose earlier estimate of very large solar proton fluxes had aroused much concern, was unable to attend the meeting. He has commented, in a private communication of September 20, 1961, on the discussion reported above as follows:

"I agree in general with the experimenters' results on solar flare radiation as these represent actual measurements which show that 100 rads or fluxes of 10^4 are reasonable upper limits on the basis of past experience." (Note: these values refer to results under several grams per cm^2).

"However, we have seen smaller sized events in which (a) the extrapolation to low energy continued as a straight line, and (b) the time extrapolation back to one hour from the flare followed the law T^{-2}. It so happens that we have seen no large events which followed these rules. Recent considerations of the problem indicate that propagation effects from the sun determine many features of the flux and time variation. We may get a surprise in having a large flare like the February 23, 1956 event, in which the full flux of low-energy particles is received near the earth. I think that none of the experimenters at the meeting would be willing to exclude this possibility. However, the probability is small and therefore unimportant compared with other risks of a lunar mission."

c. Solar Flare Prediction

Bailey was very skeptical about the prospects for predicting the occurrence of solar flares, except in the most general terms - i.e., one could certainly identify periods during the solar cycle when flares were more likely to occur. There was agreement that the probability of occurrence, of a flare

* Recent recalculations by Van Allen of the total dosage during the November 1960 events shows much higher values (about 700 r).

could not be estimated with any assurance as much as 7 days in advance. The work of K. A. Anderson and others indicates, however, that some estimates may be feasible over about 2 days.

Van Allen noted that, during 16 months of continuous observations with Explorer VII, the solar proton flux had reached levels of biological significance for a period of about one week (i.e., about 1/70 of the total period of observation).*

d. Isotropy

Trapped radiation: Although the trajectories of particles in the radiation belts are constrained by the geomagnetic field lines the radiation does not appear to be sufficiently directional to give much relief in shield design.

Solar protons: Most of the evidence from satellite and rocket observations leads to the conclusion that the solar proton flux is for the most part isotropic, due, presumably, to the operation of a storage mechanism in the solar system of large scale. However, ray-tracing studies by McCracken, et al, of a few energetic prompt events indicate that these particles come from a virtual source about 40° west of the Sun and have a divergent distribution of about 30° half angle.

Heavy particles: The cosmic ray flux of galactic origin is well known to be isotropic. However, examination of nuclear emulsions flown in rockets has shown heavy nuclei of C, N and O etc. coming from the Sun and with abundances characteristic of solar origin. These particles were of very low energy and, although their flux may be 100 times greater than that of the galactic heavy primaries, they are totally absorbed in 1 g/cm^2.

* This implies a probability of about 4% that a two week flight would have encountered significant radiation levels if launched during the 70 week period without knowledge of the solar event.

e. Bremsstrahlung

Computational procedures have been devised* and are in use for the calculation of bremsstrahlung within spacecraft. The general view was, however, - as expressed by Van Allen and endorsed by others with experience in experimental work with spacecraft - that for particular capsule designs the experimental method would be easier to apply. A suitable accelerator would be required for this purpose.

f. Future Programs in Physics

Naugle referred to the detailed program of physical research on energetic particles and magnetic fields which the NASA is planning to conduct. He offered to make available copies of an up-to-date account of this program to the group.(Ref. 11).

In discussion of the kinds of physical investigations which would be of particular significance in the assessment of the radiobiological problems the following were singled out:

1. radiation monitoring experiments with earth satellites in polar orbits.
2. identification of the low energy cut-off in the solar flare proton spectrum.
3. additional sounding rocket studies with emulsions from Fort Churchill.
4. monitoring of solar particle fluxes and energy spectra in interplanetary space.
5. improved spectral measurements in the radiation belts.

As has been emphasized repeatedly elsewhere (SSB Committee 8, Physics of Fields and Particles in Space) concurrent measurements of the magnetic field are essential requirements in all of these experiments.

* A communication dated 30 August 1961 from C. D. Zerby, Oak Ridge National Laboratory, describes work on a computer program for bremsstrahlung calculations.

Naugle pointed out that there are only two shots in the NASA program which will give results on the interplanetary conditions (4 above). These are the early Ranger (a second attempt will be made this fall) and an interplanetary probe toward Venus late in 1962. The group noted that there would be heavy reliance on the physical measurements (for assessing the radiobiological hazards) and that these were of fundamental importance to an understanding of the radiation problems in manned space flight. It is therefore vital that discontinuities in the programs for gathering physical data on radiations be avoided.

3. RADIOBIOLOGY

a. Biological effects of radiation

Schaefer emphasized the importance of knowledge of the depth dose distribution in computation of the total body radiation burden, noting also the great sensitivity of depth dose to small changes in spectra and the need for good spectral measurements. He mentioned also the importance of time in connection with dose rate and recovery from intermittent exposure. Discussion of this last point brought out the fact that the recovery half time in man is quite long (~ 30 days) and that exposures with durations short with respect to this should be considered as instantaneous. He commented also on the great lack of information on the biological effects of radiations having depth dose curves differing from those of the familiar x and gamma rays.

Most of the present knowledge about the biological effects of protons comes from experiments performed with neutrons. However, the results of experiments performed with protons agree sufficiently well with predictions from neutron experiments that the group felt this not to be a serious problem for the lunar mission.

There was general agreement that the relative biological effectiveness of energetic protons is unlikely to be greater than 2 and is probably near unity. Nevertheless, careful quantitative study of the biological effects of protons should be encouraged, especially in view of the need to prepare for space flights of much longer duration than the early lunar missions.

Chase outlined the question of damage caused by heavy primary cosmic rays and Curtis reported work with deuteron microbeams, which simulate these particles so far as ion density along the track is concerned. They concluded that the experimental evidence, taken with the known flux gave no grounds for believing that the effects of galactic cosmic radiation would be serious enough to deter lunar flight. Experiments with mouse skin and emulsions in balloons (1960) confirm the ability of heavy primary cosmic rays to produce damage but for a 14 day lunar flight no serious effect is expected.

Nevertheless, in anticipation of space flights of long duration, it would be folly not to proceed now to try to learn more about the biological effects of heavy particles and the probability of accumulated damage.

The possibility that heavy primary cosmic rays may be exceptionally carcinogenic was discussed. Although this seemed unlikely to be a problem, the lack of direct experimental evidence caused some reservations on this point, reinforcing the view expressed above.

A question was raised about the effects of simultaneous exposure to different radiations. It was asserted that the evidence shows the effects to be additive, at least within a factor of 2 and probably to $\pm$ 10-15%.

Concerning the effects of radiation combined with other stresses (e.g., weightlessness, acceleration, etc.), the group felt that work on this matter should continue but that no additional effort seemed to be required for the immediate purpose.

The effects of irradiation of part of the body were discussed. The gram-roentgen hypothesis did not appear to be well supported by experiment and comparison of studies of acute effects with those on longevity indicated that different organs were probably of controlling importance in each case.

The group felt generally that additional work would yield large returns on this subject, in view of the importance of shield weight. Partial body shielding is probably of much greater importance in very long duration space flights than in the case of the initial lunar mission. A suitable particle accelerator would greatly facilitate partial body shielding studies.

b. Proposed NASA Program

Smith explained NASA's requirement for an immediate assessment of the significance of the radiation problem in lunar flight. Although the first manned flights would not occur until later, it was necessary for engineering reasons to know before 1964 what measures would have to be taken, if any, to protect the astronaut from radiation. In assessing the problem a total duration of about 14 days should be taken as the maximum length of the lunar round trip.

He described also a series of satellite experiments which were being considered in the Office of Life Sciences as a means for obtaining and verifying the information necessary for an assessment of the quantitative aspects of the radiation risk. This program would involve a group of three satellites to be launched into orbits which would keep them near the center of the inner

Van Allen region, three in the outer belt, and three more in highly elliptic orbits extending well out into interplanetary space. The experiments aboard would comprise a mixture of physical instruments for the measurement of radiation flux and spectra accompanied by biological dosimeters and biological specimens. All of the satellites would require to be recovered. Some shielding experiments would also be incorporated in them. It is proposed that early members of each group of satellites should contain a greater preponderance of physical instruments than biological experiments and that the last of each group should contain an amount of physical instrumentation sufficient only for checking and calibration purposes, the greater part of the payload being devoted to biological experiments. Smith indicated that the program which he had outlined was by no means unanimously accepted, and it was his desire to obtain some advice on the extent to which investigations such as this were desirable or necessary. In view of the engineering timetable already alluded to, it would be most important to have such advice very soon. He also pointed out that the lunar flight program should not be thought of as a single or a small number of events but that there would be many flights both with instruments and with crews to distances short of the Moon and in orbit around the Moon before the manned landing and return could be attempted.

c. Other Research Programs

Members of the Army, Navy and Air Force very broadly outlined their programs in this area. Dr. Grahn reported that the AEC has an agreement to work closely with NASA on radiation biology generally: under this arrangement essentially all of the AEC's facilities for radiobiology would be available for work on problems of importance to NASA. Cooperative arrangements are under consideration by NASA for access to the facilities of other specialized laboratories. It was pointed out that Dr. Schaefer's laboratory at Pensacola is one among rather few in the country with a program directed toward computing biological effects from the physical data; similar work is performed at the Oak Ridge National Laboratory and at the Biophysics Division, Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico. These programs include calculations on shielding, depth dose, RBE, bremsstrahlung, etc. Encouragement of such work is desirable and it was noted that suitable facilities would be included in the new NASA Manned Space Flight Center.

d. Biological Experiments

There was considerable discussion of the role of experiments with biological material in spacecraft for the assessment of the effects of radiation, particularly in connection with the tentative program which Smith had outlined as part of the work in preparation for the lunar flights. The group agreed that there was a place for experimentation with biological specimens in spacecraft in preparation for the first manned lunar landing but there was not unanimity concerning the precise justification, within the terms of reference of the meeting, for this kind of work.

On the one hand, a majority felt that a first order assessment of the radiation risks associated with the lunar mission could best be made on the basis of physical measurements of the ambient radiation coupled with suitable biological calibrations in the laboratory with accelerators, x-ray equipment or other suitable artificial sources. Biological specimens (preferably but not exclusively mammalian) should then be flown in spacecraft together with appropriate physical instruments in order to confirm qualitatively the validity of the first estimates and to seek experimental reassurance that no serious biological effects due to radiation had been overlooked.

On the other hand, Brennan, Hansen and Haymaker were of the opinion that the physical measurements did not constitute a sufficient basis for an assessment of the biological hazard from radiation. They felt strongly that biological specimens and tissue equivalent chambers should be flown for this purpose on an equal opportunity basis with the purely physical instruments.* Lifton strongly supported the use of tissue equivalent devices and biological specimens together with physical instruments in spacecraft for studying the radiation risk in spaceflight generally, but conceded that present physical and biological knowledge was sufficient for a first assessment of the radiation hazard in lunar flight provided large solar flares could be avoided.

The present lack of information about the biological effects of the radiations of principal concern in short lunar flights pointed up the urgent need for a particle accelerator. For biological work, it should be capable of reproducing at least the energetic proton fluxes to energies of about 200 Mev and over a wide field; for the longer term interests such a machine should also be capable of producing energetic heavy ions. Existing accelerators in this country would have to be modified considerably in order to suit this purpose and since all accelerators having a high enough energy are now fully engaged for other purposes, such alterations would be difficult to make and a new machine specifically for biological work seems indicated.

* Brennan also advocated the use of thin walled instruments sensitive to β and low energy x-rays in order to investigate the possibility of superficial injury to the skin.

About half the heavy primary cosmic ray flux is accessible at 100,000 ft. in the atmosphere. Work on the biological effects of these particles can probably be done with greater facility in balloons than in spacecraft.

It was also noted (Van Allen) that the properties of the inner Van Allen belt are not representative of those of solar proton beams. Biological experiments using the belt as a substitute source would be difficult to interpret because of the differences between the energy spectra of the belt and the solar protons. Van Allen felt that it would be relatively easy to duplicate these spectra in the laboratory with an accelerator as source. (see comments above on the problems of adapting existing accelerators for this kind of work.)

It was emphasized by those who had had experience with the conduct of experiments in space that success in such research is critically dependent on the most careful preliminary calibration. Most of the really successful physical experiments flown to date had been preceded by much preparatory work in the laboratory, in ballons and in rockets. The risk of ambiguity in the interpretation of results is otherwise very considerable.

e. Criteria for Radiation Protection of the Astronauts

There was general agreement that the conventional standards of industrial radiation protection should not be rigidly applied in spacecraft design. It was felt that a dose of 25 r for the lunar mission would not be unreasonable and a dose of 150 r probably would not be catastrophic.

On the basis of present information it would seem reasonable to expect the astronauts to take a total body dose of about 25 rem on a lunar mission, assuming no large solar flare is encountered. If normal spacecraft design provides enough shielding so that there is a high probability that the dose received is less than 25 rem, then there is no problem. If not, then shielding should be added, either for the whole ship or the crew, in sufficient amount to meet the above criterion. If this principle is followed there is every expectation that a moderate flare could be encountered without the astronaut receiving an exorbitantly large dose and suffering serious injury or impairment of performance.

As knowledge of the frequency and intensity of flares increases it may be desirable to modify this statement.*

f. Human Tolerance to Radiation

The group saw no need for change in the present programs of work on the allowable radiation dose for man, but, in this connection, felt it to be important to maintain the Air Force Primate Colony. This colony has been in existence for about 8 years and is unique in this country. The results of long term studies would be lost if it were not preserved.

* The recent discovery that flares similar to that of November 1960 result in particle intensities giving doses of 700-1000 r below 1 g/cm^2 rather than about 100 r is a case in point. Several grams per cm^2 of shielding would be required to limit the dose to about 100 r in such a case. See p. 4.

Appendix A

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References

1. A Note on the RBE of Proton Radiation in Space, H. J. Schaefer, U.S. Naval School of Aviation Medicine, January 10, 1961.

2. Proceedings of Conference on Radiation Problems in Manned Space Flight, G. J. Jacobs, Ed., NASA TN D-588, December 1960.

3. Radiation Shielding for Manned Space Flight, L. E. Wallner and H. R. Kaufman, NASA TN D-681, July 1961.

4. Preliminary Study of Prediction Aspects of Solar Cosmic Ray Events, K. A. Anderson, NASA TN D-700, April 1961.

5. Discussion of Solar Proton Events and Manned Space Flight, K. A. Anderson and C. E. Fichtel, NASA TN D-671, March 1961.

6. The Shielding of Space Vehicles, J. W. Keller, NASA MTP-M-RP-61-12, May 16, 1961.

7. Observations of Solar Cosmic Rays Near the North Magnetic Pole, K. A. Anderson and D. C. Enemark, JGR 65, 9, September 1960.

8. Corpuscular Radiations in Space, J. A. Van Allen, Radiation Research, 14, 5, May 1961.

9. Observation of Galactic and Solar Cosmic Rays from October 13, 1959 to February 17, 1961 with Explorer VII (Satellite 1959 Iota), W. C. Lin, SUI 61-16, August 1961.

10. Radiation Shielding Program 1961-1963 School of Aviation Medicine.

11. Schedule for Particles and Fields Program, NASA, 13 July 1961.

12. Armed Forces-NRC Committee on Bio-Astronauts, Panel on Radiation Biology, Minutes of Meeting, 15 July 1959.