TREND-3

Radiation Environments of Astronomy Missions and LEO Missions

Final Report

ESTEC Contracts[1] No. 10725/94/NL/JG(SC) and No. 11711/95/NL/JG(SC) WO-3

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APPENDIX 4 **ESA STUDY CONTRACT REPORT**

No ESA Study Contract Report will be accepted unless this sheet is inserted at the beginning of each volume of the Report.

ESA CONTRACT NO: 10725/94/NL/JG, WO-3 to 11711/95/NL/JG	**SUBJECT:** Radiation Environments of Astronomy Missions and LEO Missions		**NAME OF CONTRACTOR:** BIRA/IASB, MSSL, MPAe
* **ESA CR( ) No:**	* **STAR CODE**	**No. of Volumes: 1** **This is Volume No: 1**	**CONTRACTOR'S REFERENCE**

ABSTRACT:

The contract work presented in this Final Report is a follow-up of the TREND-2 study (ESA/ESTEC TRP Contract No. 9828/92/NL/FM).

A number of new radiation belt models have been developed based on data from the following satellite experiments: AZUR/EI-88, SAMPEX/PET, UARS/PEM, CRRES/MEA, and ISEE/WIM. For each experiment, the mission and instrument characteristics and the data base formats have been described in detail in the Technical Notes of the project, and are summarised in this Final Report. The data binning procedures and the formats and limitations of the new models are described as well. The models have been intercompared where applicable, and have been compared to the standard NASA models AP-8 and AE-8. All new models have been implemented in the software package `UNIRAD`.

Besides the models developed in the framework of TREND-3, the ESA-SEE1 (Vampola 1996) model and the CRRESPRO (Meffert & Gussenhoven 1994) and CRRESELE (Brautigam & Bell 1995) models have also been adapted to and integrated in `UNIRAD`.

A large effort has been devoted to the development of a comprehensive Fortran subroutine library, called `UNILIB`, with the following functionalities: calculation of magnetic coordinates (e.g. B, L) and adiabatic invariants, coordinate transformations, field line and drift shell tracing, and averages of the atmospheric and ionospheric density over drift shells. The library is extensively documented on the World-Wide Web.

An extensive study has been made of the anisotropy of the low altitude trapped proton flux. After a review of the literature, one of the most commonly used models has been implemented in `UNIRAD`, together with an improved version. In addition, a method has been developed to render the anisotropy effects in terms of a natural coordinate system attached to the magnetic field. The method has been validated with the SAMPEX/PET data base.

Appropriate analytical functions have been found to fit the pitch angle distributions measured by CRRES/MEA. Finally, a new, corrected, Meteosat-3/SEM-2 data base has been produced.

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* **Sections to be completed by ESA**

** **Information to be provided by ESA Study Manager**

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List of symbols

A Detector surface area

α Pitch angle

α_0 Equatorial pitch angle

β Azimuthal angle defined in the local mirror plane

B Geomagnetic field intensity

B Geomagnetic field vector

B_m Mirror point geomagnetic field intensity

B_0 Equatorial geomagnetic field intensity

B_c Geomagnetic field intensity at the atmospheric cutoff

C Counting rate

E Particle energy

ϵ Detector efficiency

$F_{10.7}$ Solar radio flux at 10.7 cm

G Geometric factor ($\mathrm{cm}^2\mathrm{sr}$)

Γ Telescope gathering power

h Effective detector area

j Differential particle flux

J Integral particle flux

L McIlwain's (1961) parameter (R_E)

λ Wavelength (Å)

ω Solid angle (sr)

ϕ Geocentric longitude or azimuth angle

φ Angle introduced by Daly & Evans (1993)

$\mathbf{r}$ Position vector

R Telescope directional response function

S Total area

$d\sigma$ Element of surface area

t Time

T Total observation time

θ Polar angle

Z Atomic number

List of acronyms

ADC Analog to Digital Converter

ACS Attitude Control System

ACE Attitude Control Electronics

ASCII American Standard Code for Information Interchange

BIRA Belgisch Instituut voor Ruimte-Aëronomie

BFO Blood Forming Organs

CCN Contract Change Notice

CDF Common Data Format

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

ESA European Space Agency

ESTEC European Space and TEchnology Centre

FOV Field Of View

FTP File Transfer Protocol

GEI GEocentric Inertial

GEO GEostationary Orbit

GSFC Goddard Space Flight Center

GTO Geostationary Transfer Orbit

HETC High Energy Transport Code

HILT Heavy Ion Large Telescope

HTML Hierarchical Text Mark-up Language

HTTP HyperText Transfer Protocol

IASB Institut d'Aéronomie Spatiale de Belgique

IDL Interactive Data Language

IDFS Instrument Data File Set

IGRF International Geomagnetic Reference Field

IMF Interplanetary Magnetic Field

IRI International Reference Ionosphere

ISEE International Sun Earth Explorer

JPL Jet Propulsion Laboratory

LDEF Long Duration Exposure Facility

LEICA Low Energy Ion Composition Analyzer

LEO Low Earth Orbit

MAST MAss Spectrometer Telescope

MEA Medium Electrons A

MEPE Medium Energy Particle Experiment

MPAe Max Planck Institut für Aeronomie

MS-DOS MicroSoft Disk Operating System

MSIS Mass-Spectrometer-Incoherent-Scatter

MSSL Mullard Space Science Laboratory

NAPS Narrow Angle Particle Spectrometer

NASA National Aeronautics and Space Administration

NSSDC National Space Science Data Center

NOAA National Oceanic and Atmospheric Administration

PC Personal Computer

PEM Particle Environment Monitor

PET Proton/Electron Telescope

PI Principal Investigator

PLGD Phillips Laboratory Gheophysics Directorate

PS PostScript

PSI Paul Scherrer Institute

REM Radiation Environment Monitor

SAA South Atlantic Anomaly

SAMPEX Solar, Anomalous, and Magnetospheric Particle EXplorer

SDDAS Southwest Data Display and Analysis System

SEM Space Environment Monitor

SMEX SMall EXplorer

SPENVIS SPace ENVironment Information System

SwRI Southwest Research Institute

TN Technical Note

TREND Trapped Radiation ENvironment Development

UARS Upper Atmosphere Research Satellite

URL Uniform Resource Locator

VAX Virtual Address eXtension

VMS Virtual Memory System

WAPS Wide Angle Spectrometer

WIM Williams Mother

WO Work Order

WP Work Package

WWW World Wide Web

Preface

This final report contains the main results obtained by the TREND-3 team during the study "Radiation Environments of Astronomy Missions and LEO Missions". The TREND (Trapped Radiation ENvironment Development) study was initiated by E.J. Daly and funded by ESA under two earlier contracts. The present study started on 1 Feb, 1994, under ESA Contract No. 10725/94/NL/JG(SC), and was extended as WO-3 to ESA Contract No. 11711/95/NL/JG(SC). The duration of the project was 41 months.

Three institutes from three ESA member states participated in this project:

- BIRA/IASB, the Belgisch Instituut voor Ruimte-Aëronomie/Institut d'Aéronomie Spatiale, Brussels, Belgium (the prime contractor);
- MSSL, the Mullard Space Science Laboratory, Dorking, UK;
- MPAe, the Max Planck Institut für Aeronomie, Katlenburg-Lindau, Germany.

In the sections below, the work performed by each team is summarised and grouped by Work Package (WP). The resulting Technical Notes (TN) are listed as well.

Seven progress meetings have been held at BIRA/IASB, MSSL, and MPAe, and a mid-term review was held at ESTEC. The Final Presentation was given at ESTEC on 15 Sep 1998. The databases, software and models have been installed at ESTEC/WMA.

In October 1995, the BIRA/IASB TREND team has organised an international workshop in Brussels, where results of TREND-2 and TREND-3 were presented to an audience of 60 researchers in the field of radiation belt physics. The workshop proceedings have been edited by J.F. Lemaire, D. Heynderickx, and D.N. Baker, and have been published by the American Geophysical Union as Geophysical Monograph 97. This volume, entitled *Radiation Belts. Models and Standards*, has received the 1996 Honorable Mention for Geography & Earth Sciences from the Association of American Publishers, Inc. Part of the expenses for the compilation of this monograph have been charged to the present TREND contract as external services.

Work performed by BIRA/IASB

J.F. Lemaire is the overall project manager and coordinator for the BIRA/IASB team, which further consisted of D. Heynderickx (werkleider), M. Kruglanski (post doctoral research assistant),

V. Pierrard (post graduate student), M. Echim (graduate student from the Institute of Gravitation and Space Sciences, Bucharest; he visited for six months at BIRA/IASB, on the support of TREND), J.-M. Vandenberghe (graduate student), and L. Fedullo (software engineer).

D. Heynderickx was responsible for the analysis of the AZUR and SAMPEX data, and for building the data bases and empirical models resulting from these satellite observations. He has also upgraded the UNIRAD package, including the extension of the trapped particle models with the various models developed in this study, and with the ESA-SEE1, CRRESPRO, and CRRESELE models. He was in charge of WP 2.1 (Flight Data Comparisons), WP 2.2R (SAMPEX Proton Model), and WP 3.1R (UNIRAD Revisited), is the principal author of the UNIRAD user manual, has contributed to TN 5 and TN 10, and coordinated the production of this final report.

M. Kruglanski was responsible for WP 2.2 (Generalised Anisotropy Model), WP 2.1R (Improvement of ANISO Program), and WP 3.2R (UNIRAD Library). He has visited South West Research Institute, San Antonio, to get acquainted with the UARS/PEM data set and software, and to implement them at BIRA/IASB. He has written the UNILIB software library and its documentation. He is the principal author of TN 6, TN 6(2), and has contributed to TN 5, TN 10, and the UNIRAD manual.

V. Pierrard has performed a statistical analysis of the count rates and livetimes of the SAMPEX/PET detector, and has written a report. J.-M. Vandenberghe has assisted in the development of the UNILIB library and in the production of its documentation. M. Echim has assisted in the building of the UARS/PEM database and model. L. Fedullo has installed and maintained the DEC/Alpha stations and personal computers which were used at BIRA/IASB for this study.

Work performed by MSSL

A.D. Johnstone was the coordinator for Mullard Space Science Laboratory, Dorking. His team consisted of D.J. Rodgers (research assistant), S. Szita (research assistant), and G. Jones (research assistant). They were mainly concerned with the analysis of electron flux measurements made by the SEM-2 on METEOSAT and by the MEA instrument on CRRES. These observations were used to produce databases and models for the energetic electron environment.

MSSL Was in charge of WP 1.2 (Analysis of CRRES/MEA Data), WP 1.3 (Model Unification), and WP 1.3R (Creation of ISEE Electron Model). This work is described in their TN 2. They also improved the MEA electron model as part of WP 1.2R, which is documented in TN 2. The CRRES/MEA and ISEE models have been implemented in the `UNIRAD` software suite.

In TN 9 they describe how they updated and corrected the METEOSAT/SEM-2 data base and model that was developed in the TREND-2 project. This work constituted WP 4.2R.

In TN 8 they determined appropriate functions to fit the pitch angle distributions measured by the MEA detector on CRRES.

Work performed by MPAe

E. Keppler was the coordinator of the team working at Max Planck Institut für Aeronomie, Katlenburg-Lindau. He was assisted by, firstly, R. Friedel (research assistant), and later by G. Loidl (research assistant). They produced a database of the electron flux measurements made by the WIM instruments on the ISEE-1 and ISEE-2 satellites. The MPAe team was responsible for WP 1.1 (ISEE Data Analysis) and WP 1.1R (Merging of ISEE Particle and Magnetic Field Observations), and produced TN 1.

Acknowledgments

During the TREND-3 modelling effort the ESA Technical Manager E.J. Daly has closely followed the progress of the data analysis and model development. His experience and advise have been very stimulating and greatly appreciated by all TREND team members. We also benefited from H. Evans' useful suggestions and comments.

The AZUR radiation belt model for trapped protons could never have been developed without the cooperation of D. Hovestadt, Max Planck Institut für Extraterrestrische Physik, Garching, who was the PI of the EI-88 directional detectors. He provided D. Heynderickx with the necessary documentation for the analysis of the AZUR data and granted permission to use the data set. We wish to acknowledge also the Director of NSSDC, J. King, who has unearthed this historical data set from the archives of the NSSDC, at GSFC, Greenbelt.

We wish to address our special thanks to J.B. Blake, Aerospace Corporation, Los Angeles, and R.A. Mewaldt, CALTECH, Pasadena, for offering the TREND project manager the opportunity to use the proton flux measurements of the Proton/Electron Telescope (PET) obtained onboard of the SAMPEX satellite, in order to build a new trapped proton environment model. R.A. Mewaldt and J.B. Blake are PI's for this comprehensive experiment. We thank also M.D. Looper, research assistant at Aerospace Corporation for implementing the unique PET dataset during two visits at BIRA/IASB, and for many long and fruitful discussions.

The TREND team at BIRA/IASB has also been given access to the PEM proton flux measurements obtained onboard of the UARS satellite. We are very grateful to J.D. Winningham and J.R. Sharber, South West Research Institute, San Antonio, PI and Co-I of PEM, for allowing M. Kruglanski to visit SwRI, and to use the PEM observations to build a database for trapped energetic protons. The TREND project manager also thanks the SwRI personnel, especially R.A. Frahm, for allowing us to retrieve and partly process these data on their computer facilities. This database has been used by M. Kruglanski, with the assistance of M.M. Echim (visiting BIRA/IASB from the Institute of Gravitation and Space Sciences, Bucharest), to build the UARS/PEM proton environment model described in this final report.

We thank also S. Chabrillat, post-graduate student at BIRA/IASB, who improved the computer code of the MSISE-90 atmospheric model. His help in implementing this atmospheric model in the UNILIB library is appreciated.

E. Keppler and his team at Max Planck Institut für Aeronomie, Katlenburg-Lindau, wish to acknowledge T.A. Fritz, Center for Space Physics, Boston University, for transferring the ISEE electron data to Germany. We wish also to acknowledge C.T. Russell for providing his magnetic field observations, which have been incorporated in the ISEE database.

We wish to thank A.L. Vampola, Torrance, CA, for his cooperation with the TREND team working at MSSL. He provided the electron flux measurements obtained with his MEA instrument that flew onboard CRRES. The radiation belt model based on these data has been implemented in `UNIRAD`. We also thank A.L. Vampola for providing copies of the ESA-SEE1 model and documentation, and for his assistance in the implementation of the model in `UNIRAD`.

We thank E.G. Mullen, D.H. Brautigam, and M.S. Gussenhoven of Phillips Laboratory for providing us with copies of the CRRESPRO and CRRESELE models and for giving their permission to include them in `UNIRAD`. Their assistance is greatly appreciated, as well as many discussions which proved invaluable in the correct interpretation of the models.

T. Cayton (LANL) is acknowledged for providing the detectors used in the SEM-2 instrument on METEOSAT-3. The data of this detector have been used by MSSL to build the METEOSAT/SEM-2 energetic electron environment model described in this final report.

Finally, we acknowledge P. Simon, Director of BIRA/IASB, and his predecessor, Baron M. Ackerman, who gave full support to the TREND study and who have facilitated its realisation. The logistic and administrative personnel of BIRA/IASB is also generally acknowledged for its efficient help and good collaboration. We are grateful to J.-M. Vandenberghe for scanning in plots and drawings, and to A.H. Glover for carefully proof reading the manuscript.

J.F. Lemaire,

Project Manager