UNIRAD

User Manual

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Preface

UNIRAD is a software package developed by and for ESA for evaluation of the radiation fluences and doses expected in a spacecraft from a definition of the mission characteristics.

The UNIRAD package consists of a series of programs: SAPRE, BLXTRA, TREP, TREPPOS, TREPAVE, SHIELDOSE, EQFRUX, and EQFRUXGA. There also is a plotting program, UNIRAD.PRO, to produce graphs of the results. Both the individual programs in UNIRAD and the interfaces between them have been modified substantially in the course of the TREND projects (ESTEC contracts nrs. 9011/88/NL/MAC and 9828/92/NL/FM). This document is intended as a user manual to the present version of the software (v. 2.0).

The installation guide is contained in Chapter 1.

Chapter 2 contains the descriptions of the individual programs in UNIRAD. The purpose of each software package is stated, and their interaction is documented. A detailed description is given of the input files necessary for running the software and the output files that are produced.

In Chapter 3, we present the results of a sample run of the complete UNIRAD suite, in the form of a series of plots.

Chapter 4 describes the plotting routine UNIRAD.PRO.

Appendix A contains the listing of a sample NAMELIST file with all NAMELIST parameters and their default values. Appendix B contains the format description of the common interface file.

Support

If you have a question about or problems with UNIRAD first look in this documentation and make sure you followed the proper installation instructions. If you cannot find the answer:

- consult the WWW FAQ page http://magnet.oma.be/unirad/faq.html;

- contact D. Heynderickx by telephone (00-32-2-3730417, 00-32-2-3730421), fax (00-32-2-3748423) or E-mail (dh@plasma.oma.be).

Customized on-site training for end users and trainers can be organised.

Disclaimer

The UNIRAD software provides a means of conveniently running the various models described in this document. No guarantee is given concerning the capability of the models to represent actual conditions in the near Earth environment.

No liability for consequential damages: in no event shall BISA or ESA be liable for any damages whatsoever (including without limitation, damages for loss of business profits, business interruption, loss of business information, or any other pecuniary loss) arising out of the use of or inability to use the UNIRAD software, even if BISA and/or ESA have been advised of the possibility of such damages.

Copyright statements

Acknowledgments

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List of acronyms and abbreviations

AE-8	NASA empirical models for the omnidirectional flux of trapped electrons (Vette 1991)
AP-8	NASA empirical models for the omnidirectional and unidirectional flux of trapped protons (Sawyer & Vette 1976)
AL	Anomalously Large
ASCII	American Standard Code for Information Interchange
BISA	Belgian Institute for Space Aeronomy
CIRA	COSPAR International Reference Atmosphere
COSPAR	COmmittee for Space Research
CRRES	Combined Release and Radiation Effects Satellite
DEC	Digital Equipment Corporation
DGRF	Definitive Geomagnetic Reference Field
DOS	Disk Operating System
ESA	European Space Agency
IBM	International Business Machines
IDL	Interactive Data Language
IGRF	International Geomagnetic Reference Field
JPL	Jet Propulsion Laboratory
LANL	Los Alamos National Laboratory
NASA	National Aeronautics and Space Administration
NEA	Nuclear Energy Agency
NBS	National Bureau of Standards
NSSDC	National Space Science Data Center
PC	Personal Computer
PV	Precision Visuals
RAM	Random Access Memory
RSIC	Radiation Shielding Information Center
SAA	South Atlantic Anomaly
SRD	Software Requirements Document
TN	Technical Note
TREND	Trapped Radiation ENvironment Development
VAX	Virtual Address eXtension
VMS	Virtual Memory System

List of symbols

α	Pitch angle
B	Geomagnetic field intensity
B_{m}	Mirror point geomagnetic field intensity
B_0	Equatorial geomagnetic field intensity
E	Particle energy
j	Differential particle flux
J	Integral particle flux
L	McIlwain's (1961) parameter

Changes from previous versions

The UNIRAD software has been modified substantially by BISA. The modifications fall into two categories:

- internal modifications in the code which are transparent to the user;
- external modifications including:
  - changes in NAMELIST parameters;
  - changes in the format of the input and output files;
  - changes in the user interface;
  - extensions of the programs;
  - additions of programs.

Chapter 2 contains listings of all NAMELIST parameters and descriptions of all output files. The extensions of the file names of all input and output files have been shortened to three characters.

Changes in NAMELIST parameters

The NAMELISTs for all programs have been modified. The parameters which have been changed, deleted or added are listed below. Chapter 2 contains detailed descriptions of all NAMELIST parameters. Modification of a parameter may mean a change in its effect, a change in its name, a change in its default value, or a change in its data type.

The NAMELIST parameters are now reset to their default values for each trajectory in the NAMELIST file.

The NAMELIST TEXT has been deleted. The parameter TITLE has been moved to the NAMELIST SAPRE.

SAPRE The following parameters have been modified: HAPO, HPER, INCL, TANO, OEYEAR, OEMON, OEDAY, ORBNUM, and PRINT. The parameter TAPE was deleted. TITLE, TYPE, AMJD, IAE, IG50, A, E, LONGAPO, LONGPER, OELONG, SOLTIM, and IORBEL were added.

BLXTRA The following parameters have been modified: PRINTC, BLTIME, MODEL. The parameters IPLOT and DEBUG were deleted. IASCII, CUTOFF, OUTER, VALUE_KP, DEN, VEL, and DST were added.

TREP The following parameters have been modified: KPRINT, ILTV, ENERFL. The parameters IPLOT and IBUG were deleted. TREMOD, FLAMOD, FLSTAR, RAU, IFORM, SAAROT, OMNI, NENERP, NENERE, NENERS, ISPEC, and ISPSHT were added.

TREPAVE TREPAVE now requires the presence of the NAMELIST TREPAVE in the NAMELIST file PROJECT.NML.

SHIELDOSE The following parameters have been modified: IPRNT, IPLOT. ISHLD was added.

EQFRUX and EQFRUXGA The parameter IPRINT has been modified.

Changes in input files

In older versions, SAPRE, BLXTRA, TREP, and SHIELDOSE read data files with model parameters. These data have now been linked in with the programs so that the only input now needed for UNIRAD consists of a single user written NAMELIST file.

Changes in output files

The format of the common interface file PROJECT.INT generated by SAPRE and used as input by BLXTRA and TREP has changed: see Appendix B for a description of the file format. The format of the interface file PROJECT.TRI, generated by TREP, TREPPOS, and TREPAVE, and used as input by SHIELDOSE, EQFRUX, and EQFRUXGA, also has been modified. The new format is described in Table 2.7.

The layout of most printable report files has been improved. The format of the plot files has changed completely to a more compact and structured form.

New output files have been added to SAPRE, BLXTRA, and TREP.

Changes in the user interface

The user interface has been completely reworked. The programs now are run by typing the program name and, optionally, a project name as command line argument. See Chapter 1 for more details.

Extensions of programs

BLXTRA In older versions, the calculation of (B, L) coordinates was performed by a program called `SHELLG`. This program has been replaced by `BLXTRA`, which has a more effective and accurate field line tracing algorithm and has several external magnetic field models built in.

TREP The trapped proton models AP-8 MIC and AP-8 MAC in `TREP` have been replaced by AP-8 MIN and AP-8 MAX, respectively. An electron model based on geostationary LANL data has been added. The Feynman model (Feynman & Gabriel 1990) for solar flare proton fluences is now available in `TREP`.

`TREP` now calculates (B, L) coordinates internally with the appropriate magnetic field models and parameters. It is no longer necessary to run `BLXTRA` prior to `TREP`. The (B, L) values calculated by `TREP` are written to the commmon interface file `PROJECT.INT`, overwriting (B, L) values already present if `BLXTRA` has been called prior to `TREP`.

New programs

The program `EQFRUXGA` has been added. It has the same function as `EQFRUX`, but is intended for GaAs solar cells.

A plotting routine, `UNIRAD.PRO`, has been added. It is written in the IDL language.

Chapter 1

Overview and installation guide

The UNIRAD suite of programs provides information about the radiation environment in an arbitrary Earth orbit, predicting satellite exposures to particle fluxes, the resulting radiation dose, and the resulting damage-equivalent fluences for solar cell degradation calculations.

This chapter outlines the system and its constituent programs, its use, and the installation of the software. The programs outlined here are upgrades and extensions of the programs in the previous version.

1.1 Overview of UNIRAD

An orbit analysis generally consists of running one or more of the UNIRAD component programs, with communication between the programs via interface files. Both graphical and tabular output is provided.

The user input required by the system consists of a single FORTRAN NAMELIST file containing the project header, the orbital parameters, solar activity conditions, plotting and printing options, ... It is possible to run a series of projects within the same NAMELIST file. All parameters in the NAMELIST file are assigned default values when not specified, and are reset for each project.

From the orbit parameters, the system will generate a detailed trajectory, magnetic coordinates, integral and differential proton and electron fluences, doses for three shield geometries in four detector materials, and solar cell degradation information, in both printed and graphical form.

The UNIRAD package consists of the following programs:

- SAPRE: orbit generator which produces a data file used by the next two programs in the package;

- BLXTRA: calculates the geomagnetic coordinates (B, L) from the geographic coordinates generated by SAPRE;
- TREP: determines the radiation flux for the geographic coordinates generated by SAPRE from the NASA trapped radiation models AP-8 and AE-8. It produces a data file with the energy spectra of trapped protons and electrons and of solar protons;
- TREPPOS: calculates the trapped radiation flux for pairs of (B, L) or $(B/B_0, L)$ coordinates interactively input by the user. It produces a data file with the energy spectra of trapped protons and electrons;
- TREPAVE: averages the spectra generated by TREP or TREPPOS for different orbits;
- SHIELDOSE: reads the energy spectra resulting from TREP and converts them to radiation dose-depth curves for different detector materials and simple shielding geometries;
- EQFRUX: determines 1 MeV electron damage equivalent fluences from the TREP spectra to evaluate degradation of Si solar cells;
- EQFRUXGA: idem as EQFRUX, but for GaAs solar cells.
- UNIRAD.PRO: a set of IDL routines to produce graphical output.

The flow diagram of the UNIRAD package is represented in Fig. 1.1. This diagram illustrates the interdependence of the various programs making up UNIRAD. Except for the interface files, the output files are not shown in Fig. 1.1.

1.2 Inputs and outputs

A complete UNIRAD radiation analysis requires only one user input file: the NAMELIST file PROJECT.NML, where PROJECT represents the project name to be chosen by the user. If the programs are run in the proper order, all succesively needed input files are generated by UNIRAD. Alternatively, the user may supply his own input files according to the specifications given in Chapter 2.

All programs in UNIRAD (except TREPPOS) require input from the NAMELIST input file PROJECT.NML. In Sect. 1.2.1 a general description of NAMELIST files and syntax is given. The NAMELIST parameters for the different programs in UNIRAD are listed and discussed in Chapter 2. The input files necessary for the programs in UNIRAD are listed in Table 1.1 together with the programs that generate them, and their format.

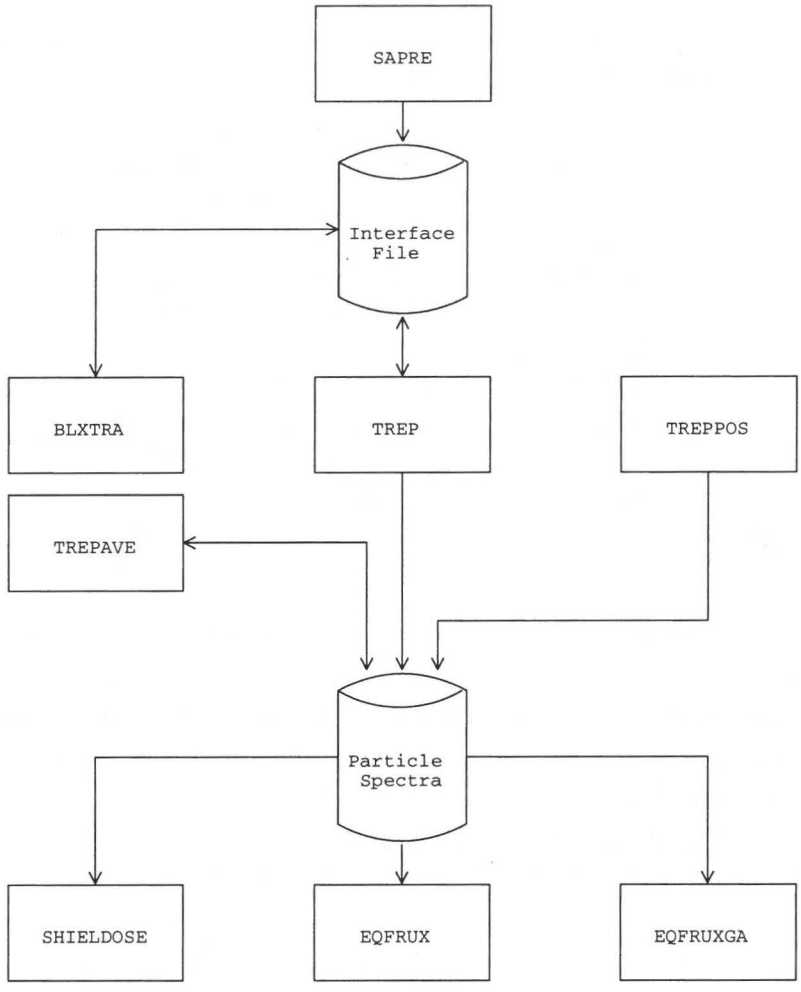

Figure 1.1. Flow diagram of UNIRAD

The output generated by UNIRAD consists of binary or ASCII files with file names of the form PROJECT.XXX, where XXX identifies the program generating the file and the type of information in the file. PROJECT must be chosen so that PROJECT.XXX represents a valid file name. A list of all output files is presented in Sect. 1.2.2.

1.2.1 Namelist file input

UNIRAD requires a composite NAMELIST file named PROJECT.NML, where PROJECT represents the project name to be chosen by the user. The NAMELIST file should contain a NAMELIST for each program to be executed, except for TREPPOS. NAMELISTs do not have to contain all input variables and may even be empty, in which cases default values will be chosen, but must be present in the file. NAMELISTs for more

Table 1.1. List of input files for the programs in UNIRAD. Every program (except TREPPOS) also requires the NAMELIST file PROJECT.NML

Program name	File name	Format
SAPRE	None	
BLXTRA	PROJECT.INT	Binary
TREP	PROJECT.INT	Binary
TREPPOS	None	
TREPAVE	PROJECT.TRI	ASCII
SHIELDOSE	PROJECT.TRI	ASCII
EQFRUX	PROJECT.TRI	ASCII
EQFRUXGA	PROJECT.TRI	ASCII

than one project may be put in the same file. The general syntax rules for NAMELIST input follow.

Namelist file input consists of a record delimited by the dollar sign $ (except on PC, where an ampersand & should be used) which starts in the second column (the first column must be blank).

Generally, NAMELIST input has the form:

```
$NAME PARAMETER=VALUE [, PARAMETER=VALUE, ... ]  $[END]
```

where

- $ is the special dollar sign symbol that indicates the beginning and end of input and the start of a namelist section. Optionally an ampersand (&) may be used instead of a dollar sign (mandatory on PC).
- NAME is the name of the namelist file section. This name may not contain any spaces or tabs.
- PARAMETER is the name of one of the input parameters of the program for which the namelist file provides the data. The parameter list does not have to be exhaustive, i.e. not all parameters have to be given. A PARAMETER name that does not correspond to any parameter defined by the NAMELIST in the calling program will generate an error.
- VALUE is a constant or list of constants.
- END is an optional part of the last delimiter. On PCs, a NAMELIST should be terminated with a slash /.

The following syntax rules for namelist file input must be obeyed.

1. The NAMELIST name NAME may not contain spaces or tabs.
2. The PARAMETER names appearing on the left-hand side of the equals sign in a value assignment may not contain spaces or tabs.
3. Each constant that appears in a VALUE assignment must be one of the following types:
   - integer, in the form of a whole number with no decimal point. An integer may have a leading sign (+ or −). Leading zeros are ignored;
   - real, in the form of a number with a decimal point or an exponent (or both). An exponent letter (E or D) must be followed by an exponent;
   - character, consisting of at least one printable character or string of characters delimited by apostrophes (’). The value does not include delimiting apostrophes but does include all spaces and tabs. Apostrophes in the input string are represented by two consecutive apostrophes (’’). Quotation marks (") cannot be used in place of apostrophes.
4. Valid separators in lists of values are spaces, tabs and commas. Except within character strings (enclosed within apostrophes) any number of consecutive spaces or tabs is equivalent to one space.
5. A null value is specified by two consecutive commas. Spaces before and after commas are ignored. A null value may be entered for a complete value only, not for part of it.
6. The equals sign in a value assignment may be preceded or followed by a space or tab. Multiple spaces or tabs are treated as one space.

A sample namelist file TEST.NML containing the default values for the namelist parameters for all UNIRAD programs is provided with the distribution and listed in Appendix A.

Each program in UNIRAD will process all NAMELISTs intended for it’s use. It is the user’s responsability to ensure that each NAMELIST corresponds to the intended program run. When a NAMELIST is missing, the program will terminate but will not generate an error.

1.2.2 Output files generated by UNIRAD

UNIRAD produces different types of output files. SAPRE creates the common interface file PROJECT.INT, which is used as input by BLXTRA and TREP. Each program creates

Table 1.2. List of output files generated or modified by the programs in UNIRAD. The first column identifies the output file, the second column specifies binary or ASCII format. The third column lists the NAMELIST parameters affecting the creation or format of the file. "Always" means that the file is always created or modified, "None" that the output is not affected by any NAMELIST parameters. The fourth column describes the contents of the files.

File name	Format	NAMELIST parameter	Description
		SAPRE	
PROJECT.INT	Binary	None	Common interface file
PROJECT.SAP	ASCII	IPRINT, EPHMR, IBUG	Ephemeris
PROJECT.ORB	ASCII	IPRINT, EPHMR, IORBEL	Orbital Elements
		BLXTRA	
PROJECT.INT	Binary	None	Common interface file
PROJECT.BLP	ASCII	IPRINT	Report file
PROJECT.BLA	ASCII	IASCII	Ephemeris and magnetic field components
		TREP	
PROJECT.INT	Binary	None	Common interface file
PROJECT.TRI	ASCII	INTERF	Interface file for TREPAVE, SHIELDOSE, EQFRUX, EQFRUXGA
PROJECT.TRP	ASCII	IPRINT	Report file
PROJECT.SPP	ASCII	ISPEC	Ephemeris and full proton spectrum
PROJECT.SPE	ASCII	ISPEC	Ephemeris and full electron spectrum
PROJECT.TRW	ASCII	ISPSHT	Fluence spectrum in spreadsheet format
		TREPPOS	
PROJECT.TRI	ASCII	INTERF	Interface file for TREPAVE, SHIELDOSE, EQFRUX, EQFRUXGA
		TREPAVE	
PROJECT.TAI	ASCII	None	Averaged fluence spectra

Table 1.2. (continued)

File name	Format	NAMELIST parameter	Description
		SHIELDOSE	
PROJECT.SHP	ASCII	Always, IPRINT, ISHLD	Report file
PROJECT.SHG	ASCII	IPLOT, ISHLD	Input file for plotting routines
		EQFRUX	
PROJECT.EQP	ASCII	Always, IPRINT	Report file
PROJECT.EQG	ASCII	IPLOT	Input file for plotting routines
		EQFRUXGA	
PROJECT.EGP	ASCII	Always, IPRINT	Report file
PROJECT.EGG	ASCII	IPLOT	Input file for plotting routines

an ASCII file named PROJECT.XXP, which contains a printable overview of the main input parameters and the results. In addition, ASCII files named PROJECT.XXG are optionally produced by SHIELDOSE, EQFRUX, and EQFRUXGA. These latter files can be used by plotting software to produce plots of the results. Finally, TREP, TREPPOS and TREPAVE optionally write the interface file PROJECT.TRI which serves as the main input for SHIELDOSE, EQFRUX, and EQFRUXGA.

Table 1.2 lists all output files together with the program that generates them, their format, and the NAMELIST parameters that control their creation or format, if applicable.

In Chapter 2 a description is presented of the functioning of the UNIRAD programs, of their inputs and outputs, and of the NAMELISTs that drive them.

1.3 Installation

This section contains the installation instructions for the platforms and operating systems that are supported.

1.3.1 Distribution format

The software distribution consists of:

- a set of executables for the platform and operating system specified in the purchase order;
- a sample NAMELIST file which contains the default values for all input parameters;
- the output files produced from the sample NAMELIST parameters, which can be compared to the output produced after installation;
- the plotting program UNIRAD.PRO;
- a printed copy of this manual.
- a PostScript version of this manual.

The programs are run by changing to a user directory (current directory) and typing the program name, optionally followed by the project name PROJECT. The project name may contain a path name, in which case it is not necessary to set the current directory to the specified path. If PROJECT was not given on the command line, the program will prompt for it to be input. The current directory (or the path in the project name) should contain the NAMELIST file of the current project. The output files generated by UNIRAD will be placed in the same directory. No other data files are needed since all model data have been linked into the executables. In this respect, the UNIRAD component programs are standalone.

1.3.2 Installation procedure

The product is delivered in the form of compressed files with a command procedure to extract the package. The executables are placed in a user specified directory, together with the sample NAMELIST file TEST.NML, the sample output files, and a PostScript version of this document. The following sections contain platform specific instructions.

VMS

The VMS version is shipped as a backup file UNIRAD.BCK. To install the software, proceed as follows:

1. Create a directory and make it the current directory, e.g.:
   `CREATE/DIRECTORY MY$DISK:[UNIRAD]` Return
   `SET DEFAULT MY$DISK:[UNIRAD]` Return.
2. Mount the DAT tape, optical disk or TK 50 tape:
   `MOUNT/FOREIGN MY$TAPE: UNIRAD` Return.

3. Extract the backup file:
   `BACKUP/RESTORE MY$TAPE:[UNIRAD.BCK] [...]*.*` Return.
   This will extract the executables and other files in the current directory and subdirectories.

4. Using the `TYPE` command, read the file `MY$DISK:[UNIRAD.DOC]README.TXT` for any changes to the documentation since its publication. Check the file for any new information about installing `UNIRAD`.

5. Add the file `MY$DISK:[UNIRAD]UNIRAD.COM` to your `LOGIN.COM` file. Alternatively, add a line to your `LOGIN.COM` file that executes `UNIRAD.COM`, or execute `UNIRAD.COM` before a `UNIRAD` run.

6. Add the `UNIRAD` path to the IDL input directory path.

To run the programs:

1. Change directory to a user directory, e.g.:
   `SET DEFAULT MY$DISK:[PROJECT]` Return
   (if necessary, create this directory first).

2. Using a text editor, create a `NAMELIST` file (e.g. `PROJECT.NML`) and enter the `NAMELIST` parameters you will need for the run.

3. Run a `UNIRAD` program by typing its name and (optionally) the project name `PROJECT` (with the full path if the `NAMELIST` file is not in the current directory) and pressing the Return key. Run the programs in the proper order so that all necessary files are created.

4. Run `UNIRAD.PRO` in an IDL or PV-Wave session by typing 'UNIRAD', optionally followed by a comma and the project name in single quotes.

UNIX

The UNIX version is shipped as a compressed file `UNIRAD.Z`. To install the software, proceed as follows:

1. Create a directory and make it the current directory, e.g.:
   `mkdir unirad` Return
   `cd unirad` Return.

2. Load the distribution file from the DAT tape or optical disk:
   `dd unirad.pro` Return.

3. Decompress the file:
   `decompress unirad.Z` Return.
   This will extract the executables and other files in the current directory and subdirectories.

4. Using the `CAT` command, read the file `unirad/doc/readme.txt` for any changes to the documentation since its publication. Check the file for any new information about installing `UNIRAD`.

5. Add the `UNIRAD` directory to your path.

6. Add the `UNIRAD` path to the IDL input directory path.

To run the programs:

1. Change directory to a user directory, e.g.:
   `cd project` Return
   (if necessary, create this directory first).

2. Using a text editor, create a `NAMELIST` file (e.g. `project.nml`) and enter the `NAMELIST` parameters you will need for the run.

3. Run a `UNIRAD` program by typing its name and (optionally) the project name `project` (with the full path if the `NAMELIST` file is not in the current directory) and pressing the Return key. Run the programs in the proper order so that all necessary files are created.

4. Run `UNIRAD.PRO` in an IDL or PV-Wave session by typing 'unirad', optionally followed by a comma and the project name in single quotes.

All file extensions used and generated by `UNIRAD` are lowercase.

MS-DOS

The MS-DOS version is shipped on two or more disks, depending on the disk format specified in the purchase order. Each disk contains a self-extracting executable.

To install the software, proceed as follows:

1. Make backup copies of the distribution disk(s) using the `COPY` or `DISKCOPY` command in MS-DOS.

2. Using the `TYPE` command, read the `README.TXT` file on the first disk for any changes to the documentation since its publication. Check the file for any new information about installing `UNIRAD`.

3. Create a directory on the hard disk and make it the current directory, e.g.:
   `md c:\unirad` Return
   `cd c:\unirad` Return.

4. Insert the first disk in the drive and type
   `a:\install` Return
   (assuming your floppy drive is "a", otherwise substitute the appropriate drive letter). This will extract the executables on this particular disk in the current directory.

5. Repeat step 4 with the other disks.

6. Add the installation directory to the `PATH` statement in the `AUTOEXEC.BAT` file.

7. Add the `UNIRAD` path to the IDL input directory path.

To run the programs:

1. Using a text editor, create a `NAMELIST` file (e.g. `PROJECT.NML`) in a user directory (if necessary, create this directory first) and enter the `NAMELIST` parameters you will need for the run.

2. Change directory to the user directory, e.g.:
   `cd c:\project` Return.
   If the path name of this directory is specified in the project name in step 3, this step (2) may be skipped.

3. Run a `UNIRAD` program by typing its name and (optionally) the project name `PROJECT` and pressing the Return key. Run the programs in the proper order so that all necessary files are created.

4. Run `UNIRAD.PRO` in an IDL or PV-Wave session by typing 'UNIRAD', optionally followed by a comma and the project name in single quotes.

The programs were compiled for MS-DOS with MS-Fortran. The executables require an additional program `DOSXMSF.EXE` (from Phar Lap), which is included in the distribution. You should check whether another version of this utility is already present on your hard disk. If this is the case, you may delete the `DOSXMSF.EXE` file included with the `UNIRAD` distribution.

Chapter 2

Description of programs in UNIRAD

The UNIRAD package consists of an orbit generator, geomagnetic field models, trapped particle models, solar flare models, a code for computing doses in simple geometries and codes for computing solar cell damage-equivalent fluences.

This chapter contains detailed descriptions of the models and programs and of all input files and output files.

2.1 Overview

The orbit generator provides geodetic coordinates on a user defined orbit. The geomagnetic field model program computes the corresponding (B, L) coordinates. The geodetic coordinates also serve as input for the trapped particle model program, which (independently from the geomagnetic field model program) computes $(B/B_0, L)$ coordinates and accesses the standard NSSDC trapped particle models (Vette 1991b).

The trapped particle models used are AP-8 for protons (Sawyer & Vette 1976) and AE-8 for electrons (Vette 1991a). These models provide integral omnidirectional proton and electron fluxes as a function of particle energy E, L and B/B_0. In addition, directional proton fluxes can be computed. The program uses these flux data to compute integral and differential fluxes as a function of orbit time and generates orbit-averaged spectra.

Solar flare particle events are treated statistically. Models of mean, worst-case and anomalous solar flare proton spectra based on King (1974) are used together with the Burrell distribution. Depending on the mission duration and timing, a number of flares are predicted and the resulting total fluence spectrum is produced.

The model of Feynman & Gabriel (1990) is also implemented.

Dose in simple aluminium geometries is calculated using the resulting fluence spectra and a data set containing dose/unit fluence generated by runs of a Monte Carlo transport code (Seltzer 1979). The Monte Carlo method follows the transport of populations of particles explicitly, including energy loss, scattering and the generation of secondary particles. Doses due to electrons, electron induced Bremsstrahlung, and protons are included in the data sets.

Finally, damage-equivalent fluences for solar cell degradation are computed for Si and GaAs.

Facilities are available for averaging orbital results to produce mission averages and for producing spectra at single (B, L) or $(B/B_0, L)$ locations.

2.2 SAPRE

2.2.1 Function and structure

`SAPRE` computes trajectory osculatory orbital elements using either a numerical Runge-Kutta integration method or a Kozai parameter update analytical method.

The numerical Runge-Kutta orbit generator can be used for low altitude orbits, geostationary orbits, and highly eccentric orbits. It takes into account the oblateness of the Earth, the gravitational attraction of Sun and Moon, air drag (by means of the CIRA atmospheric model) and solar radiation pressure.

The Kozai analytic orbit generator may be used for low altitude orbits only ($< 8100\,\mathrm{km}$). This generator takes into account the oblateness of the Earth and the gravity effects of Sun and Moon, but ignores the air drag and solar radiation pressure.

The independent variable is the eccentric anomaly. Osculatory elements are computed at constant equidistant eccentric anomaly steps.

2.2.2 Input to SAPRE

The input to `SAPRE` is a description of an orbital trajectory of a space system. Each trajectory is divided into one or more orbital arcs, where each orbital arc consists of a series of orbital points.

The description of the trajectory is contained in the `NAMELIST` file `PROJECT.NML`. This file consists of one or more `$SAPRE` sections. Each `$SAPRE` section specifies the project title with the `NAMELIST` parameter `TITLE` (80 characters including blank spaces). If the title contains blank spaces, it must be enclosed in quotation marks

Table 2.1. (continued)

Parameter	Data Type	Default	Function
LONGAPO	REAL*8	999.9	Apogee longitude (deg)
LONGPER	REAL*8	999.9	Perigee longitude (deg)
OELONG	REAL*8	−9999.999	East longitude (deg), only for geostationary orbit
SOLTIM	REAL*8	−9999.999	Local solar time (hrs), only for heliosynchronous orbit
EPDUR	REAL*8	0	Duration of trajectory (days). If 0, ORBITS is used.
ORBITS	REAL*8	1	Number of orbits, used if EPDUR=0
STEP	REAL*8	2	Eccentric anomaly step (deg). For Runge-Kutta generator only.
DT1	REAL*8	240	Time step for output (s). Used if altitude < DH2.
DT2	REAL*8	1200	Time step for output (s). Used if DH2 < altitude < DH3.
DT3	REAL*8	1200	Time step for output (s). Used if altitude > DH3.
DH2	REAL*8	1.0D6	Use DT1 if height < DH2.
DH3	REAL*8	1.0D6	Use DT2 if height < DH3.
WIBAIR	REAL*8	0	Air drag parameter. Used if altitude < 700 km. For Runge-Kutta generator only.
WIBSPR	REAL*8	0	Solar radiation pressure. For Runge-Kutta generator only.
ORBNUM	REAL*8	1	Orbit identification number
NCIRA	INTEGER	5	CIRA atmosphere density model number (1–10). Used if WIBAIR$\neq$ 0. For Runge-Kutta generator only.
SUN	INTEGER	1	Flag for gravitational perturbations from Sun (Runge-Kutta generator).
MOON	INTEGER	1	Flag for gravitational perturbations from Moon (Runge-Kutta generator).
KZONAL	INTEGER	6	Number of zonal harmonic gravity coefficients (0–8). Ignore oblateness of Earth if KZONAL and KTESS $\leq$ 1. For Runge-Kutta generator only.

Table 2.1. NAMELIST parameters for SAPRE

Parameter	Data Type	Default	Function
TITLE	CHARACTER*80	80*' '	Project title
TYPE	CHARACTER*3	GEN	Orbit type GEN: General GEO: Geostationary HEL: Heliocentric GTO: Geostationary Transfer
OEYEAR	INTEGER	1995	Orbit epoch year
OEMON	INTEGER	1	Orbit epoch month
OEDAY	INTEGER	1	Orbit epoch day
OEHRS	INTEGER	0	Orbit epoch hour
OEMIN	INTEGER	0	Orbit epoch minute
OESEC	REAL*8	0	Orbit epoch second
SEYEAR	INTEGER	−1	Orbit start year
SEMON	INTEGER	−1	Orbit start month
SEDAY	INTEGER	−1	Orbit start day
SEHRS	INTEGER	−1	Orbit start hour
SEMIN	INTEGER	−1	Orbit start minute
SESEC	REAL*8	−1	Orbit start second
AMJD	REAL*8	−1	Orbit epoch in Modified Julian Day
HAPO	REAL*8	36000	Apogee height (km)
HPER	REAL*8	300	Perigee height (km)
RINCL	REAL*8	0	Orbit inclination (deg)
IAE	INTEGER	0	Input control: 0: Perigee and apogee. 1: Semi-major axis, eccentricity.
A	REAL*8	6671	Semi-major axis (km)
E	REAL*8	0	Eccentricity
IG50	INTEGER	1	Choice of coordinate system: 0: Greenwich coordinate system 1: γ_{50} coordinate system
RAAN	REAL*8	0	Right ascension (deg) of ascending node w.r.t. γ_{50}
ARGPER	REAL*8	0	Argument of perigee (deg)
TRANO	REAL*8	0	True anomaly (deg)

Table 2.1. (continued)

Parameter	Data Type	Default	Function
KTESS	INTEGER	3	Number of tesseral harmonic gravity coefficients (0–4). Ignore oblateness of Earth if KZONAL and KTESS ≤ 1. For Runge-Kutta generator only.
OGEN	INTEGER	1	Choice of orbit generator: 0: Results from previous run 1: Runge-Kutta generator is used 2: If EPHMR $\neq 0$, KOZAI generator is used
IPRINT	INTEGER	1	Output table control: 0: Lists each ephemeris step 1: Lists each 60^{th} step
EPHMR	INTEGER	2	Selects output table format: 0: No ephemerids are printed 1: World map coordinates and geocentric inertial ephemerids are printed 2: Earth centred ecliptic coordinates and events are printed.
IORBEL	INTEGER	0	0: Orbital elements are not printed 1: Orbital elements are printed
IBUG	INTEGER	0	1: Extra output in report file.
RUN	INTEGER	1	Run number.
PP	REAL*8(2)	22.164,15	Bow shock paraboloid constants. Only used when EPHMR=2.
XP	REAL*8(2)	15.25,10	Magnetopause paraboloid constants. Only used when EPHMR=2.

('). $SAPRE further contains the apogee and perigee altitudes, inclination, ascending node (ω, υ), orbit start time and date, perturbations, calculation step (in seconds) and the prediction method to be used for the orbital arcs. Other (optional) parameters may be specified, but usually the default values for these parameters are sufficient.

The SAPRE NAMELIST parameters are listed in Table 2.1 with their data type and default value, and a brief description (more detailed descriptions of the main parameters are given below). A sample NAMELIST file containing all parameters and

their default values is listed in Appendix . The parameters not specified in the NAMELIST file are given their default values. A NAMELIST with no parameters will generate one orbit of a trajectory with perigee 300 km, apogee 36,000 km, inclination 0°.

HPER and HAPO specify the altitude (in km) of the perigee and apogee of the trajectory, respectively, above the mean radius of the Earth (6378 km).

The parameters OEYEAR, OEMON, OEDAY, OEHRS, OEMIN, OESEC define the trajectory epoch, i.e. the epoch of the first perigee. Alternatively, the trajectory epoch can be given in Modified Julian Day with the parameter AMJD. When the Runge-Kutta generator is used, the start time of the orbit can be chosen by setting SEYEAR, SEMON, SEDAY, SEHRS, SEMIN, SESEC to positive values.

The air drag parameter WIBAIR is defined as

$$\texttt{WIBAIR} = \frac{1}{2} C_{\mathrm{D}} \frac{A}{M} 10^{6} ,$$

where C_{D} is the coefficient of drag, A is the cross-sectional area in square meters, and M is the mass in kg. This parameter is ignored for orbit altitudes greater than 700 km. It is used with the Runge-Kutta generator only. The default value is 0.

The solar radiation pressure parameter WIBSPR is defined as

$$\texttt{WIBSPR} = 0.451 \times 10^{-8} K \frac{A}{M} ,$$

where

- K is the material parameter:

  $= 1 - \tau + \rho$ for a plate,
  $= 1 - \tau$ for a sphere,
  $= 2$ for a plate with perfect specular reflection,
  $= 1$ for a sphere with perfect specular reflection of perfect absorption,
  $= 1.44$ for a sphere with perfect diffuse reflection;

- A is the total reflective area in square meters;

- M is the mass in kg;

- τ and ρ are the transmissivity and reflectivity (constants).

The parameter WIBSPR is used with the Runge-Kutta generator only. Its default value is 0.

KZONAL and KTESS are used with the Runge-Kutta generator only. If KZONAL ≤ 1 and KTESS ≤ 1, the oblateness of the Earth is ignored. The default values are 6 and 3, respectively.

NCIRA is the number of the CIRA atmospheric density model, ranging between 1 and 10. The CIRA models are for:

1: extremely low solar activity
2: very low solar activity
3: low solar activity
4: between low and mean solar activity
5: mean solar activity
6: between mean and high solar activity
7: lower level of high solar activity
8: upper level of high solar activity
9: very high solar activity
10: extremely high solar activity

The parameter NCIRA is used with the Runge-Kutta generator only. Its default value is 5.

The upper atmospheric density is available as a function of the local time for each two hour step of the day and as a function of the altitude in the range from 120 km to 700 km above the surface of the Earth. If the altitude is greater than 700 km, the density is set to 0. If the altitude is less than 120 km, the program will abort and an error message will be issued.

IPRINT is a flag for writing the ephemeris to the report file PROJECT.SAP. The ephemeris and world map data are generated for a specified constant time step (DT). If IPRINT $= 0$, each ephemeris step is listed. If IPRINT > 0, each 60^{th} step is listed. The default value of IPRINT is 1. Orbital elements are printed to a separate file PROJECT.ORB if IORBEL=1.

EPHMR selects the format of the report file PROJECT.SAP. If EPHMR=0, no ephemeris is output. If EPHMR=1, the world map coordinates and geocentric inertial ephemeris are sent to the report file PROJECT.SAP. If EPHMR=2, Earth centred ecliptic coordinates are printed as well, the distance between the satellite and the bow shock paraboloid, magnetopause paraboloid, and northern neutral point are calculated and the summary tables include details of eclipses, crossings of the bow shock and magnetopause, and the nearest approach to the northern neutral point. The default value is 2.

The bow shock and magnetopause paraboloid parameters are defined by PP(2) and XP(2). The general form for the paraboloids is given by the equation

$$Y^2 + Z^2 = \mathtt{PP}\,(X - \mathtt{XP})\,.$$

These parameters need only be given when EPHMR=2.

Table 2.2. Suggested values for the Runge-Kutta generator

Orbit eccentricity	STEP (decimal degrees)
$e < 0.5$	5
$e \geq 0.5$	2

2.2.3 Output from SAPRE

The output of SAPRE consists of three files: the common interface file PROJECT.INT, the report file PROJECT.SAP, and the optional orbital element file PROJECT.ORB. SAPRE does not produce separate plot files.

The common interface file contains the orbital trajectory data and serves as input for BLXTRA and TREP. The format of this file is described in Appendix B.

The report file is a printable file containing the input data, the orbit parameters and (if requested) the summary tables.

2.2.4 Using the Runge-Kutta orbit generator

When using the Runge-Kutta orbit generator, appropriate values are needed for the eccentric anomaly step ΔE (STEP) and for the time increment Δt for the ephemeris output. To achieve a stable integration process the figures shown in Table 2.2 should be used as guides.

A value for Δt must be chosen so that the Van Allen belts are sampled securely, primarily at perigee. This is achieved by determining the minimum time step corresponding to a ΔE step with the equation

$$\Delta t_{\min} = T\,(1 - e)\,\frac{\Delta E}{360^\circ}\,,$$

where T is the orbital period in minutes.

As an example, suppose that $T = 2$ days, $e = 0.8$, and $E = 1^\circ$:

$$\Delta t_{\min} = 2 \times 1440\,(1 - 0.8)\,\frac{1^\circ}{360^\circ} = 1.6\,.$$

In this case, since SAPRE requires that the values must be entered as multiples of minutes, specify DT1 = DT2 = DT3 = 2. The values for DT2 and DT3 can be increased in combination with the altitudes DH1 and DH2, which determine the maximum altitudes (in km) for which DT1 and DT2, respectively, will be used (for altitudes greater than DH2, DT3 is used).

2.3 BLXTRA

2.3.1 Function and structure

BLXTRA converts geographical positions given in geodetic longitude, latitude, and height into the (B, L) coordinate system (McIlwain 1961) using an internal geomagnetic field representation and optionally an external magnetic field. The field line tracing in BLXTRA uses an algorithm developed by Pfitzer (1991), which was modified by BISA.

BLXTRA First reads and updates the header information in the common interface file PROJECT.INT. For each orbital point, the modified Julian day is read, which is then used to derive universal time. The geodetic coordinates are transformed into geocentric coordinates [except when the geomagnetic field model of Jensen & Cain (1962) is used]. If an external field is specified, the necessary coordinate transformations are executed. BLXTRA then calculates (B, L) using the pitch angle read from the interface file, and adds the (B, L) to the common interface file.

2.3.2 Pitch angle dependence

The (B, L) coordinates are associated with a particle moving through a point P with given geographical coordinates, and having a given pitch angle α. In the special case $\alpha = 90°$, P is a mirror point for the particle considered (the conjugate mirror points will be denoted by M and M').

The standard software routines used for calculating (B, L) coordinates for a point in space implicitly make the assumption that this point is the mirror point of a particle on the geomagnetic field line passing through it. This approach was adopted for use with older trapped particle models, since these generally are given in terms of omnidirectional fluxes. More modern measurements, however, include flux measurements with high directional resolution. Therefore, in order to make use of this additional information, pitch angle dependence was implemented in the calculation of B and L.

The mirror point M of a particle with pitch angle $\alpha \neq 90°$, measured at P, does not coincide with P. The magnetic field intensity B_m at M is given by

$$B_m = \frac{B}{\sin^2 \alpha}, \tag{2.1}$$

where B is the value of the magnetic field intensity at P. The field line tracing procedure used to calculate the second adiabatic invariant I has to be extended beyond P to the mirror point M (and to the conjugate mirror point M').

The pitch angle dependent coordinates (B_m, L_m) have been implemented in the latest version of BLXTRA (from here on we drop the subscript "m"). For each orbital point, one pitch angle value is given in the common interface file. When the common interface file is created by SAPRE, the value $\alpha = 90°$ is written for all orbital points. If other values are needed, a separate program has to be used to alter the values of α. Such a program is not provided in UNIRAD.

2.3.3 Input and output

BLXTRA takes as input the NAMELIST BLXTRA, and reads geodetic coordinates, modified Julian day, and pitch angle from the common interface file PROJECT.INT. The header of the common interface file is updated. The calculated (B, L) values are appended to the data records in the common interface file. The B value written by BLXTRA is the magnetic field intensity at the point specified by the geodetic coordinates, not that at the mirror point. The NAMELIST parameters for BLXTRA are listed in Table 2.3 with their data type and default value, and a brief description.

When the field line tracing in the calculation of the second adiabatic invariant breaks down, a negative L value is returned. These negative values serve as flags, indicating the problem that occurred. The values of the error flags are listed in Table 2.4.

BLXTRA produces a report file PROJECT.BLP. In addition, when IASCII=1, an ASCII file PROJECT.BLA is created. This latter file contains the information written to the common interface file plus the vector components of the magnetic field vector in geocentric coordinates. The format of the file PROJECT.BLA is given in Table 2.5. BLXTRA does not produce separate plot files.

2.3.4 Magnetic field models in BLXTRA

By default BLXTRA uses the DGRF/IGRF internal magnetic field models and no external model. The inner and outer models available are described below.

Internal magnetic field models

The user has a choice of three internal geomagnetic field models:

1. DGRF/IGRF (1945–1990),
2. Jensen & Cain (1962),
3. GSFC12/66 (Cain et al. 1967).

Table 2.3. NAMELIST parameters for BLXTRA

Parameter	Data Type	Default	Function
IPRINT	INTEGER	60	Frequency of points in listing
IASCII	INTEGER	0	ASCII file with geographic and (B, L) coordinates is created when not 0
CUTOFF	REAL*8	9999	Maximum orbit time (hours)
BLTIME	REAL*8	1995	Epoch for internal magnetic field model
MODEL	INTEGER	0	Choice of internal magnetic field model: 0: DGRF/IGRF for epoch BLTIME 1: Jensen & Cain (1962) for epoch 1960 2: GSFC 12/66 (Cain et al. 1967) for epoch BLTIME
OUTER	INTEGER	0	Choice of external magnetic field model: 0: No external field 1: Mead & Fairfield (1975) 2: Tsyganenko (1987) short 3: Tsyganenko (1987) long 4: Tsyganenko (1989) 5: Olson & Pfitzer (1977) quiet 6: Olson & Pfitzer (1988) dynamic
VALUE_KP	REAL*8	0	Geomagnetic activity index K_p
DEN	REAL*8	25	Density ρ of solar wind
VEL	REAL*8	300	Velocity V of solar wind
DST	REAL*8	−30	Geomagnetic activity index D_{st}

Table 2.4. Possible negative L values indicating a problem encountered during field line tracing

Value	Error
−1	—Geomagnetic latitude—> 80°
−2	Field line crosses the magnetopause
−3	Tracing is beyond valid field limits ($B < 0.00004$)
−4	Maximum step number has been reached
−6	Less than three points in field line tracing

Table 2.5. Format of the ASCII file `PROJECT.BLA` produced by `BLXTRA`. N signifies the number of orbital points. If more than one trajectory were specified, the whole structure is repeated.

Record	Format	Description
1	`1X,A80`	Project header
2	`2(1X,A32)`	Header of internal and external magnetic field model
3	`2I3,F7.1`	`MODEL, OUTER, BLTIME`
4		Table headers
$5 \ldots (N+4)$	`F12.5,F8.2,F7.2, F10.2,F6.1,4F10.6, F8.4`	Modified Julian Day, geographic coordinates, pitch angle, geocentric components of $\boldsymbol{B}$, (B, L)
$N+5$	`F12.5,F8.2,F7.2, F10.2,F6.1,4F10.6, F8.4`	`10*-1.0`: sentinel record to signify end of trajectory

The internal models are selected with the parameter `MODEL`. The expansion coefficients for the internal geomagnetic field models are linked in with `BLXTRA`.

The coefficients of the Jensen & Cain model do not depend on time and have epoch 1960. The other models are time dependent and are extrapolated to epoch `BLTIME`. When the DGRF/IGRF models are chosen, the program selects the model whose epoch is closest to `BLTIME`. The Jensen & Cain and GSFC 12/66 models have been included since they were used to build AP-8 and AE-8 (Heynderickx & Lemaire 1993).

External magnetic field models

Six external magnetic field models are available:

1. Mead & Fairfield (1975),
2. Tsyganenko (1987) short,
3. Tsyganenko (1987) long,
4. Tsyganenko (1989),
5. Olson & Pfitzer (1977) quiet,

6. Olson & Pfitzer (1988) dynamic.

The models are selected with the parameter `OUTER` (see Table 2.3).

The coordinate transformations necessary for the use of the external models are performed by `BLXTRA`. The dipole tilt angle also is calculated internally when necessary and thus is not an input parameter.

The Mead & Fairfield (1975) model is included for historical reasons. There are no input parameters for this model.

The Tsyganenko models The Tsyganenko models are sets of models each representing a different K_p level. The models were created as fits to data from eight IMP and two HEOS satellites covering the period 1966–1980, with the data binned according to activity. The Tsyganenko (1989) model is tilt dependent and was developed primarily as a tail model.

The Tsyganenko models are claimed to be valid up to $X = -70\,R_E$ but may differ nevertheless from the observed field in this region for several reasons (Stern & Tsyganenko 1992):

- The models only give average values of the field whereas actual values vary greatly around such averages. This is true for the other external models as well.
- The high latitude coverage of the data used to build the models is sparse.
- The models use only one magnetospheric index, the planetary geomagnetic activity index K_p.

The Olson-Pfitzer models The tilt dependent model of Olson & Pfitzer (1977) is an average models fit to quiet conditions ($K_p = 0, 1$) using data from OGO 3 and 5 (inner magnetosphere) and Explorer 33 and 35 (tail). This model is valid from $2.5\,R_E$ to $15.0\,R_E$. There are no input parameters for this model.

The Olson & Pfitzer (1988) dynamic model is a scalable model depending upon the activity level. It uses the current systems in the tilt dependent Olson & Pfitzer (1977) model, but scale factors are introduced to separately adjust the strength of all current systems and the geometry of the magnetopause and tail currents. The input parameters that determine the scale factors are the standoff distance of the magnetopause and the activity index D_{st}. The spatial validity in the tail has been extended out to $60\,R_E$ for this model.

The Olson & Pfitzer (1988) dynamic model does not have a tilt dependence. The input parameters are:

1. DEN: density (cm^{-3}) of the solar wind (default: 25),
2. VEL: velocity ($km\,s^{-1}$) of the solar wind (default: 300),
3. DST: geomagnetic activity index (nT) D_{st} (default: -30.0).

2.4 TREP

2.4.1 Function and structure

TREP calculates orbital radiation environment fluxes for arbitrary spacecraft trajectories. It estimates fluxes of trapped particles in function of (B, L) coordinates, and computes solar proton event probabilities to estimate solar proton fluences. The output consists of:

1. the time dependent fluxes of trapped protons, solar protons, and trapped electrons;
2. trajectory-averaged spectra for trapped protons and electrons;
3. solar flare fluence spectra, taking into account geomagnetic shielding.

2.4.2 Trapped particle models

TREP accesses the NASA trapped particle models AP-8 (Sawyer & Vette 1976) and AE-8 (Vette 1991a) at each orbital point contained in the common interface file. The NASA trapped radiation models AP-8 and AE-8 are distributed as tables of omnidirectional fluxes in function of particle energy E and $(B/B_0, L)$, where

$$B_0 = \frac{0.311653}{L^3}. \tag{2.2}$$

The NASA models AP-8 and AE-8 are static models built with data obtained in the sixties and seventies. There are two sets of models: AP-8 MAX and AE-8 MAX for solar maximum conditions, and AP-8 MIN and AE-8 MIN for solar minimum conditions. Since these models were built with specific magnetic field models, the same magnetic field models should be used to calculate the $(B/B_0, L)$ values that serve as input to AP-8 and AE-8. The appropriate magnetic field models are: Jensen & Cain (1962) for AE-8 MIN, AP-8 MIN, and AE-8 MAX, and GSFC 12/66 (Cain et al. 1967) updated to epoch 1970 for AP-8 MAX (Heynderickx & Lemaire 1993).

The position of the SAA in the old magnetic field models to be used with AP-8 and AE-8 is different from its actual position due to the secular variation on the

geomagnetic field (Fraser-Smith 1987). This may have important effects on the prediction of trapped particle fluxes for low altitude orbits. Therefore, a correction has been built into TREP: when the NAMELIST parameter SAAROT is set to 1, a correction term $\Delta\phi(t)$ is added to the geodetic longitude before the calculation of (B, L) (the actual value of the longitude on the interface file is not changed):

$$\delta\phi(t) = 0.3^\circ\,(t - \texttt{EPOCH})\,. \tag{2.3}$$

where t is the orbit epoch as written in the header of the common interface, and EPOCH is the epoch of the geomagnetic field model.

Originally, TREP read (B, L) values, calculated by BLXTRA, from the common interface file. TREP has since been modified so that it calculates (B, L) independently, with the appropriate magnetic field models. Consequently, one can pass directly from SAPRE to TREP. (B, L) are calculated (twice, if necessary, for the two geomagnetic field models) and written on the interface file [always the (B, L) values calculated for the electron model].

The energy spectrum for trapped protons, trapped electrons, and solar flare protons is specified with the NAMELIST parameters PROEN(30), ELEEN(30), and ENERFL(30), respectively. The values are threshold energies (in MeV) for integral flux. The maximum number of energies is 30 for each of the three types of particle, the minimum is 10. The number of energies is specified with the NAMELIST parameters NENERP, NENERE, and NENERS, which default to 30.

Trapped protons

In addition to the omnidirectional models AP-8 there also exists a version of the AP-8 models in terms of perpendicular fluxes (Vette, unpublished report), which has been added to TREP. See the section on pitch angle dependence for instructions on how to use this model. Please note that SHIELDOSE, EQFRUX, and EQFRUXGA expect omnidirectional fluences as input, which means that the unidirectional AP-8 model should not be used for computations of doses or damage equivalent electron fluences.

Trapped electrons

The influence of local time on electron fluxes can be included. The model used is an extension of the AE-4 local time model of Singley & Vette (1972a). It is called by setting ILTV=1 (the default value is 0). Electron local time variation parameters then are initialized and the local time correction to the logarithm of the flux is computed.

A statistical model describing the distribution of observed electron flux levels has been introduced. Electron fluxes are modified according to an extension of the

AE-4 statistical model of Singley & Vette (1972a). The model is activated by setting ISIG to one of the values -2, -1, 1, 2 (the default value is 0), which results in the calculation of standard deviations from the mean flux.

Instead of the electron model AE-8, a model developed for the geostationary environment on the basis of LANL omnidirectional measurements (Lemaire et al. 1991) may be used. The model is activated by setting TREMOD=2 (TREMOD=1, the default value, selects AE-8). This model is valid only for geostationary orbits and gives zero fluxes everywhere else.

Pitch angle dependence

Since the dependence on pitch angle has been introduced in TREP, the magnetic coordinates (B, L) written to the interface file are now interpreted as the magnetic field intensity at the geodetic coordinates and the L value obtained by tracing the field line to the mirror point.

The user can choose between the calculation of omnidirectional or unidirectional proton fluxes by means of the NAMELIST parameter OMNI. With OMNI=1 (the default), omnidirectional proton fluxes are calculated, setting OMNI=0 results in unidirectional proton fluxes.

For the calculation of unidirectional proton fluxes, B_m is derived with Eq. (2.1), since the flux in direction α at the point with coordinates (B, L) is equal to the perpendicular flux at the point with coordinates (B_m, L). The coordinates $(B_m/B_0, L)$ then are used as input to the unidirectional proton model.

The user should be aware that if $\alpha \neq 90°$, the omnidirectional flux is calculated for the mirror point of the particle, which in that case does not coincide with the geographic coordinates!

2.4.3 Solar flare protons

Solar flare particle events, because of their unpredictability and large variability in magnitude, duration and spectral characteristics, have to be treated statistically. In TREP solar flare proton spectra are generated with the models of King (1974) or Feynman & Gabriel (1990), which are described below. For both models, geomagnetic shielding has to be evaluated.

The mission duration (in years) is specified with the NAMELIST parameter TFLARE (default is one year). TREP computes the mission time during solar active years from TFLARE and the orbit epoch year and month OEYEAR and OEMON which are written in the header of the common interface file PROJECT.INT. The starting offset (in years) in the solar active cycle can also be given explicitly with the NAMELIST parameter

FLSTAR. When FLSTAR≥ 0 this value is used to calculate the time during solar active years instead of the orbit epoch.

The King model

King (1974) used Burrell's modified Poisson distribution for predicting the number of events expected and the spectra. Burrell's distribution gives the probability p of a number of events n occurring during a time t, based on a previously observed frequency N during time T:

$$p(n,t;N,T) = \frac{(n+N)!\,(t/T)^n}{n!\,N!\,(1+t/T)^{N+n+1}}\,. \tag{2.4}$$

Most planning is based on worst case confidence levels (95%) and a model of the August 1972 anomalously large (AL) event. This anomalously large flare dominates all others in terms of peak flux, integrated flux, and duration.

King (1974) examined IMP energetic proton data for a number of flare events and, treating the 1972 AL flare separately, produced a log normal distribution of ordinary flare fluences as a function of proton energy and an exponential fit to the 1972 AL fluence spectrum:

$$J(>E) = 7.9^9\,\exp\!\left(\frac{30-E}{26.5}\right)\,, \tag{2.5}$$

with E in MeV and J in cm^{-2}.

Models of mean, worst case and anomalous solar flare proton spectra based on King's work are used in TREP, together with the Burrell distribution. Depending on the mission duration and timing, a number of flares is predicted and the resulting total fluence spectrum is produced.

The number of anomalously large solar flares and of ordinary solar flares can be input with the NAMELIST parameters NAL and NOR, respectively. Note that if NOR is input as, or predicted to be, 1, and the probability level is 90% or greater, a worst case ordinary flare spectrum is produced.

The Feynman & Gabriel model

The predictive model of Feynman & Gabriel (1990) for the >10 MeV and >30 MeV solar proton environment is based on observations made from 1956 through 1985. In this data set the distinction between "ordinary events" and "anomalously large events" disappeared, which permitted the use of of the statistical analysis methods that have been developed for "ordinary events" to be used on the entire data set.

The > 10 MeV fluences expected with the new model are about twice those expected on the basis of earlier models. At energies > 30 MeV the old and new models agree.

The results obtained with the Feynman & Gabriel (1990) model do not depend critically on the fluence from any one event and are independent of the size of the sunspot cycle.

With the NAMELIST parameter IFORM, the user can choose between a solar proton spectral form that is exponential in energy (IFORM=0, the default) or exponential in rigidity (IFORM=1).

Geomagnetic shielding

Geomagnetic shielding of flare protons is computed on the basis of the trajectory in (B, L) space. Stassinopoulos and King (1973) reported a model which has total cutoff at $L = 5$: it is assumed that no protons can penetrate to lower values. Computing the geomagnetic cutoff for vertically arriving protons, one finds that this model corresponds to a quiet magnetosphere vertical cutoff model excluding protons with energy below 200 MeV from $L < 5\,R_{\mathrm{E}}$. This model is adequate for most cases and is included in TREP and is selected by setting the NAMELIST parameter IFLATT=0 (this is the default value).

Protons of lower energy can penetrate below $L = 5$ with other arrival directions, especially in a disturbed magnetosphere when the geomagnetic shielding is weakened. For westward arrival at the $L = 5$ geomagnetic equator in a disturbed magnetosphere, the energy cutoff could be as low as 30 MeV. A model for flare proton cutoff that depends on the arrival direction is available in TREP. It is selected by setting the NAMELISTparameter IFLATT=1.

For missions that do not remain at a heliocentric radial distance r of 1 AU a correction should be applied to the solar flare fluence: the fluence should be multiplied by a factor which depends on the actual trajectory, i.e. the integration of the radial dependence of the fluence over the mission trajectory. The radial dependence used in TREP is an inverse r cubed dependence for $r \leq 1$ AU and an inverse r squared dependence for $r > 1$ AU. These radial dependencies are worst case choices. r can be input with the NAMELIST parameter RAU, whose default value is 1.

2.4.4 Input and output

Input files

TREP takes as input the NAMELIST TREP, and reads modified Julian day, geodetic coordinates, and pitch angle from the common interface file. The NAMELIST parameters for TREP are listed in Table 2.6 with their data type and default value, and a

Table 2.6. NAMELIST parameters for TREP

Parameter	Data Type	Default	Function
SOLACT	CHARACTER*3	MAX	Solar activity level for NASA trapped radiation models (MAX, MIN)
TREMOD	INTEGER	1	1: Electron model AE-8 2: Electron model LANL
PERIOD	REAL*4	0	0: Orbital period (hrs). If 0, the period is computed from the apogee and perigee.
NENERP	INTEGER	30	Number of energies in trapped proton spectrum (10 $\leq$NENERP$\leq$ 30).
PROEN	REAL*4(30)		Trapped proton threshold energies (MeV). Default: 0.1, 0.5, 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 17, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 125, 150, 175, 200, 300
NENERE	INTEGER	30	Number of energies in trapped electron spectrum (10 $\leq$NENERE$\leq$ 30).
ELEEN	REAL*4(30)		Trapped electron threshold energies (MeV). Default: 0.04, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 1.0, 1.25, 1.5, 1.75, 2.0, 2.25, 2.5, 2.75, 3.0, 3.25, 3.5, 3.75, 4.0, 4.25, 4.5, 4.75, 5.0, 5.5, 6.0, 6.5, 7.0
NENERS	INTEGER	30	Number of energies in solar flare proton spectrum (10 $\leq$NENERS$\leq$ 30).
ENERFL	REAL*4(30)		Threshold energies (MeV) for solar flare protons. Default: 0.1, 0.5, 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 17, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 120, 140, 160, 180, 200
ETHP	REAL*4(2)	1, 10	Trapped proton energy thresholds (MeV) for prints, plots, and interface file
ETHE	REAL*4(2)	0.1, 1	Trapped electron energy thresholds (MeV) for prints, plots, and interface file
FLUXTH	REAL*4(2)	1, 1	Threshold fluxes ($cm^{-2}s^{-1}$) for protons and electrons for flux-free time tables
ILTV	INTEGER	0	Local time variation (LTV) flag. 0: no LTV of electron fluxes 1: include LTV of electron fluxes
ISIG	INTEGER	0	Extension of AE-4 statistical model. Values: $-2, -1, 0, 1, 2$

Table 2.6. (continued)

Parameter	Data Type	Default	Function
FLAMOD	INTEGER	1	Select solar flare model. 0: No solar protons 1: Feynman & Gabriel's (1990) flare model 2: King's (1974) flare model
TFLARE	REAL*4	1	Mission duration (years)
FLSTAR	REAL*4	−1	Starting offset in solar activity cycle (years)
FLPROB	REAL*4	95	Probability (in %) of not exceeding solar proton fluence
NAL	INTEGER	0	Number of anomalously large solar flares for King (1974) model. If 0, computed from Burrell distribution.
NOR	INTEGER	0	Number of ordinary solar flares for King model. If 0, computed from Burrell distribution.
IFLATT	INTEGER	0	Flare particle attenuation flag 0: Stassinopoulos-King model 1: Model of non-vertical proton arrival
RAU	REAL*4	1	Integrated heliocentric radial distance
IFORM	INTEGER	0	Solar proton spectral form for Feynman & Gabriel model 0: Exponential in energy 1: Exponential in rigidity
IPRINT	INTEGER	60	Frequency of points in listing
INTERF	INTEGER	1	1: Produce interface file PROJECT.TRI. Not produced if 0.
ISPEC	INTEGER	0	1: Produce ASCII files PROJECT.SPP and PROJECT.SPE. Not produced if 0.
ISPSHT	INTEGER	0	1: Produce spreadsheet file PROJECT.TRW. Not produced if 0.
SAAROT	INTEGER	0	0: No correction for drift of SAA 1: Eastward rotation of SAA of 0.3°/yr
OMNI	INTEGER	1	0: Unidirectional AP-8 proton fluxes 1: Omnidirectional proton fluxes

Table 2.7. (continued)

Record nr.	Format	Description
16+NENERP+ NENERE	3E11.4	Proton energy, integral and differential fluence
⋮		
16+NENERP+ NENERE+NENERS	3E11.4	Solar proton energy, integral and differential fluence
17+NENERP+ NENERE+NENERS		Blank line

brief description.

Output files

The header in the common interface file is updated. The (B, L) coordinates and the integral proton and electron fluxes for the energy thresholds specified in the NAMELIST parameters ETHP and ETHE are appended to the data records in the common interface file.

TREP produces the report file PROJECT.TRP, but no separate plot files. An additional output file PROJECT.TRI is created when the NAMELIST parameter INTERF=1 (this is the default). This file contains the orbit-averaged spectra of trapped protons and electrons, and of solar protons if a solar flare model was specified. The file serves as input to SHIELDOSE, EQFRUX, and EQFRUXGA. The format of this file is described in Table 2.7. The orbit-averaged spectra can also be output in spreadsheet format (i.e. as comma separated columns with one header line) on the file PROJECT.TRW, which is created when ISPSHT is set to 1 (the default value is 0). The format of the file PROJECT.TRW is given in Table 2.9.

When ISPEC=1, TREP produces two ASCII files, PROJECT.SPP and PROJECT.SPE for protons and electrons, respectively. These files contain, for each orbital point, modified Julian day, geodetic coordinates, pitch angle, geocentric components of the magnetic field vector, (B, L), and the full particle flux spectrum. The format of the files PROJECT.SP* is given in Table 2.8.

Table 2.7. Format of the interface file PROJECT.TRI. NENER* signifies the number of spectral energies. If more than one trajectory was specified, the whole structure is repeated.

Record	Format	Description
1	1X,A80	Project header
2	1X,A3, 2(1X,A8)	Solar activity level, trapped particle model headers
3	2(1X,A32)	Headers for internal magnetic field models
4	2(1X,A32)	Headers for external magnetic field models
5	4I3,2F8.1	Numbers of internal and external magnetic field models, BLTIME(2)
6	F6.1,2F8.1, E11.4	Orbit inclination (deg), perigee height (km), apogee height (km), period (hrs)
7	F7.3,F7.2, 2I4,2E11.4, I3	Mission duration (years), probability of not exceeding proton fluence (%), number of anomalously large flares, number of ordinary flares, fraction of orbit time in solar active period, total orbit time (hrs), number of solar flare model
8	3E11.4	Flux threshold FLUXTH(1) and energy thresholds ETHP for protons
9	2E11.4	Time (hrs) spent in regions where proton flux is above ETHP
10	3E11.4	Flux threshold FLUXTH(2) and energy thresholds ETHE for electrons
11	2E11.4	Time (hrs) spent in regions where electron flux is above ETHE
12	3I4	Number of energies in spectra of trapped protons, trapped electrons, solar flare protons
13	3E11.4	Proton energy, integral and differential flux
⋮		
12+NENERP	3E11.4	Proton energy, integral and differential flux
13+NENERP		Blank line
14+NENERP	3E11.4	Electron energy, integral and differential flux
⋮		
14+NENERP+ NENERE	3E11.4	Electron energy, integral and differential flux
15+NENERP+ NENERE		Blank line

Table 2.8. Format of the ASCII file `PROJECT.SP*` produced by `TREP`. N signifies the number of orbital points. If more than one trajectory was specified, the whole structure is repeated. `NENER` signifies the number of energies in the spectrum.

Record	Format	Description
1	`1X,A80`	Project header
2	`2(1X,A32)`	Header of internal and external magnetic field model
3	`2I3,F7.1,I3`	`MODEL`, `OUTER`, `BLTIME`, number of energies
4		Table headers
5	`F12.5,F8.2,F7.2, F10.2,F6.1,4F10.6, F8.4,30E11.4`	Modified Julian Day, geographic coordinates, pitch angle, geocentric components of $\boldsymbol{B}$, (B, L), `NENER` flux values
⋮		
$N+5$	`F12.5,F8.2,F7.2, F10.2,F6.1,4F10.6, F8.4, 30E11.4`	`(10+NENER)*-1.0`: sentinel record to signify end of trajectory

Table 2.9. Format of the spreadsheet file `PROJECT.TRW`. If more than one trajectory was specified, the whole structure is repeated.

Record	Format	Description
1	`1X,A80`	Project header
2	`2(3(E11.4,','), 2(E11.4,','),E11.4`	Energy, integral flux and differential flux for trapped protons and electrons, and solar flare proton fluence
⋮		
31	`2(3(E11.4,',')), 2(E11.4,','),E11.4`	Energy, integral flux and differential flux for trapped protons and electrons, and solar flare protons

2.5 TREPPOS

TREPPOS works interactively and allows calculation of trapped particle fluxes at particular positions in the Earth's radiation belts. The user has to supply a project name, a title, the proton and electron energies (which default to the values in Table 2.6) and a series of (B, L) or $(B/B_0, L)$ coordinate pairs.

TREPPOS calculates omnidirectional trapped proton and electron fluxes with the NASA models AP-8 and AE-8. The local time variation model and the statistical model (both described in Sect. 2.4.2) can be applied to the electron fluxes.

2.5.1 Inputs and outputs

TREPPOS takes its input interactively from the keyboard. Only one output file can be produced, i.e. PROJECT.INT, which can serve as input for TREPAVE, SHIELDOSE, EQFRUX, and EQFRUXGAwhen a proper NAMELIST file is created. TREPPOS prompts for the project name PROJECT which serves as the first part of the names of the output file. The NAMELIST file written by the user for use with other programs in UNIRAD should have the name PROJECT.NML.

2.6 TREPAVE

TREPAVE takes the results from the TREP interface file PROJECT.TRI for each orbit and produces average proton and electron fluxes using appropriate weightings, contained in the NAMELIST parameter WEIGHTS, which is the sole parameter in the NAMELIST TREPAVE. WEIGHTS is a REAL*4 vector of 200 elements, with default values 1.0. Solar proton fluences are not averaged as TREP provides predictions of flares for a certain period.

2.6.1 Inputs and outputs

TREPAVE reads the NAMELIST file PROJECT.NML and the file PROJECT.TRI produced by TREP. The averaged spectra are written to the file PROJECT.TAI, which has the same format as PROJECT.TRI (see Table 2.7). The file PROJECT.TAI can be used as input for SHIELDOSE, EQFRUX, and EQFRUXGA, but should be renamed to a file with extension .TRI. An appropriate NAMELIST file should also be set up.

Table 2.10. NAMELIST parameters for SHIELDOSE.

Parameter	Data Type	Default	Function
IDET	INTEGER	3	Selects detector material: 1: AL detector 2: H_2O detector 3: SI detector 4: SiO_2 detector
TINTER	REAL*8	365.25	Mission duration (days)
IUNT	INTEGER	3	Selects units for shield depths: 1: Shield depths in mils 2: Shield depths in $g\,cm^{-2}$ 3: Shield depths in mm
IMAX	INTEGER	25	Number of shield depth values
Z	REAL*4(50)		Shield depth values. Defaults: 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 25*100.0
IPRINT	INTEGER	0	Dose spectra are listed when set to 1
IPLOT	INTEGER	1	0: No graphical output 1: Output file PROJECT.SHG is created
ISHLD	INTEGER	4	Selects shield configurations

2.7 SHIELDOSE

SHIELDOSEmakes use of pre-calculated, mono-energetic depth-dose data for an isotropic fluence of radiation incident on uniform aluminium plane media and integrates these mono-energetic data over the incident flux spectrum. The output of SHIELDOSE consists of doses in four different detector materials (Al, H_2O, Si, SiO_2) as a function of shield depth for three different shielding geometries: finite slab, semi-infinite, spherical.

2.7.1 Input files

SHIELDOSE takes as input the NAMELIST SHIELDOSE and the interface file PROJECT.TRI created by TREP, TREPPOS, or TREPAVE. The interface file contains the orbit-averaged spectra of trapped protons and electrons, and of solar protons if a solar flare model

was specified.

The NAMELIST parameters for SHIELDOSE are listed in Table 2.10 with their data type and default value, and a brief description.

The number of shield depth values in input with the NAMELIST parameter IMAX. The shield depth values themselves are contained in the vector Z. By default, the units of Z are mm. By setting the parameter IUNT to 1 or 2, the values in Z are interpreted as mils or $g\,cm^{-2}$, respectively, and are converted by the program to mm.

The shield configuration is selected with the NAMELIST parameter ISHLD. This parameter can take the values 1, 2, and 4 for finite slab, semi-infinite, and spherical, respectively, and combinations of these three values. For instance, ISHLD=7 will generate prints and plots for all three shield configurations, ISHLD=3 selects only the infinite slab and semi-infinite configurations. The default value is 4.

2.7.2 Output files

SHIELDOSE produces the report file PROJECT.SHP, and the plot file PROJECT.SHG when the NAMELIST parameter IPLOT=1. The format of the file PROJECT.SHG is given in Table 2.11. The same format is used for the plot files PROJECT.EQG and PROJECT.EGG created by EQFRUX and EQFRUXGA, respectively. For SHIELDOSE, the first three numbers in the third record always are zero, since there is only one series of output plots.

2.8 EQFRUX

EQFRUX calculates 1 MeV damage equivalent electron fluences for exposure to the fluences predicted by TREP or TREPPOS, for a specified duration. The conversion to damage equivalent fluences is based on damage ratios published by JPL for Si cells.

2.8.1 Input files

EQFRUX takes as input the NAMELIST EQFRUX and the interface file PROJECT.TRI created by TREP, TREPPOS, or TREPAVE. This file contains the orbit-averaged fluence spectra of trapped protons and electrons, and of solar protons if a solar flare model was specified. The NAMELIST parameters for EQFRUX are listed in Table 2.12 with their data type and default value, and a brief description.

The NAMELIST parameter TINTER specifies the mission duration in days. It is used for the trapped particle fluxes only. For solar flares, the fluence spectrum produced by TREP is used and is not dependent on the value of TINTER.

Table 2.11. Format of the plot files generated by `SHIELDOSE`, `EQFRUX`, and `EQFRUXGA`. When more than one trajectory is in the interface file, the whole structure is repeated. The first set of plots is not present in `PROJECT.SHG`. The format `A*` means that the length of the string is variable.

Record	Format	Description
1	`1X,A80`	Project header
2	`1X,A*`	Mission description
3	`6I3`	Number of plots, number of values of dependent variable, number of independent variables, for full and summary plots (NPF, NDF, NIF, NPS, NDS, NIS)
4	`1X,A*`	General plot title
5	`1X,A*`	Vertical axis label
6	`1X,A*`	Horizontal axis label and NIF legends (separated by commas)
7...(6+NDF)	`(1+NIF)E11.4`	Independent variable and NIF dependent variables
⋮	`(1+NIF)E11.4`	NPF−1 repetitions of records 4...(6+NDF)
4+(3+NDF)*NPF	`1X,A*`	General plot title
5+(3+NDF)*NPF	`1X,A*`	Vertical axis label
6+(3+NDF)*NPF	`1X,A*`	Horizontal axis label and NIS legends (separated by commas)
7+(3+NDF)*NPF... 6+(3+NDF)*NPF+NDS	`(1+NIS)E11.4`	Independent variable and NIS dependent variables
⋮	`(1+NIS)E11.4`	NPS−1 repetitions of records 7+(3+NDF)*NPF to 6+(3+NDF)*NPF+NDS

Table 2.12. NAMELIST parameters for EQFRUX

Parameter	Data Type	Default	Function
TINTER	REAL*8	365.25	Mission duration (days)
BSF	REAL*8	1	Backshielding factor
PEDRI	REAL*8	3000	Damage ratio between protons and electrons for ISC
PEDRV	REAL*8	3000	Damage ratio between protons and electrons for VOC
IPRINT	INTEGER	0	0: Summary tables of flux vs. depth only 1: Tables of equivalent fluence vs. energy as well
IPLOT	INTEGER	1	0: No graphical output 1: Only summary plots of flux vs. depth 2: Full difference fluence spectra vs. energy as well

2.8.2 Output files

EQFRUX produces the report file PROJECT.EQP, and the plot file PROJECT.EQG when the NAMELIST parameter IPLOT> 0. The format of the file PROJECT.EQG is given in Table 2.11. The same format is used for the plot files PROJECT.SHG and PROJECT.EGG created by SHIELDOSE and EQFRUXGA, respectively.

2.9 EQFRUXGA

EQFRUXGA calculates 1 MeV damage equivalent electron fluences for exposure to the fluences predicted by TREP or TREPPOS, for a specified duration. The conversion to damage equivalent fluences is based on damage ratios published by JPL for GaAs cells.

2.9.1 Input files

EQFRUXGA takes as input the NAMELIST EQFRUX and the interface file PROJECT.TRI created by TREP, TREPPOS, or TREPAVE. This file contains the orbit-averaged fluence spectra of trapped protons and electrons, and of solar protons if a solar flare model

Table 2.13. NAMELIST parameters for EQFRUXGA

Parameter	Data Type	Default	Function
TINTER	REAL*8	365.25	Mission duration (days)
BSF	REAL*8	1	Backshielding factor
PEDRI	REAL*8	400	Damage ratio between protons and electrons for ISC
PEDRV	REAL*8	1400	Damage ratio between protons and electrons for VOC
PEDRP	REAL*8	1000	Damage ratio between protons and electrons for P-MAX
IPRINT	INTEGER	0	0: Summary tables of flux vs. depth only 1: Tables of equivalent fluence vs. energy as well
IPLOT	INTEGER	1	0: No graphical output 1: Summary plots of flux vs. depth only 2: Full difference fluence spectra vs. energy as well

was specified. The NAMELIST parameters for EQFRUXGA are listed in Table 2.12 with their data type and default value, and a brief description.

The NAMELIST parameter TINTER specifies the mission duration in days. It is used for the trapped particle fluxes only. For solar flares, the fluence spectrum produced by TREP is used and is not dependent on the value of TINTER.

2.9.2 Output files

EQFRUXGA produces the report file PROJECT.EGP, and the plot file PROJECT.EGG when the NAMELIST parameter IPLOT> 0. The format of the file PROJECT.EGG is given in Table 2.11. The same format is used for the plot files PROJECT.SHG and PROJECT.EQG created by SHIELDOSE and EQFRUX, respectively.

3.2 Output from BLXTRA

The B and L values calculated for the sample orbit are plotted in Fig. 3.1.

3.3 Output from TREP

The positional proton and electron fluxes calculated for the sample orbit are plotted in Figs. 3.2 and 3.3, respectively. Note that the (B, L) values have been recalculated by `TREP` with the proper geomagnetic field models.

The orbit averaged proton and electron fluence spectra are represented in Figs. 3.4 and 3.5, respectively. The solar proton spectrum is shown in Fig. 3.6.

3.4 Output from SHIELDOSE

The dose curves calculated for the sample orbit are plotted in Figs. 3.7–3.9 for the three shield configurations.

3.5 ——

3.6 — —

3.7 Figures from unirad.

Chapter 3

A sample run of UNIRAD

In this chapter, we present the output of a sample run of UNIRAD. The default values for the NAMELIST parameters (see Appendix A) were used, except for the parameters listed in Table 3.1. The project name of the sample run is TEST.

The plots in this chapter were produced with UNIRAD.PRO.

3.1 Output from SAPRE

Figure 3.1 represents the orbit generated for the sample project.

Table 3.1. Non-default NAMELIST parameters for the sample run

Parameter	Value
SHIELDOSE	
ISHLD	7
EQFRUX	
IPLOT	2
EQFRUXGA	
IPLOT	2

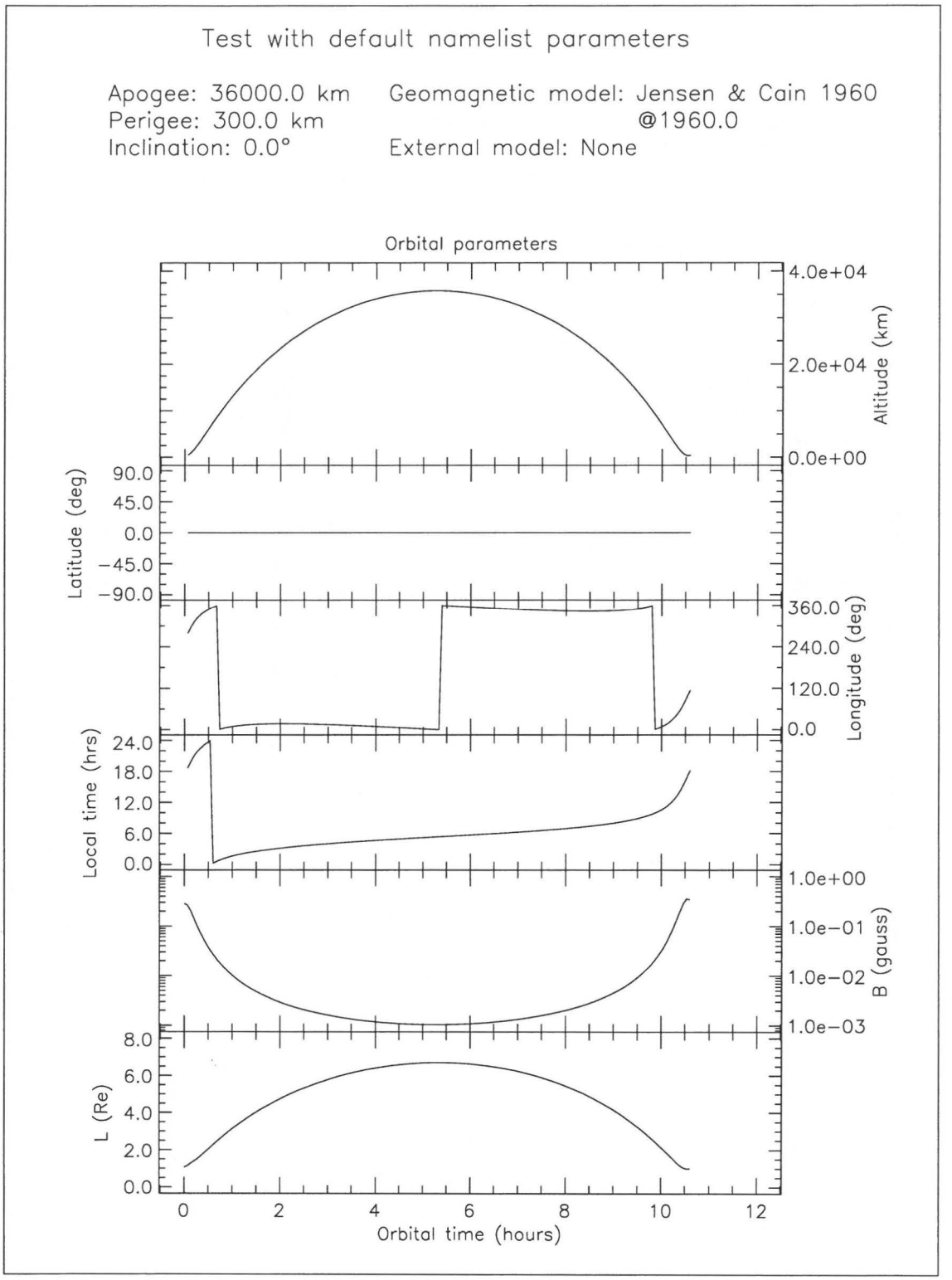

Figure 3.1. Geographic and magnetic coordinates for the sample orbit.

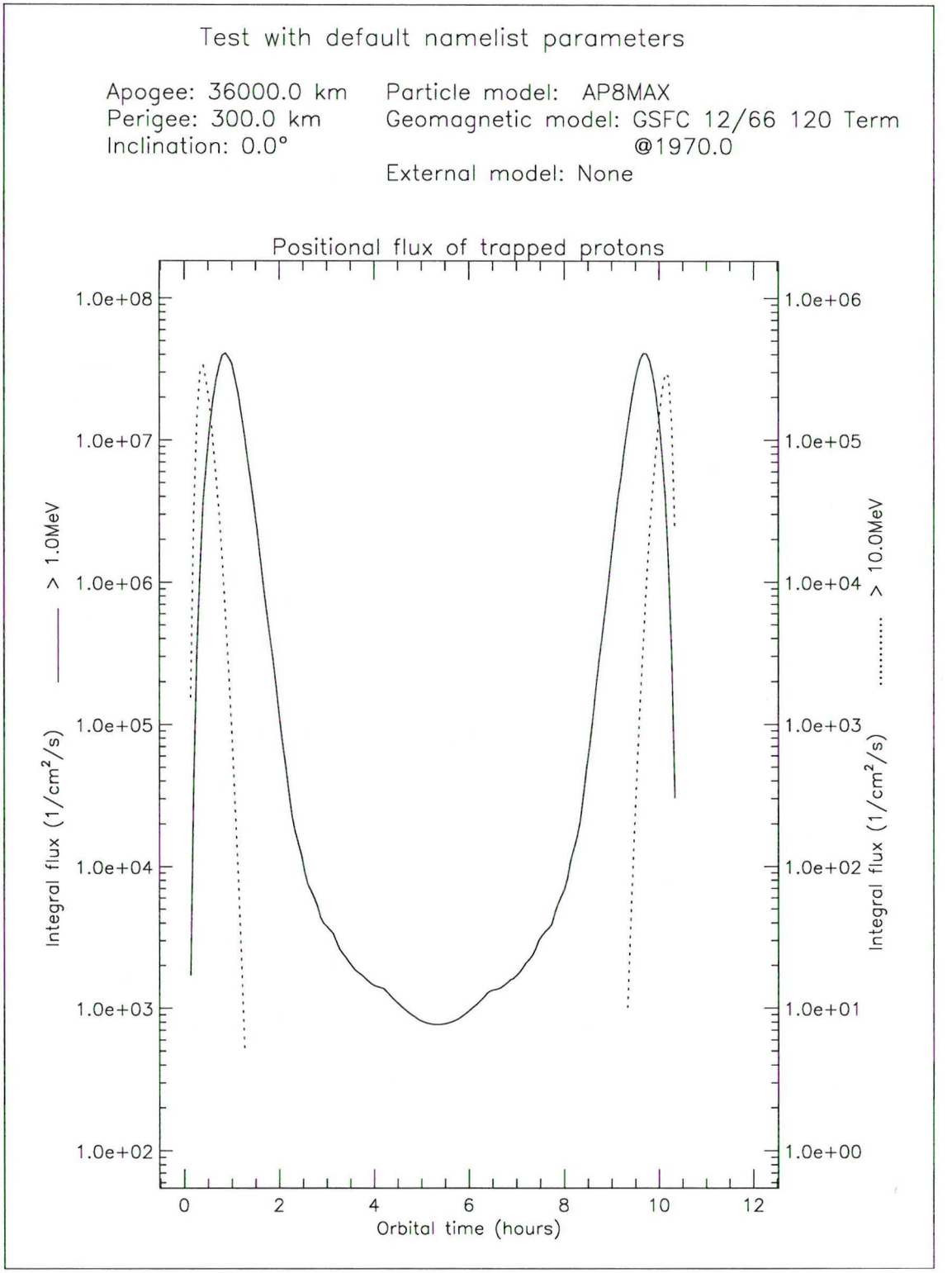

Figure 3.2. Integral trapped proton fluxes for the sample orbit.

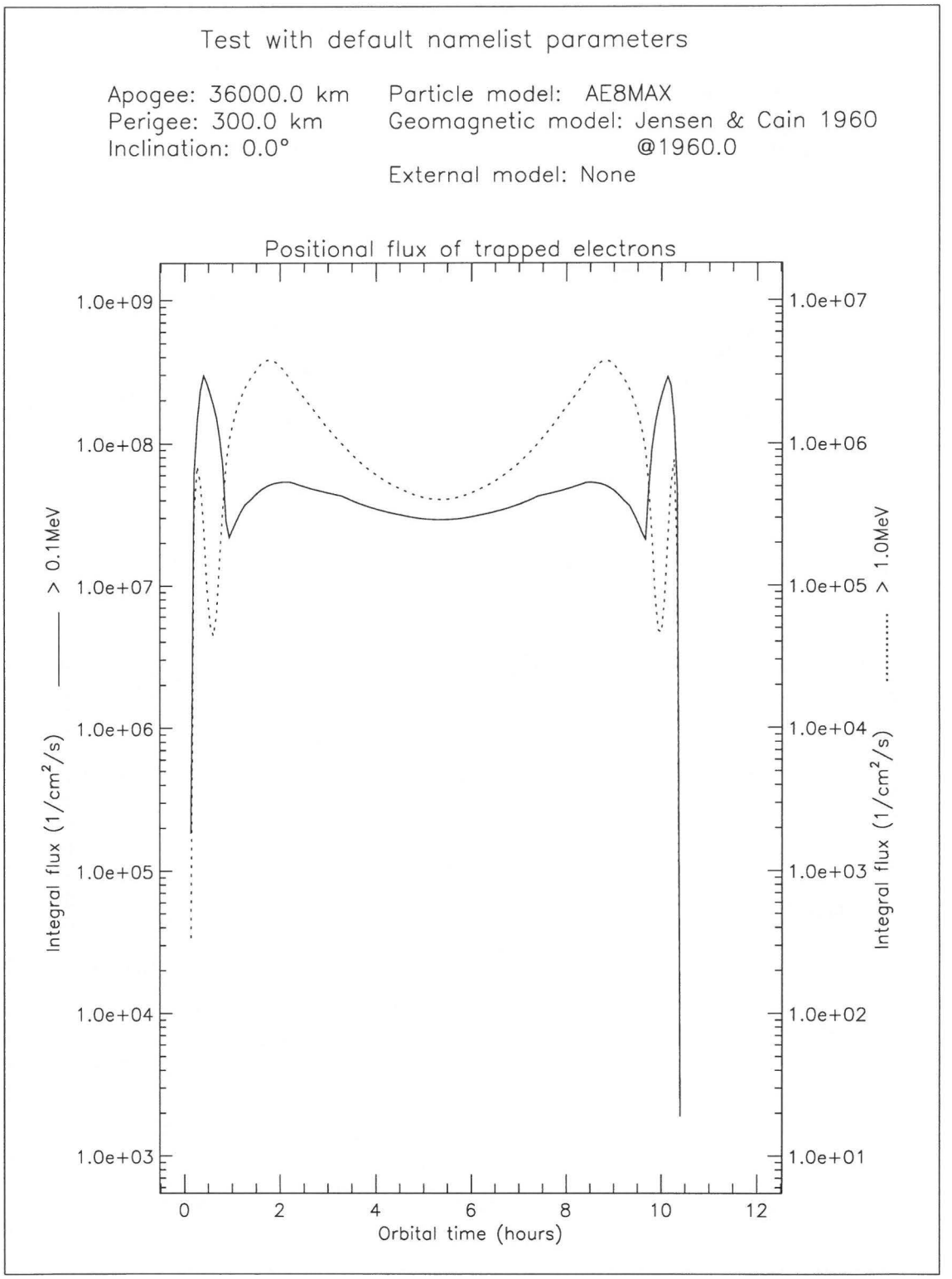

Figure 3.3. Integral trapped electron fluxes for the sample orbit.

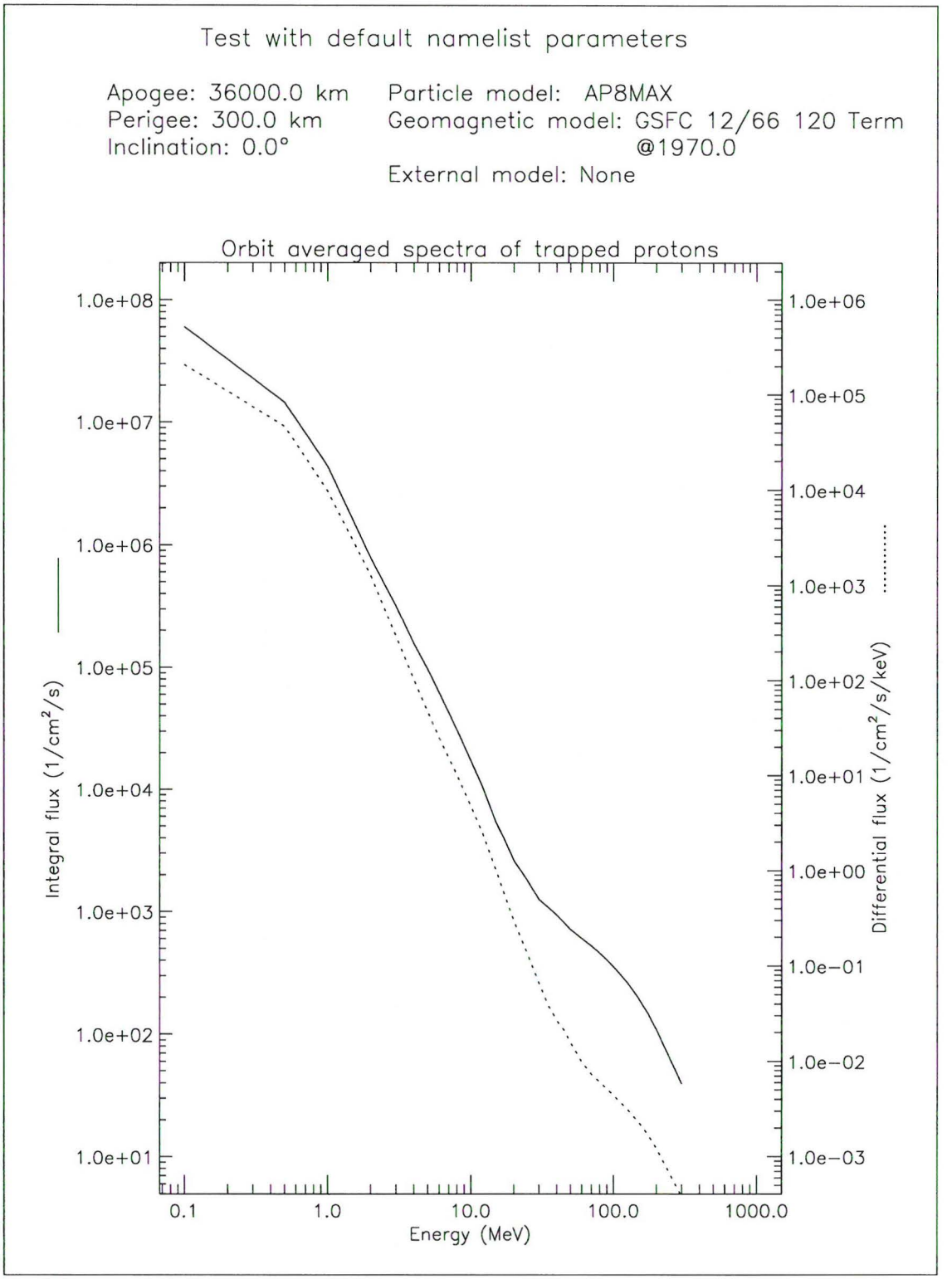

Figure 3.4. Integral and differential trapped proton spectrum for the sample orbit.

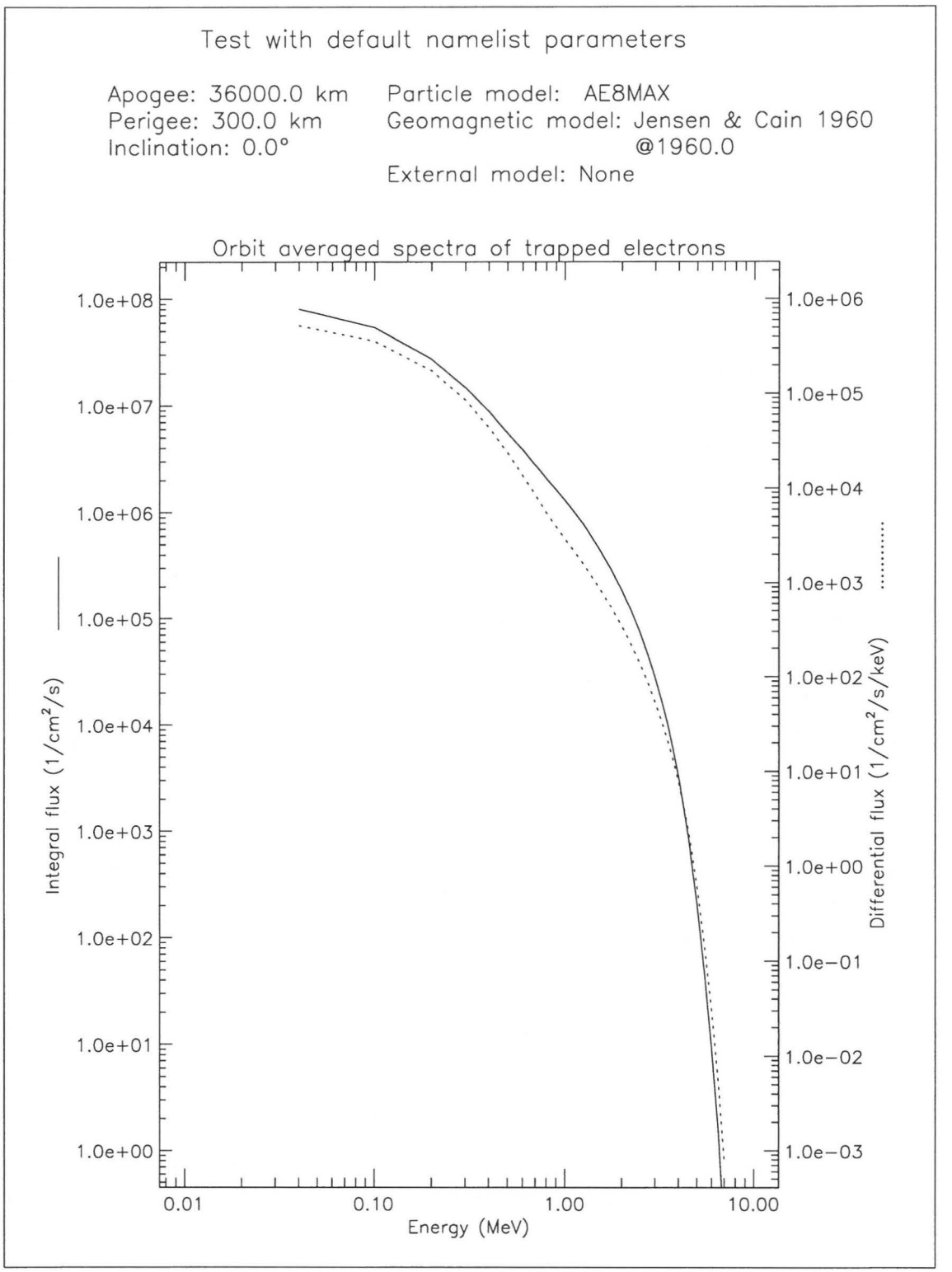

Figure 3.5. Integral and differential trapped electron spectrum for the sample orbit.

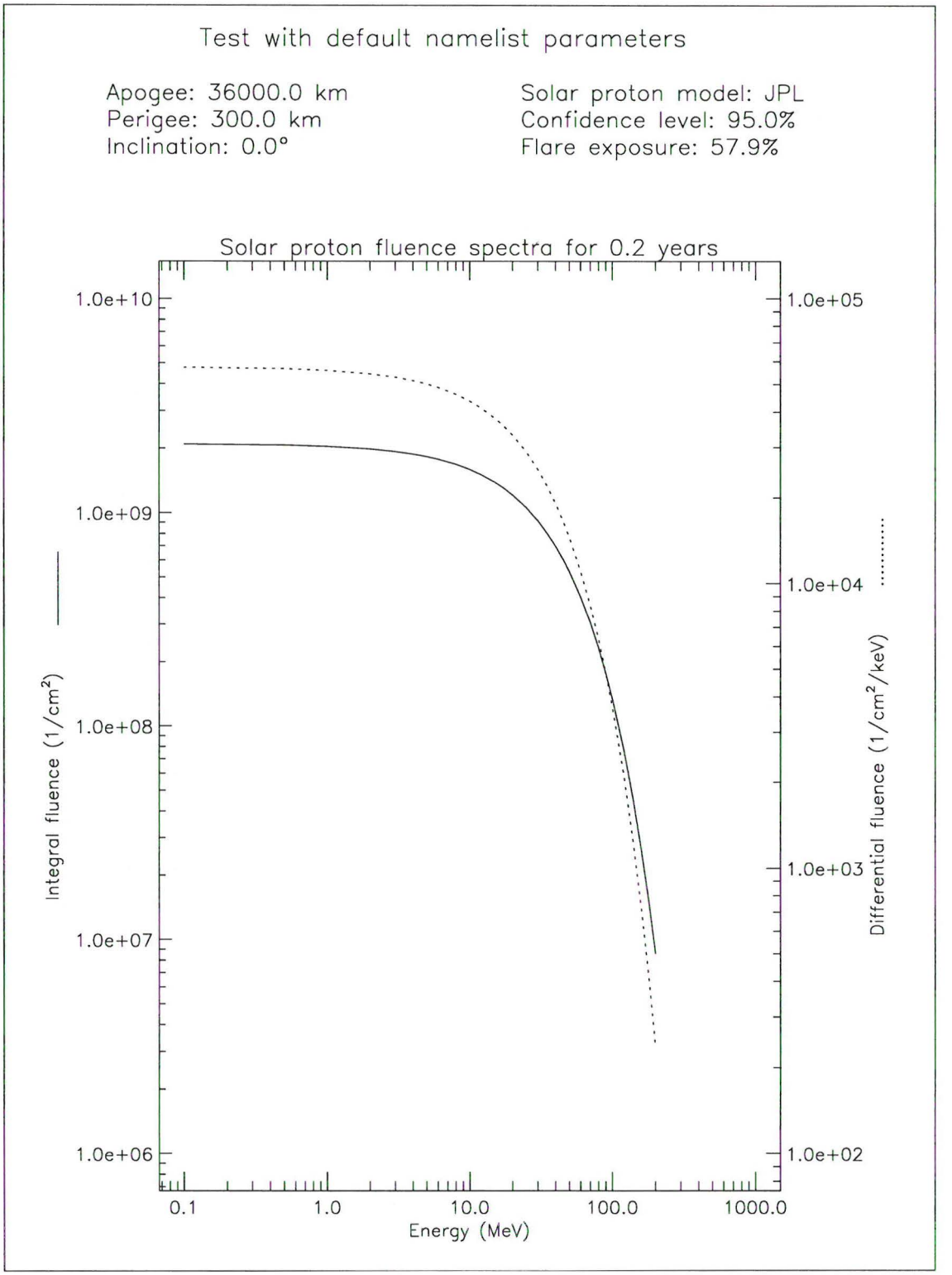

Figure 3.6. Integral and differential solar proton spectrum for the sample orbit.

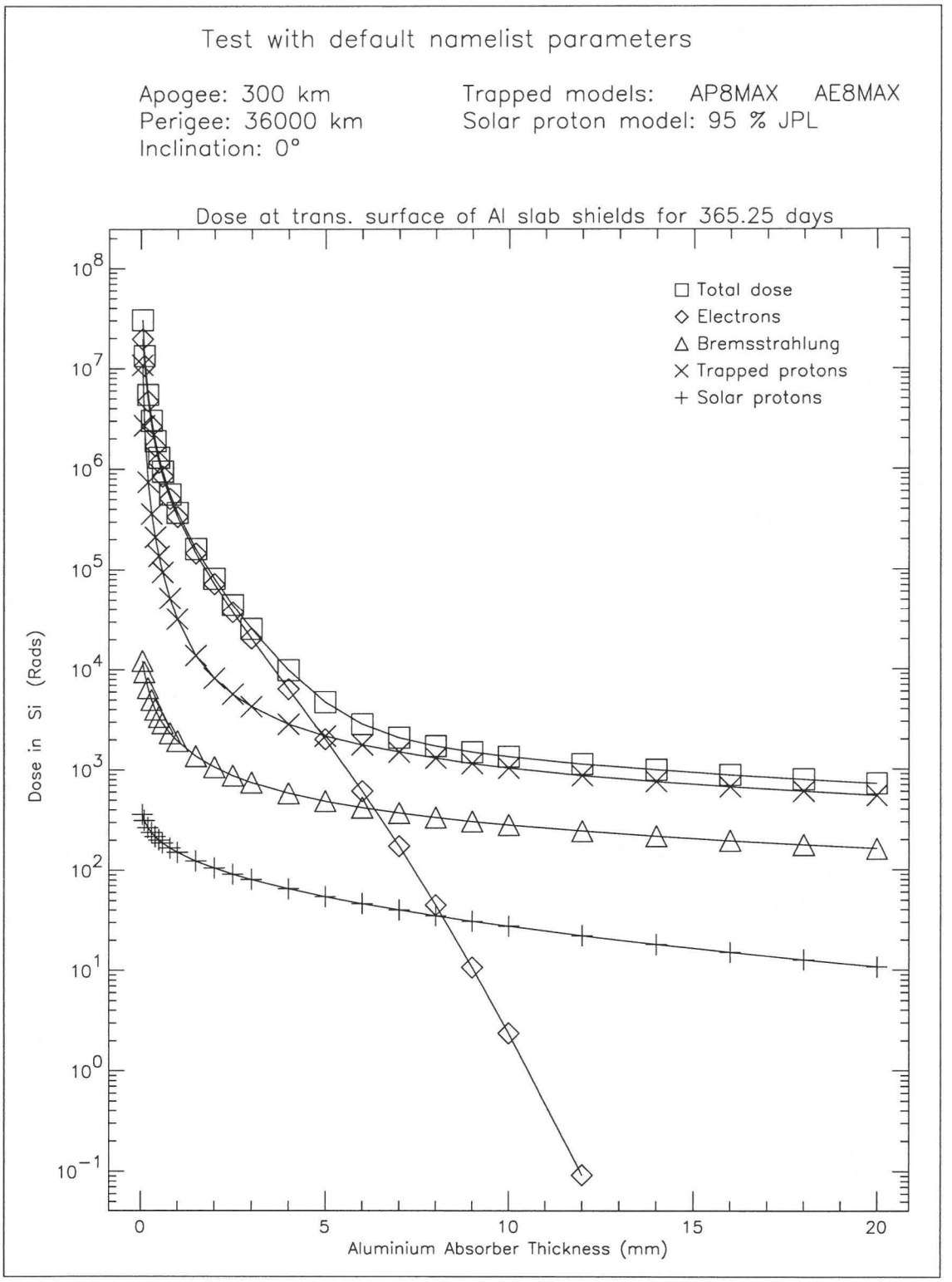

Figure 3.7. Dose in Si behind an Al slab shield for the sample orbit.

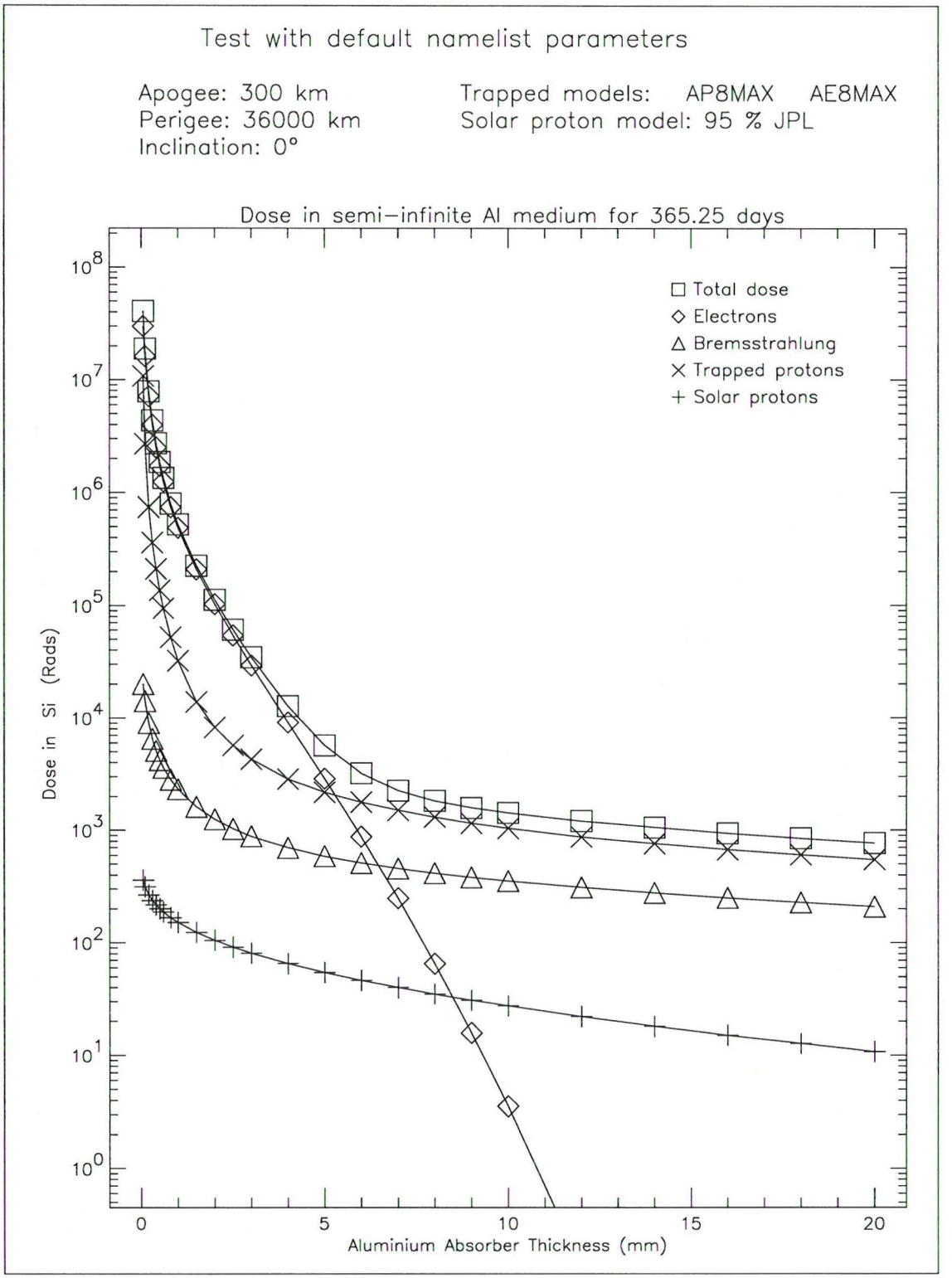

Figure 3.8. Dose in Si behind a semi-infinite Al medium for the sample orbit.

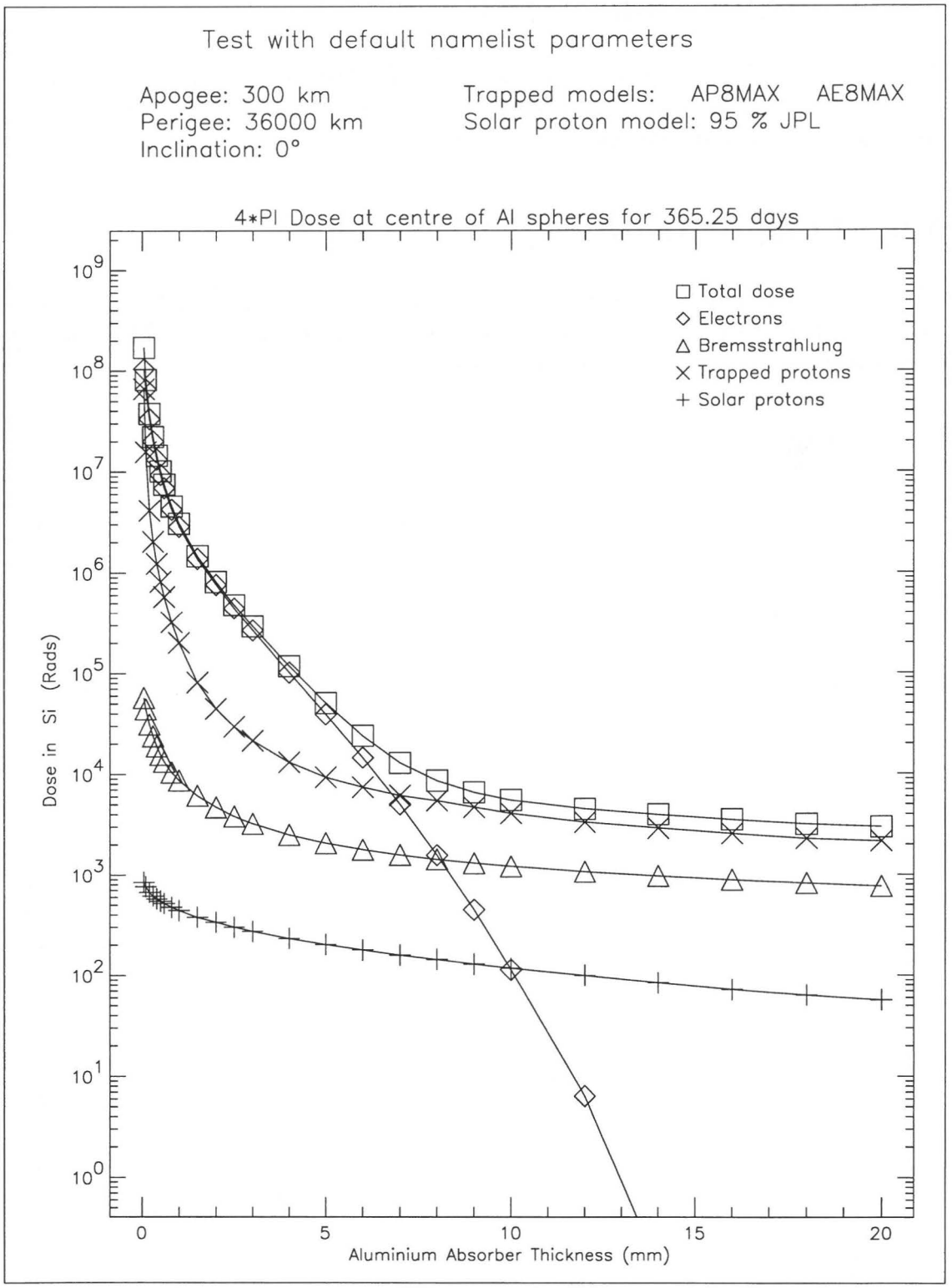

Figure 3.9. Dose in Si at the centre of Al spheres for the sample orbit.

3.5 Output from EQFRUX

The damage equivalent fluxes in Si, calculated for the sample orbit are plotted in Figs. 3.10 and 3.11 as a function of glass cover depth. Figures 3.12–3.16 show the dependence of the damage equivalent fluxes on energy.

3.6 Output from EQFRUXGA

The damage equivalent fluxes in GaAs, calculated for the sample orbit are plotted in Figs. 3.17–3.19 as a function of glass cover depth. Figures 3.20–3.24 show the dependence of the damage equivalent fluxes on energy.

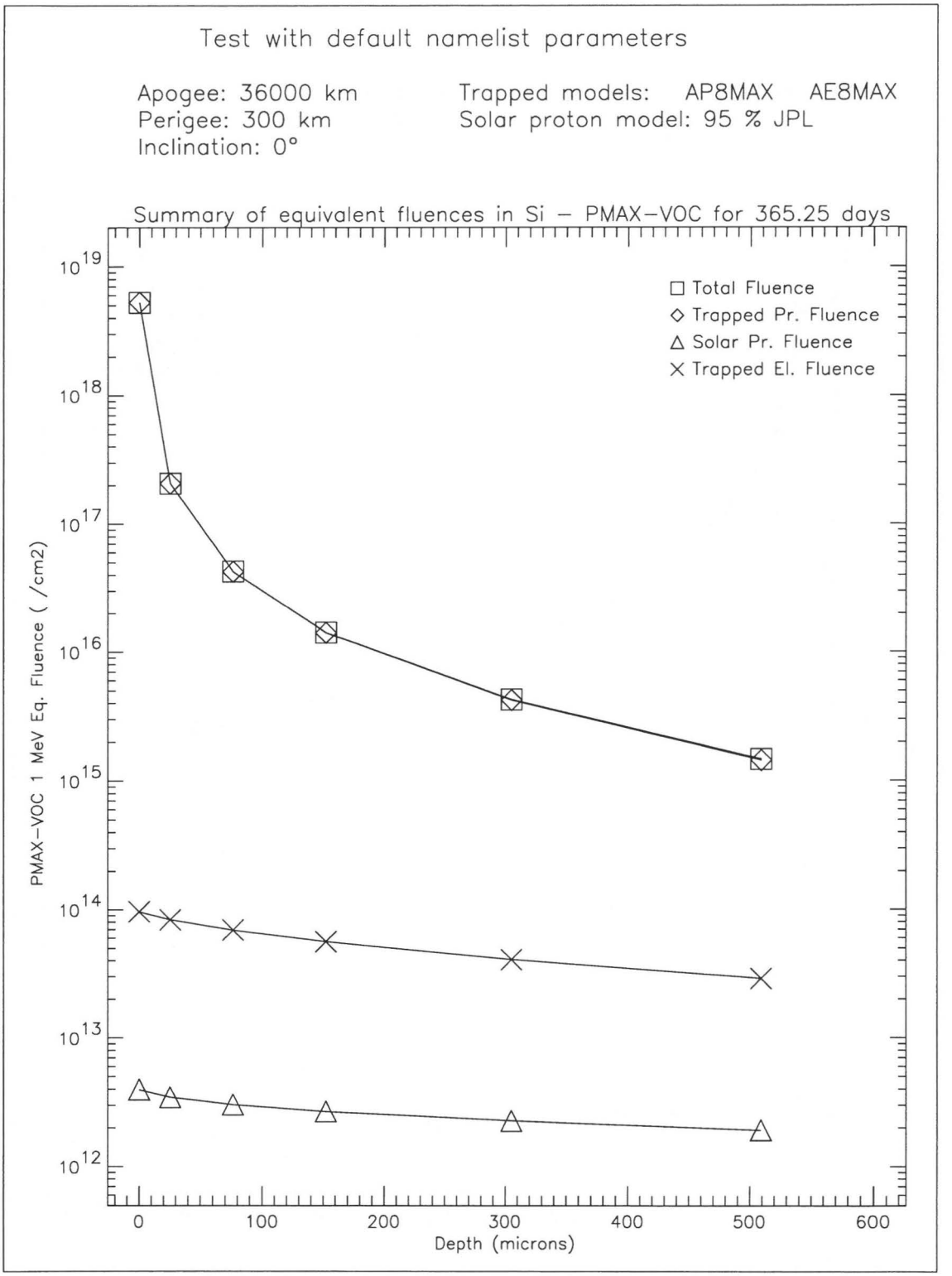

Figure 3.10. Summary of PMAX-VOC equivalent fluences for the sample orbit.

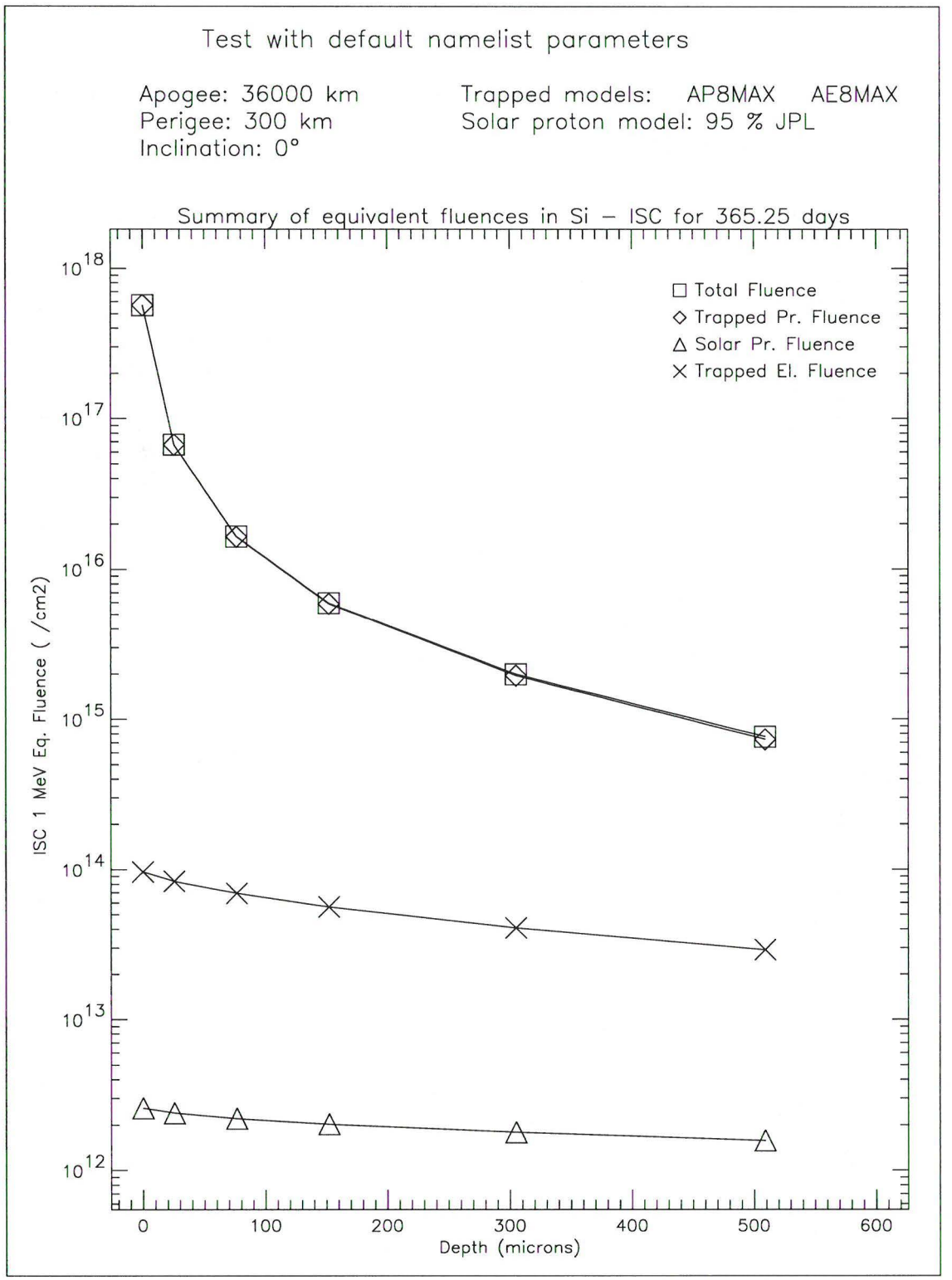

Figure 3.11. Summary of ISC equivalent fluences for the sample orbit.

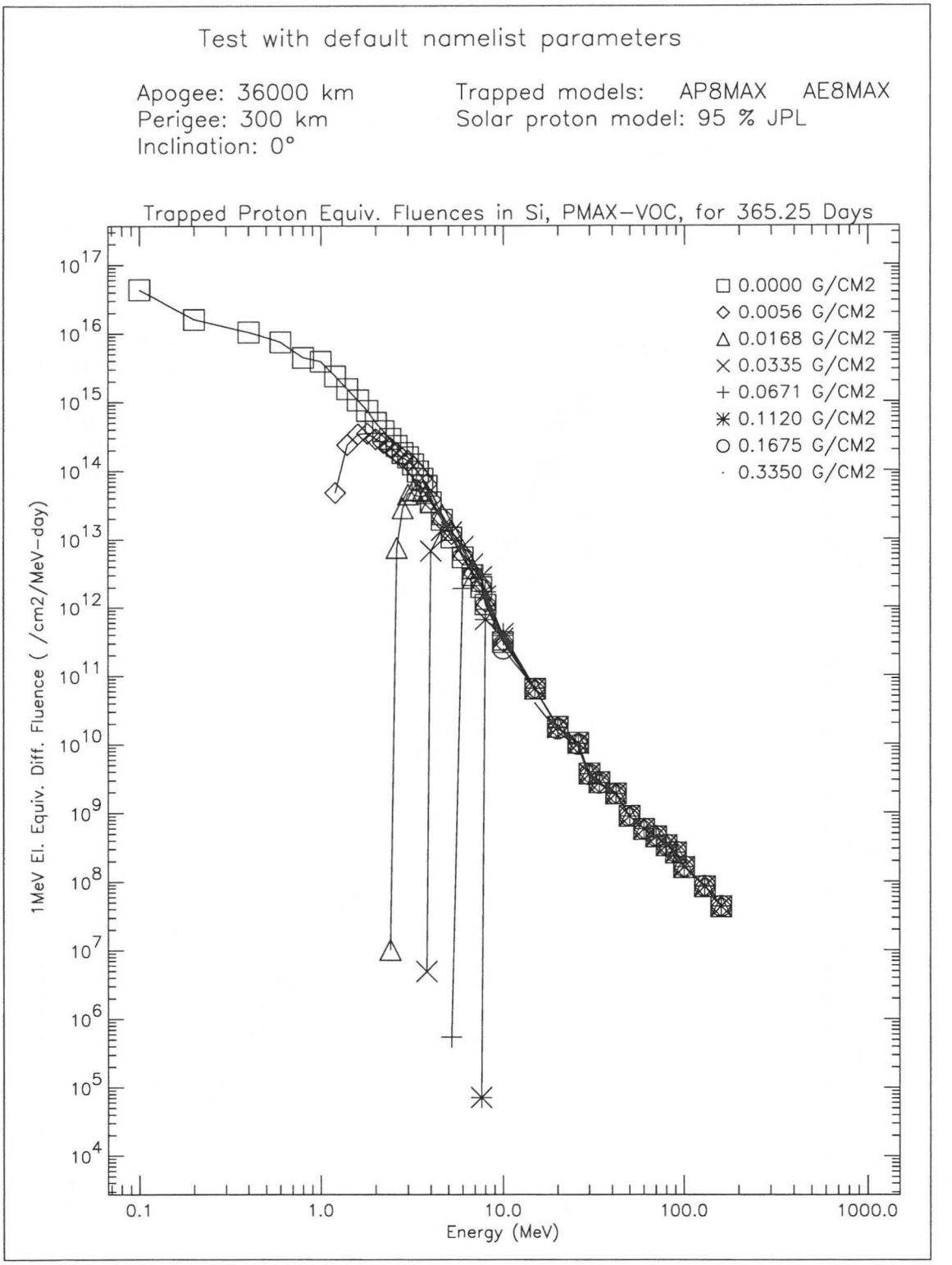

Figure 3.12. Trapped proton equivalent fluences (PMAX-VOC) for the sample orbit.

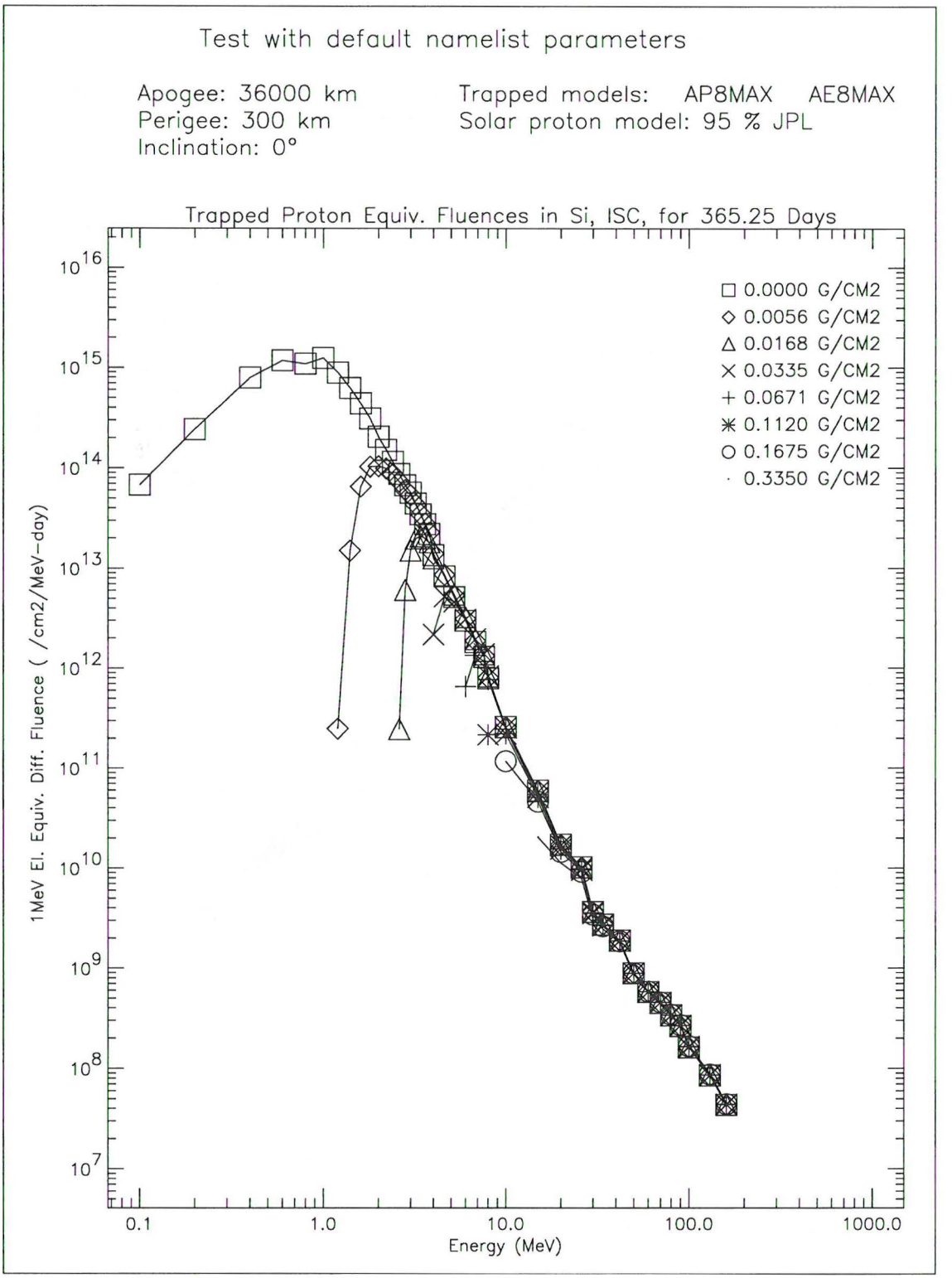

Figure 3.13. Trapped proton equivalent fluences (ISC) for the sample orbit.

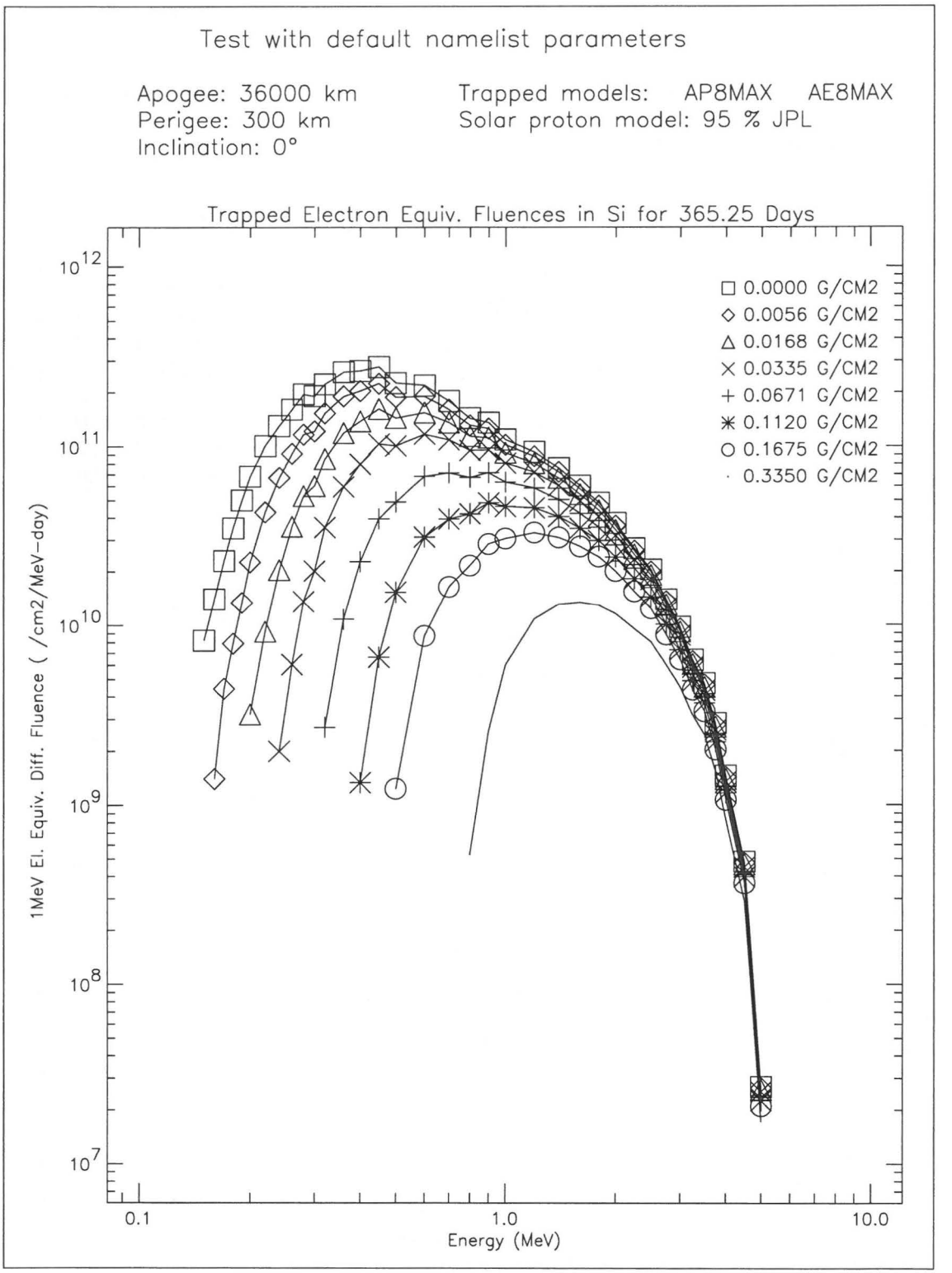

Figure 3.14. Trapped electron equivalent fluences for the sample orbit.

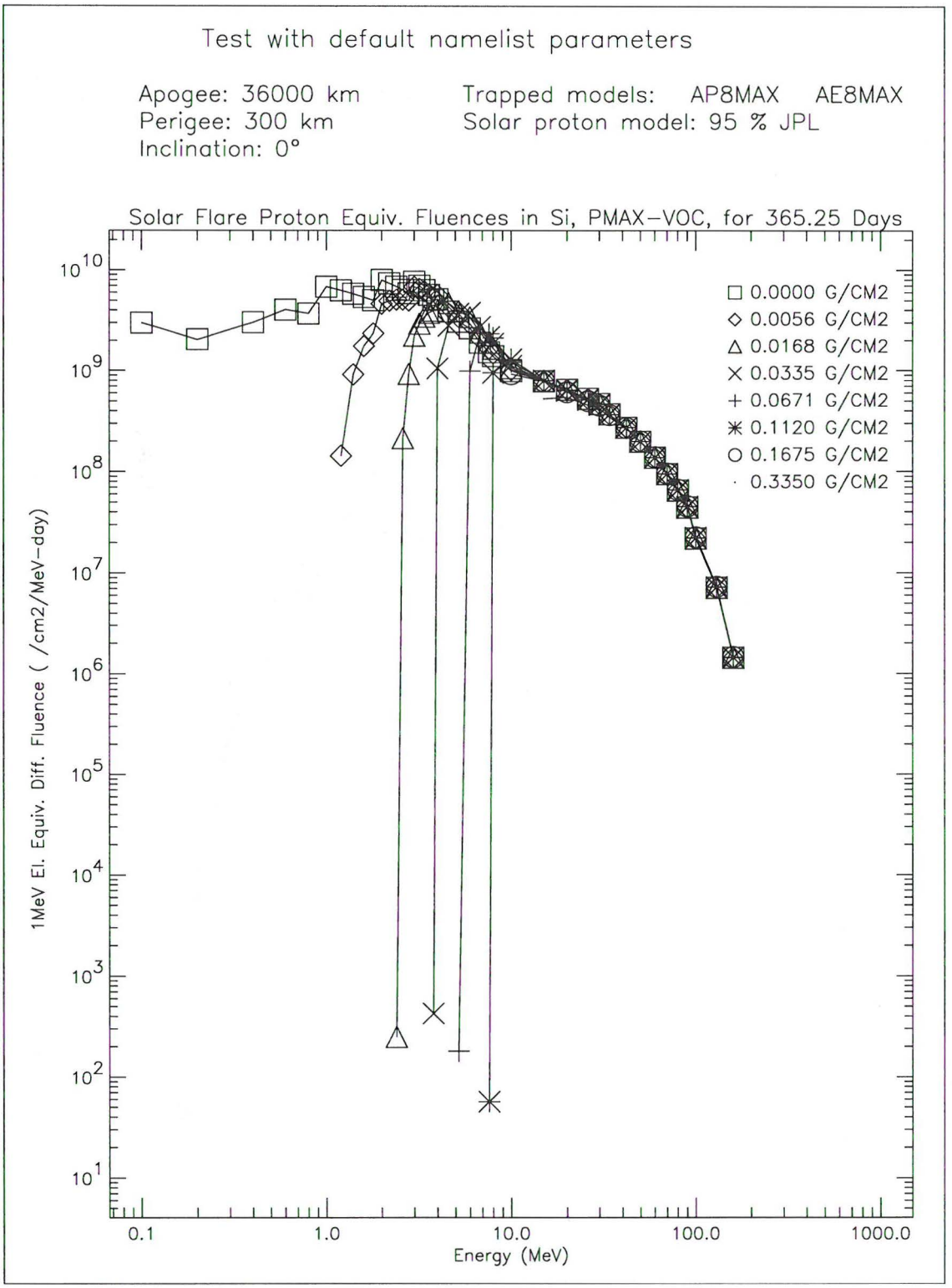

Figure 3.15. Solar flare proton equivalent fluences (PMAX-VOC) for the sample orbit.

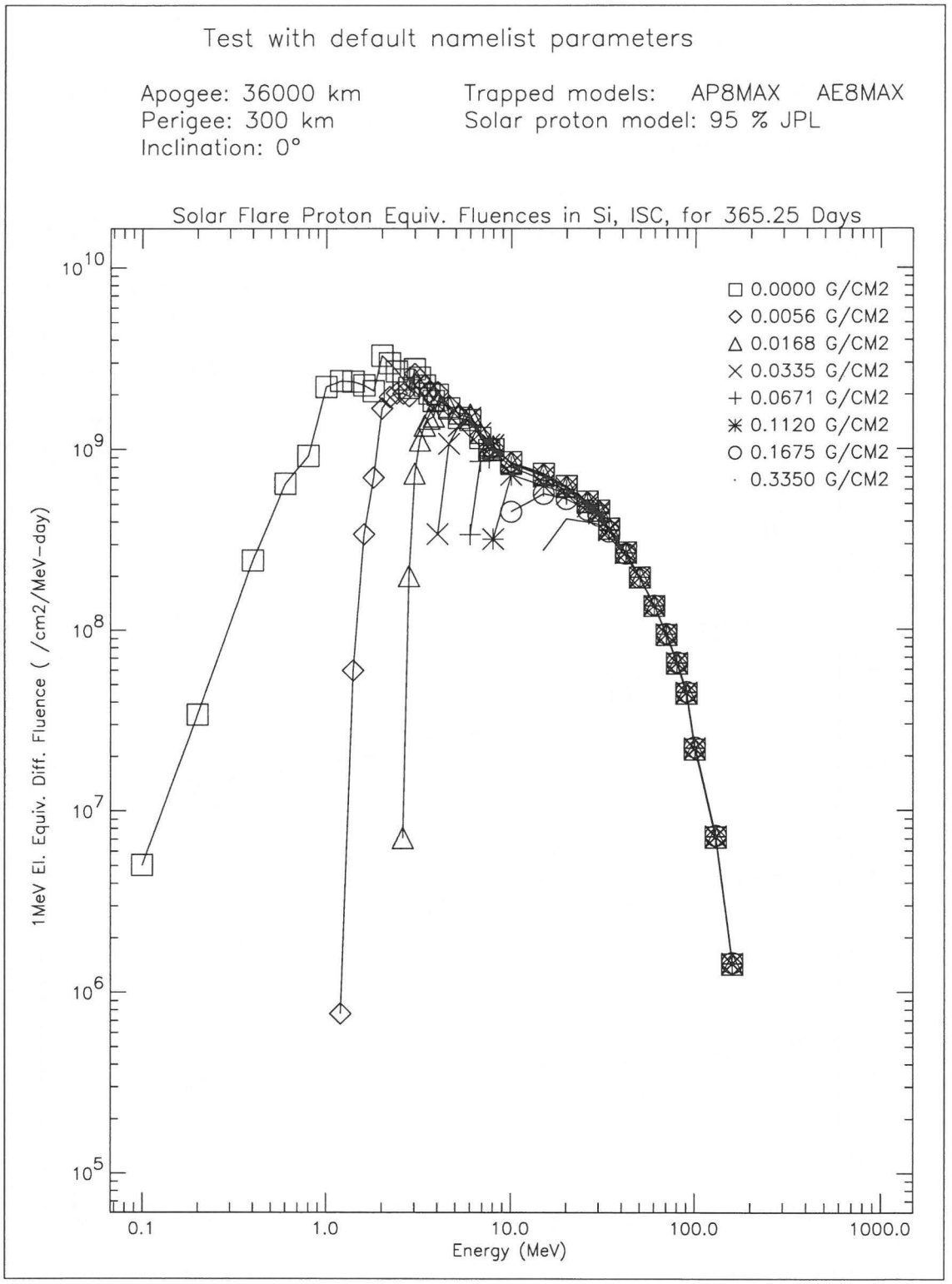

Figure 3.16. Solar flare proton equivalent fluences (ISC) for the sample orbit.

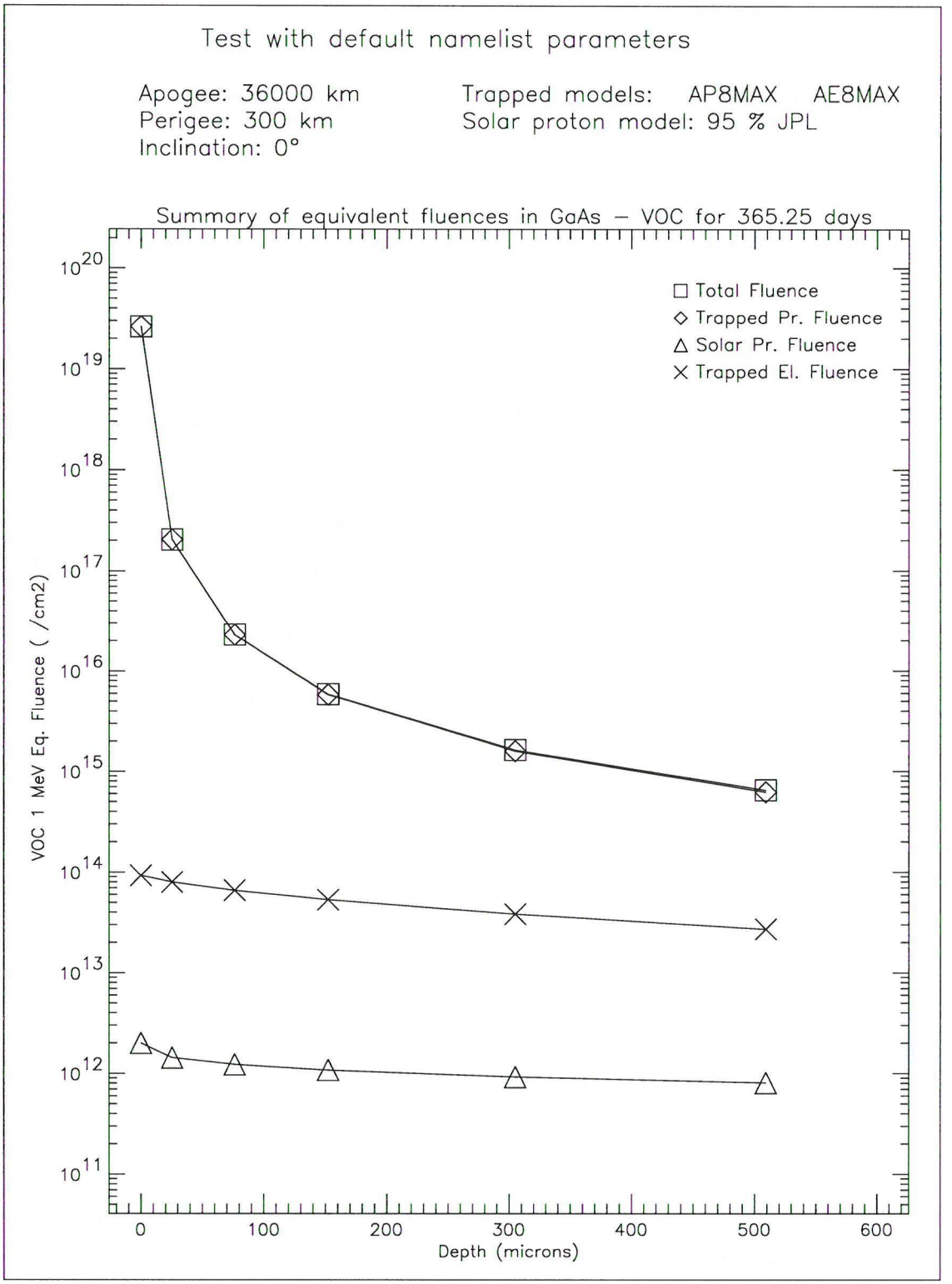

Figure 3.17. Summary of VOC equivalent fluences for the sample orbit.

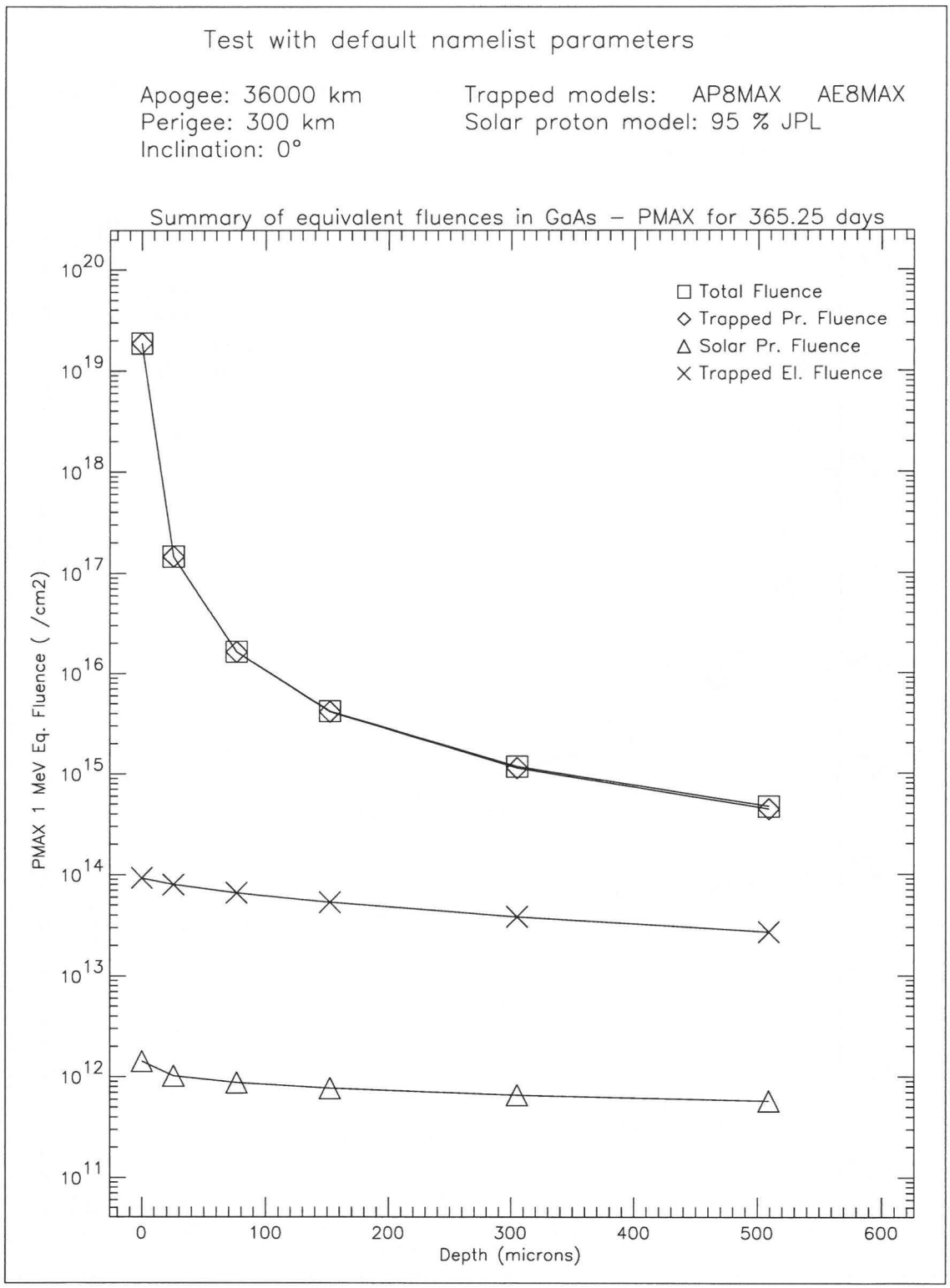

Figure 3.18. Summary of PMAX equivalent fluences for the sample orbit.

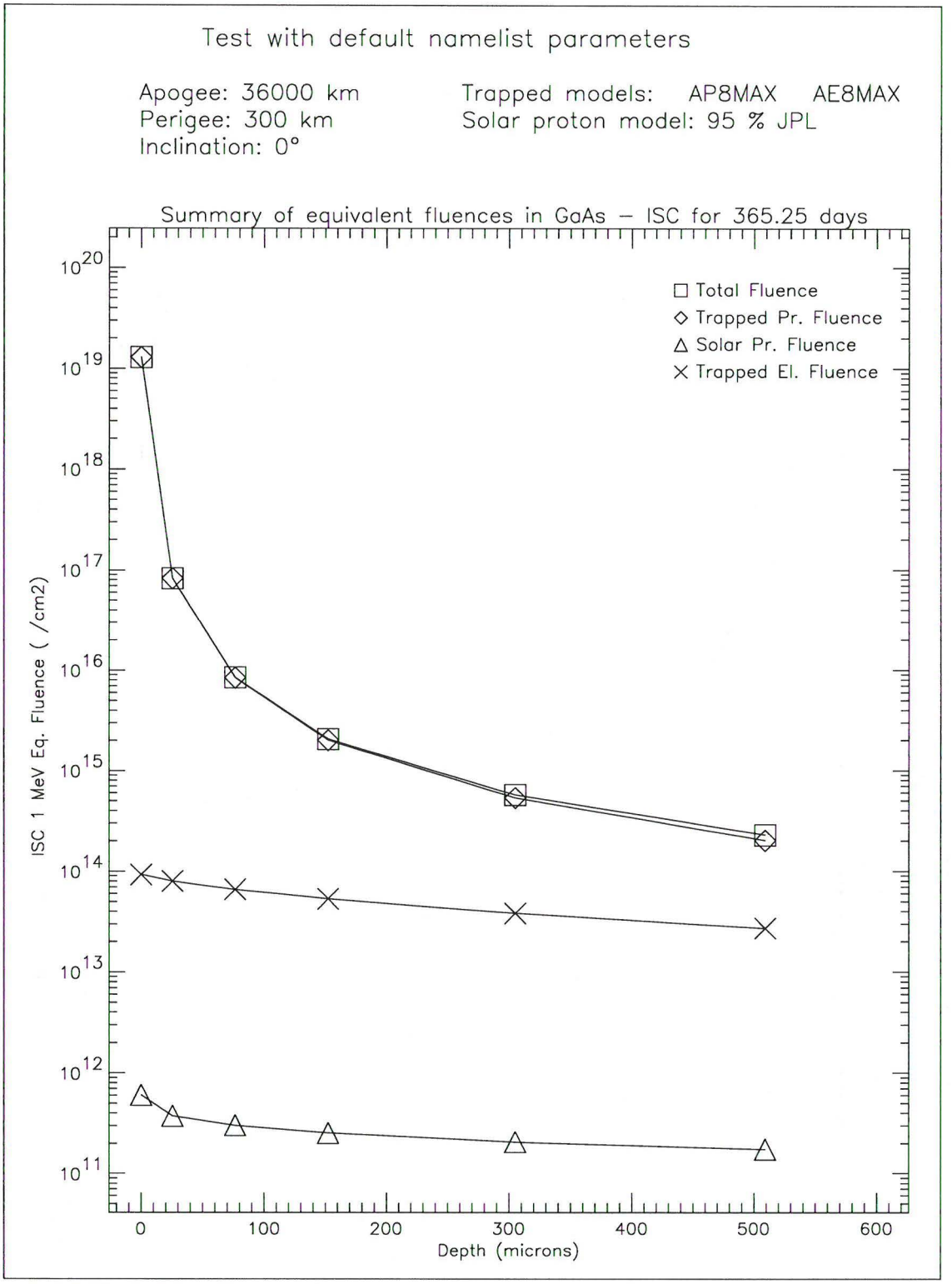

Figure 3.19. Summary of ISC equivalent fluences for the sample orbit.

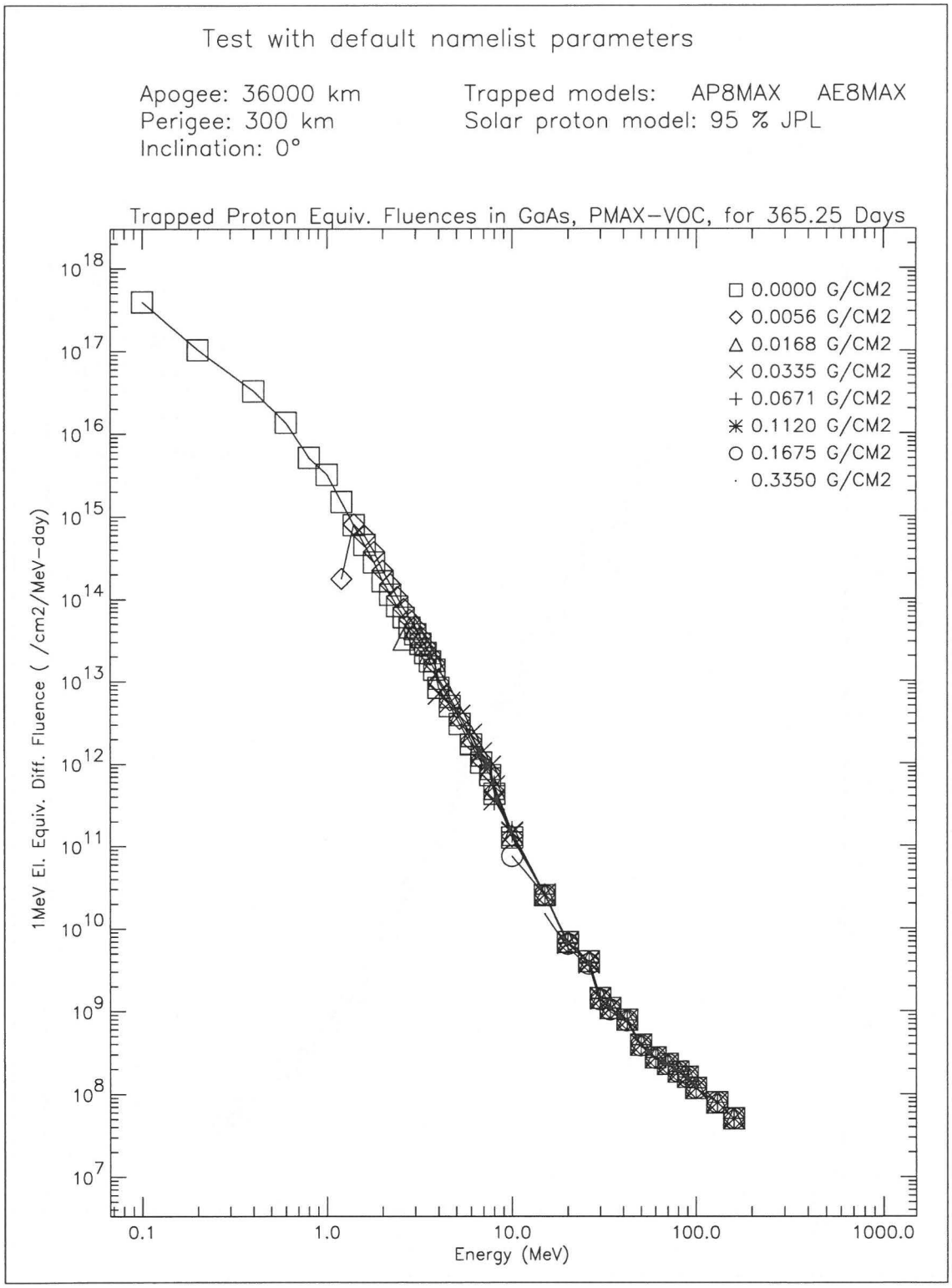

Figure 3.20. Trapped proton equivalent fluences (PMAX-VOC) for the sample orbit.

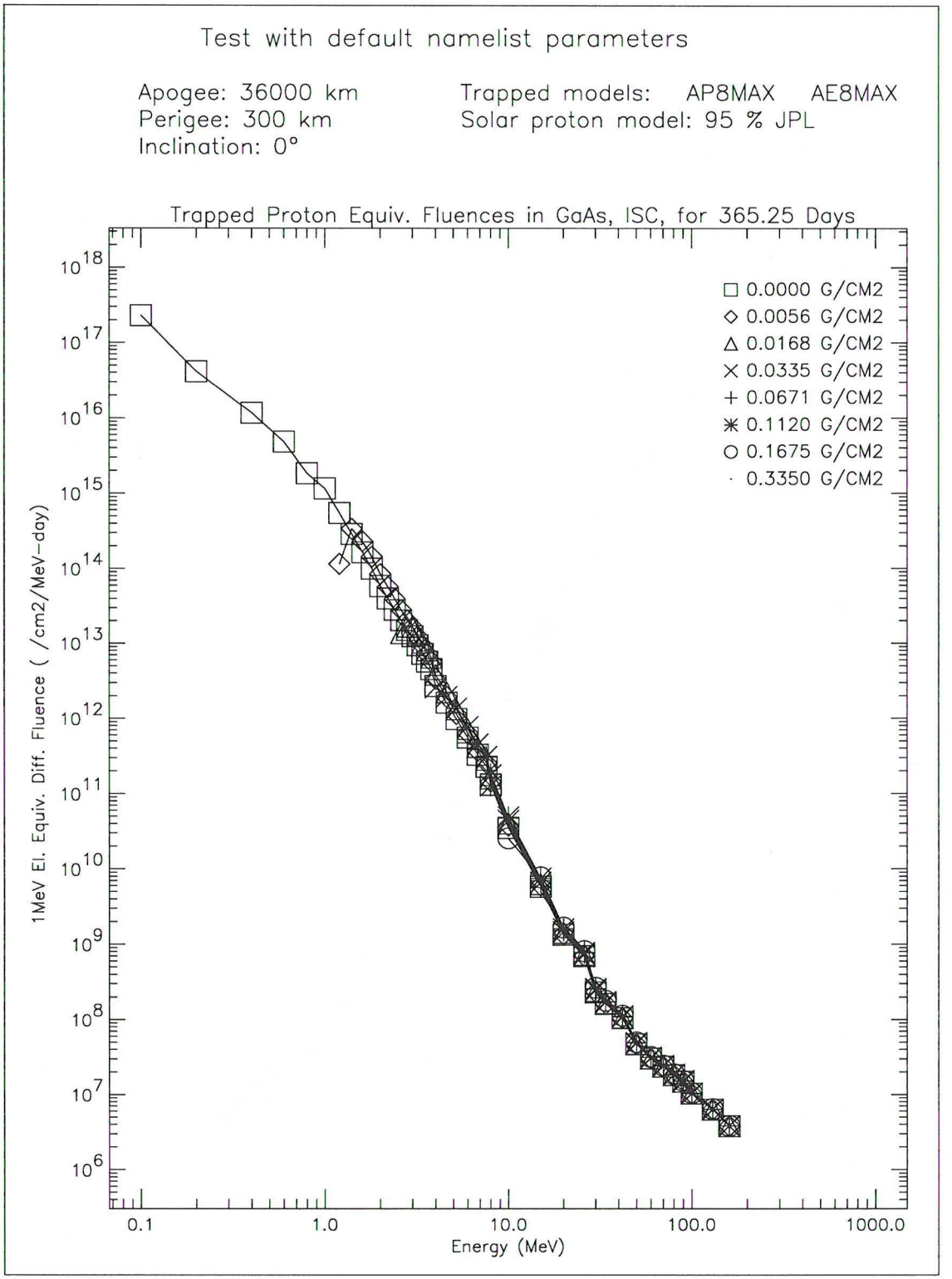

Figure 3.21. Trapped proton equivalent fluences (ISC) for the sample orbit.

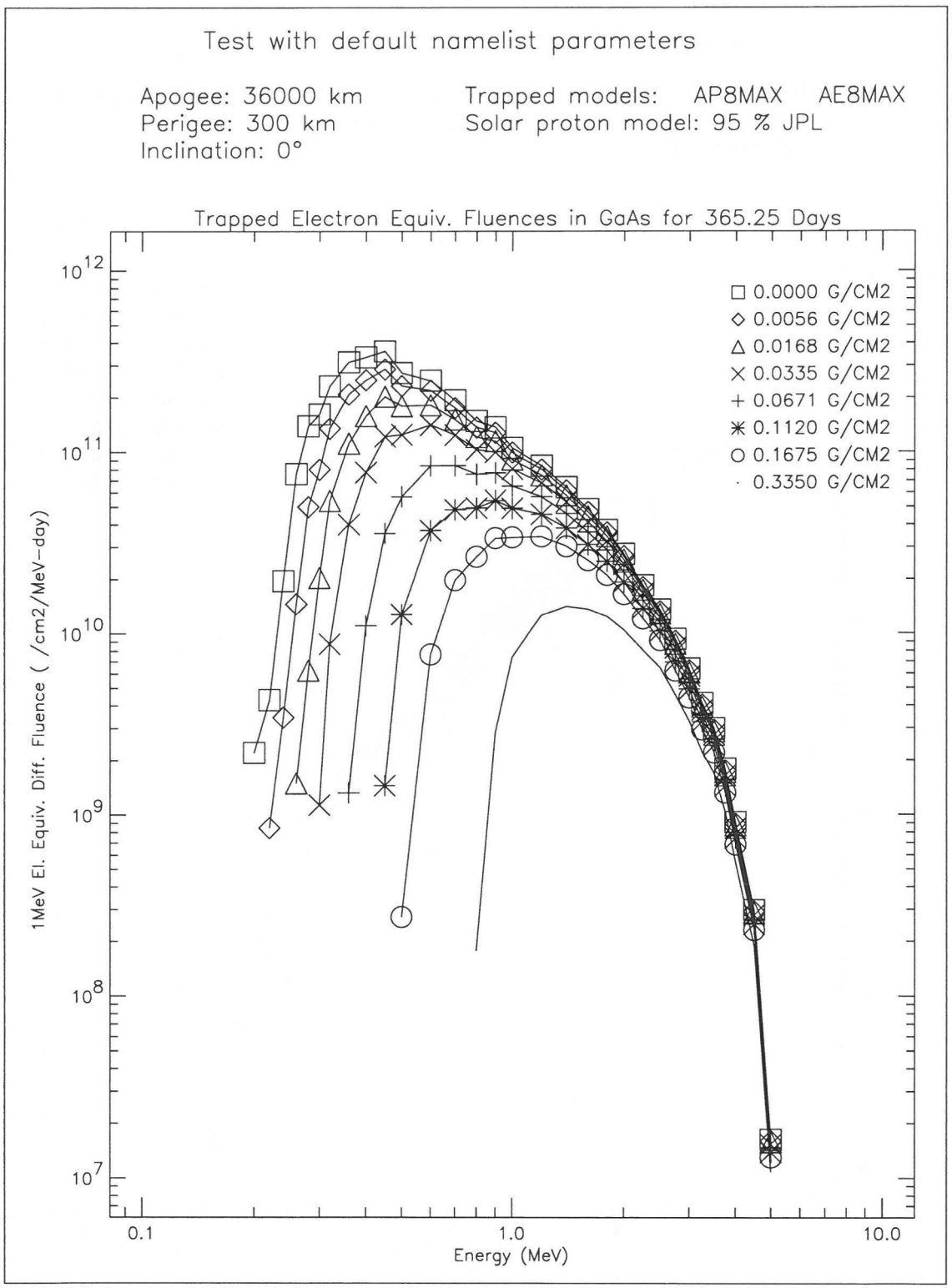

Figure 3.22. Trapped electron equivalent fluences for the sample orbit.

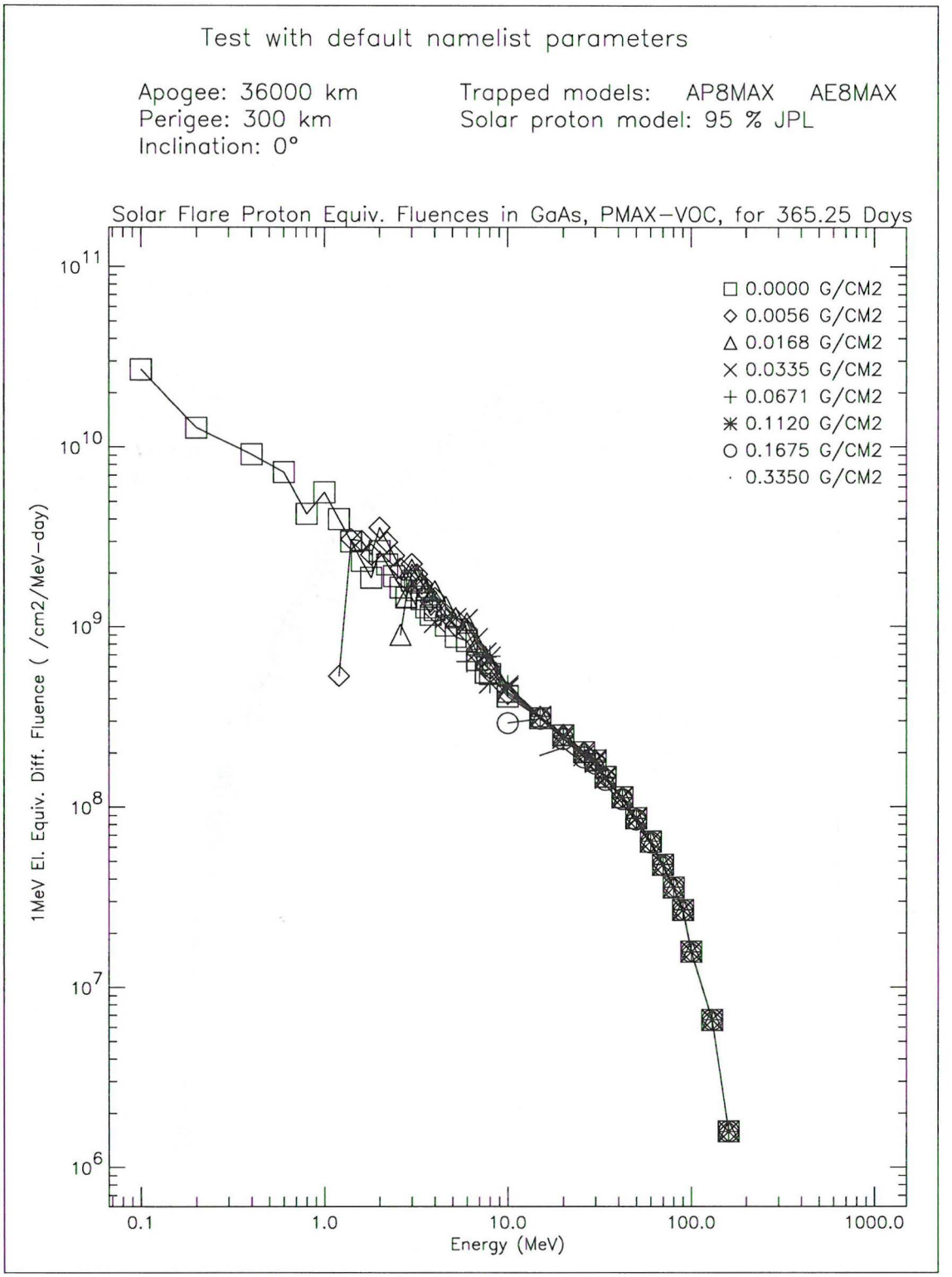

Figure 3.23. Solar flare proton equivalent fluences (PMAX-VOC) for the sample orbit.

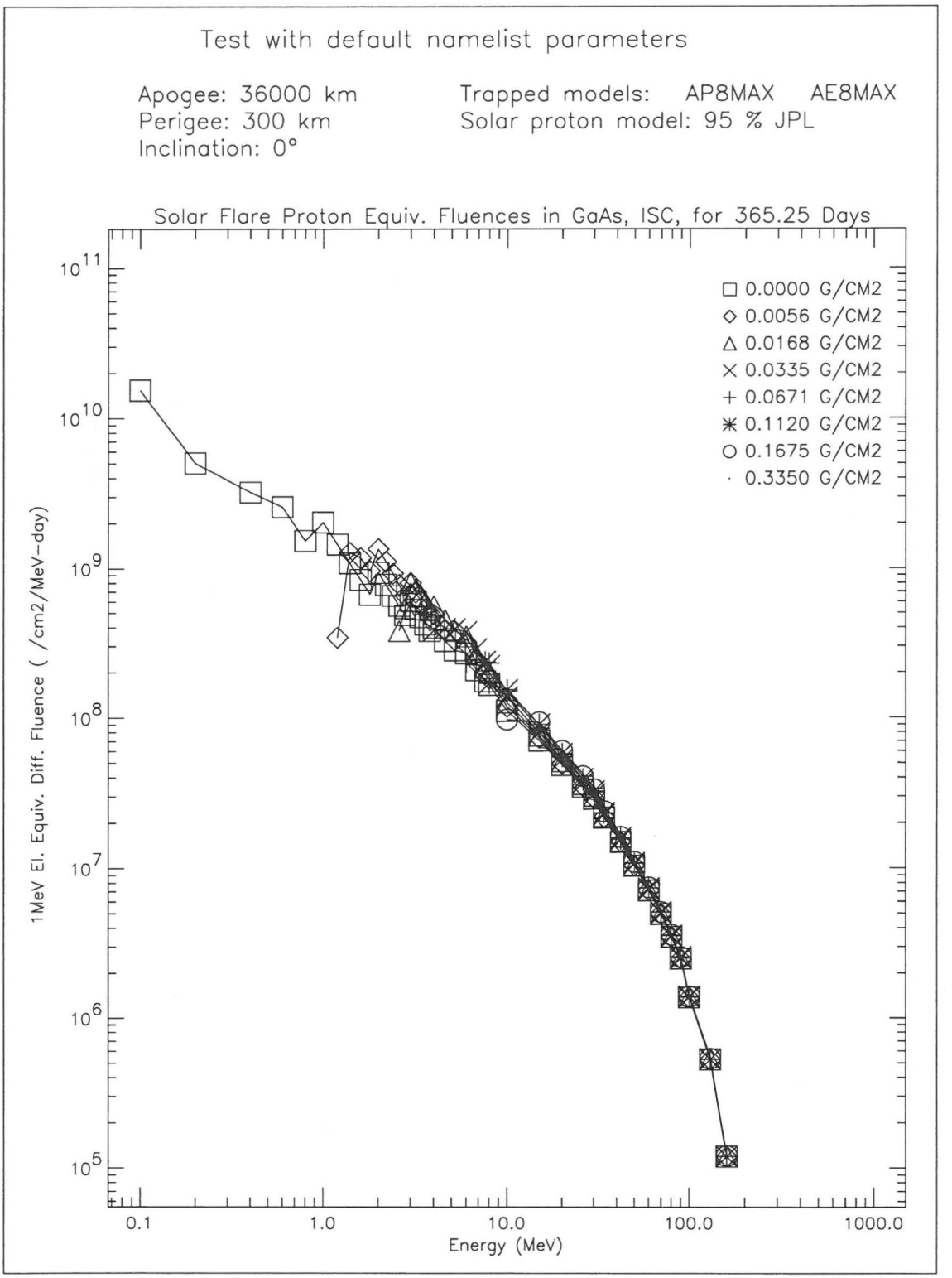

Figure 3.24. Solar flare proton equivalent fluences (ISC) for the sample orbit.

Chapter 4

The plotting program UNIRAD.PRO

The IDL[1] routine `UNIRAD.PRO` is a menu driven plotting program that provides a graphical representation of the various output files produced by `UNIRAD`. The plots can be shown on the screen or sent to files in PostScript format.

4.1 Function and use

`UNIRAD.PRO` consists of one file with IDL code. The program is run as follows, after starting an IDL session:

1. Change directory to a user directory containing output files from `UNIRAD`, e.g.: `SET DEFAULT MY$DISK:[PROJECT]` Return.

2. Compile the program by typing
   `.RUN UNIRAD.PRO` Return. In order for IDL to locate the source file, the path containing the file should be added to the user directory path in the IDL configuration file. Alternatively, the full directory can be specified in the `.RUN` command.

3. To run the program, type
   `UNIRAD,'PROJECT'` Return
   where `PROJECT` is the name of the project of the `UNIRAD` run.

[1] `UNIRAD.PRO` will also run in PV-Wave. However, the binary file `PROJECT.INT` will not be read correctly with PV-Wave on a VAX station. In addition, abnormally long tick marks may appear in some plots when using PV-Wave.

The program will check which UNIRAD output files are available in the current directory, and present a menu with options. On an X terminal the menu is a graphical one and is activated by clicking an option with the mouse. On other terminals the menu is in text format and expects numerical input from the keyboard. After making a selection from the main menu, other menus will appear depending on the UNIRAD output files available in the current directory.

4.2 Output from the program

When a selection is made from the menu, UNIRAD.PRO produces a plot on the screen[2]. The user then has the option to produce a PostScript version of this plot by making the appropriate menu selection. The program creates PostScript files in the current directory. The extension in the file names is tt PS. The first part of the file names is of the form PROJECT_XXX_L_M_N, where

- XXX identifies the type of output (INT, TRI, SHG, EQG, or EGG);
- L is the trajectory number (this is equal to one when only one trajectory was specified with the UNIRAD run);
- M is used to distinguish summary plots (M=2) and full plots (M=1) in the case of SHIELDOSE, EQFRUX, and EQFRUXGA. For the other programs _M is not used.
- N identifies the selection made in the lowest level menu.

The top level menu contains the option "All plots in PostScript format". If this option is selected, the program will generate automatically all plot files that can be produced with the output files present in the current directory.

[2]The appearance of the plot on the screen depends on the device, e.g. X-window, MS-Windows, and may not always be satisfactory. However, the PostScript output is independent of the platform on which IDL is run.

Appendix A

Listing of sample namelist file TEST.NML

This appendix contains the listing of the sample NAMELIST file TEST.NML provided in the distribution. PC users should note that a NAMELIST has to end with / instead of &END.

```
&SAPRE
 TITLE='Test run'
 TYPE   = 'GEN'
 IAE    = 0
 IG50   = 1
 OEYEAR = 1995
 OEMON  = 1
 OEDAY  = 1
 OEHRS  = 0
 OEMIN  = 0
 OESEC  = 0.0D0
 AMJD = -1.0D0
 SEYEAR = -1
 SEMON  = -1
 SEDAY  = -1
 SEHRS  = -1
 SEMIN  = -1
 SESEC  = -1.0D0
 HAPO   = 36000.0D0
 HPER   = 300.0D0
 RINCL  = 0.0D0
 A = 6671.0D0
```

```
 E = 0.0D0
 RAAN   = 0.0D0
 ARGPER = 0.0D0
 TRANO  = 0.0D0
 LONGAPO = 999.9D0
 LONGPER = 999.9D0
 OELONG = -9999.999D0
 SOLTIM = -9999.999D0
 ORBITS = 1.0D0
 STEP   = 2.0D0
 EPDUR  = 0.0D0
 DT1    = 240.0D0
 DT2    = 1200.0D0
 DT3    = 1200.0D0
 DH2    = 1.0D6
 DH3    = 1.0D6
 WIBAIR = 0.0D0
 WIBSPR = 0.0D0
 ORBNUM = 1.0D0
 NCIRA  = 5
 SUN    = 1
 MOON   = 1
 KZONAL = 6
 KTESS  = 3
 IPRINT = 1
 OGEN   = 1
 EPHMR  = 2
 IORBEL = 0
 RUN    = 1
 IBUG   = 0
 PP(1)  = 22.164D0
 PP(2)  = 15.0D0
 XP(1)  = 15.25D0
 XP(2)  = 10.0D0
&END
&BLXTRA
 CUTOFF = 9999.0D0
 BLTIME = 1995.0D0
 MODEL = 0
 IPRINT = 60
 OUTER = 0
```

```
 VALUE_KP = 0.0D0
 DEN = 25.0D0
 VEL = 300.0D0
 DST = -30.0D0
 IASCII = 0
&END
&TREP
 SOLACT = 'MAX'
 TREMOD = 1
 IPRINT = 60
 INTERF = 1
 ISPEC = 0
 ISPSHT = 0
 PERIOD = 0.0
 NAL = 0
 NOR = 0
 IFORM = 0
 RAU = 1.0
 TFLARE = 1.0
 FLSTAR = -1.0
 FLPROB = 95.0
 FLAMOD = 1
 IFLATT = 0
 ISIG = 0
 ILTV = 0
 FLUXTH(1) = 1.0
 FLUXTH(2) = 1.0
 ETHP(1) = 1.0
 ETHP(2) = 10.0
 ETHE(1) = 0.1
 ETHE(2) = 1.0
 SAAROT = 0
 OMNI = 1
 NENERP = 30
 NENERE = 30
 NENERS = 30
 PROEN =   0.1,  0.5,  1.,  2.,  3.,  4.,   5.,   6.,   8.,
          10.,  12.,  15., 17., 20., 25.,  30.,  35.,  40.,
          45.,  50.,  60., 70., 80., 90., 100., 125., 150.,
         175., 200., 300.
 ELEEN = 0.04, 0.1, 0.20, 0.3, 0.40, 0.5, 0.60, 0.7, 0.80, 1.0,
```

```
          1.25, 1.5, 1.75, 2.0, 2.25, 2.5, 2.75, 3.0, 3.25, 3.5,
          3.75, 4.0, 4.25, 4.5, 4.75, 5.0, 5.50, 6.0, 6.50, 7.0
 ENERFL =   0.1,  0.5,  1.,  2.,   3.,   4.,   5.,   6.,   8.,
           10.,  12.0, 15.0, 17., 20.,  25.,  30.,  35.,  40.,
           45.,  50.,  60.0, 70.0, 80., 90., 100., 120., 140.,
          160., 180., 200.
&END
&TREPAVE
 WEIGHTS = 200*1.0
&END
&SHIELDOSE
 IPRINT = 0
 IPLOT = 1
 IDET = 3
 TINTER = 365.25
 Z = 0.05, 0.1,  0.2,  0.3,  0.4,  0.5, 0.6, 0.8, 1.0,
     1.5,  2.0,  2.5,  3.0,  4.0,  5.0, 6.0, 7.0, 8.0, 9.0,
    10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 25*100.0
 IMAX = 25
 IUNT = 3
 ISHLD = 4
&END
&EQFRUX
 TINTER = 365.25D0
 IPLOT  = 1
 IPRINT = 0
 BSF = 1.0D0
 PEDRI = 3000.0D0
 PEDRV = 3000.0D0
&END
&EQFRUXGA
 TINTER = 365.25D0
 BSF = 1.0D0
 PEDRI = 400.0D0
 PEDRV = 1400.0D0
 PEDRP = 1000.0D0
 IPRINT = 0
 IPLOT  = 1
&END
```

Appendix B

Format of the common interface file

The program flow in UNIRAD was modified so that SAPRE, BLXTRA and TREP make use of one common data file for input and output. We have further modified the structure of this file in order to incorporate the use of external magnetic field models and the implementation of pitch angle dependence.

The new structure of the interface file is given in Table B.1. The file is in FORTRAN UNFORMATTED format, with fixed record length of 98 bytes, in direct access. The first four records contain header information on orbit parameters, magnetic field models, and energy thresholds for flux calculations. The next records are data records, one record per orbital point. These records contain the modified Julian day (AMJD), position vector, α, B at the orbital point, L_{m}, and the integral proton and electron fluxes for the two threshold energies specified in the header. The last record contains negative values and signifies the end of the orbit. This whole structure may be repeated for another orbit.

Table B.1. Record structure of the common interface file. All entries are in `REAL*8` format, except when specified otherwise.

Header Records

Record	Description
1	Project descriptor (`CHARACTER*80`)
2	Year (`INT*4`), month (`INT*4`), day (`INT*4`), hour (`INT*4`), minute (`INT*4`), second of trajectory epoch, height of apogee and perigee, orbit inclination
3	Description labels (`CHARACTER*32`) and model numbers (`INT*4`) for two internal magnetic field models
4	Description labels (`CHARACTER*32`) and model numbers (`INT*4`) for two external magnetic field models
5	Epochs (`BLTIME`) for two internal magnetic field models, geomagnetic moment `GMAGMO`, four energy thresholds (`REAL*4`), two each for protons and electrons, headers of trapped particle models (`CHARACTER*8`), solar flare model number `FLAMOD (INT*4)`

Data Records

Word	Description
1	Modified Julian day (in days)
2	Not used
3	Eastern longitude (in degrees)
4	Latitude (in degrees)
5	Height above the Earth's surface (in km)
6	Pitch angle (in degrees)
7	Total magnetic field at the orbital point (in Gauss)
8	L_{m} (in Earth radii)
9–10	Integral proton fluxes above two energy thresholds
11-12	Integral electron fluxes above two energy thresholds

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