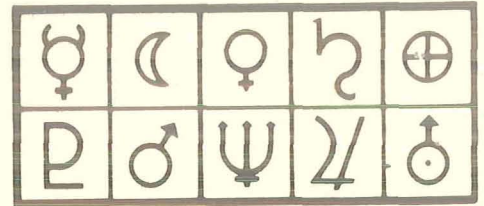


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A PRELIMINARY ANALYSIS OF THE
RADIATION BURDEN OF A TYPICAL
MARS LANDER MISSION

NASA CR116144

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SYSTEMS STUDIES DIVISION 1741

CASE FILE
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SC-RR-70-769

A PRELIMINARY ANALYSIS OF THE
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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/cm², 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.

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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 minimum 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.

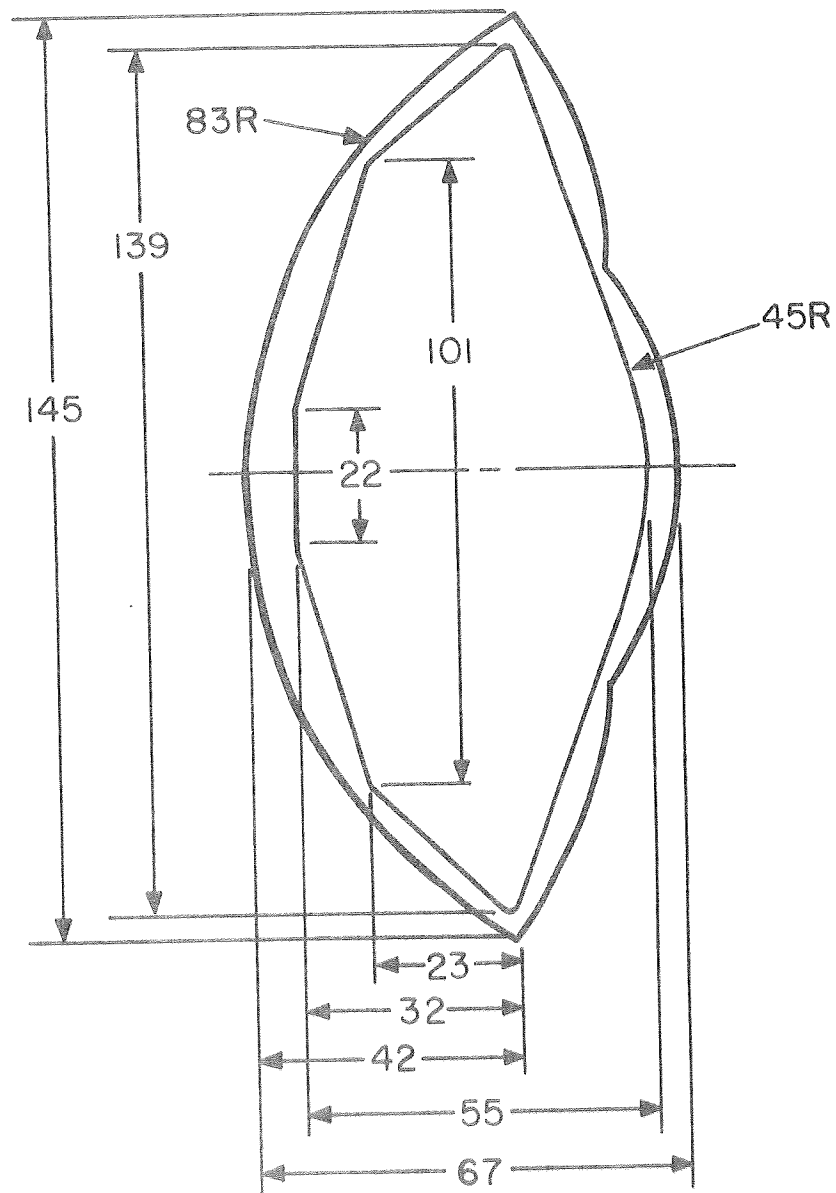


FIGURE 1
A TYPICAL LANDER GEOMETRY

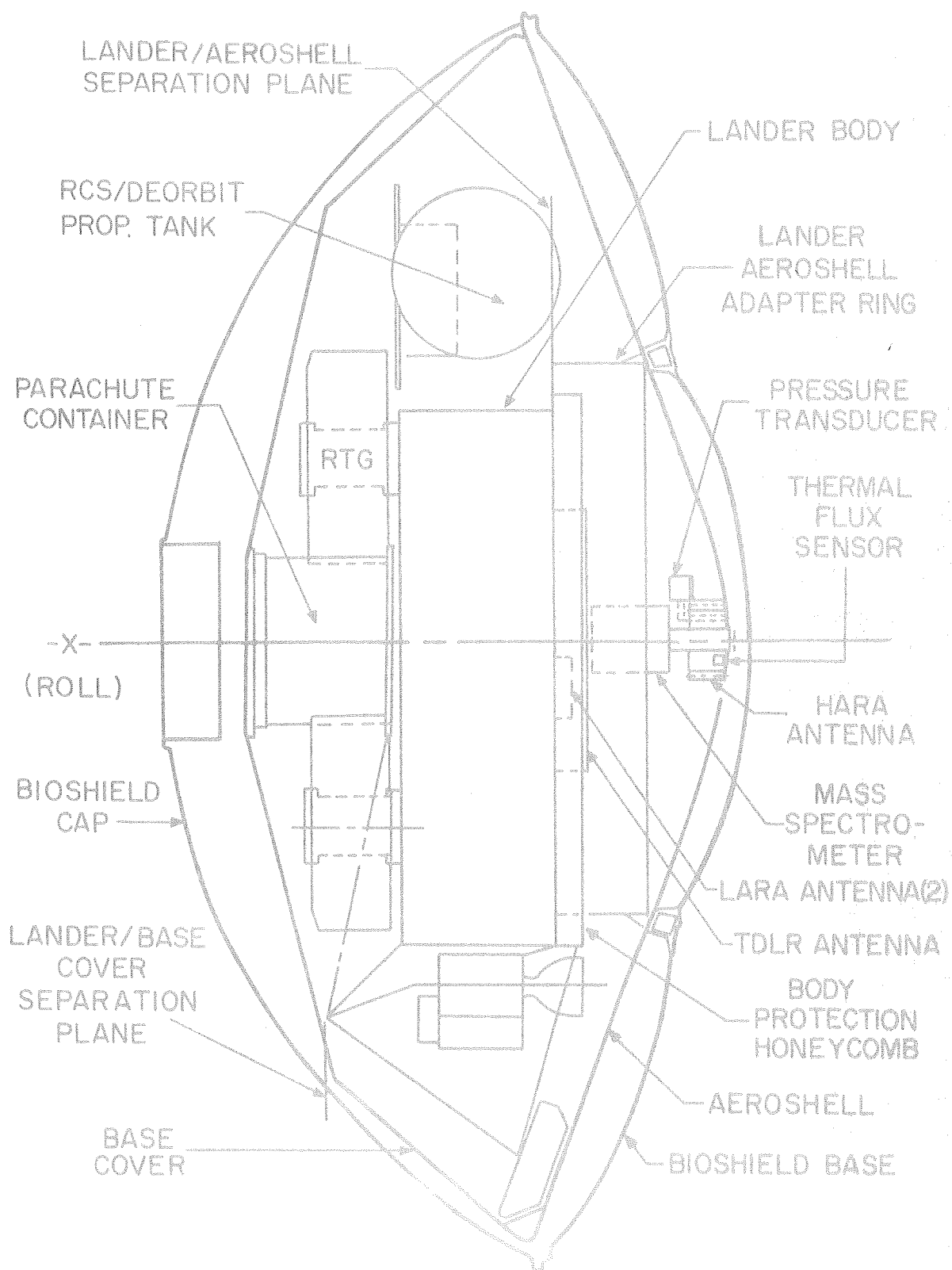


FIGURE 2
COMPONENTS OF A TYPICAL LANDER

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 Bottom: Aluminum, 60#

Equipment
Compartment 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 ($4 \text{ particles/cm}^2\text{-sec.}$) of very energetic ($10^8 - 10^{19} \text{ eV}$) 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 $^{238}\text{PuO}_2$ 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

$$\text{RAD} = \text{REM}/\text{R.B.E.}$$

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

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

TABLE IV

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

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

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/cm² plastic $\approx$.255 gm/cm² Al.

1.13 gm/in.² fiberglass = .175 gm/cm² fiberglass $\approx$.159 gm/cm² Al.

6.7 gm/in.² Al. = 1.039 gm/cm² Al. $\approx$ 1.039 gm/cm² Al.

TOTAL: 1.453 gm/cm² 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

Free Space

Galactic Cosmic Rays - 11 Rads

Solar Flare - 2500 Rads

Mars Surface

Galactic Cosmic Rays - 3 Rads

Solar Flare - 65 Rads

TOTAL: 2585 Rads

Solar Min: Belt - 6 Rads

Free Space

Galactic Cosmic Rays - 18 Rads

Solar Flare - 300 Rads

Mars Surface

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*

<u>Z Class</u>	<u>Integrated Flux-Nuclei/cm²</u>	<u>Absorbed Dose (Millirad)</u>
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

<u>Number of prongs</u>	<u>Number of stars recorded</u>
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.

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