SC-RR-70-769
DECEMBER 1970

PLANETARY QUARANTINE

A PRELIMINARY ANALYSIS OF THE RADIATION BURDEN OF A TYPICAL MARS LANDER MISSION

VIRGIL L. DUGAN
PLANETARY QUARANTINE
SYSTEMS STUDIES DIVISION 1741

SANDIA LABORATORIES

OPERATED FOR THE U. S. ATOMIC ENERGY COMMISSION BY SANDIA CORPORATION | ALBUQUERQUE, NEW MEXICO; LIVERMORE, CALIFORNIA

Issued by Sandia Corporation,
a prime contractor to the
United States Atomic Energy Commission

SC-RR-70-769

A PRELIMINARY ANALYSIS OF THE RADIATION BURDEN OF A TYPICAL MARS LANDER MISSION

Virgil L. Dugan
Planetary Quarantine
Systems Studies Division 1741
Sandia Laboratories
Albuquerque, New Mexico

December 1970

ABSTRACT

This paper provides an analysis of the total radiation which a typical Mars lander would experience. The dose from each source of radiation is calculated for spacecraft shielding of 1 and 10 gm/cm^2, assuming a one year flight time and a six month operational period on the planet's surface. These doses are upper bound calculations for each case considered, and the totals are upper bounds which may be used to establish rationale concerning the use of gamma radiation for spacecraft sterilization purposes.

*This work was conducted under Contract No. W-12, 853 Bioscience Division, Office of Space Science and Application, NASA Headquarters, Washington, D. C.

TABLE OF CONTENTS

LIST OF FIGURES

A PRELIMINARY ANALYSIS OF THE RADIATION BURDEN OF A TYPICAL MARS LANDER MISSION

I. SUMMARY

Upper bounds on the radiation burden of a typical Mars lander mission's sensitive components are determined in this paper for a one-year travel time and a six-month operational period on the planet's surface. The total radiation burden for this period is the sum of the components due to trapped particulate radiation in the earth's geomagnetic field, solar flares, galactic radiation, and radiation from the on-board radioisotope thermoelectric generators (RTG's). During years of maximum solar activity the total burden for the entire eighteen-month period will be approximately 6389 rads or less for a shielding density of 1.0 gm/cm^2 and will be approximately 3510 rads or less for a shielding density of 10.0 gm/cm^2. These two extremes of shielding should bracket the actual shielding of any sensitive component. During years of minimim solar activity these doses are reduced to approximately 3724 rads and 3315 rads for shielding of 1.0 and 10.0 gm/cm^2 respectively. The contribution from the RTG's will provide approximately 3250 rads of these total doses and will therefore be one of the major contributors. The radiation from the RTG also provides the only appreciable amount of gamma radiation. This gamma dose is approximately 1130 rads.

If the system's sensitive components are selected to withstand a total dose of several hundred thousand rads in a thermoradiation environment, the doses contributed by natural sources and by the RTG's

are essentially insignificant. Therefore, use of gamma radiation in a thermoradiation sterilization procedure for a typical Mars lander should not be excluded on the basis of an excessive radiation burden due to natural sources.

In addition, if in future years components and systems are qualified for use on grand tour missions of the outer planets, for which case the total natural burden would be very high, these same systems could also be used on shorter missions with low natural burdens and could easily accommodate thermoradiation sterilization.

and 2 and Table I* provide the assumed data which may be used to calculate a minimum value for the shielding parameter of the typical lander. This minimum shielding is provided by the bioshield cap plus the base cover; also included in the minimum shielding is the equipment compartment paneling along the top surface of the lander while it is in route. Simple calculations show a shielding density of 2.11 gm/in^2 for the bioshield cap, 1.13 gm/in^2 for the base cap, and 6.7 gm/in^2 for the compartment cover. This gives a total shielding capability equivalent to approximately 1.453 gm/cm^2 Al. (See Appendix). If other features which provide shielding are considered (such as fuel tanks, parachutes plus container, RTG's, landing rockets, etc.), then this value could reach 10 gm/cm^2 for the effective shielding of the lander's sensitive components. In this analysis the feasible extremes of 1 gm/cm^2 and 10 gm/cm^2 are used to provide the estimates of lowest and highest radiation dose rates over a one-year travel time and a six-month period on the Martian surface.

*Obtained from Mr. Bruce Nelson, Martin-Marietta Corp., Denver, Colo.

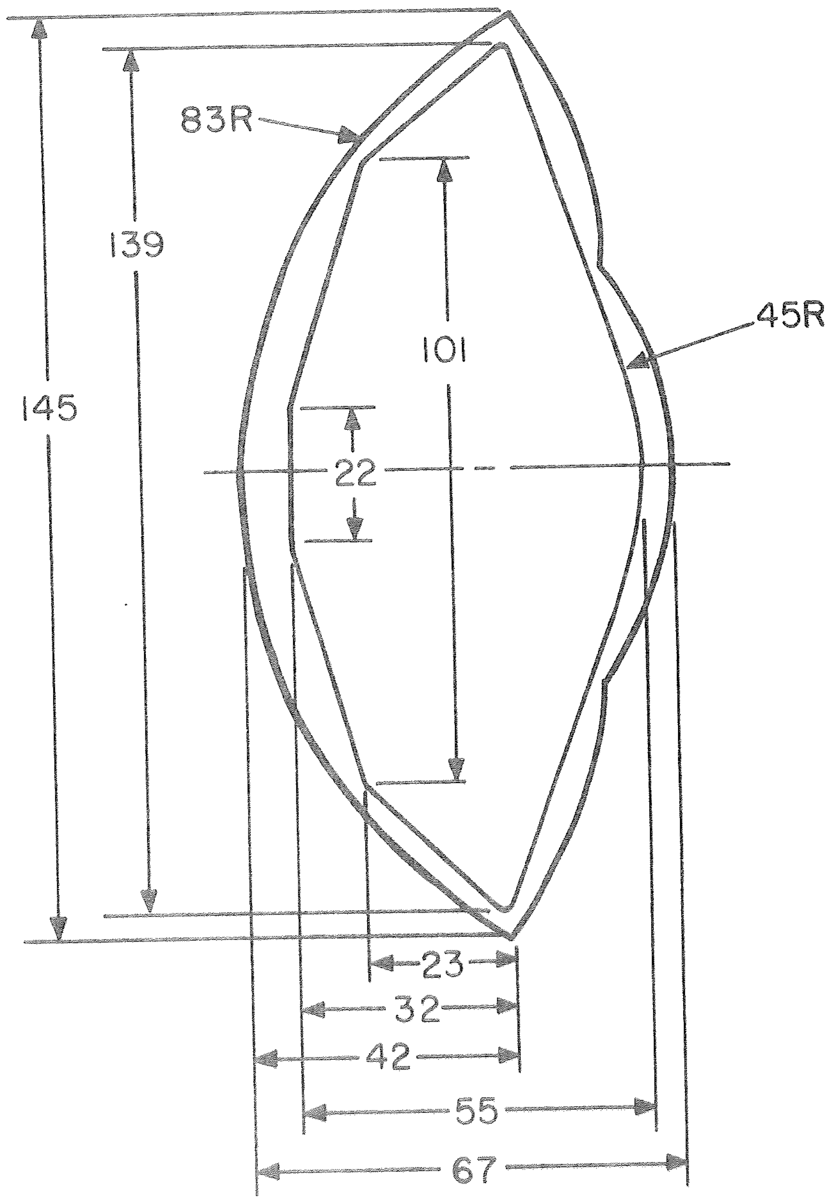

FIGURE 1

A TYPICAL LANDER GEOMETRY

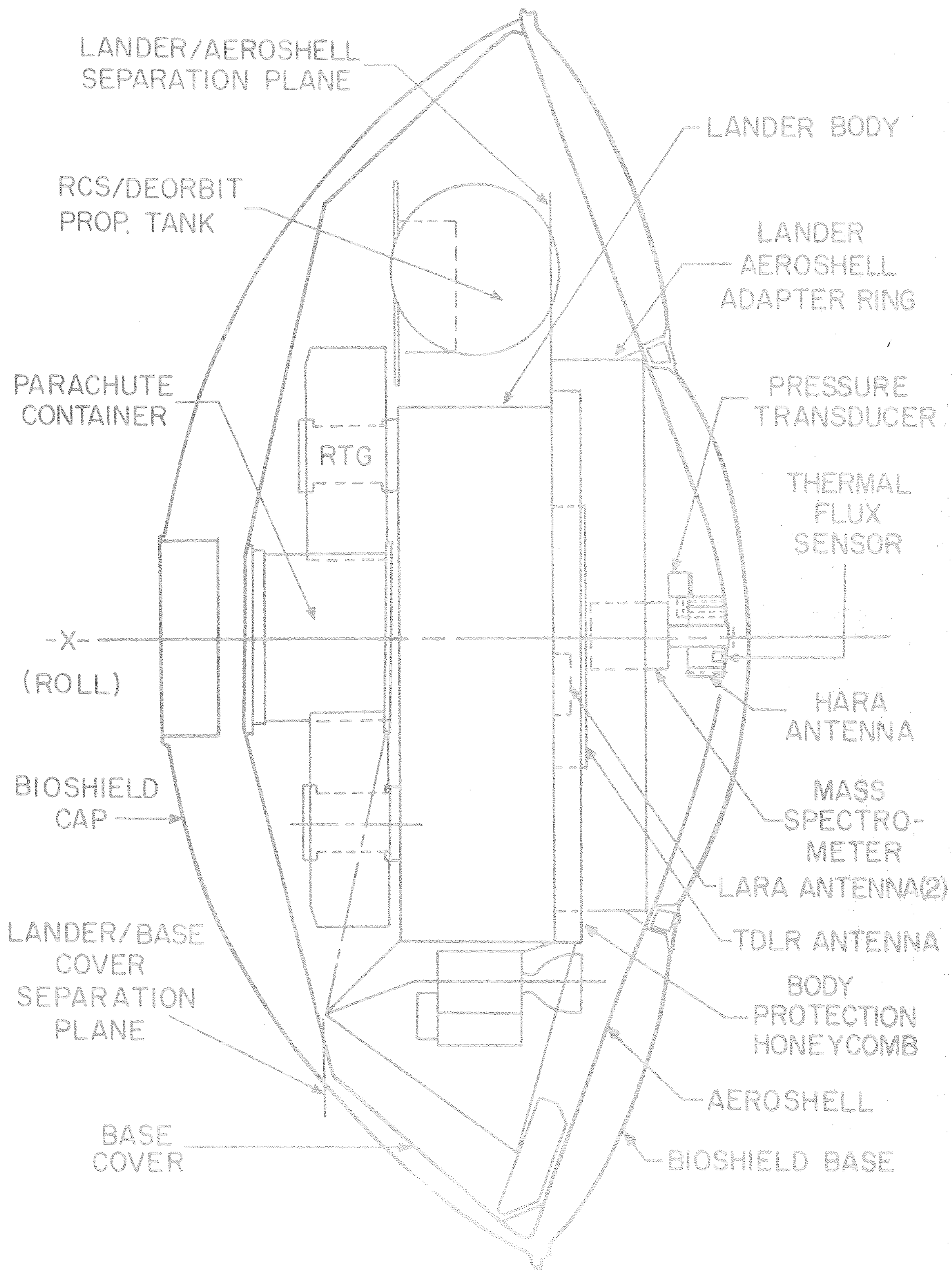

FIGURE 2
COMPONENTS OF A TYPICAL LANDER

TABLE I

Assumed Spacecraft Weights and Materials

Bioshield Cap: Plastic, 100#

Bioshield Base: Plastic, 100#

Aeroshell: Aluminum, 130#

Ablator, 45#

Base Cover: Fiberglass, 50#

Parachute + Truss: Aluminum, #50

Dacron, 80#

	Insulation: Fiberglass, 15#
	Top: Aluminum, 60#
Survivable Equipment Compartment	Bottom: Aluminum, 60#
	Leg Area + Legs: Aluminum, 40# each
	Sides: Thinner than top and bottom
	Boxes Inside: 300# Total — Magnesium + Electronics

Fuel Tanks: Titanium

Hydrazine

(More boxes outside survivable eq. box.)

TOTAL WEIGHT $\cong$ 2000#

III. RADIATION TRAPPED IN THE GEOMAGNETIC FIELD

The particulate radiation trapped in the geomagnetic field of the earth (Van Allen radiation) consists primarily of relatively low energy electrons and of protons. An indication of the contribution of this type of radiation to the dose received by the Mars lander may be obtained from the information gathered on previous space flights, especially manned flights. The highest total dose rate recorded on Gemini IV [1] was 125 mrad/hr. inside the capsule. The peak dose rates which were recorded by Apollo 6 inside the command module [2] were 2.6 and 3.6 rads/hr. for shielded and unshielded detectors, respectively. At the very localized points of maximum charge concentration the dose rate for minimum shielding of less than 0.4 gm/cm^2 [3] may approach values as high as 100 rads/hr. These regions normally occur where the magnetic field density B is approximately 0.10 Gauss. However, even though the electron flux density is very high, the electron energies are very low, and for shielding greater than 0.4 gm/cm^2 [4] the electron dose rate is less than 0.1 rad/hr. For shielding greater than or equal to 5 gm/cm^2 [5] the primary electron dose is completely negligible. This is true since a minimum shielding of 0.62 gm/cm^2 of aluminum combined with 0.6 gm/cm^2 of plastic will eliminate electrons with energies less than 2.26 mev [6], and the bulk of the electron energy spectra is below this level.

At 0.62 gm/cm^2 aluminum plus 0.6 gm/cm^2 plastic the minimum penetrating energy for protons is 33.4 mev [6]. For shielding of 1 gm/cm^2 the maximum proton dose rate [4] within the geomagnetic field is approximately 60 rads/hr. For this same shielding condition, the secondary bremsstrahlung also contributes a peak value of approximately 1.5 rads/hr. At 10 gm/cm^2 the peak proton dose rate is approximately 13.0 rads/hr. and the bremsstrahlung dose rate is approximately 0.26 rad/hr. [4].

The maximum average dose rate from the Van Allen radiation in an earth orbit mode occurs at 3000 km. For 1.0 gm/cm^2 and an equatorial orbit the dose rate is 1 kilorad/day, and for 10.0 gm/cm^2 the dose rate is 300 rads/day [4]. This dose rate decreases very rapidly for orbits of both lesser and greater altitudes. At 31,000 km the rates are 3 rads/day and 0.5 rad/day, and at 600 km the rates are 5 rads/day, and 2 rads/day for shielding of 1.0 gm/cm^2 and 10.0 gm/cm^2, respectively. Therefore, the total Van Allen dose is heavily dependent upon the type of trajectory used for the mission and the length of time that the launch system is in a parking orbit. For typical high thrust trajectories, this total time in the high radiation zone would be less than one hour. Therefore, the total dose received from the trapped radiation could not exceed 41.5 rads for the 1.0 gm/cm^2 shielding or 12.5 rads for the 10.0 gm/cm^2 shielding based on the maximum orbital dose rates at 3000 km. This dose could conceivably be slightly greater if significant amounts of time were spent at the point of the maximum proton dose rate, but most probably the dose would be less than 41.5 or 12.5 rads and would be more in line with the peak Apollo 6 rate of 3.6 rads/hr.

IV. SOLAR RADIATION

Solar radiation is present in the form of low energy photons (i.e., infrared, u.v., and visible light), low energy protons and electrons which comprise the so-called "solar wind" and high energy protons and alpha particles produced by solar storms or solar flares. The photon radiation and the particulate radiation of the solar wind have an energy spectra so low that the very slightest amount of shielding eliminates them from being considered [4]. However, the solar flares do provide particulate radiation which must be considered.

Of the particulate radiation present during the flares, the protons are by far the most important since the alpha particles present have a minimal penetrating ability. The proton dose per solar flare is a random variable, but the number of flares which will occur during any defined period and their average intensity is a rather deterministic situation with a cyclical behavior. The projected years for the first Martian lander missions (1974-1975) are years of relative solar minimum, years in which the solar activity is at its lowest point [4]. There is approximately a factor of ten variation between the measured activity of a solar maximum and a solar minimum, and there is an eleven-year period between maximums and minimums. For 0.5 gm/cm^2 shielding the highest recorded dose for a solar flare is 1300 rads [7]. From the data presented in [7] there is a 0.01 probability of a one-year mission encountering a dose greater than 1.0 kilorad for 1.0 gm/cm^2 shielding or a dose greater than 100 rads for 5 gm/cm^2 shielding. From data presented in [4] there is a 0.01 probability of a 12-month mission encountering a dose greater than 3.0 kilorads for 1.0 gm/cm^2 shielding or a dose greater than 150 rads for 10 gm/cm^2 shielding. For the six months on the Martian surface the flare contribution is expected to be approximately one-half that of the free space value using 10 gm/cm^2 shielding or 75 rads.

Since the solar flare radiations are high energy particulate radiations, there is the question of the added secondary radiation due to the interaction of the primary radiation with the shielding. However, if the shielding is less than 30 gm/cm^2, then this secondary radiation is negligible [4].

For the total flare dose consideration in this report, the estimates of 3.075 kilorads for a 18-month mission with 1 gm/cm^2 shielding and 225 rads for a 18-month mission with a 10 gm/cm^2 will be used for the upper bounds on the dose due to solar flares. This is definitely an upper bound since these estimates are based upon the probability of flare occurrence during years of solar maximum whereas the first Mars missions will occur during a relative solar minimum.

V. GALACTIC RADIATION

Galactic or cosmic radiation is a low flux (4 particles/cm^2-sec.) of very energetic (10^8 - 10^{19} eV) bare nuclei [4]. The intensity of the flux is almost exactly out of phase with the intensity of solar phenomena; therefore, the first Mars missions will occur during a period of high galactic radiation. The dose rate for this type of radiation varies between a minimum of 17 mrad/day [5] and a maximum of 50 mrad/day [4] for shielding between 1.0 and 10.0 gm/cm^2. For a twelve-month transient time the received dose would be 18.25 rads using the larger dose rate. The dose rate for galactic radiation on the Martian surface is approximately one-half the free space value [4]; therefore, the received dose over a hypothesized six-month operational period on the surface would be 4.56 rads. The total dose of galactic radiation over the 18-month period would then be 22.81 rads.

Although this total dose is small relative to that provided by solar flares, it may be of more importance since the high Z cosmic rays may individually provide significant damage to instruments and detectors.

VI. RADIOISOTOPE THERMOELECTRIC GENERATOR

The electrical power on a typical Martian lander will probably be supplied by two 680-thermal watt SNAP-19 radioisotope thermoelectric generators (RTG's) which will probably be positioned approximately one meter apart on the top surface of the lander [8]. The RTG's are unique in that they provide the only appreciable source of gamma radiation which a spacecraft will see unless additional gamma radiation is used for sterilization purposes.

Although radiation measurements will have to be made after the fuel has been manufactured for the RTG's used, a good indication of the amount of radiation which will be provided by the RTG's can be obtained from data on previous systems of this type. The radiation measurements for a $^{238}PuO_2$ fueled, 629-thermal watt SNAP-19B power source [9] are shown in Table II below:

TABLE II

RADIATION MEASUREMENTS FOR A SNAP-19B 629-WATT POWER SOURCE

Distance From End (in.)	Neutron Radiation (mrem/hr.)	Gamma Radiation (mrem/hr.)
7.9	756	80
9.85	433	40
15.7	155	12
19.7	98	6.8
36.0	31	1.8

A rem is defined by the relationship

$$RAD = REM/R.B.E.$$

where the R.B.E. or relative biological effectiveness is equal to 1.0 for gamma radiation and is between 5 and 10.5 for the energy spectrum of neutrons being considered [4].

Since the RTG's will typically be separated by more than three feet, a coarse estimate for an upper dose bound may be obtained by using the dose rate at a small distance from one of the sources. Assuming that each RTG will produce approximately 680 thermal watts, the measurement 7.9 inches from the end of the source would be approximately 819 mrem/hr. of neutron radiation and 86.4 mrem/hr. of gamma radiation in line with a linear extrapolation. This would be approximately 0.164 rads/hr. for neutrons with an R.B.E. of 5.0 and .0864 rads/hr. for gamma photons with an R.B.E. of 1.0. These values can be used as average dose rates for estimating upper bounds.

Again assuming a trip time of 12 months and an operational period of 6 months on the Martian surface, the dose contributed by the RTG's will be 2.12 kilorads of neutron radiation and 1.13 kilorads of gamma radiation for a total of 3.25 kilorads.

VII. SUMMARY OF UPPER BOUND ESTIMATES

This section presents a summary of the upper bound estimates of the radiation which a typical Mars lander could receive from both space radiation and RTG radiation. Table III presents the results for the lower extreme of space shielding of 1 gm/cm^2 and Table IV presents the results for 10 gm/cm^2.

TABLE III

AN ESTIMATE OF THE UPPER BOUND ON A MARS LANDER MISSION RADIATION BURDEN ASSUMING A SPACE SHIELDING OF 1.0 GM/CM^2

Source of Radiation		Amount (Rads)
Geomagnetic Field (Van Allen)		41.5
Solar Flares		3075.0
Galactic Radiation		22.8
RTG Radiation		3250.0
	Total	6389.3

TABLE IV

AN ESTIMATE OF THE UPPER BOUND ON A MARS LANDER MISSION RADIATION BURDEN ASSUMING A SPACE SHIELDING OF 10 GM/CM^2

Source of Radiation		Amount (Rads)
Geomagnetic Field		12.5
Solar Flares		225.0
Galactic Radiation		22.8
RTG Radiation		3250.0
	Total	3510.3

As has been stated, the total radiation doses described in Tables III and IV are probably very liberal upper bounds since the estimate of the solar flare contribution is based upon rates during years of solar maximum, whereas the years of the middle 70's are years of solar minimum. During the years of solar minimum, the flare contribution for a 12-month trip with 1.0 gm/cm^2 shielding is approximately 400 rads, and the contribution with 10 gm/cm^2 shielding is only 20 rads [4]. Also, for the six months on the Martian surface the flare contribution is expected to be one-half that of the free space value using 10 gm/cm^2 shielding. This value is 10 rads. Using the expected flare doses during a solar minimum, the total dose would be approximately 3724 rads for 1.0 gm/cm^2 shielding. Hence, a conclusion which may be drawn is that the RTG will provide the largest share of the total radiation dose of any 18-month mission during the middle 1970's.

Another point which should be stressed is that the analysis presented here is based upon the sensitive materials of the lander having a minimum shielding of 1 gm/cm^2. The exposed surfaces of a bioshield will receive a much greater dose. For example, Haffner [4] estimates that a Martian mission with a flight time of 220 days will receive approximately 2000.0 rads of Van Allen radiation, 11.25 rads of galactic radiation, and as much as 4×10^4 rads of solar radiation on the exposed outer surfaces. Thus, the outer surface of the bioshield could receive a dose greater than 42 kilorads on a twelve-month voyage time.

Of importance concerning the possible sterilization of spacecraft using gamma radiation combined with heat is the fact that the only gamma contribution to the lander radiation burden is supplied by the RTG's. This dose of gamma radiation is at the most 1.13 kilorads for a localized area near the RTG with no shielding. Shielding possibilities for the RTG gamma output are entirely feasible since the gamma radiation energy spectra is dominant at relatively low energies of 43.5, 99.4, and 152.71 keV [10]. For comparison, the energy of ^{60}Co gamma radiation is 1.1 to 1.3 MeV. Therefore, the total gamma burden could be made as small as desired.

The following Appendix which was prepared by Lt. Keith C. Hopkins of the Biomedical Group (SAH) at the Air Force Weapons Laboratory, Kirtland Air Force Base, Albuquerque, New Mexico, provides an independent analysis of this same problem. This study was done assuming a space shielding of approximately 1.5 gm/cm^2. The information is broken down into the three categories of naturally occurring space radiations, and data is specifically provided for periods of solar maximum and solar minimum. Also included is some data on very high energy cosmic radiations in the form of heavy nuclei.

APPENDIX

Assumed Shielding

3.11 $gm/in.^2$ plastic = .327 gm/cm^2 plastic $\simeq$ .255 gm/cm^2 Al.

1.13 $gm/in.^2$ fiberglass = .175 gm/cm^2 fiberglass $\simeq$ .159 gm/cm^2 Al.

6.7 $gm/in.^2$ Al. = 1.039 gm/cm^2 Al. $\cong$ 1.039 gm/cm^2 Al.

TOTAL: 1.453 gm/cm^2 Al.

Doses

The following numbers are from Radiation and Shielding in Space by Haffner.

BELT DATA

6 Rads

GALACTIC COSMIC RAYS

Assuming 1 year in free space -

Solar Max - 11 Rads

Solar Min - 18 Rads

Assuming 6 months on surface of Mars

Solar Max - 3 Rads

Solar Min - 4 1/2 Rads

SOLAR FLARE DATA*

For 12 months in Free Space

Solar Max - 2500 Rads

Solar Min - 300 Rads

*Based on 1956-61 data which is considered to be a more energetic cycle than normal.

For 6 months on Mars Surface

Solar Max - 65 Rads

Solar Min - 8 Rads

The total dose for a typical mission is as follows:

Solar Max: Belt - 6 Rads

<u>Free Space</u>

Galactic Cosmic Rays - 11 Rads

Solar Flare - 2500 Rads

<u>Mars Surface</u>

Galactic Cosmic Rays - 3 Rads

Solar Flare - 65 Rads

TOTAL: 2585 Rads

Solar Min: Belt - 6 Rads

<u>Free Space</u>

Galactic Cosmic Rays - 18 Rads

Solar Flare - 300 Rads

<u>Mars Surface</u>

Galactic Cosmic Rays - 4 1/2 Rads

Solar Flare - 8 Rads

TOTAL: 336.5 Rads

Of more importance to instruments and detectors flown to Mars may be High Z Cosmic Ray tracks and stars. The following information is based on a NASA Joint Report by Shaefer and Sullivan published in June 1970 on "The Apollo XI Mission to the Moon." This data does not include the six months on Mar's surface.

Heavy Nuclei Predicted Exposure in Free Space*

Z Class	Integrated Flux-Nuclei/cm^2	Absorbed Dose (Millirad)
6-9	20800	36.3
10-12	2300	98.6
13-21	3750	34.1
22-30	3400	69.9

Mission dose 238.9 millirads

The following information is also based on the Shaefer and Sullivan Report. Mars Surface data is not included.

Prong spectrum of disintegration Stars in Ilford k.2 Emulsions

Number of prongs	Number of stars recorded
2	17500
3	13800
4	8750
5	6600
7	2380
8	1930
9	1525
10	1614
11-15	3150
16-24	1120

*Does not include data on Mars.

REFERENCES

1. Janni, J. and Holly, F. E., "The Current Experimental Approach to the Radiological Problems of Spaceflights--Conclusions," Aerospace Medicine, Vol. 40, No. 12, Section 2, Dec. 1969, p. 1566.

2. Richmond, R., "A Review of Gemini and Apollo Astronaut Dosimetry Data," Aerospace Medicine, Vol. 40, No. 12, Sec. 2, Dec. 1969, page 1525.

3. Radke, G., "An Evaluation of Current Methods of Predicting Space Radiation Doses," Aerospace Medicine, Vol. 40, No. 12, Sec. 2, Dec. 1969, page 1560.

4. Haffner, J. W., Radiation and Shielding in Space, Academic Press, New York, 1967, pp. 273, 305, 299-300, 301, 267, 45, 279, 315, 118, 312.

5. Case, R., "Techniques Used for the Calculations of Space Radiation Dose," Aerospace Medicine, Vol. 40, No. 12, Sec. 2, Dec. 1969, pages 1456-1457.

6. Radke, G., "Dose Measurements from the OV1-4 Satellite and the WL-304 Space Probe," Aerospace Medicine, Vol. 40, No. 12, Sec. 2, Dec. 1969, page 1504.

7. Adams, D. A. and Holly, F. E., "Space Radiation Environment," Aerospace Medicine, Vol. 36, No. 2, Sec. 2, February 1965, pages 8-9.

8. Personal Communication with T. D. Harrison, Space Isotope Power Department, Sandia Laboratories, Albuquerque, New Mexico.

9. Personal Communication with C. H. Davenport, Monsanto Research Corporation, Miamisburg, Ohio.

10. Abrahamson, S. G., et al., "Plutonium - 238 Isotopic Fuel Form Data Sheets," Monsanto Research Corporation Report MLM-1691, October 1969, page 6.

ACKNOWLEDGMENT

The author would like to express his sincere appreciation to Lt. Keith Hopkins, Biomedical Group, Air Force Weapons Laboratory, Kirtland Air Force Base, Albuquerque, New Mexico, for his contribution to this effort in the form of an independent evaluation of the lander radiation burden. This evaluation along with other pertinent information may be found in the Appendix.

Thanks are also due Mr. Leo P. Daspit, Jr., Viking Project Quarantine Officer, Langley Research Center, for his contribution of a typical Mars lander's trajectory to be used in the radiation burden calculations.

Distribution:

NASA, Code SC
Grants and Contracts
400 Maryland Avenue S. W.
Washington, D. C. 20546 (25)

L. B. Hall, NASA, Code SB
400 Maryland Avenue S. W.
Washington, D. C. 20546 (25)

B. W. Colston, Director
Space & Special Programs Division
Office of Operations
U. S. Atomic Energy Commission
Albuquerque, New Mexico 87115

L. P. Daspit, Jr.
Viking Project Quarantine Officer
Viking Project Office, NASA
Langley Research Center
Hampton, Virginia 23365

University of California
P. O. Box 808
Livermore, California 94551
Attn: Tech. Info. Div.
For: Report Librarian

Los Alamos Scientific Laboratory
P. O. Box 1663
Los Alamos, New Mexico 87544
Attn: Report Librarian

Richard G. Bond
School of Public Health
College of Medical Science
University of Minnesota
Minneapolis, Minnesota 55455

John H. Brewer
Star Route 2
Brownwood, Texas 76801

Edward B. Kasner
Director of Research Services
Graduate College
University of New Mexico
Albuquerque, New Mexico

Frank B. Engley, Jr., Chairman
Department of Microbiology
School of Medicine
University of Missouri
Columbia, Missouri

Gilbert V. Levin
Biospherics, Inc.
4928 Wyaconda Road
Rockville, Maryland 20853

Irving J. Pflug
Professor of Environmental Health
University of Minnesota
College of Medical Sciences
Minneapolis, Minnesota 59455

Gerald Silverman
Dept. of the Army
U. S. Army Natick Laboratories
Natick, Massachusetts 01760

John A. Ulrich
School of Medicine
University of New Mexico
Albuquerque, New Mexico 87106

Samuel Schalkowsky
Exotech Incorporated
525 School Street S. W.
Washington, D. C. 20024

Mark A. Chatigny
Research Engineer
Naval Biological Laboratory
Naval Supply Center
University of California, Berkeley
Oakland, California 94625

Richard G. Cornell
Associate Professor of Statistics
Department of Statistics
Florida State University
Tallahassee, Florida

Dr. Richard C. Corlett
Dept. of Mechanical Engineering
University of Washington
Seattle, Washington 98105

Martin S. Favero
Department of Health, Education
and Welfare
CDC-Phoenix Field Station
4402 North 7th Street
Phoenix, Arizona 85014

Mr. James Martin
Viking Project Engineer
Langley Research Center, NASA
Langley Station
Hampton, Virginia 23365

Q. Ussery
Code NC3, Quality Assurance Branch
Manned Spacecraft Center, NASA
Houston, Texas

F. J. Beyerle
George C. Marshall Space Flight Center
Manufacturing Engineering Laboratory
Code R-ME-MMC
Huntsville, Alabama 35812

J. Gayle
Code SOP
Kennedy Space Center, NASA
Cape Canaveral, Florida

Murray Schulman
Division of Biology and Medicine
Headquarters, AEC
Washington, D. C. 20545

N. H. MacLeod
Space Biology Branch
Code 624, Bldg. 21, Rm. 161
Goddard Space Flight Center
Greenbelt, Maryland 20771

J. E. Campbell
U. S. Public Health Service
222 E. Central Parkway
Cincinnati, Ohio 45202

G. Rotariu
Process Radiation Staff
Division of Isotopes Development
Headquarters, AEC
Washington, D. C. 20545

Martin G. Koesterer, Microbiologist
Bioscience Operation
General Electric
P. O. Box 8555
Philadelphia, Pennsylvania 19101

Carl Bruch
Chief, Bacteriology Branch
Division of Microbiology
Food and Drug Administration
3rd & C.,S.W.,Room 3876
Washington, D. C. 20204

John W. Beakley
Department of Biology
University of New Mexico
Albuquerque, New Mexico 87106

Loren D. Potter, Chairman
Department of Biology
University of New Mexico
Albuquerque, New Mexico 87106

Loris W. Hughes
Department of Biology
New Mexico State University
University Park, New Mexico

Richard W. Porter
Corporate Engineering Staff
General Electric Company
570 Lexington Avenue
New York, New York

Fred L. Whipple
Smithsonian Astrophysical Observatory
Cambridge, Massachusetts 02138

J. J. McDade
Biohazards Group
Pitman-Moore Company
Dow Chemical Company
P. O. Box 10
Zionsville, Indiana 46077

Otto Hamberg
Aerospace Corporation
Building A2, Room 2019
2350 East El Segundo Blvd.
El Segundo, California

Lawrence P. Chambers
NASA Headquarters
Office of Manned Space Flight
Code MLR
Washington, D. C. 20546

Arthur H. Neill
Code SB
400 Maryland Avenue, SW
Washington, D. C. 20546

Richard Green
Jet Propulsion Laboratory
4800 Oak Grove Dr.
Pasadena, California 91103

Rudy Puleo
Public Health Service
Spacecraft Bioassay Laboratory
Drawer Y
Cape Canaveral, Florida 32900

USAEC, Division of Technical Information
P. O. Box 62
Oak Ridge, Tennessee 37830
Attn: Reference Branch
P. E. Postell

Carl Sagan
Cornell University
Center for Radiophysics and Space Research
Space Science Building
Ithaca, New York 14850

Document Library
Lovelace Foundation for Medical Education and Research
5200 Gibson Blvd. SE
Albuquerque, New Mexico 87108

Martin S. Tierney
Group J-10
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

E. C. Pollard
Professor of Biophysics
Pennsylvania State University
618 Life Sciences Building
University Park, Pennsylvania 16802

Robert Angelotti
Deputy Director
Division of Microbiology
Food and Drug Administration
Health, Education and Welfare
200 C. Street SW
Washington, D. C. 20546

Vance I. Oyama, Chief
Life Detection Systems Branch
NASA, Ames Research Center
Moffett Field, California 94035

Byron W. Brown, Jr.
Department of Community and Preventive Medicine
Stanford University School of Medicine
Stanford University Medical Center
Stanford, California 94305

Don G. Fox
Sterility Control Officer
NASA Headquarters, Code SB
400 Maryland Avenue SW
Washington, D. C. 20546

A. A. Rothstein
Manager, Planetary Quarantine
Martin Marietta Corporation
Mail No. 8401
Denver, Colorado 80201

Hillel S. Levinson
U. S. Army Natick Laboratory
Natick, Massachusetts

B. S. Schweigert, Chairman
Department of Food Science
College of Agriculture
Michigan State University
East Lansing, Michigan 48823

H. O. Halvorson
Biochemistry Department
St. Paul Campus
University of Minnesota
St. Paul, Minnesota

Jack Kaye
11607 Georgetowne Court
Patomic, Maryland 20854

A. Anellis
U. S. Army Natick Laboratories
Natick, Massachusetts

H. W. Johnson, LTC
U. S. Army Medical Research and
Development Command
Washington, D. C. 20314

Donald A. Kautter
Dept. of HEW
Food and Drug Administration
Div. of Microbiology
BF-135
200 C Street S. W.
Washington, D. C. 20204

Lt. Keith C. Hopkins (SAH)
Biomedical Group
Air Force Weapons Laboratory
Kirtland Air Force Base
ALbuquerque, New Mexico 87115

J. A. Hornbeck, 1
J. M. Wiesen, 100
W. J. Howard, 1000
D. B. Shuster, 1200
W. A. Gardner, 1500
H. E. Lenander, 1600
T. M. Burford, 1700
C. Winter, 1710
D. R. Morrison, 1720
J. W. Worrell, Jr., 1721
D. P. Peterson, 1724
R. G. Clem, 1730
H. D. Sivinski, 1740 (35)
A. A. Lieber, 1750
R. W. Henderson, 2000
C. B. McCampbell, 2310
B. H. Van Domelen, 2345
S. J. Buchsbaum, 5000
L. C. Hebel, 5200
A. W. Snyder, 5220
R. M. Jefferson, 5221
J. E. McDonald, 5300
L. M. Berry, 5500
D. W. Ballard, 7361
L. S. Ostrander, 8232
G. A. Fowler, 9000
J. H. Scott, 9200
A. Y. Pope, 9300
L. A. Hopkins, Jr., 9500
R. S. Gillespie, 3411
J. L. Gardner, 3422
Calla Ann Crepin, 3424-1

hev