Space Station Ionizing Radiation Design Environment

International Space Station Alpha

Revision C

3 June 1994

european space agency

NASDA
National Space Development Agency of Japan

Canadian Space Agency
Agence spatiale canadienne

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SPACE STATION PROGRAM OFFICE

SPACE STATION IONIZING RADIATION DESIGN ENVIRONMENT

JUNE 3, 1994

PREFACE

This revision of SSP 30512 defines the ionizing radiation environment that is applicable for the design of the International Space Station Alpha (ISSA). This environment represents a reasonable worst case of the true environment which the International Space Station is expected to experience during its orbital lifetime.

Section 3.0 of this document contains the detailed definition of the external ionizing radiation environment which is used in the design of the US orbiting segment and external end items. This document also contains parametric calculations of internal induced ionizing radiation environments which are used in the design of internal equipment and end items. This document is under control of the Space Station Control Board and any changes or revisions to this document shall be approved by the Program Manager.

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INTERNATIONAL SPACE STATION ALPHA PROGRAM

SPACE STATION IONIZING RADIATION DESIGN ENVIRONMENT

JUNE 3, 1994

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INTERNATIONAL SPACE STATION ALPHA PROGRAM

SPACE STATION IONIZING RADIATION DESIGN ENVIRONMENT

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INTERNATIONAL SPACE STATION ALPHA PROGRAM

SPACE STATION IONIZING RADIATION DESIGN ENVIRONMENT

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SPACE STATION PROGRAM OFFICE

SPACE STATION IONIZING RADIATION DESIGN ENVIRONMENT

LIST OF CHANGES

JUNE 3 1994

All changes to paragraphs, tables, and figures in this document are shown below:

SSCBD	ENTRY DATE	CHANGE	PARAGRAPH(S)
000008 R1	6–3–94	REVISION C	1.1, 1.2, 2.0, 3.0, 3.1.2, 3.1.3, 3.2, 3.2.1, 3.2.1.1, 3.2.1.2, 3.2.1.3, 3.2.1.4, and 3.2.2
			TABLE(S)
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			FIGURE(S)
000008 R1	6–3–94	REVISION C	3–7, 3–8, 3–9, 3–10, 3–11, 3–12
			APPENDIX(ES)
			ADDENDA

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1.0 GENERAL

1.1 SCOPE

This document defines the ionizing radiation environment which is specified as an environmental design and operations requirement for the International Space Station Alpha (ISSA) and is recommended for use as the design environment for other on–orbit segments. This document provides definition for the external ionizing radiation environment as well as the internal induced ionizing radiation environment applicable to internal equipment and end items. These environments may also be applied as design requirements for internal and external payloads and to assess crew exposure.

1.2 PURPOSE

This document establishes the ionizing radiation design susceptibility environment for the ISSA system, segments, and associated end items.

2.0 REFERENCE DOCUMENTS

23rd ICRC 1993	GOES Observations of Energetic Protons E>685 MeV: Ground Level Events from 10/83 to 7/92, H. Sauer, 23rd ICRC, Alberta, Canada
NBS Technical Note 1116 May, 1980	SHIELDOSE: A computer Code for Space–Shielding Radiation Dose Calculations, National Bureau of Standards, Stephen Seltzer
NRL Memorandum Report 5901 December 31, 1986	Cosmic Ray Effects on MicroElectronics, Part IV Naval Research Laboratory, James Adams
NSSDC/WDC–A–R&S 76–06 1976	AP–8 Trapped Proton Environment for Solar Maximum and Solar Minimum, National Science Data Center, Donald M. Sawyer and James I. Vette
NSSDC/WDC–A–R&S 91–24 November 1991	The AE–8 Trapped Electron Model Environment, National Space Science Data Center, Goddard Space Flight Center, James I. Vette

3.0 IONIZING RADIATION ENVIRONMENT

The ionizing radiation environment results from the natural radiation in low earth orbit due to trapped electrons, trapped protons, and solar, anomalous, and galactic cosmic rays. The contribution of other low earth orbit environmental constituents such as neutrons and x–rays are negligible and are not included in establishing the ionizing radiation design environment. The ionizing radiation environment interacts with devices and materials to produce radiation dose effects and single event effects (SEE).

3.1 RADIATION DOSE ENVIRONMENT

Dose effects are ionizing radiation–induced changes in devices and materials resulting from exposure to the trapped proton and electron environment during the orbital lifetime. Dose effects are usually manifested as degradation of electronic device and material performance and are cumulative with exposure to the ionizing radiation environment. The ionizing radiation design environment for dose effects consists of trapped electrons and trapped protons.

3.1.1 PROTON AND ELECTRON ENVIRONMENT FOR DOSE

The ionizing radiation trapped proton and electron environment for dose effects is determined by using an orbital altitude for radiation exposure of 500 kilometers, an orbital inclination of 51.6 degrees, the particle flux/solar activity environments as described by AE8MAX for trapped electrons and AP8MAX for trapped protons, the Epoch 1970 geomagnetic field, and the equipment on–orbit design lifetime. The integral and differential energy spectra for trapped electrons, determined for these conditions, are given in Table 3.1.1–1 and illustrated in figures 3.1.1–1 and 3.1.1–2; the corresponding energy spectra for trapped protons are given in Table 3.1.1–2 and illustrated in figures 3.1.1–3 and 3.1.1–4. AE8MAX is documented in NSSDC/WDC–A–R&S 91–24 while AP8MAX is documented in NSSDC/WDC–A–R&S 76–06.

3.1.2 TOTAL DOSE FOR ELECTRONIC DEVICES AND SURFACE COATINGS

The radiation dose in electronic devices and surface coatings is a function of the material in which the dose is absorbed and the shielding between the electron/proton environment and the device or material. Doses in silicon at the center of an aluminum sphere, representative of doses to electronic devices shielded by an equivalent thickness of aluminum, are given in Table 3.1.2–1. These doses are based on the above electron and proton environments and are given for a range of aluminum shield thicknesses. The dose resulting from protons and electrons (including electron–induced bremsstrahlung) are indicated. Table 3.1.2–2 gives similar data for the dose in silicon detectors at various depths in aluminum semi–infinite slabs, representative of doses to surface materials. All doses are calculated from the trapped proton /electron environment using the SHIELDOSE model, documented in NBS Technical Note 1116.

3.1.3 COMBINED PARTICLE TOTAL DOSE

The total dose environment for electronic devices and surface coatings is a summation of doses resulting from trapped protons and electrons (including electron–induced bremsstrahlung). This total dose is given in Table 3.1.2–1 and 3.1.2–2 and illustrated in figures 3.1.3–1 and 3.1.3–2.

3.1.4 ORBITAL LIFETIME ADJUSTMENTS

The total dose environment defined in paragraph 3.1.3 is based on an orbital lifetime of one year. The total dose environment for orbital lifetimes other than one year is a linear extrapolation of the given value.

3.2 SINGLE EVENT EFFECTS ENVIRONMENT

SEE are ionizing radiation–induced effects produced when single, ionized particles interact with electronic devices to change the electrical states or characteristics of the devices. These effects include single event upset, transients, latchup, burnout, and gate rupture. The ionizing radiation environment for SEE is divided into a nominal environment and an extreme environment.

3.2.1 NOMINAL SINGLE EVENT EFFECTS ENVIRONMENT

The nominal SEE design environment is the environment which the Space Station will typically experience, and consists of trapped protons and cosmic rays.

3.2.1.1 SINGLE EVENT EFFECTS PROTON ENVIRONMENT

The nominal SEE trapped proton environment is determined using an orbital altitude for radiation exposure of 500 km, an orbital inclination of 51.6 degrees, the Epoch 1964 geomagnetic field, and the AP8MIN solar flux/activity environment. The daily average integral and differential energy spectra for trapped protons for various shielding thicknesses are given in Table 3.2.1.1–1 and 3.2.1.1–2. The spectra in these two tables are generated using AP8MIN, which is documented in NSSDC/WDC–A–R&S 76–06, and CREME, which is documented in NRL Menorandum Report 5901.

3.2.1.2 PEAK SINGLE EVENT EFFECTS PROTON ENVIRONMENT

The SEE trapped proton environment defined in paragraph 3.2.1.1 represents daily average proton fluxes. The trapped proton flux is a maximum during passes through the South Atlantic Anomaly (SAA), where fluxes are more severe than the daily average environment. Space Station will pass through the SAA on 50% of its orbits and will spend 5–10 minutes of these orbits in the SAA. The SAA pass peak SEE proton environment is determined using an orbital altitude for radiation exposure of 500 km, an orbital inclination of 51.6 degrees, the Epoch 1964 geomagnetic field, and the AP8MIN solar flux/activity environment for the orbit experiencing the most severe fluxes. The SAA pass peak integral and differential energy spectra for trapped protons are given in Tables 3.2.1.2–1 and 3.2.1.2–2. The spectra in these tables are generated using both AP8MIN and CREME.

3.2.1.3 SINGLE EVENT EFFECTS COSMIC RAY ENVIRONMENT

The SEE cosmic ray environment is determined using an orbital altitude for radiation exposure of 500 km, an orbital inclination of 51.6 degrees, the geomagnetic cutoff, magnetically quiet conditions, no shadowing effect, the Epoch 1964 geomagnetic field, and the AP8MIN solar flux/activity environment and the CREME model with a weather index of M=4.

3.2.1.4 COMBINED PARTICLE SINGLE EVENT EFFECTS ENVIRONMENT

The integral flux spectra for the cosmic ray environment combined with the trapped proton environment are given in Table 3.2.1.4–1 and Figure 3.2.1.4–1. These spectra give the flux at the center of solid aluminum spheres of various radii as a function of the particle Linear Energy Transfer (LET) for silicon.

3.2.2 EXTREME SINGLE EVENT EFFECTS ENVIRONMENT

The extreme SEE design environment consists of protons and heavy ions emitted during the most intense solar flares in a solar cycle. The extreme environment occurs once over an 11 year solar cycle period, and lasts for approximately 24 hours. Three different aspects of this environment are defined: a) peak proton flux, b) peak heavy ion flux, and c) orbit–averaged heavy ion fluence for the worst case flare event. The solar flare peak integral and differential flux spectra for the extreme solar proton environment (October 1989 flare) are given in Tables 3.2.2–1 and 3.2.2–2 respectively and are based on the data given by H. Sauer, 23rd ICRC. The corresponding solar flare heavy ion environment, described in terms of the maximum solar flare peak integral heavy ion flux, is given in Table 3.2.2–3 and illustrated in Figure 3.2.2–1. These proton and heavy ion spectra represent the peak flux rate which is experienced over each approximately 10–minute period per half orbit when the ISSA is at the magnetic latitude extremes of its orbit for the worst 6–8 orbits of the 24 hour day. The maximum solar flare event orbit–averaged integral heavy ion fluence is given in Table 3.2.2–4 and illustrated in Figure 3.2.2–2.

TABLE 3.1.1–1 AE8MAX DIFFERENTIAL AND INTEGRAL FLUX ENERGY SPECTRA FOR TRAPPED ELECTRONS

Energy (MeV)	Integral Flux (elecrons/cm^2–day)	Differential Flux (electrons/cm^2–day–MeV)
0.01	1.974E+10	1.708E+11
0.04	1.523E+10	1.311E+11
0.07	1.178E+10	1.005E+11
0.10	9.128E+09	8.289E+10
0.20	3.457E+09	3.104E+10
0.30	1.507E+09	1.076E+10
0.50	4.409E+08	1.940E+09
0.70	2.348E+08	6.194E+08
0.90	1.509E+08	3.142E+08
1.00	1.241E+08	2.176E+08
1.10	1.060E+08	1.660E+08
1.20	9.072E+07	1.413E+08
1.30	7.766E+07	1.205E+08
1.40	6.652E+07	1.028E+08
1.50	5.701E+07	8.951E+07
1.60	4.859E+07	7.759E+07
1.70	4.143E+07	6.600E+07
1.80	3.533E+07	5.617E+07
1.90	3.015E+07	4.782E+07
2.00	2.573E+07	4.015E+07
2.50	1.193E+07	2.018E+07
2.75	7.491E+06	1.375E+07
3.00	4.766E+06	8.715E+06
3.25	3.002E+06	5.495E+06
3.50	1.909E+06	3.665E+06
4.00	6.902E+05	1.489E+06
4.50	2.199E+05	5.079E+05
5.00	6.850E+04	1.770E+05
5.40	2.178E+04	6.239E+04

TABLE 3.1.1–2 AP8MAX DIFFERENTIAL AND INTEGRAL FLUX ENERGY SPECTRA FOR TRAPPED PROTONS		
Energy (MeV)	Integral Flux (protons/cm^2–day)	Differential Flux (protons/cm^2–day–MeV)
0.01	8.251E+07	5.060E+08
0.05	6.456E+07	3.658E+08
0.25	2.266E+07	9.764E+07
0.50	9.335E+06	2.326E+07
1.00	3.892E+06	4.131E+06
1.50	2.820E+06	1.431E+06
2.00	2.310E+06	6.088E+05
2.50	2.117E+06	3.255E+05
3.00	1.978E+06	2.345E+05
3.75	1.831E+06	1.517E+05
4.50	1.742E+06	9.828E+04
6.00	1.621E+06	6.184E+04
10.00	1.435E+06	2.995E+04
20.00	1.244E+06	1.469E+04
30.00	1.128E+06	1.022E+04
50.00	9.533E+05	8.440E+03
80.00	7.213E+05	6.914E+03
100.00	5.920E+05	6.141E+03
150.00	3.434E+05	3.623E+03
200.00	2.060E+05	2.192E+03
250.00	1.184E+05	1.299E+03
300.00	6.876E+04	7.385E+02
350.00	4.045E+04	4.288E+02
400.00	2.382E+04	2.507E+02
450.00	1.412E+04	1.510E+02
500.00	8.171E+03	8.710E+01
550.00	4.861E+03	5.340E+01
600.00	2.719E+03	3.397E+01
650.00	1.389E+03	2.623E+01
700.00	3.683E+02	9.778E+00

TABLE 3.1.2–1 ONE YEAR DOSE AT THE CENTER OF A SOLID ALUMINUM SPHERE (RADS SI) Sheet 1 of 2

SHIELDING (MILS)	SHIELDING (MM)	SHIELDING (G/CM^2)	ELECTRONS	PROTONS	TOTAL DOSE
3.000E–02	7.620E–04	2.118E–04	9.016E+05	9.762E+04	9.922E+05
1.000E–01	2.540E–03	7.061E–04	7.355E+05	4.083E+04	7.763E+05
3.000E–01	7.620E–03	2.118E–03	5.463E+05	9.423E+03	5.557E+05
5.000E–01	1.270E–02	3.531E–03	4.555E+05	4.487E+03	4.600E+05
7.000E–01	1.778E–02	4.943E–03	3.997E+05	2.722E+03	4.025E+05
9.000E–01	2.286E–02	6.355E–03	3.564E+05	1.865E+03	3.582E+05
1.100E+00	2.794E–02	7.767E–03	3.240E+05	1.428E+03	3.255E+05
1.300E+00	3.302E–02	9.179E–03	2.944E+05	1.100E+03	2.955E+05
1.500E+00	3.810E–02	1.059E–02	2.679E+05	9.381E+02	2.689E+05
1.700E+00	4.318E–02	1.200E–02	2.508E+05	7.680E+02	2.515E+05
1.900E+00	4.826E–02	1.342E–02	2.292E+05	6.439E+02	2.298E+05
2.000E+00	5.080E–02	1.412E–02	2.189E+05	6.258E+02	2.195E+05
3.000E+00	7.620E–02	2.118E–02	1.533E+05	4.413E+02	1.538E+05
4.000E+00	1.016E–01	2.824E–02	1.136E+05	3.425E+02	1.140E+05
5.000E+00	1.270E–01	3.531E–02	8.534E+04	2.809E+02	8.562E+04
6.000E+00	1.524E–01	4.237E–02	6.755E+04	2.250E+02	6.780E+04
7.000E+00	1.778E–01	4.943E–02	5.328E+04	2.182E+02	5.350E+04
8.000E+00	2.032E–01	5.649E–02	4.262E+04	2.026E+02	4.282E+04
9.000E+00	2.286E–01	6.355E–02	3.619E+04	1.931E+02	3.639E+04
1.000E+01	2.540E–01	7.061E–02	3.048E+04	1.778E+02	3.066E+04
1.500E+01	3.810E–01	1.059E–02	1.442E+04	1.492E+02	1.456E+04
2.000E+01	5.080E–01	1.412E–01	8.644E+03	1.293E+02	8.773E+03
2.500E+01	6.350E–01	1.765E–01	5.845E+03	1.138E+02	5.959E+03
3.000E+01	7.620E–01	2.118E–01	4.317E+03	1.061E+02	4.423E+03
3.500E+01	8.890E–01	2.471E–01	3.373E+03	1.023E+02	3.476E+03
4.000E+01	1.016E+00	2.824E–01	2.761E+03	9.531E+01	2.856E+03
4.500E+01	1.143E+00	3.177E–01	2.290E+03	9.168E+01	2.382E+03
5.000E+01	1.270E+00	3.531E–01	1.939E+03	9.013E+01	2.029E+03
6.000E+01	1.524E+00	4.237E–01	1.475E+03	8.160E+01	1.556E+03
7.000E+01	1.778E+00	4.943E–01	1.163E+03	7.694E+01	1.239E+03
8.000E+01	2.032E+00	5.649E–01	9.355E+02	7.658E+01	1.012E+03
9.000E+01	2.286E+00	6.355E–01	7.537E+02	7.103E+01	8.247E+02
1.000E+02	2.540E+00	7.061E–01	6.065E+02	6.643E+01	6.729E+02
1.500E+02	3.810E+00	1.059E+00	2.181E+02	6.056E+01	2.787E+02
2.000E+02	5.080E+00	1.412E+00	7.327E+01	5.497E+01	1.282E+02

TABLE 3.1.2–1 ONE YEAR DOSE AT THE CENTER OF A SOLID ALUMINUM SPHERE (RADS SI) Sheet 2 of 2					
SHIELDING (MILS)	SHIELDING (MM)	SHIELDING (G/CM^2)	ELECTRONS	PROTONS	TOTAL DOSE
2.500E+02	6.350E+00	1.765E+00	2.520E+01	5.214E+01	7.734E+01
3.000E+02	7.620E+00	2.118E+00	7.909E+00	4.925E+01	5.716E+01
3.500E+02	8.890E+00	2.471E+00	3.407E+00	4.587E+01	4.928E+01
4.000E+02	1.016E+01	2.824E+00	1.877E+00	4.439E+01	4.626E+01
4.500E+02	1.143E+01	3.177E+00	1.507E+00	4.278E+01	4.429E+01
5.000E+02	1.270E+01	3.531E+00	1.363E+00	4.088E+01	4.224E+01
6.000E+02	1.524E+01	4.237E+00	1.197E+00	3.820E+01	3.940E+01
7.000E+02	1.778E+01	4.943E+00	1.079E+00	3.619E+01	3.727E+01
1.000E+03	2.540E+01	7.061E+00	8.360E–01	2.995E+01	3.079E+01
1.500E+03	3.810E+01	1.059E+01	6.098E–01	2.333E+01	2.394E+01
2.000E+03	5.080E+01	1.412E+01	4.779E–01	1.892E+01	1.940E+01
3.000E+03	7.620E+01	2.118E+01	3.085E–01	1.264E+01	1.295E+01
4.000E+03	1.016E+02	2.824E+01	1.927E–01	9.266E+00	9.459E+00
5.000E+03	1.270E+02	3.531E+01	1.143E–01	7.131E+00	7.245E+00

TABLE 3.1.2–2 ONE YEAR DOSE IN SEMI–INFINITE ALUMINUM MEDIUM (RADS SI) Sheet 1 of 2

SHIELDING (MILS)	SHIELDING (MM)	SHIELDING (G/CM^2)	ELECTRONS	PROTONS	TOTAL DOSE
3.000E–02	7.620E–04	2.118E–04	3.795E+05	2.904E+04	4.086E+05
8.000E–02	2.032E–03	5.649E–04	3.021E+05	1.209E+04	3.142E+05
1.000E–01	2.540E–03	7.061E–04	2.834E+05	9.044E+03	2.924E+05
1.500E–01	3.810E–03	1.059E–03	2.490E+05	5.271E+03	2.543E+05
2.000E–01	5.080E–03	1.412E–03	2.247E+05	3.486E+03	2.282E+05
3.000E–01	7.620E–03	2.118E–03	1.912E+05	1.921E+03	1.932E+05
4.000E–01	1.016E–02	2.824E–03	1.682E+05	1.273E+03	1.695E+05
5.000E–01	1.270E–02	3.531E–03	1.505E+05	9.225E+02	1.514E+05
6.000E–01	1.524E–02	4.237E–03	1.366E+05	7.147E+02	1.373E+05
7.000E–01	1.778E–02	4.943E–03	1.250E+05	5.730E+02	1.255E+05
8.000E–01	2.032E–02	5.649E–03	1.149E+05	4.812E+02	1.154E+05
9.000E–01	2.286E–02	6.355E–03	1.065E+05	4.107E+02	1.069E+05
1.100E+00	2.794E–02	7.767E–03	9.232E+04	3.201E+02	9.264E+04
1.200E+00	3.048E–02	8.473E–03	8.622E+04	2.856E+02	8.650E+04
1.300E+00	3.302E–02	9.179E–03	8.088E+04	2.626E+02	8.114E+04
1.400E+00	3.556E–02	9.885E–03	7.608E+04	2.411E+02	7.633E+04
1.500E+00	3.810E–02	1.059E–02	7.170E+04	2.260E+02	7.192E+04
1.600E+00	4.064E–02	1.130E–02	6.771E+04	2.123E+02	6.792E+04
1.700E+00	4.318E–02	1.200E–02	6.400E+04	1.979E+02	6.419E+04
1.800E+00	4.572E–02	1.271E–02	6.050E+04	1.896E+02	6.069E+04
1.900E+00	4.826E–02	1.342E–02	5.732E+04	1.806E+02	5.750E+04
2.000E+00	5.080E–02	1.412E–02	5.445E+04	1.734E+02	5.462E+04
2.500E+00	6.350E–02	1.765E–02	4.291E+04	1.431E+02	4.305E+04
3.000E+00	7.620E–02	2.118E–02	3.443E+04	1.253E+02	3.456E+04
3.500E+00	8.890E–02	2.471E–02	2.834E+04	1.122E+02	2.846E+04
4.000E+00	1.016E–01	2.824E–02	2.368E+04	1.020E+02	2.378E+04
4.500E+00	1.143E–01	3.177E–02	1.992E+04	9.422E+01	2.001E+04
5.000E+00	1.270E–01	3.531E–02	1.708E+04	8.844E+01	1.717E+04
6.000E+00	1.524E–01	4.237E–02	1.290E+04	7.976E+01	1.298E+04
7.000E+00	1.778E–01	4.943E–02	9.975E+03	7.312E+01	1.005E+04
8.000E+00	2.032E–01	5.649E–02	7.997E+03	6.888E+01	8.066E+03
9.000E+00	2.286E–01	6.335E–02	6.539E+03	6.492E+01	6.604E+03
1.000E+01	2.540E–01	7.061E–02	5.406E+03	6.190E+01	5.468E+03
1.500E+01	3.810E–01	1.059E–01	2.634E+03	5.167E+01	2.685E+03
2.000E+01	5.080E–01	1.412E–01	1.609E+03	4.563E+01	1.655E+03
2.500E+01	6.350E–01	1.765E–01	1.111E+03	4.180E+01	1.153E+03

TABLE 3.1.2–2 ONE YEAR DOSE IN SEMI–INFINITE ALUMINUM MEDIUM (RADS SI) Sheet 2 of 2

SHIELDING (MILS)	SHIELDING (MM)	SHIELDING (G/CM^2)	ELECTRONS	PROTONS	TOTAL DOSE
3.000E+01	7.620E–01	2.118E–01	8.277E+02	3.924E+01	8.670E+02
3.500E+01	8.890E–01	2.471E–01	6.458E+02	3.708E+01	6.829E+02
4.000E+01	1.016E+00	2.824E–01	5.197E+02	3.528E+01	5.550E+02
5.000E+01	1.270E+00	3.531E–01	3.568E+02	3.259E+01	3.894E+02
6.000E+01	1.524E+00	4.237E–01	2.575E+02	3.047E+01	2.879E+02
7.000E+01	1.778E+00	4.943E–01	1.907E+02	2.899E+01	2.197E+02
8.000E+01	2.032E+00	5.649E–01	1.430E+02	2.766E+01	1.706E+02
9.000E+01	2.286E+00	6.355E–01	1.080E+02	2.644E+01	1.345E+02
1.000E+02	2.540E+00	7.061E–01	8.227E+01	2.560E+01	1.079E+02
1.500E+02	3.810E+00	1.059E+00	2.229E+01	2.229E+01	4.458E+01
2.000E+02	5.080E+00	1.412E+00	6.274E+00	2.010E+01	2.638E+01
3.500E+02	8.890E+00	2.471E+00	5.639E–01	1.591E+01	1.647E+01
5.000E+02	1.270E+01	3.531E+00	3.857E–01	1.335E+01	1.374E+01

TABLE 3.2.1.1–1 DAILY AVERAGE INTERNAL PROTON INTEGRAL FLUX SPECTRUM
protons/cm^2–day>E at indicated shielding thicknesses

Energy (MeV)	0 Mils	50 Mils	500 Mils	1000 Mils shielding	2000 Mils	4000 Mils	7000 Mils
10.00	3.29E+06	2.51E+06	1.59E+06	1.20E+06	7.67E+05	3.95E+05	1.86E+05
12.24	3.03E+06	2.44E+06	1.58E+06	1.19E+06	7.64E+05	3.94E+05	1.86E+05
14.97	2.77E+06	2.36E+06	1.56E+06	1.18E+06	7.59E+05	3.92E+05	1.85E+05
18.32	2.54E+06	2.27E+06	1.54E+06	1.17E+06	7.52E+05	3.89E+05	1.84E+05
22.41	2.35E+06	2.17E+06	1.51E+06	1.15E+06	7.43E+05	3.86E+05	1.83E+05
27.42	2.19E+06	2.06E+06	1.47E+06	1.13E+06	7.31E+05	3.81E+05	1.81E+05
33.56	2.03E+06	1.94E+06	1.42E+06	1.09E+06	7.13E+05	3.74E+05	1.79E+05
41.06	1.87E+06	1.80E+06	1.35E+06	1.05E+06	6.89E+05	3.64E+05	1.75E+05
50.24	1.69E+06	1.63E+06	1.26E+06	9.87E+05	6.56E+05	3.51E+05	1.71E+05
61.47	1.50E+06	1.45E+06	1.15E+06	9.11E+05	6.13E+05	3.33E+05	1.64E+05
75.21	1.29E+06	1.26E+06	1.01E+06	8.16E+05	5.60E+05	3.11E+05	1.55E+05
92.03	1.07E+06	1.05E+06	8.61E+05	7.04E+05	4.96E+05	2.83E+05	1.43E+05
112.60	8.48E+05	8.32E+05	6.98E+05	5.82E+05	4.20E+05	2.48E+05	1.29E+05
137.80	6.36E+05	6.25E+05	5.39E+05	4.57E+05	3.37E+05	2.07E+05	1.11E+05
168.60	4.48E+05	4.43E+05	3.93E+05	3.38E+05	2.56E+05	1.64E+05	9.17E+04
206.30	2.96E+05	2.93E+05	2.66E+05	2.34E+05	1.82E+05	1.22E+05	7.06E+04
252.40	1.83E+05	1.81E+05	1.66E+05	1.48E+05	1.19E+05	8.30E+04	5.02E+04
308.80	1.04E+05	1.03E+05	9.49E+04	8.40E+04	6.98E+04	5.07E+04	3.25E+04
377.80	5.30E+04	5.26E+04	4.87E+04	4.25E+04	3.62E+04	2.77E+04	1.90E+04
462.30	2.37E+04	2.36E+04	2.22E+04	1.87E+04	1.62E+04	1.32E+04	9.87E+03
565.70	8.78E+03	8.73E+03	8.26E+03	5.76E+03	5.24E+03	4.62E+03	3.93E+03
692.20	1.50E+03	1.49E+03	1.39E+03	2.39E+02	2.78E+02	3.48E+02	5.00E+02

TABLE 3.2.1.1–2 DAILY AVERAGE INTERNAL PROTON DIFFERENTIAL FLUX SPECTRUM
protons/cm^2–day–MeV at indicated shielding thicknesses

Energy (MeV)	0 Mils	50 Mils	500 Mils	1000 Mils shielding	2000 Mils	4000 Mils	7000 Mils
10.00	1.26E+05	3.44E+04	4.64E+03	2.67E+03	1.36E+03	5.28E+02	1.79E+02
12.24	1.07E+05	2.82E+04	5.32E+03	3.08E+03	1.57E+03	6.13E+02	2.08E+02
14.97	8.36E+04	2.85E+04	6.07E+03	3.56E+03	1.82E+03	7.10E+02	2.41E+02
18.32	5.51E+04	2.59E+04	6.73E+03	4.01E+03	2.06E+03	8.06E+02	2.73E+02
22.41	3.66E+04	2.27E+04	7.52E+03	4.57E+03	2.36E+03	9.27E+02	3.15E+02
27.42	2.81E+04	2.04E+04	8.37E+03	5.17E+03	2.70E+03	1.06E+03	3.65E+02
33.56	2.27E+04	1.94E+04	9.02E+03	5.72E+03	3.04E+03	1.20E+03	4.19E+02
41.06	2.06E+04	1.84E+04	9.64E+03	6.31E+03	3.42E+03	1.37E+03	4.86E+02
50.24	1.80E+04	1.68E+04	9.93E+03	6.67E+03	3.74E+03	1.51E+03	5.55E+02
61.47	1.63E+04	1.54E+04	9.94E+03	6.94E+03	3.91E+03	1.61E+03	6.21E+02
75.21	1.41E+04	1.34E+04	9.40E+03	6.88E+03	3.84E+03	1.64E+03	6.80E+02
92.03	1.19E+04	1.15E+04	8.54E+03	6.42E+03	3.79E+03	1.71E+03	7.16E+02
112.60	9.69E+03	9.40E+03	7.30E+03	5.43E+03	3.60E+03	1.71E+03	7.21E+02
137.80	7.20E+03	6.98E+03	5.40E+03	4.52E+03	2.95E+03	1.52E+03	6.55E+02
168.60	4.98E+03	4.88E+03	4.06E+03	3.21E+03	2.33E+03	1.26E+03	6.11E+02
206.30	3.10E+03	3.06E+03	2.70E+03	2.31E+03	1.62E+03	9.85E+02	5.07E+02
252.40	1.81E+03	1.79E+03	1.62E+03	1.44E+03	1.09E+03	7.13E+02	3.79E+02
308.80	9.90E+02	9.81E+02	9.02E+02	8.15E+02	6.49E+02	4.33E+02	2.48E+02
377.80	4.86E+02	4.81E+02	4.36E+02	3.86E+02	3.25E+02	2.32E+02	1.42E+02
462.30	2.08E+02	2.06E+02	1.93E+02	1.78E+02	1.49E+02	1.12E+02	7.49E+01
565.70	8.14E+01	8.10E+01	7.70E+01	7.25E+01	6.38E+01	5.30E+01	4.00E+01
692.20	3.37E+01	3.35E+01	3.16E+01	1.48E+01	1.47E+01	1.46E+01	1.43E+01

TABLE 3.2.1.2–1 SAA PASS INTERNAL PEAK PROTON INTEGRAL FLUX SPECTRUM
protons/cm^2–day>E at indicated shielding thicknesses

Energy (MeV)	0 Mils	50 Mils	500 Mils	1000 Mils shielding	2000 Mils	4000 Mils	7000 Mils
10.00	1.76E+08	1.62E+08	1.25E+08	9.60E+07	6.22E+07	3.25E+07	1.57E+07
12.24	1.72E+08	1.61E+08	1.24E+08	9.55E+07	6.20E+07	3.24E+07	1.57E+07
14.97	1.67E+08	1.59E+08	1.23E+08	9.47E+07	6.16E+07	3.22E+07	1.56E+07
18.32	1.63E+08	1.57E+08	1.21E+08	9.37E+07	6.11E+07	3.20E+07	1.56E+07
22.41	1.59E+08	1.54E+08	1.19E+08	9.24E+07	6.04E+07	3.17E+07	1.55E+07
27.42	1.54E+08	1.50E+08	1.16E+08	9.04E+07	5.94E+07	3.13E+07	1.53E+07
33.56	1.49E+08	1.45E+08	1.13E+08	8.78E+07	5.80E+07	3.08E+07	1.51E+07
41.06	1.42E+08	1.38E+08	1.08E+08	8.43E+07	5.61E+07	3.00E+07	1.49E+07
50.24	1.31E+08	1.28E+08	1.01E+08	7.96E+07	5.34E+07	2.90E+07	1.45E+07
61.47	1.18E+08	1.15E+08	9.20E+07	7.36E+07	5.00E+07	2.76E+07	1.39E+07
75.21	1.03E+08	1.01E+08	8.16E+07	6.61E+07	4.58E+07	2.58E+07	1.32E+07
92.03	8.61E+07	8.42E+07	6.97E+07	5.73E+07	4.06E+07	2.36E+07	1.22E+07
112.60	6.86E+07	6.73E+07	5.68E+07	4.76E+07	3.45E+07	2.07E+07	1.10E+07
137.80	5.18E+07	5.10E+07	4.40E+07	3.75E+07	2.79E+07	1.75E+07	9.55E+06
168.60	3.68E+07	3.63E+07	3.24E+07	2.80E+07	2.14E+07	1.40E+07	7.88E+06
206.30	2.46E+07	2.44E+07	2.22E+07	1.97E+07	1.55E+07	1.05E+07	6.04E+06
252.40	1.56E+07	1.54E+07	1.42E+07	1.27E+07	1.03E+07	7.17E+06	4.22E+06
308.80	9.00E+06	8.92E+06	8.22E+06	7.31E+06	6.06E+06	4.32E+06	2.63E+06
377.80	4.56E+06	4.52E+06	4.17E+06	3.66E+06	3.07E+06	2.25E+06	1.41E+06
462.30	1.92E+06	1.91E+06	1.78E+06	1.50E+06	1.26E+06	9.47E+05	6.07E+05
565.70	6.01E+05	5.97E+05	5.57E+05	3.72E+05	3.14E+05	2.40E+05	1.57E+05
692.20	4.92E+04	4.87E+04	4.43E+04	2.36E+00	2.76E+00	3.55E+00	5.24E+00

TABLE 3.2.1.2–2 SAA PASS INTERNAL PEAK PROTON DIFFERENTIAL FLUX SPECTRUM
protons/cm^2–day–MeV at indicated shielding thicknesses

Energy (MeV)	0 Mils	50 Mils	500 Mils	1000 Mils shielding	2000 Mils	4000 Mils	7000 Mils
10.00	2.08E+06	7.00E+05	3.16E+05	2.10E+05	1.07E+05	4.23E+04	1.45E+04
12.24	1.82E+06	6.35E+05	3.63E+05	2.43E+05	1.24E+05	4.91E+04	1.68E+04
14.97	1.50E+06	6.86E+05	4.16E+05	2.80E+05	1.44E+05	5.68E+04	1.95E+04
18.32	1.11E+06	6.97E+05	4.65E+05	3.15E+05	1.63E+05	6.45E+04	2.21E+04
22.41	8.98E+05	7.18E+05	5.25E+05	3.59E+05	1.87E+05	7.42E+04	2.55E+04
27.42	8.59E+05	7.78E+05	5.92E+05	4.07E+05	2.14E+05	8.51E+04	2.96E+04
33.56	9.02E+05	8.86E+05	6.50E+05	4.50E+05	2.41E+05	9.61E+04	3.40E+04
41.06	1.04E+06	1.03E+06	7.15E+05	4.96E+05	2.72E+05	1.09E+05	3.95E+04
50.24	1.19E+06	1.13E+06	7.67E+05	5.24E+05	2.98E+05	1.21E+05	4.51E+04
61.47	1.14E+06	1.09E+06	7.82E+05	5.46E+05	3.12E+05	1.28E+05	5.07E+04
75.21	1.08E+06	1.04E+06	7.39E+05	5.43E+05	3.08E+05	1.30E+05	5.57E+04
92.03	9.36E+05	9.00E+05	6.72E+05	5.09E+05	3.04E+05	1.36E+05	5.91E+04
112.60	7.64E+05	7.41E+05	5.80E+05	4.35E+05	2.89E+05	1.36E+05	6.03E+04
137.80	5.74E+05	5.57E+05	4.34E+05	3.63E+05	2.35E+05	1.23E+05	5.61E+04
168.60	3.99E+05	3.92E+05	3.25E+05	2.56E+05	1.86E+05	1.03E+05	5.29E+04
206.30	2.47E+05	2.43E+05	2.15E+05	1.85E+05	1.31E+05	8.31E+04	4.47E+04
252.40	1.47E+05	1.46E+05	1.33E+05	1.19E+05	9.25E+04	6.20E+04	3.40E+04
308.80	8.51E+04	8.44E+04	7.79E+04	7.08E+04	5.71E+04	3.89E+04	2.26E+04
377.80	4.37E+04	4.32E+04	3.93E+04	3.50E+04	2.96E+04	2.10E+04	1.27E+04
462.30	1.88E+04	1.86E+04	1.74E+04	1.60E+04	1.33E+04	9.88E+03	6.24E+03
565.70	6.79E+03	6.74E+03	6.32E+03	5.86E+03	4.96E+03	3.79E+03	2.47E+03
692.20	1.94E+03	1.93E+03	1.78E+03	1.48E+01	1.47E+01	1.46E+01	1.43E+01

TABLE 3.2.1.4–1 COMBINED INTEGRAL FLUX LET SPECTRA (WI = 4)
NO SOLAR FLARE FLUX Sheet 1 of 2
particles/cm^2–day>LET at indicated shielding thicknesses

LET (MeV cm^2/mg)	50 Mils	500 Mils	1000 Mils shielding	2000 Mils	4000 Mils	7000 Mils
1.69E–03	2.848E+06	1.687E+06	1.286E+06	8.538E+05	4.695E+05	2.571E+05
2.12E–03	2.779E+06	1.618E+06	1.217E+06	7.855E+05	4.021E+05	1.903E+05
2.65E–03	2.737E+06	1.579E+06	1.181E+06	7.542E+05	3.792E+05	1.745E+05
3.31E–03	2.613E+06	1.467E+06	1.081E+06	6.743E+05	3.259E+05	1.441E+05
4.13E–03	2.403E+06	1.286E+06	9.269E+05	5.588E+05	2.574E+05	1.086E+05
5.16E–03	2.108E+06	1.045E+06	7.309E+05	4.255E+05	1.870E+05	7.564E+04
6.45E–03	1.783E+06	7.954E+05	5.416E+05	3.026E+05	1.286E+05	5.089E+04
8.06E–03	1.461E+06	5.632E+05	3.689E+05	2.017E+05	8.231E+04	3.067E+04
1.01E–02	1.187E+06	3.854E+05	2.439E+05	1.309E+05	5.257E+04	1.880E+04
1.26E–02	9.565E+05	2.552E+05	1.569E+05	8.261E+04	3.295E+04	1.156E+04
1.57E–02	7.708E+05	1.673E+05	1.006E+05	5.247E+04	2.089E+04	7.271E+03
1.96E–02	6.155E+05	1.063E+05	6.285E+04	3.263E+04	1.302E+04	4.529E+03
2.45E–02	4.780E+05	6.707E+04	3.917E+04	2.033E+04	8.157E+03	2.859E+03
3.07E–02	3.566E+05	4.118E+04	2.394E+04	1.247E+04	5.051E+03	1.792E+03
3.83E–02	2.579E+05	2.556E+04	1.488E+04	7.815E+03	3.214E+03	1.162E+03
4.79E–02	1.715E+05	1.562E+04	9.152E+03	4.872E+03	2.045E+03	7.565E+02
5.98E–02	1.108E+05	9.820E+03	5.827E+03	3.166E+03	1.368E+03	5.225E+02
7.48E–02	6.718E+04	5.850E+03	3.500E+03	1.922E+03	8.389E+02	3.209E+02
9.34E–02	4.169E+04	3.696E+03	2.253E+03	1.266E+03	5.680E+02	2.221E+02
1.17E–01	2.509E+04	2.275E+03	1.409E+03	8.061E+02	3.679E+02	1.449E+02
1.46E–01	1.472E+04	1.353E+03	8.450E+02	4.851E+02	2.198E+02	8.447E+01
1.82E–01	8.440E+03	8.353E+02	5.383E+02	3.189E+02	1.486E+02	5.775E+01
2.28E–01	4.680E+03	5.171E+02	3.464E+02	2.123E+02	1.015E+02	3.967E+01
2.85E–01	2.530E+03	3.144E+02	2.175E+02	1.363E+02	6.572E+01	2.539E+01
3.56E–01	1.272E+03	1.897E+02	1.367E+02	8.794E+01	4.271E+01	1.622E+01
4.44E–01	5.622E+02	1.079E+02	8.099E+01	5.301E+01	2.545E+01	9.268E+00
5.55E–01	6.798E+01	5.778E+01	4.837E+01	3.365E+01	1.651E+01	5.867E+00
6.94E–01	5.788E+01	4.897E+01	4.084E+01	2.823E+01	1.367E+01	4.751E+00
8.67E–01	4.842E+01	4.077E+01	3.384E+01	2.320E+01	1.105E+01	3.740E+00
1.08E+00	3.927E+01	3.295E+01	2.728E+01	1.861E+01	8.792E+00	2.931E+00
1.35E+00	1.479E+01	1.224E+01	1.011E+01	6.804E+00	3.163E+00	1.037E+00
1.69E+00	5.344E+00	4.309E+00	3.550E+00	2.315E+00	1.034E+00	3.305E–01
2.11E+00	2.887E+00	2.270E+00	1.903E+00	1.233E+00	5.492E–01	1.780E–01
2.64E+00	1.706E+00	1.256E+00	1.068E+00	6.936E–01	3.089E–01	1.006E–01

TABLE 3.2.1.4–1 COMBINED INTEGRAL FLUX LET SPECTRA (WI = 4)
NO SOLAR FLARE FLUX Sheet 2 of 2
particles/cm^2–day>LET at indicated shielding thicknesses

LET (MeV cm^2/mg)	50 Mils	500 Mils	1000 Mils shielding	2000 Mils	4000 Mils	7000 Mils
3.30E+00	1.080E+00	7.212E–01	6.204E–01	4.037E–01	1.795E–01	5.861E–02
4.12E+00	7.152E–01	4.214E–01	3.644E–01	2.374E–01	1.053E–01	3.436E–02
5.15E+00	4.870E–01	2.490E–01	2.153E–01	1.402E–01	6.191E–02	2.011E–02
6.44E+00	3.302E–01	1.477E–01	1.275E–01	8.281E–02	3.629E–02	1.167E–02
8.04E+00	2.144E–01	8.509E–02	7.307E–02	4.723E–02	2.042E–02	6.453E–03
1.01E+01	1.376E–01	4.945E–02	4.241E–02	2.734E–02	1.176E–02	3.686E–03
1.26E+01	8.579E–02	2.777E–02	2.374E–02	1.520E–02	6.469E–03	1.995E–03
1.57E+01	5.079E–02	1.463E–02	1.250E–02	7.927E–03	3.340E–03	1.008E–03
1.96E+01	2.856E–02	7.613E–03	6.496E–03	4.096E–03	1.719E–03	5.142E–04
2.45E+01	1.351E–02	3.210E–03	2.720E–03	1.697E–03	7.076E–04	2.093E–04
3.06E+01	3.346E–05	6.596E–05	5.739E–05	3.504E–05	1.417E–05	3.966E–06
3.82E+01	1.600E–06	2.754E–06	1.981E–06	1.010E–06	2.781E–07	4.648E–08
4.78E+01	6.727E–07	1.197E–06	8.324E–07	4.067E–07	9.899E–08	1.420E–08
5.97E+01	2.640E–07	4.865E–07	3.309E–07	1.553E–07	3.390E–08	4.316E–09
7.46E+01	8.124E–08	1.595E–07	1.064E–07	4.739E–08	9.124E–09	1.005E–09
9.32E+01	1.121E–08	2.326E–08	1.539E–08	6.594E–09	1.176E–09	1.206E–10
1.04E+02	7.750E–10	1.508E–09	9.807E–10	3.910E–10	6.416E–11	6.079E–12

TABLE 3.2.2–1 MAXIMUM SOLAR FLARE PEAK PROTON INTEGRAL FLUX SPECTRUM
protons/cm^2–day>E at indicated shielding thicknesses

Energy (MeV)	0 Mils	50 Mils	500 Mils	1000 Mils shielding	2000 Mils	4000 Mils	7000 Mils
10.00	2.90E+10	1.94E+10	4.14E+09	2.07E+09	9.11E+08	3.46E+08	1.38E+08
12.24	2.62E+10	1.80E+10	4.06E+09	2.05E+09	9.05E+08	3.45E+08	1.37E+08
14.97	2.30E+10	1.63E+10	3.95E+09	2.01E+09	8.96E+08	3.43E+08	1.37E+08
18.32	1.95E+10	1.43E+10	3.80E+09	1.97E+09	8.84E+08	3.40E+08	1.36E+08
22.41	1.58E+10	1.21E+10	3.61E+09	1.90E+09	8.67E+08	3.36E+08	1.35E+08
27.42	1.22E+10	9.85E+09	3.37E+09	1.82E+09	8.43E+08	3.30E+08	1.34E+08
33.56	9.13E+09	7.84E+09	3.07E+09	1.71E+09	8.12E+08	3.22E+08	1.32E+08
41.06	6.78E+09	6.06E+09	2.71E+09	1.57E+09	7.69E+08	3.12E+08	1.29E+08
50.24	4.92E+09	4.51E+09	2.31E+09	1.41E+09	7.13E+08	2.97E+08	1.25E+08
61.47	3.48E+09	3.25E+09	1.89E+09	1.21E+09	6.46E+08	2.78E+08	1.20E+08
75.21	2.39E+09	2.27E+09	1.47E+09	1.01E+09	5.66E+08	2.54E+08	1.13E+08
92.03	1.60E+09	1.54E+09	1.10E+09	7.95E+08	4.75E+08	2.26E+08	1.03E+08
112.60	1.04E+09	1.01E+09	7.86E+08	5.95E+08	3.79E+08	1.93E+08	9.19E+07
137.80	6.52E+08	6.39E+08	5.29E+08	4.24E+08	2.87E+08	1.57E+08	7.86E+07
168.60	3.96E+08	3.90E+08	3.40E+08	2.87E+08	2.04E+08	1.21E+08	6.43E+07
206.30	2.31E+08	2.29E+08	2.06E+08	1.83E+08	1.38E+08	8.76E+07	4.93E+07
252.40	1.29E+08	1.28E+08	1.19E+08	1.08E+08	8.85E+07	5.85E+07	3.51E+07
308.80	6.90E+07	6.86E+07	6.44E+07	5.99E+07	5.15E+07	3.63E+07	2.32E+07
377.80	3.45E+07	3.43E+07	3.26E+07	3.07E+07	2.73E+07	2.11E+07	1.37E+07
462.30	1.57E+07	1.56E+07	1.50E+07	1.43E+07	1.30E+07	1.06E+07	7.25E+06
565.70	5.80E+06	5.78E+06	5.59E+06	5.39E+06	4.99E+06	4.23E+06	3.14E+06
692.20	8.94E+05	8.91E+05	8.69E+05	8.49E+05	8.12E+05	7.20E+05	5.81E+05

TABLE 3.2.2–2 MAXIMUM SOLAR FLARE PEAK PROTON DIFFERENTIAL FLUX SPECTRUM
protons/cm^2–day–MeV at indicated shielding thicknesses

Energy (MeV)	0 Mils	50 Mils	500 Mils	1000 Mils shielding	2000 Mils	4000 Mils	7000 Mils
10.00	1.31E+09	6.22E+08	3.48E+07	1.01E+07	2.59E+06	6.00E+05	1.50E+05
12.24	1.22E+09	6.31E+08	3.91E+07	1.16E+07	3.00E+06	6.95E+05	1.73E+05
14.97	1.11E+09	6.36E+08	4.32E+07	1.32E+07	3.45E+06	8.05E+05	2.00E+05
18.32	9.79E+08	5.76E+08	4.55E+07	1.46E+07	3.88E+06	9.12E+05	2.27E+05
22.41	8.18E+08	5.01E+08	4.73E+07	1.62E+07	4.41E+06	1.05E+06	2.60E+05
27.42	6.20E+08	3.82E+08	4.92E+07	1.75E+07	4.97E+06	1.20E+06	2.98E+05
33.56	3.78E+08	2.74E+08	4.91E+07	1.80E+07	5.45E+06	1.35E+06	3.36E+05
41.06	2.48E+08	2.00E+08	4.63E+07	1.82E+07	5.94E+06	1.52E+06	3.89E+05
50.24	1.58E+08	1.36E+08	4.05E+07	1.80E+07	6.13E+06	1.66E+06	4.43E+05
61.47	9.87E+07	8.82E+07	3.46E+07	1.66E+07	5.91E+06	1.73E+06	4.95E+05
75.21	5.93E+07	5.45E+07	2.60E+07	1.37E+07	5.72E+06	1.70E+06	5.39E+05
92.03	3.48E+07	3.27E+07	1.80E+07	1.13E+07	5.14E+06	1.62E+06	5.63E+05
112.60	1.98E+07	1.89E+07	1.26E+07	8.12E+06	4.15E+06	1.58E+06	5.60E+05
137.80	1.09E+07	1.05E+07	7.77E+06	5.48E+06	3.19E+06	1.33E+06	4.96E+05
168.60	5.78E+06	5.65E+06	4.56E+06	3.44E+06	2.17E+06	1.00E+06	4.29E+05
206.30	2.96E+06	2.91E+06	2.51E+06	2.09E+06	1.32E+06	7.58E+05	3.69E+05
252.40	1.45E+06	1.44E+06	1.29E+06	1.14E+06	8.40E+05	5.06E+05	2.46E+05
308.80	6.88E+05	6.82E+05	6.32E+05	5.78E+05	4.72E+05	2.79E+05	1.76E+05
377.80	3.12E+05	3.10E+05	2.90E+05	2.68E+05	2.31E+05	1.63E+05	1.01E+05
462.30	1.35E+05	1.34E+05	1.28E+05	1.21E+05	1.08E+05	8.40E+04	5.13E+04
565.70	5.58E+04	5.55E+04	5.36E+04	5.14E+04	4.71E+04	3.93E+04	2.82E+04
692.20	2.19E+04	2.18E+04	2.11E+04	2.04E+04	1.90E+04	1.62E+04	1.22E+04

TABLE 3.2.2–3 MAXIMUM SOLAR FLARE PEAK HEAVY ION INTEGRAL FLUX
Sheet 1 of 2
particles/cm^2–day>LET at indicated shielding thicknesses

LET (MeV cm^2/mg)	50 Mils	500 Mils	1000 Mils shielding	2000 Mils	4000 Mils	7000 Mils
1.61E–03	1.82E+10	4.18E+09	2.04E+09	8.82E+08	3.31E+08	1.32E+08
2.13E–03	1.82E+10	4.17E+09	2.03E+09	8.75E+08	3.25E+08	1.28E+08
2.81E–03	1.82E+10	4.12E+09	1.98E+09	8.34E+08	2.96E+08	1.09E+08
3.71E–03	1.80E+10	3.95E+09	1.84E+09	7.34E+08	2.39E+08	8.03E+07
4.90E–03	1.75E+10	3.60E+09	1.58E+09	5.80E+08	1.70E+08	5.22E+07
6.47E–03	1.66E+10	3.05E+09	1.23E+09	4.07E+08	1.09E+08	3.12E+07
8.55E–03	1.50E+10	2.34E+09	8.63E+08	2.61E+08	6.52E+07	1.77E+07
1.13E–02	1.26E+10	1.64E+09	5.55E+08	1.55E+08	3.74E+07	9.78E+06
1.49E–02	9.50E+09	1.06E+09	3.34E+08	8.88E+07	2.09E+07	5.37E+06
1.97E–02	5.94E+09	6.38E+08	1.91E+08	4.94E+07	1.15E+07	2.92E+06
2.61E–02	2.35E+09	3.63E+08	1.05E+08	2.67E+07	6.13E+06	1.56E+06
3.44E–02	8.55E+07	2.02E+08	5.73E+07	1.44E+07	3.30E+06	8.35E+05
4.55E–02	8.11E+07	1.10E+08	3.09E+07	7.72E+06	1.76E+06	4.45E+05
6.01E–02	7.31E+07	5.94E+07	1.65E+07	4.10E+06	9.33E+05	2.36E+05
7.94E–02	6.09E+07	3.16E+07	8.71E+06	2.17E+06	4.92E+05	1.24E+05
1.05E–01	4.54E+07	1.65E+07	4.52E+06	1.12E+06	2.55E+05	6.42E+04
1.39E–01	3.11E+07	8.31E+06	2.27E+06	5.64E+05	1.28E+05	3.22E+04
1.83E–01	1.96E+07	4.13E+06	1.13E+06	2.78E+05	6.30E+04	1.59E+04
2.42E–01	1.19E+07	1.92E+06	5.20E+05	1.28E+05	2.89E+04	7.29E+03
3.19E–01	7.20E+06	8.38E+05	2.25E+05	5.51E+04	1.24E+04	3.12E+03
4.22E–01	4.41E+06	2.93E+05	7.66E+04	1.84E+04	4.11E+03	1.03E+03
5.57E–01	2.75E+06	2.21E+04	3.30E+03	3.78E+02	3.21E+01	2.90E+00
7.36E–01	1.75E+06	1.26E+04	1.81E+03	1.99E+02	1.65E+01	1.48E+00
9.73E–01	1.09E+06	6.78E+03	9.32E+02	9.85E+01	7.86E+00	6.93E–01
1.29E+00	6.58E+05	3.38E+03	4.37E+02	4.29E+01	3.17E+00	2.67E–01
1.70E+00	3.54E+05	1.33E+03	1.45E+02	1.06E+01	4.61E–01	2.08E–02
2.24E+00	2.37E+05	7.80E+02	8.28E+01	5.90E+00	2.51E–01	1.12E–02
2.96E+00	1.51E+05	4.44E+02	4.56E+01	3.16E+00	1.32E–01	5.87E–03
3.91E+00	9.28E+04	2.44E+02	2.42E+01	1.63E+00	6.69E–02	2.93E–03
5.17E+00	5.29E+04	1.20E+02	1.13E+01	7.19E–01	2.73E–02	1.11E–03
6.83E+00	2.85E+04	5.43E+01	4.82E+00	2.89E–01	1.01E–02	3.79E–04
9.03E+00	1.41E+04	2.14E+01	1.71E+00	9.03E–02	2.56E–03	7.55E–05
1.19E+01	6.56E+03	7.98E+00	5.83E–01	2.66E–02	6.14E–04	1.41E–05
1.58E+01	2.91E+03	2.95E+00	2.02E–01	7.99E–03	1.48E–04	2.41E–06
2.08E+01	1.31E+03	1.22E+00	8.21E–02	3.14E–03	5.47E–05	8.05E–07

TABLE 3.2.2–3 MAXIMUM SOLAR FLARE PEAK HEAVY ION INTEGRAL FLUX
Sheet 2 of 2
particles/cm^2–day>LET at indicated shielding thicknesses

LET (MeV cm^2/mg)	50 Mils	500 Mils	1000 Mils shielding	2000 Mils	4000 Mils	7000 Mils
2.75E+01	2.45E+02	2.20E–01	1.47E–02	5.57E–04	9.58E–06	1.39E–07
3.63E+01	2.11E–01	1.01E–04	4.84E–06	1.29E–07	1.34E–09	1.16E–11
4.80E+01	6.29E–02	1.96E–05	7.30E–07	1.39E–08	8.80E–11	4.14E–13
6.34E+01	1.65E–02	3.42E–06	9.75E–08	1.28E–09	4.83E–12	1.32E–14
8.37E+01	3.94E–03	6.50E–07	1.67E–08	1.85E–10	5.19E–13	9.11E–16

TABLE 3.2.2–4 MAXIMUM SOLAR FLARE ORBIT–AVERAGED HEAVY ION INTEGRAL FLUENCE Sheet 1 of 2
particles/cm^2>LET at indicated shielding thicknesses

LET (MeV cm^2/mg)	50 Mils	500 Mils	1000 Mils shielding	2000 Mils	4000 Mils	7000 Mils
1.61E–03	5.26E+08	1.85E+08	1.08E+08	5.65E+07	2.59E+07	1.20E+07
2.13E–03	5.25E+08	1.83E+08	1.07E+08	5.65E+07	2.51E+07	1.14E+07
2.81E–03	5.19E+08	1.78E+08	1.02E+08	5.15E+07	2.21E+07	9.37E+06
3.71E–03	5.04E+08	1.66E+08	9.14E+07	4.33E+07	1.71E+07	6.65E+06
4.90E–03	4.77E+08	1.44E+08	7.47E+07	3.25E+07	1.17E+07	4.22E+06
6.47E–03	4.33E+08	1.16E+08	5.56E+07	2.19E+07	7.27E+06	2.48E+06
8.55E–03	3.72E+08	8.47E+07	3.76E+07	1.36E+07	4.27E+06	1.39E+06
1.13E–02	2.99E+08	5.67E+07	2.36E+07	7.95E+06	2.42E+06	7.68E+05
1.49E–02	2.23E+08	3.54E+07	1.40E+07	4.51E+06	1.34E+06	4.20E+05
1.97E–02	1.54E+08	2.10E+07	7.97E+06	2.50E+06	7.35E+05	2.29E+05
2.61E–02	9.90E+07	1.18E+07	4.36E+06	1.35E+06	3.93E+05	1.21E+05
3.44E–02	6.12E+07	6.60E+06	2.39E+06	7.30E+05	2.11E+05	6.52E+04
4.55E–02	3.62E+07	3.61E+06	1.29E+06	3.91E+05	1.13E+05	3.47E+04
6.01E–02	2.10E+07	1.95E+06	6.87E+05	2.08E+05	5.97E+04	1.84E+04
7.94E–02	1.21E+07	1.04E+06	3.64E+05	1.10E+05	3.15E+04	9.69E+03
1.05E–01	6.86E+06	5.47E+05	1.89E+05	5.69E+04	1.63E+04	5.01E+03
1.39E–01	3.77E+06	2.78E+05	9.56E+04	2.86E+04	8.18E+03	2.51E+03
1.83E–01	2.03E+06	1.40E+05	4.76E+04	1.42E+04	4.04E+03	1.24E+03
2.42E–01	1.06E+06	6.63E+04	2.23E+04	6.56E+03	1.86E+03	5.69E+02
3.19E–01	5.56E+05	3.01E+04	9.82E+03	2.84E+03	7.98E+02	2.44E+02
4.22E–01	2.85E+05	1.15E+04	3.51E+03	9.72E+02	2.66E+02	8.06E+01
5.57E–01	1.38E+05	2.11E+03	3.64E+02	4.69E+01	4.52E+00	4.62E–01
7.36E–01	9.52E+04	1.25E+03	2.06E+02	2.53E+01	2.35E+00	2.36E–01
9.73E–01	6.47E+04	7.12E+02	1.11E+02	1.30E+01	1.15E+00	1.12E–01
1.29E+00	4.27E+04	3.86E+02	5.68E+01	6.11E+00	4.87E–01	4.46E–02
1.70E+00	2.66E+04	1.86E+02	2.42E+01	2.08E+00	1.06E–01	5.58E–03
2.24E+00	1.84E+04	1.14E+02	1.43E+01	1.18E+00	5.78E–02	3.01E–03
2.96E+00	1.23E+04	6.79E+01	8.12E+00	6.38E–01	3.06E–02	1.58E–03
3.91E+00	8.08E+03	3.87E+01	4.44E+00	3.36E–01	1.57E–02	7.97E–04
5.17E+00	5.05E+03	2.02E+01	2.20E+00	1.56E–01	6.79E–03	3.20E–04
6.83E+00	3.00E+03	9.84E+00	1.01E+00	6.74E–02	2.69E–03	1.16E–04
9.03E+00	1.65E+03	4.36E+00	4.14E–01	2.48E–02	8.20E–04	2.79E–05
1.19E+01	8.39E+02	1.85E+00	1.65E–01	8.75E–03	2.38E–04	6.16E–06
1.58E+01	4.02E+02	7.68E–01	6.66E–02	3.16E–03	7.06E–05	1.34E–06

TABLE 3.2.2–4 MAXIMUM SOLAR FLARE ORBIT–AVERAGED HEAVY ION INTEGRAL FLUENCE Sheet 2 of 2
particles/cm^2>LET at indicated shielding thicknesses

LET (MeV cm^2/mg)	50 Mils	500 Mils	1000 Mils shielding	2000 Mils	4000 Mils	7000 Mils
2.08E+01	1.83E+02	3.28E–01	2.81E–02	1.30E–03	2.75E–05	4.83E–07
2.75E+01	3.47E+01	5.98E–02	5.09E–03	2.32E–04	4.86E–06	8.43E–08
3.63E+01	1.48E–01	7.57E–05	3.76E–06	1.09E–07	1.30E–09	1.16E–11
4.80E+01	6.29E–02	1.96E–05	7.30E–07	1.39E–08	8.80E–11	4.14E–13
6.34E+01	1.65E–02	3.42E–06	9.75E–08	1.28E–09	4.83E–12	1.32E–14
8.37E+01	3.94E–03	6.50E–07	1.67E–08	1.85E–10	5.19E–13	9.11E–16

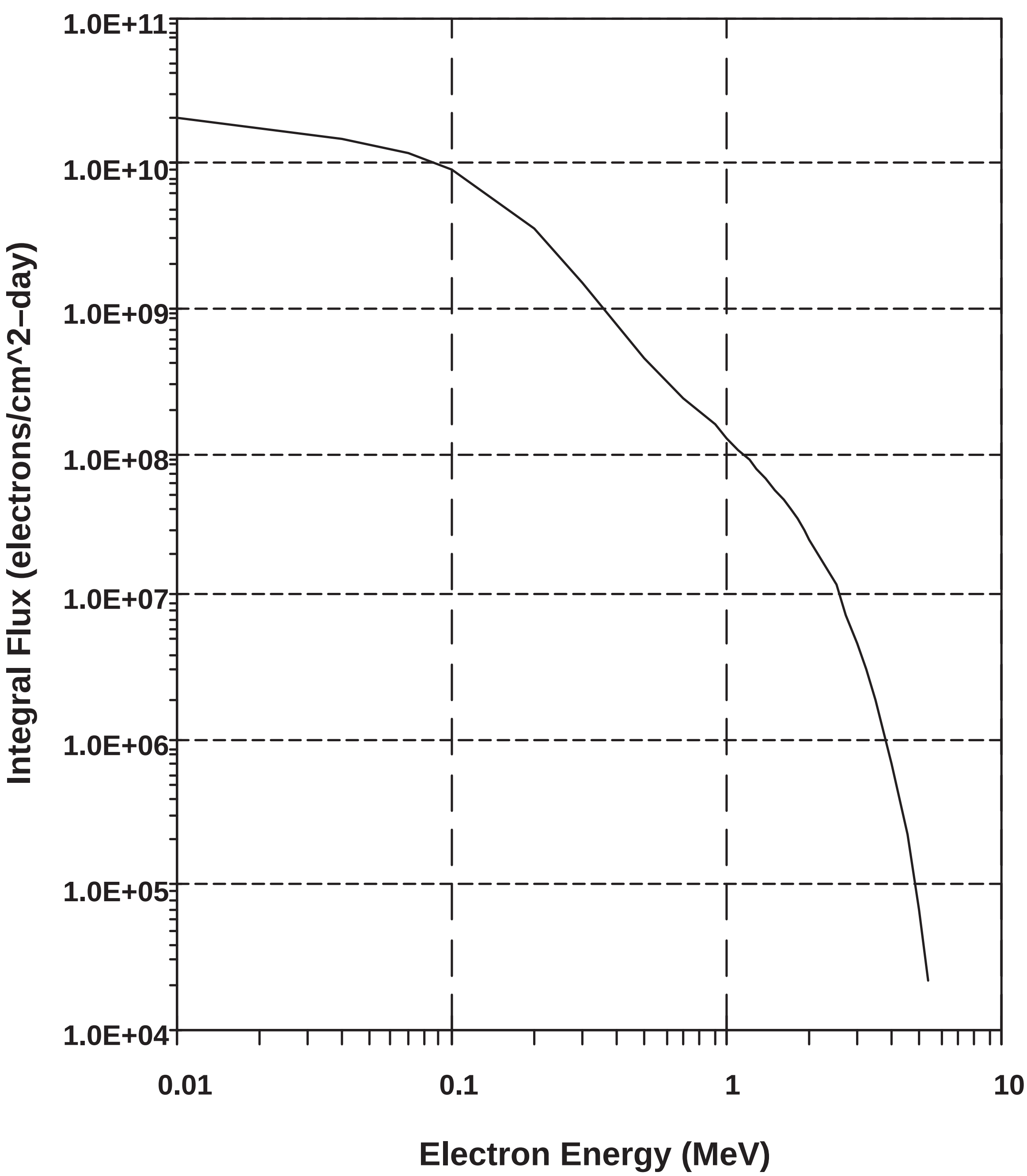

FIGURE 3.1.1–1 AE8MAX ELECTRON INTEGRAL FLUX

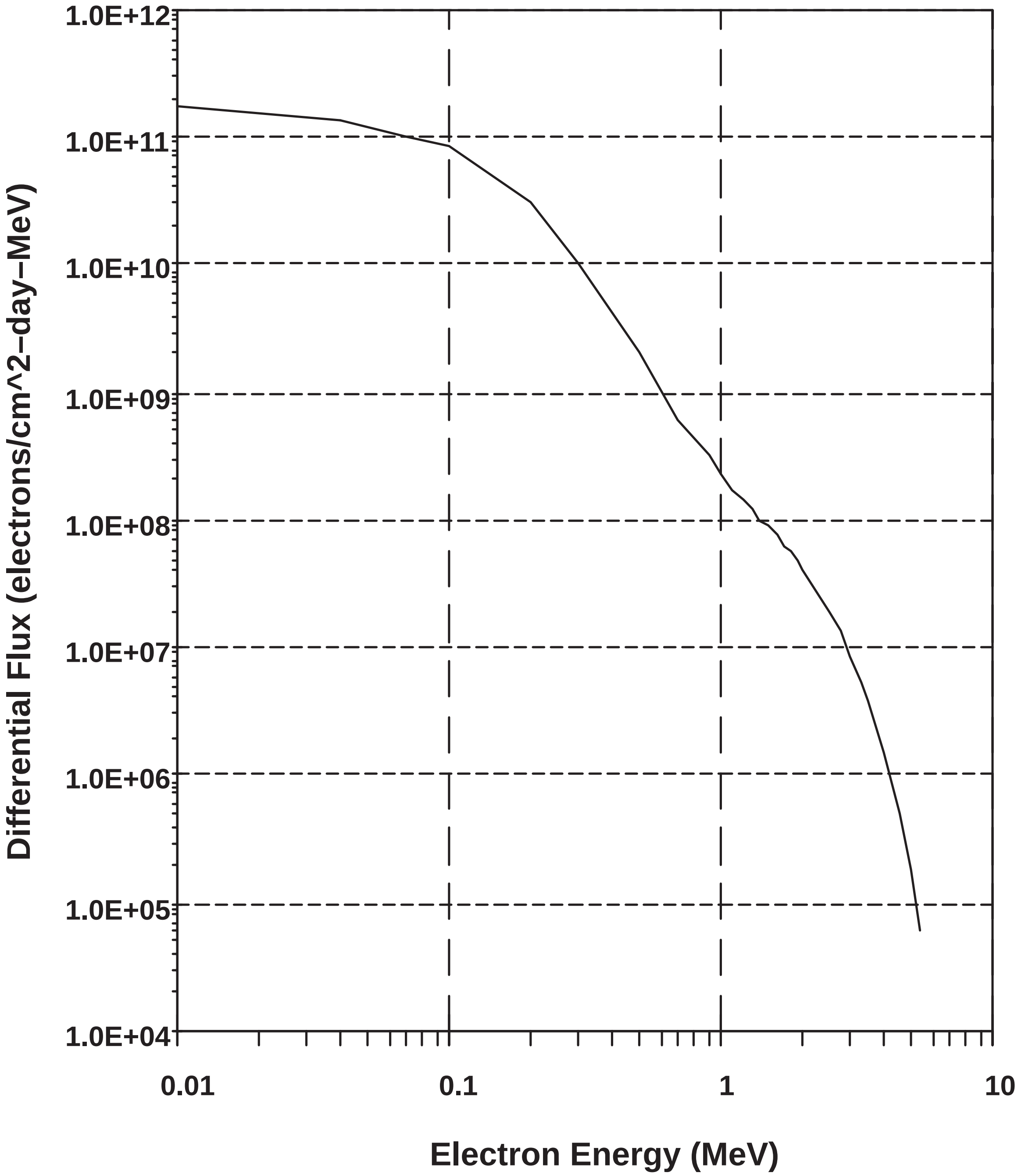

FIGURE 3.1.1–2 AE8MAX ELECTRON DIFFERENTIAL FLUX

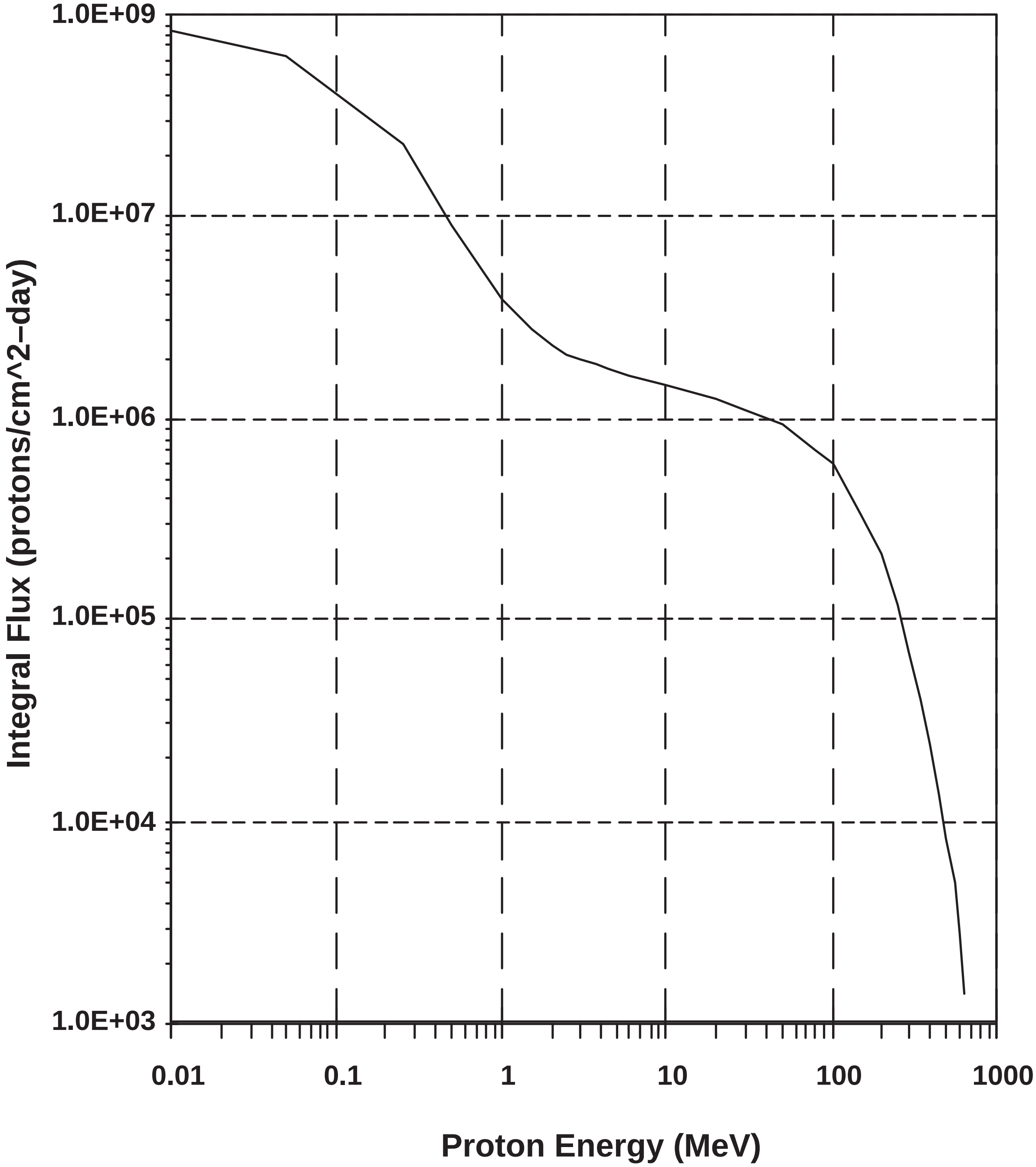

FIGURE 3.1.1–3 AP8MAX PROTON INTEGRAL FLUX

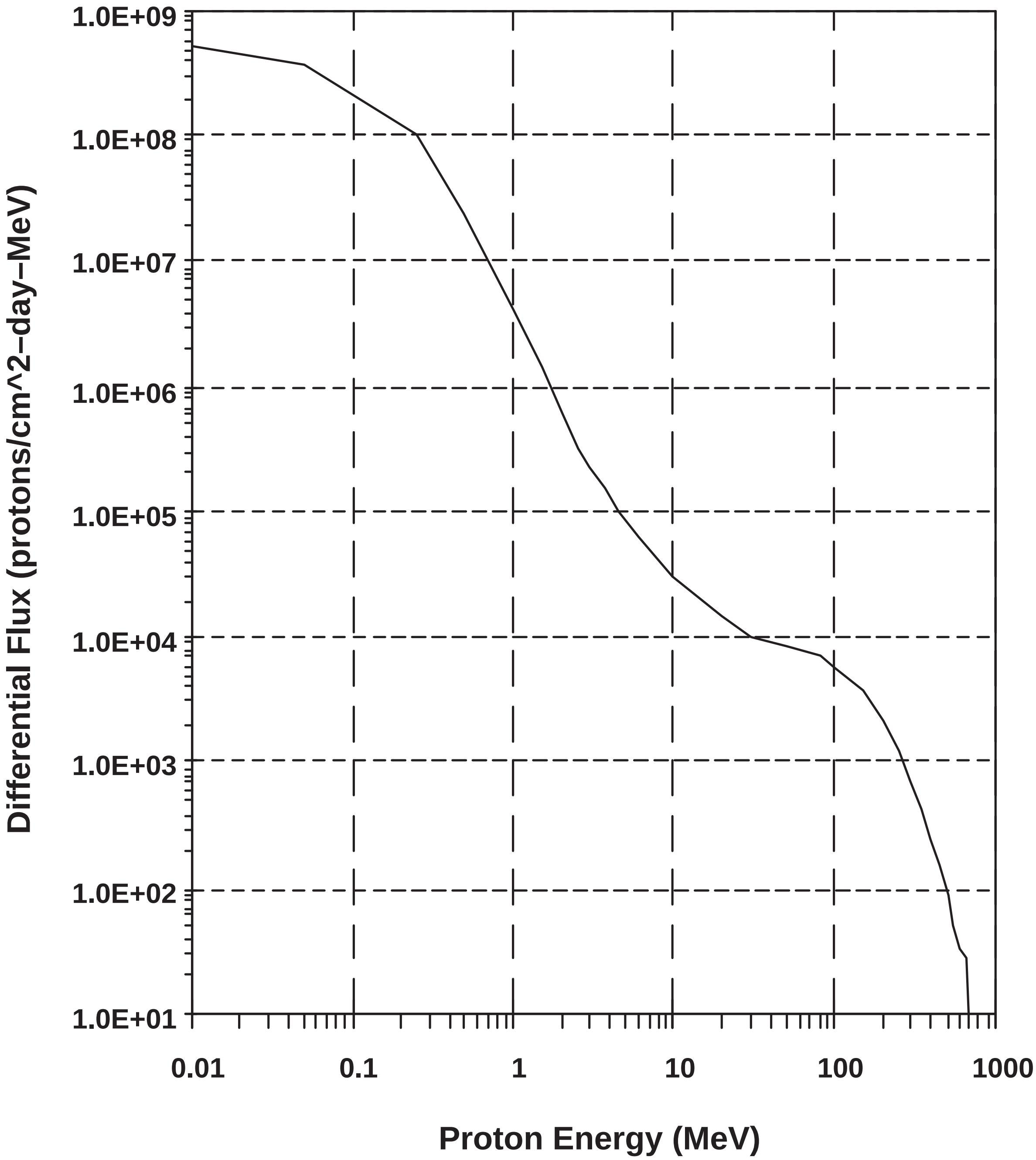

FIGURE 3.1.1–4 AP8MAX PROTON DIFFERENTIAL FLUX

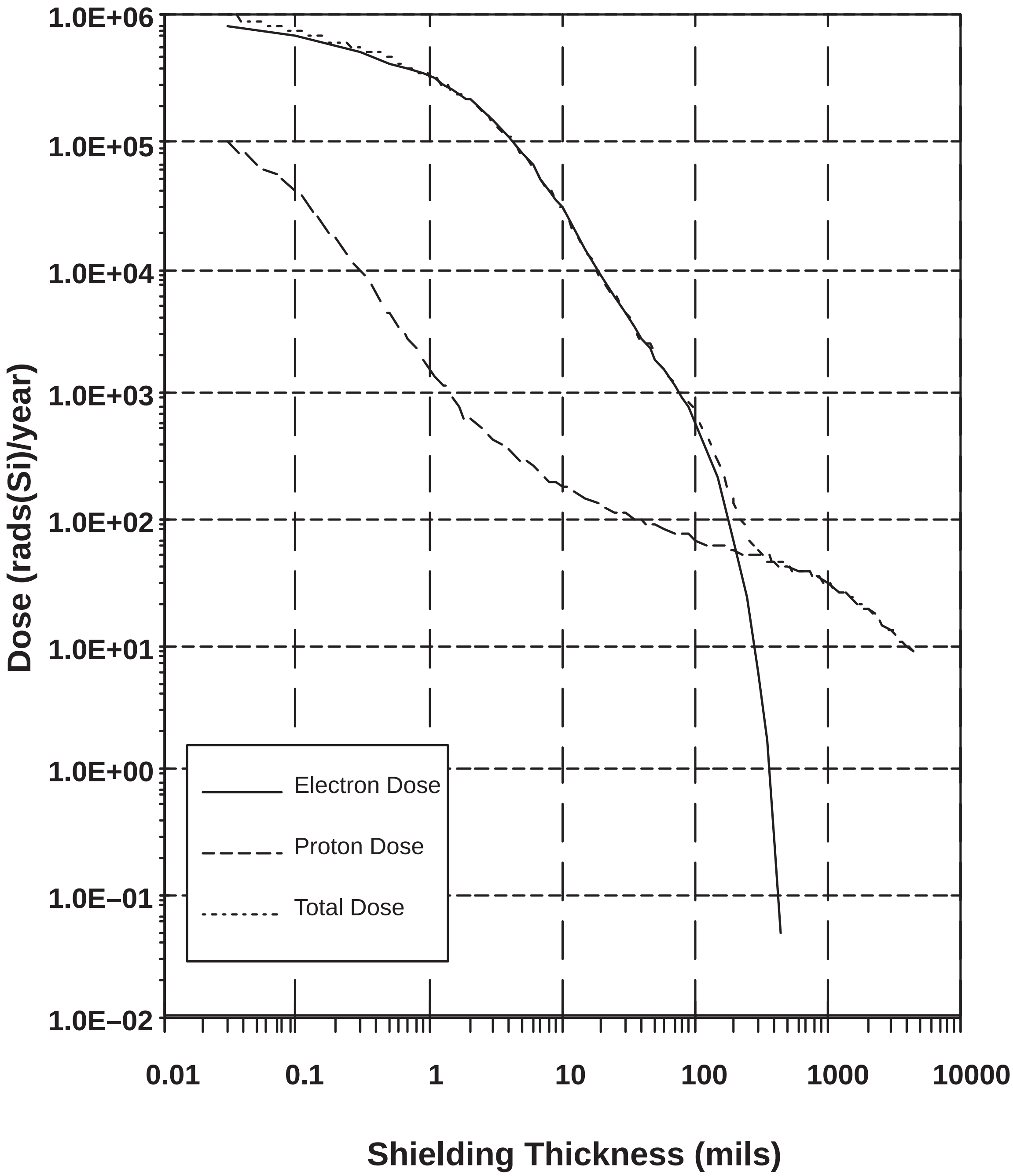

FIGURE 3.1.3–1 ONE YEAR DOSE AT THE CENTER OF A SOLID ALUMINUM SPHERE

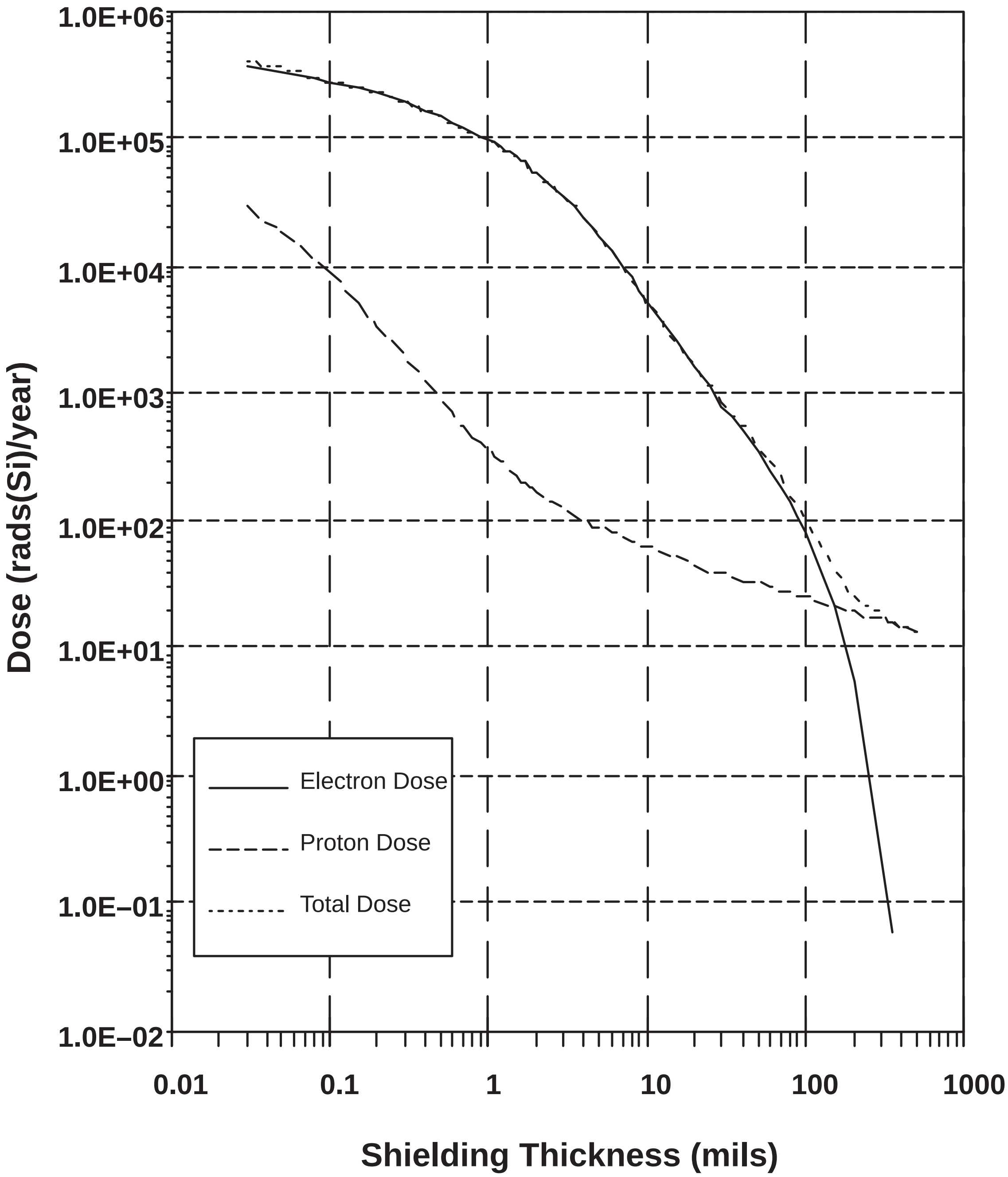

FIGURE 3.1.3–2 ONE YEAR DOSE IN A SEMI–INFINITE ALUMINUM MEDIUM

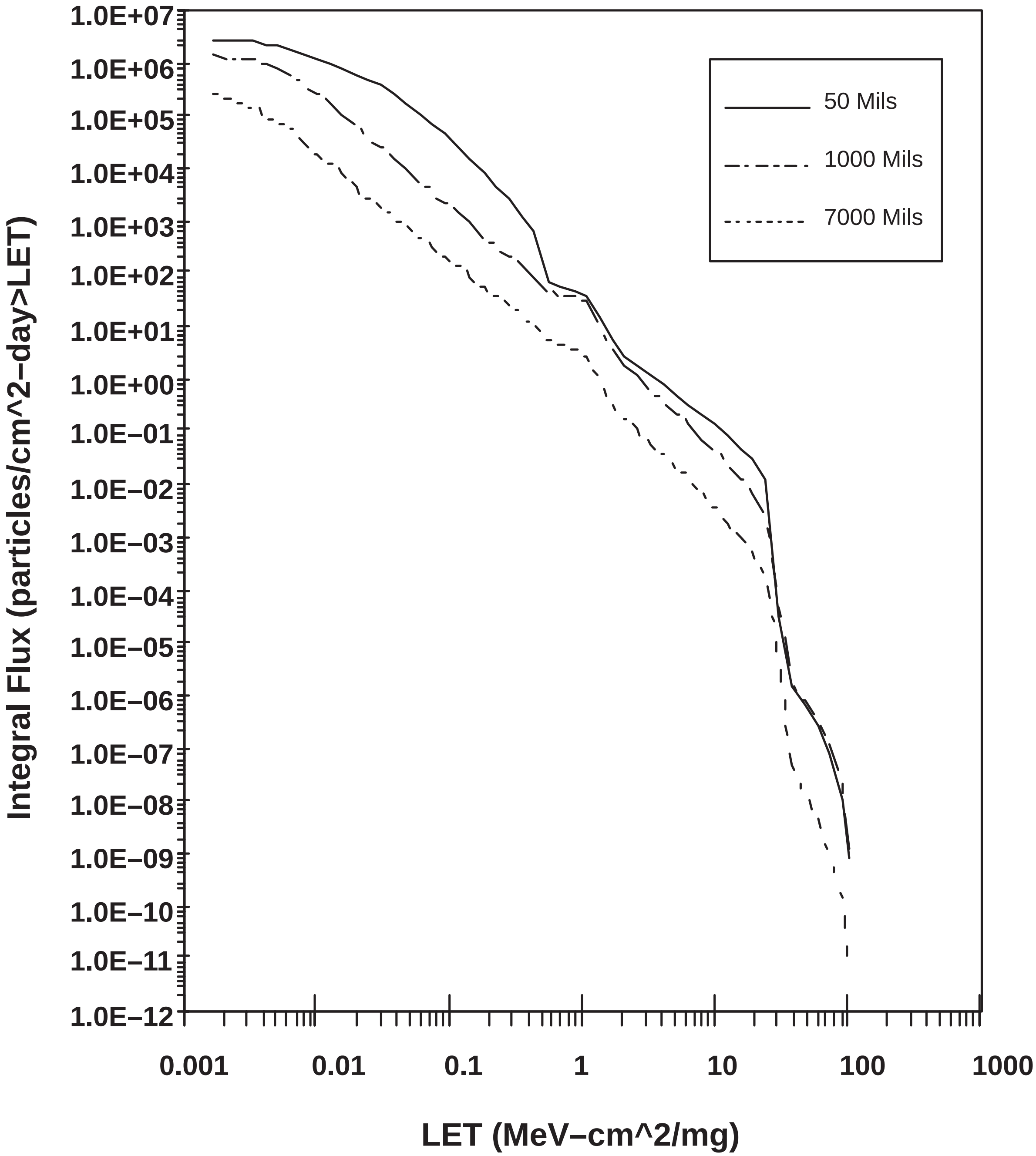

FIGURE 3.2.1.4–1 COMBINED INTEGRAL FLUX LET SPECTRA (WI=4) NO SOLAR FLARE FLUX

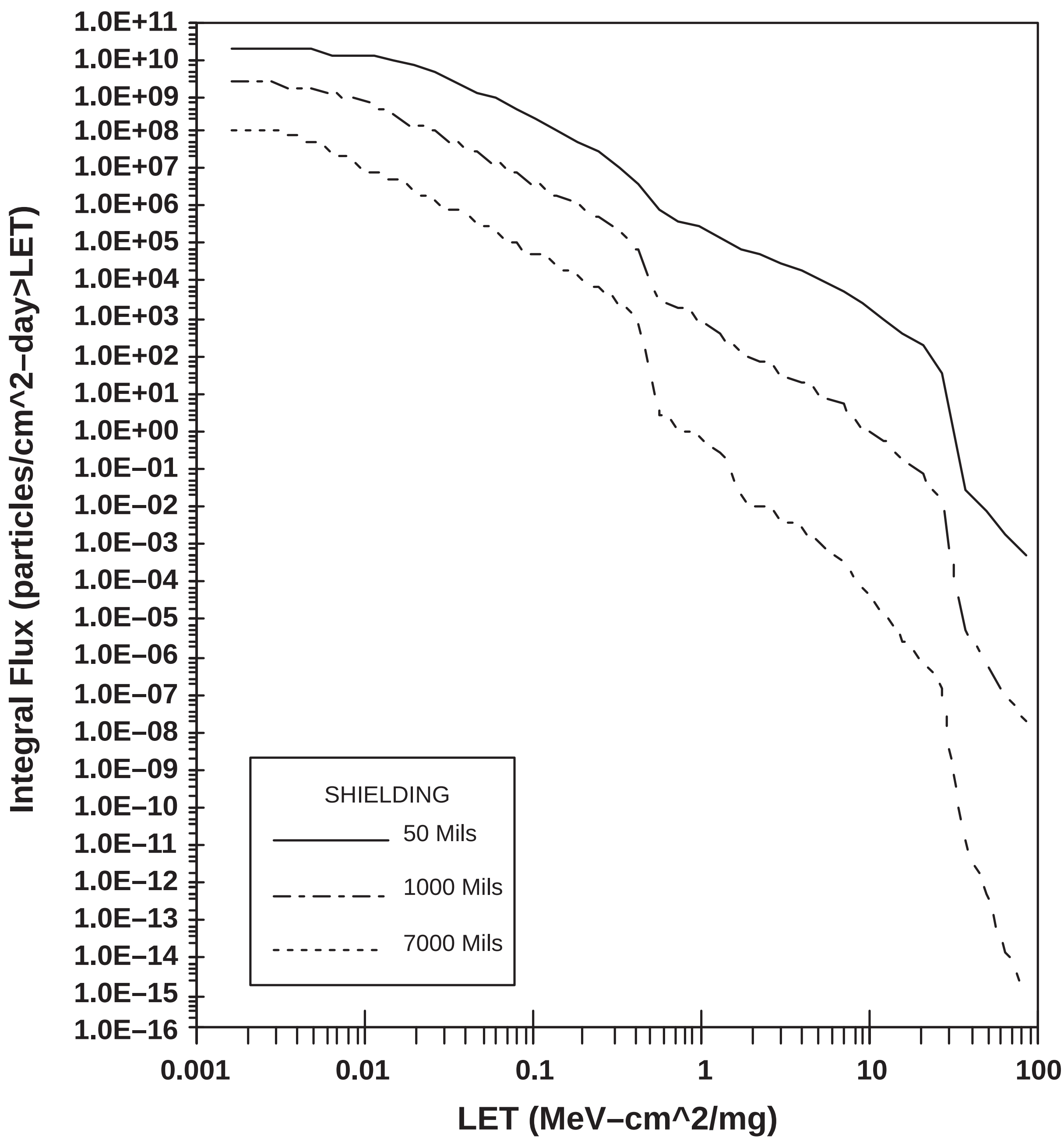

FIGURE 3.2.2–1 MAXIMUM SOLAR FLARE PEAK HEAVY ION INTEGRAL FLUX

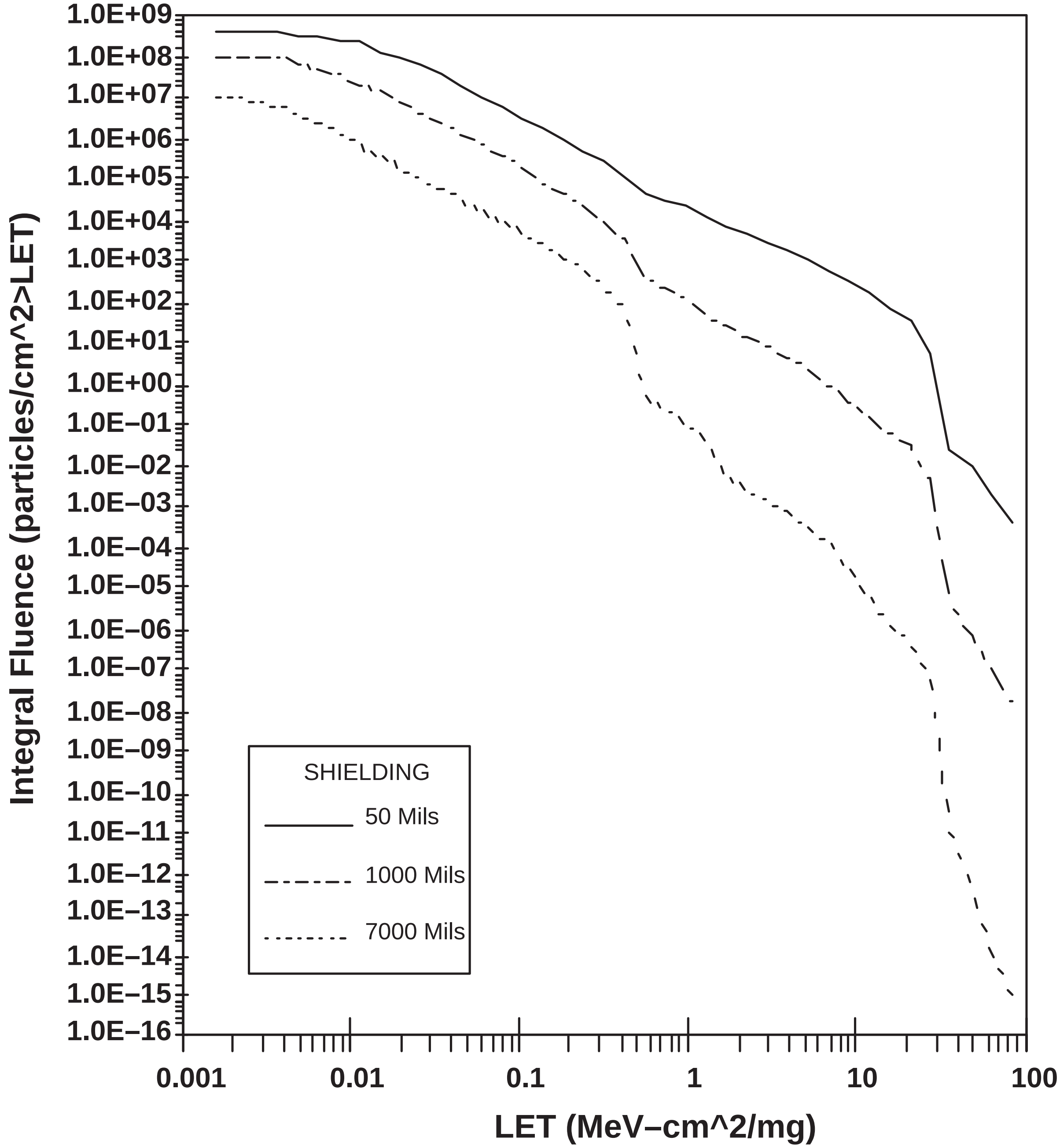

FIGURE 3.2.2–2 MAXIMUM SOLAR FLARE ORBIT–AVERAGED INTEGRAL HEAVY ION FLUENCE

APPENDIX A ABBREVIATIONS AND ACRONYMS

A	Atomic weight
BREM	Boeing Radiation Exposure Model
cm	centimeters
CREME	Cosmic Ray Effects on MicroElectronics Codes
g	Gram
ISSA	International Space Station Alpha
km	kilometer
LET	Linear Energy Transfer
MeV	Megaelectron Volts (10^6 electron Volts)
mil	0.001 inches
mg	milligrams
ORU	Orbital Replacement Unit
rad[Si]	Radiation Absorbed Dose in Silicon
SAA	South Atlantic Anomaly
SEE	Single Event Effect
Si	Silicon
Z	Atomic Number

APPENDIX B GLOSSARY

BREMSSTRAHLUNG

Electromagnetic radiation produced by the acceleration of charged particles. It is only important for electrons.

DIFFERENTIAL FLUX

The number or particles per unit area per unit time per unit energy or Linear Energy Transfer (LET).

DOSE

Total energy per unit mass deposited in a material or medium by ionizing radiation.

FLUX

Number of particles through a unit area per unit time which can be represented in an integral or differential form.

INTEGRAL FLUX

Total flux of particles above a given parameter, e.g., energy or LET.

LATCH–UP

A loss of functionality which can be affected by controlled input changes. The device is effectively disabled and can be usually only enabled by the removal and reapplication of supply power. This failure mode typically results in damage to the device if current limiting is not provided.

LINEAR ENERGY TRANSFER (LET)

The linear density of all forms of energy transferred to an absorbing medium or material by a charged particle.

RAD[S]

A measure of the radiation absorbed dose in silicon. The energy per unit mass imparted to silicon. The energy density of 1 rad[Si] is equal to 100 ergs/gram.

SINGLE EVENT EFFECT

A generalized category of anomalies that result from a single ionizing particle. This term includes such effects as single event upsets, transients, latch–up, permanent upset, and device burnout effects.

SINGLE EVENT UPSET

An unintentional change in the state of a digital device, resulting in erroneous data or control induced by ionizing radiation. The change of a state is not permanent in that complete functionality can be restored by reprogramming.

TRANSIENT

An undesired temporary change in state of an electronic device induced by ionizing particle interaction in the device. The device returns to its steady state without outside intervention.

APPENDIX C EXAMPLES

EXAMPLE 1

Perform a first–order worst–case analysis to determine the dose susceptibility of a device to be used in an Orbital Replacement Unit (ORU) with a design life of 10 years to be used on the truss.

For a first–order worst–case analysis use the thinnest wall (in terms of g/cm^2 of aluminum) of the ORU box cover per paragraph 3.1.2.

Assuming that the wall is 32 mils of steel with a density of 7.82 g/cm^3, the thickness in g/cm^2 of steel is

X_{St} = (7.82 g/cm^3) (32 mils) (1 inch/1000 mils) (2.54 cm/1 inch)

and

X_{St} = 0.64 g/cm^2.

The aluminum equivalent thickness is approximated by

$X_{Al} = (A_{Al} / Z_{Al}) (Z_{St}/A_{St}) X_{St}$

where Z is atomic number and A is atomic weight. The approximation assumes that equal numbers of aluminum–bound electrons are equivalent in terms of ionization loss by the interacting particle. Assuming the percent weight composition of steel is 72.9% iron, 18% chromium, 9% nickel, and 0.1% carbon, then

X_{Al} = (27/13) [0.729(26/56) + 0.18 (24/52) + 0.09 (28/59) + 0.001 (6/12)]0.64 g/cm^2.

X_{Al} = 0.62 g/cm^2.

Log–log interpolation in Table 3.1.2–1 using this value yields a one year does of 861 rads. For a 10–year life, the dose susceptibility is 8.61 x 10^3 rads.

EXAMPLE 2

For the ORU described in Example 1, a part with a tolerance of 8000 rads is a candidate for selection. Can the part meet the dose susceptibility requirements?

Develop a geometrical model of the ORU and surrounding structure in a radiation transport program such as BREM which can consider complex geometries. Include such details as device packaging if the device is thinly shielded.

Use the electron fluxes as defined in Table 3.1.1–1 to calculate the electron dose and the proton fluxes as defined in Table 3.1.1–2 to calculate the proton dose as indicated in paragraph 3.1.2.

Add the yearly electron and proton doses (see Paragraph 3.1.3) and multiply by 10 to get the design–life dose.

Double the dose to satisfy end–item specifications.

If the resulting dose is less than 8000 rads the part can be selected.