NASA TECHNICAL MEMORANDUM

NASA TM X-64929

(NASA-TM-X-64929) NATURAL ENVIRONMENT DESIGN CRITERIA FOR THE SOLAR ELECTRIC PROPULSION STAGE (SEPS) (NASA) 16 p HC $3.25 CSCL 21C

N75-23682

Unclas
G3/20 21862

NATURAL ENVIRONMENT DESIGN CRITERIA FOR THE SOLAR ELECTRIC PROPULSION STAGE (SEPS)

By Jerry J. Wright
Space Sciences Laboratory

May 20, 1975

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.
NASA TM X-64929

2. GOVERNMENT ACCESSION NO.

3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE
Natural Environment Design Criteria for the Solar Electric Propulsion Stage (SEPS)

5. REPORT DATE
May 20, 1975

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Jerry J. Wright

8. PERFORMING ORGANIZATION REPORT #

9. PERFORMING ORGANIZATION NAME AND ADDRESS

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

13. TYPE OF REPORT & PERIOD COVERED
Technical Memorandum

12. SPONSORING AGENCY NAME AND ADDRESS

National Aeronautics and Space Administration
Washington, D. C. 20546

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Prepared by Space Sciences Laboratory, Science and Engineering

16. ABSTRACT

The natural environment design criteria are given for six different Solar Electric Propulsion Stage (SEPS) missions. These environment data include the neutral atmosphere; ionosphere; trapped radiation; free-space radiation environment; and meteoroid, asteroid, and comet environments. The electromagnetic radiation environment (direct, reflected, or scattered) at the planets and interplanetary regions is also included.

17. KEY WORDS

18. DISTRIBUTION STATEMENT

Jerry J. Wright
Unclassified — Unlimited

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	14	NTIS

MSFC Form 3292 (Rev December 1972)

For sale by National Technical Information Service, Springfield, Virginia 22151

FOREWORD

The natural environment design criteria in this report are the same as those in NASA TMX-64761, Natural Environment Design Requirements for the Solar Electric Propulsion Stage (SEPS), July 1973, except for the section on radiation. This report updates and supersedes NASA TMX-64761 for all future SEPS studies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TECHNICAL MEMORANDUM X-64929

NATURAL ENVIRONMENT DESIGN CRITERIA FOR THE SOLAR ELECTRIC PROPULSION STAGE (SEPS)

1.0 PURPOSE AND SCOPE

The purpose of this document is to define the natural environment design criteria for the Solar Electric Propulsion Stage (SEPS).

2.0 NATURAL ENVIRONMENT — GENERAL

The natural environment criteria given in this document shall be used in the design of the Solar Electric Propulsion Stage. Design value requirements of natural environment parameters not specifically defined herein will be obtained from NASA Technical Memorandum X-64757, "Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development, 1973 Revision," [1] and NASA Technical Memorandum X-64627, "Space and Planetary Environment Criteria Guidelines for Use in Space Vehicle Development, 1971 Revision" [2]. Wherever practical, the SEPS sensitivity to natural environment conditions during assembly, checkout, and operation shall be minimized. Natural environmental data not contained in the aforementioned documents and required in design or mission analysis studies for the SEPS will be requested from, or approved by, the cognizant NASA contract representative prior to use.

3.0 MISSIONS

Natural environment data are given for six different SEPS missions:

(1) 1979 Out of the Ecliptic

(2) 1981 Mariner Jupiter Orbiter

(3) 19[illegible] Earth Orbiter

(4) 1981 Encke Rendezvous

(5) 1986 Asteroid (Metis) Rendezvous

(6) 1987 Mercury Orbiter

4.0 NEUTRAL ATMOSPHERE

4.1 Earth's Atmosphere: For the Earth's atmospheric environment, Section 2.2 of NASA TMX-64627 shall be used.

4.2 Jupiter's Atmosphere: For the atmospheric environment of Jupiter, Section 8.1 of NASA TMX-64627 shall be used.

4.3 Mercury's Atmosphere: For the atmospheric environment of Mercury, Section 5.1 of NASA TMX-64627 shall be used.

5.0 IONOSPHERE

5.1 Ionosphere of Earth: The data in Section 2.3 of NASA TMX-64627 shall be used for ionosphere environment (electron density, etc.).

5.2 Ionosphere of Jupiter: The data in Section 8.1.3 of NASA TMX-64627 shall be used for the ionosphere environment of Jupiter.

5.3 Ionosphere of Mercury: The data in Section 5.1.4 of NASA TMX-64627 shall be used for the iorosphere environment of Mercury.

6.0 RADIATION

In addition to the following, use Section 2.4 of NASA TMX-64627. The SEPS shall be designed to provide necessary protection to insure the safe dosage limits of the equipment.

6.1 Galactic Cosmic Radiation: Galactic cosmic radiation consists of low-intensity, extremely high-energy charged particles. These particles—about 85 percent protons, 13 percent alphas, and the remainder heavier nuclei — bombard the solar system from all directions. They have energies from 10^8 to 10^{19} electron volts per particle and are encountered essentially everywhere in space. The intensity of this environment in "free space"; e.g., outside the influence of the earth's magnetic field, is relatively constant (0.2 to 0.4 particles/cm^2/steradian/second) except during periods of enhanced solar activity when the fluxes of cosmic rays have been observed to decrease due to an increase in the strength of the interplanetary magnetic field, which acts as a shield to incoming particles. Near the earth, cosmic rays are similarly influenced by the earth's magnetic field, resulting in a spatial variation in their intensity as a function of orbit inclination and altitude. The maximum of the galactic cosmic ray environment is at sunspot minimum. Figure 1 shows the galactic (cosmic) proton flux as a function of distance from the sun. See Section 2.4.1 of NASA TMX-64627 for additional data on this subject.

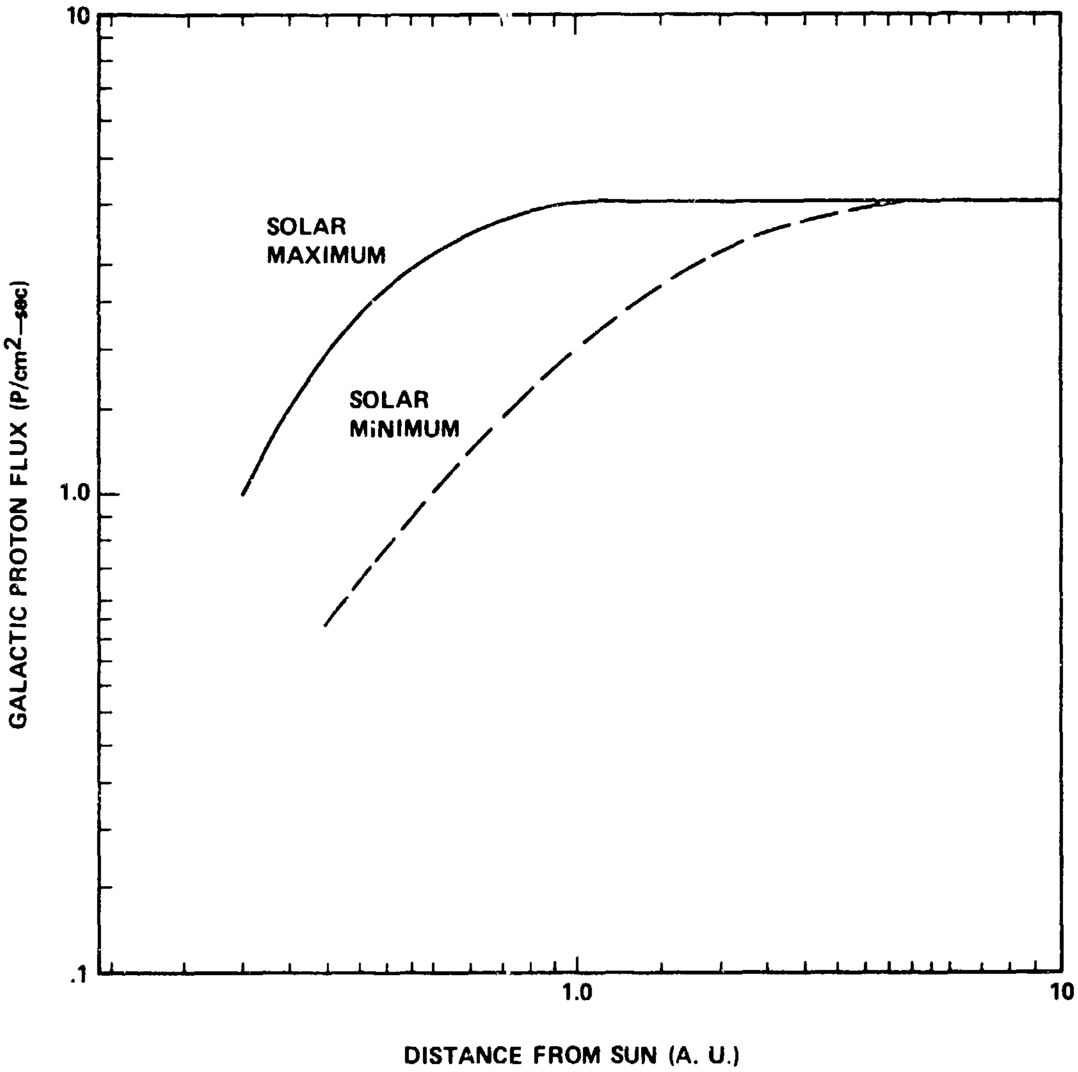

Figure 1. Integral flux of galactic (cosmic) protons as a function of distance from the sun ($E \geq 100$ MeV)

6.2 Trapped Radiation

6.2.1 Earth's Trapped Radiation: The geomagnetically trapped radiation environment will be taken from NASA SP-3024 or from TRECO Computer Code (National Space Science Data Center, NASA/ Goddard Space Flight Center) and merged with trajectory information to find particle fluxes and spectra. The fluxes and spectra will be converted to dose by data and/or computer codes provided by NASA/ Marshall Space Flight Center. See Section 2.4.2 of NASA TMX-64627.

6.2.2 Jupiter's Trapped Radiation: Fluxes of energetic electrons and protons in Jupiter's radiation belts are defined by the following model:

The form used to represent the integral flux J is

$$\log J = C - \beta x + (B - Dx)\,\frac{E^2}{A^2 + E^2} + \frac{m}{2}\,\log\left[\frac{(\cos\lambda)^6}{\sqrt{4 - 3(\cos\lambda)^2}}\right] \quad . \qquad (1)$$

Here $x = \log E$ for electron energy $E = E_e$ in MeV and $\log J$ is linear in the parameters B, C, D, β, and m, but not in A. Values for these parameters, all constant or linear in L within two segments, are specified for both models in Table 1, yielding values for $\log J$ in $cm^{-2}s^{-1}$ which are also linear in L within the two segments (broken at $L = 6.5$). For $E << A$, Eq. (1) resembles a power law spectrum $(J = 10^{B+C}/E^{\beta + D})$. The differential flux $j = (dJ/dE)$ is given by

$$j = \frac{J}{E}\left[\beta + D\,\frac{E^2}{A^2 + E^2} - (B - Dx)\,\frac{2A^2\,(\ln 10)\,E^2}{(A^2 + E^2)^2}\right] \quad . \qquad (2)$$

The parameter values in Table 1 lead to values for J and j which are both positive and continuous in energy for all $E > 0$. For the low flux model, in which data at only three energies were fitted, parameter values were selected which minimize j in the region $1 < E < 5$ MeV. In those few regions where the low flux model flux

TABLE 1. PARAMETERS FOR JULY 1974 JUPITER RADIATION MODELS, TO BE USED WITH EQUATIONS (1) AND (2); IF LOW FLUX ELECTRON FLUXES EXCEED THE HIGH FLUX ONES, SUBSTITUTE THE LATTER [3].

MODEL	L RANGE	A	B	C	D	β	m
HIGH FLUX ELECTRONS	$2.85 < L < 6.5$	15	1.7-(0.15)L	9.21-(0.17)L	1.21+(0.05)L	0.811-(0.048)L	4
	$6.5 < L < 15.0$	8	4.99-(0.57)L	9.15-(0.125)L	4.18-(0.31)L	0.047+(0.043)L	2
LOW FLUX ELECTRONS	$2.85 < L < 6.5$	5	B=D	7.89-(0.09)L	-1.37+(0.45)L	0.233+(0.031)L	4
	$6.5 < L < 12.0$	8	B=D	7.74-(0.06)L	2.44-(0.07)L	-1.139+(0.226)L	2
PROTONS	$2.85 < L \leq 3.4$	60	-67.02+(21.9)L	6.40+(0.39)L	-30.34+(10.62)L	-0.054+(0.13)L	5
	$3.4 \leq L < 6.0$	60	7.95-(0.15)L	9.494-(0.52)L	6.04-(0.08)L	-0.36+(0.22)L	5
	$6.0 < L < 11.0$	60	23.6-(1.62)L	9.16-(0.205)L	11.24-(0.51)L	2.25-(0.025)L	4

exceeds the high one, the smaller of the two fluxes is taken as the low flux model (the high one stands). These models specify the integral and differential omnidirectional particle flux which are continuous in energy (0.06 to 35 MeV for electrons, and 1 to 100 MeV for protons) and magnetic latitude, and linear in magnetic shell parameter between about 3 and 15 Jupiter radii. The models represent most all the data within a factor of two.

6.3 Solar Particle Events: Solar particle events are composed of energetic protons and alpha particles which occur sporadically and may last for several days. The free-space particle event model to be used for SEPS studies is given in Section 1.3.2.1.2 of NASA TMX-64627. Table 2 presents the updated model.

6.4 Solar Wind: The solar wind proton, electron, and other ions and nuclei at 1 AU and other interplanetary distances are obtained from Table 3. See Section 1.3.3 of NASA TMX-64627 for additional information.

7.0 METEOROIDS, ASTEROIDS, AND COMETS

7.1 Meteroid Environment

7.1.1 Earth's Meteoroid Environment: For the SEPS, the Meteoroid Environmental Model near Earth, as listed in Section 2.5 of NASA TMX-64627, shall be used.

7.1.2 Jupiter's Meteoroid Environment: For Jupiter, use Section 8.1.8.

7.1.3 Mercury's Meteoroid Environment: For the planet Mercury, the meteoroid environment given in Section 5.1.8 shall be used.

7.1.4 Interplanetary Meteoroid Environment: For the interplanetary meteoroid environment, use Section 1.4.

7.2 Asteroid and Comet Environment: The interplanetary asteroid and comet space environment for the SEPS missions is defined in Section 1.4 of NASA TMX-64627.

TABLE 2. SOLAR PROTON EVENTS

The probability of N large events during a time of t weeks exposure is given by the Poisson Distribution:

$$P(N;t) \quad \frac{e^{-\lambda t}(\lambda t)^N}{N!}, \quad N = 0, 1, 2, \ldots .$$

The best estimate at present is $\lambda = 0.02$ (events/week), for very large events. Thus,

$$P(N \geq 1; t) = 1 - e^{-0.02t}$$

The proton event integral flux to be used for solar cell effects is:

$\phi(> p) = N_o e^{-p/p_o}$ protons/cm^2-event

$N_o = 1 \times 10^{11}$

$p_o = 91$ Mv

$p = \sqrt{E^2 + 1876E} \geq 239$ Mv (30 MeV)

E = MeV (energy)

p = Mv (rigidity)

Thus, the differential energy spectrum becomes:

$$\phi(E) = \frac{N_o}{p_o} \frac{E + 938}{\sqrt{E^2 + 1876E}} \exp\left(-\frac{\sqrt{E^2 + 1876E}}{p_o}\right) =$$

protons/cm^2-MeV-event.

NOTE: This description is for the proton flux outside the earth's magnetosphere. Hence, a spectrum correction is needed for orbits below about 36,000 kilometers. However, the large solar proton event is accompanied by a large magnetic storm which partly cancels the earth's magnetic field. Thus, one may extend the free-space flux down to about 18,000 km (10,000 n. mi.).

TABLE 3. VALUES NEAR 1 AU AND RADIAL DEPENDENCES FOR SOLAR WIND PARAMETERS[4].

		AVERAGE	RANGE	RADIAL DEPENDENCE
PROTON	Concentration, cm^{-3}	5	7 to 2.5	S^{-2}
	Flow speed, km/s	425	350 to 550	None
	Thermal speed, km/s	50	35 to 70	$S^{-0.5}$
	Temperature, K	8×10^4	$(5$ to $15) \times 10^4$	$S^{-1\pm0.5}$
	Energy (flow), eV	900	600 to 1500	None
	Flux (flow), $m^{-2} s^{-1}$	$2 \times$ [illegible]^{12}	$(2.5$ to $1.4) \times 10^{12}$	S^{-2}
	Pressure, N/m^2	1.5×10^{-9}	$(1.6$ to $1.2) \times 10^{-9}$	S^{-2}
ELECTRON	Concentration, cm^{-3}	5	7 to 2.5	S^{-2}
	Flow speed, km/s	425	350 to 550	None
	Thermal speed, km/s	?700	2100 to 3300	$S^{-0.5}$
	Temperature, K	1.5×10^5	$(1$ to $2) \times 10^5$	$S^{-1\pm0.5}$
	Energy (thermal), eV	20	13 to 30	$S^{-1\pm0.5}$
	Flux (thermal) $m^{-2} s^{-1}$	10^{13}	$(5$ to $15) \times 10^{12}$	$S^{-2.5+0.25}$
OTHER IONS	Concentration, cm^{-3}	5	7 to 2.5	S^{-2}
	Flow speed, km/s	425	350 to 550	None
	Thermal speed, km/s	50	35 to 70	$S^{-0.5}$
	Energy, eV/nucleon		≤ 1000	None
MAGNETIC FIELD	Strength, nT (gammas)	5	2 to 8	S^{-1}

8.0 ASTRODYNAMIC CONSTANTS

The values given in Sections 2.7, 5.1.10, 8.1.10, and 1.6 of NASA TMX-64627 shall be used for the SEPS Earth, Mercury, Jupiter, and interplanetary missions, respectively.

9.0 ELECTROMAGNETIC RADIATION

The electromagnetic radiation environment includes the X-ray, ultraviolet, infrared, and microwave portions of the spectrum. These data contain the solar electromagnetic radiation (direct, reflected, or scattered) environment at the planets and interplanetary regions. Radiation emission from the planets is also included in these data. The electromagnetic radiation environment for the SEPS studies shall be obtained from NASA TMX-64627 for the following regions:

Interplanetary	-	Section 1.3.3
Earth	-	Section 2.4.5
Mercury	-	Section 5.1.7
Jupiter	-	Section 8.1.6

REFERENCES

1. Daniels, Glenn E., ed.: Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development, 1973 Revision. NASA TMX-64757, July 5, 1973.

2. Smith, Robert E., ed.: Space and Planetary Environment Criteria Guidelines for Use in Space Vehicle Development, 1971 Revision. NASA TMX-64627, November 15, 1971.

3. Divine, T. N.: Jupiter Radiation Belt Models (July 1974). Jet Propulsion Laboratory Technical Memorandum 33-715, November 15, 1974.

4. Divine, T. N.: Interplanetary Charged Particles (1973). Jet Propulsion Laboratory Technical Memorandum 33-637, October 1973.

APPROVAL

NATURAL ENVIRONMENT DESIGN CRITERIA
FOR THE SOLAR ELECTRIC PROPULSION STAGE (SEPS)

By Jerry J. Wright

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

Robert E. Smith

ROBERT E SMITH
Chief, Orbital and Space Environment Branch

William W. Vaughan

WILLIAM W. VAUGHAN
Chief, Aerospace Environment Division

Charles A. Lundquist

CHARLES A. LUNDQUIST
Director, Space Sciences Laboratory

☆ U.S. GOVERNMENT PRINTING OFFICE 1975–640-454/321 REGION NO. 4