Available online at www.sciencedirect.com
SCIENCE DIRECT®
Advances in Space Research 33 (2004) 2219–2221
ADVANCES IN SPACE RESEARCH
(a COSPAR publication)
www.elsevier.com/locate/asr

# A space radiation shielding model of the Martian radiation environment experiment (MARIE)

W. Atwell [a,*], P. Saganti [b], F.A. Cucinotta [c], C.J. Zeitlin [d]

[a] The Boeing Company, 13100 Space Center Blvd., Mail Code: HZ1-10, Houston, TX 77058-3556, USA
[b] Lockheed-Martin, NASA Johnson Space Center, Houston, TX 77058, USA
[c] NASA Johnson Space Center, Houston, TX 77058, USA
[d] Lawrence Berkeley National Laboratory, One Cyclotron Road, Berkeley, CA 94720, USA

**Abstract**

The 2001 Mars Odyssey spacecraft was launched towards Mars on April 7, 2001. Onboard the spacecraft is the Martian radiation environment experiment (MARIE), which is designed to measure the background radiation environment due to galactic cosmic rays (GCR) and solar protons in the 20–500 MeV/n energy range. We present an approach for developing a space radiation-shielding model of the spacecraft that includes the MARIE instrument in the current mapping phase orientation. A discussion is presented describing the development and methodology used to construct the shielding model. For a given GCR model environment, using the current MARIE shielding model and the high-energy particle transport codes, dose rate values are compared with MARIE measurements during the early mapping phase in Mars orbit. The results show good agreement between the model calculations and the MARIE measurements as presented for the March 2002 dataset.


*Keywords:* Radiation shielding model; Mars radiation environment; MARIE

## 1. Introduction

The 2001 Mars Odyssey spacecraft was launched on April 7, 2001 from the Kennedy Space Center launch complex. Onboard the spacecraft are three primary science experiments: gamma ray spectrometer (GRS), thermal emission imaging system (THEMIS) and the Martian radiation environment experiment (MARIE). The 2001 Mars Odyssey spacecraft is shown in the mapping configuration in Fig. 1 and the MARIE instrument is shown in Fig. 2. In this paper we discuss the development of a space radiation shielding model of the MARIE instrument and a comparison of calculated radiation dose rates using the environment and shielding models with the onboard MARIE measurements. The MARIE (for a description of the MARIE instrument, see Zeitlin et al., 2003) consists of a series of solid-state silicon detectors that measure GCR particles and solar protons in the 20–500 MeV/n (million electron volts per nucleon) energy range. These data represent the "first ever" space radiation measurements taken in Mars orbit.

## 2. Methodology

A stand-alone shield model of the MARIE was first generated from a 3-D CAD (Fig. 2) dataset of the instrument using a combinatorial geometry approach. The MARIE instrument shielding model consists of the aluminum alloy container, circuit boards for each of the A, B, C, position-sensitive detectors (PSD) and Cerenkov detectors along with a CPU, memory cards and power supply electronics. The MARIE shielding model was used to generate 1488 shield thicknesses (rays) using an equal solid angle ray tracing technique.

The 2001 Mars Odyssey spacecraft model consists of nearly 3000 elements, which contains the major bulk mass components of the spacecraft and can be modeled as geometrical volumes. Again, 1488 rays were

* Corresponding author. Tel.: +281-804-3673; fax: +281-461-8163.
*E-mail addresses:* bigshot@houston.rr.com, william.atwell@boeing.com (W. Atwell).

0273-1177/$30 © 2003 COSPAR. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/S0273-1177(03)00527-1

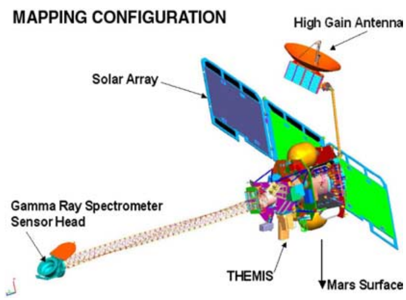


Fig. 1. 2001 Mars Odyssey spacecraft in the mapping configuration showing the location of MARIE.

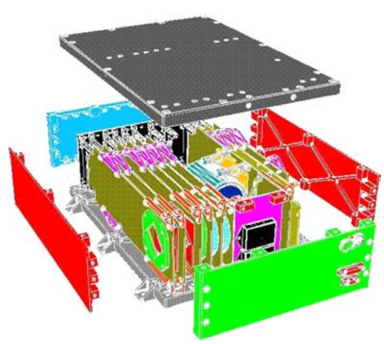

Fig. 2. 3-D CAD representation (left) of the MARIE showing the various solid-state silicon detectors mounted on their respective boards and associated electronics.

generated and the shield thicknesses for the spacecraft and the MARIE were combined, ray for ray, to obtain the total mass distribution.

This total mass distribution was then used to calculate the GCR transport through the spacecraft from all directions including the instrument's field of view (FOV) direction. From the calculated flux at the central axes, the dose rate (mrad/day) was computed using the high-energy particle transport code, HZETRN (Wilson et al., 1991). The calculated MARIE dose rates based on the Badhwar and O'Neill (1996) GCR environment model provide a comparison with the actual MARIE measurements of the free-space GCR environment in the 400 km Martian orbit.

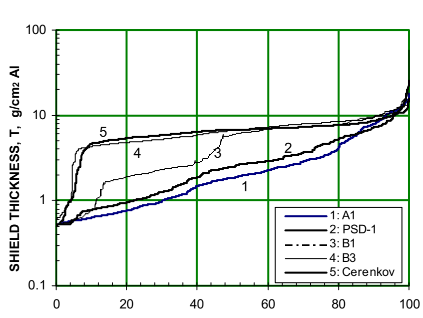


Fig. 3. Shielding distributions for several MARIE detectors.

## 3. Results

Calculated shield data for the 1488 rays (thicknesses) from the central axes of the MARIE instrument were converted to an aluminium equivalent areal density (g/cm$^2$). These data were then used to calculate the radiation dose rate for a given day at the instrument location.

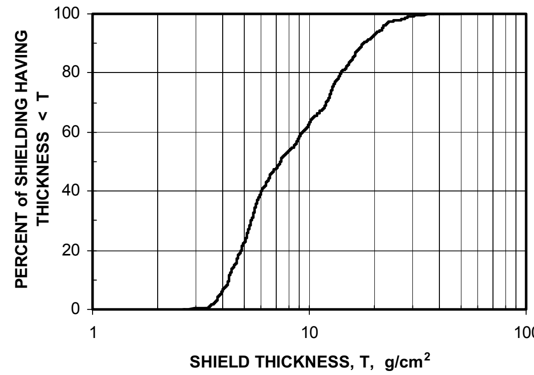


Fig. 4. Shielding distribution of the 2001 Mars Odyssey spacecraft for a point at the center of the MARIE.

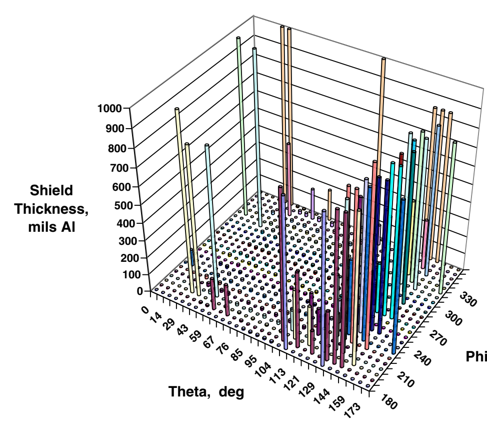


Fig. 5. Shielding distribution at the MARIE looking in the direction of the instrument field of view.

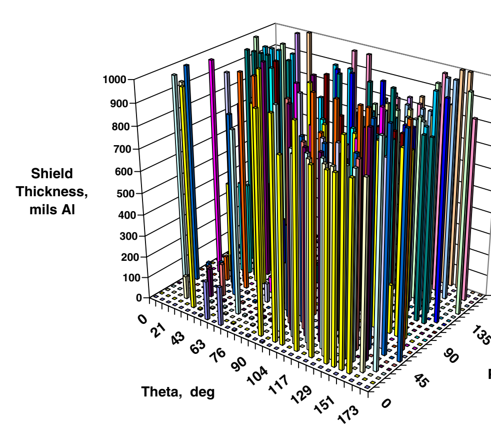


Fig. 6. Shielding distribution at the MARIE looking in the opposite direction of the instrument field of view.

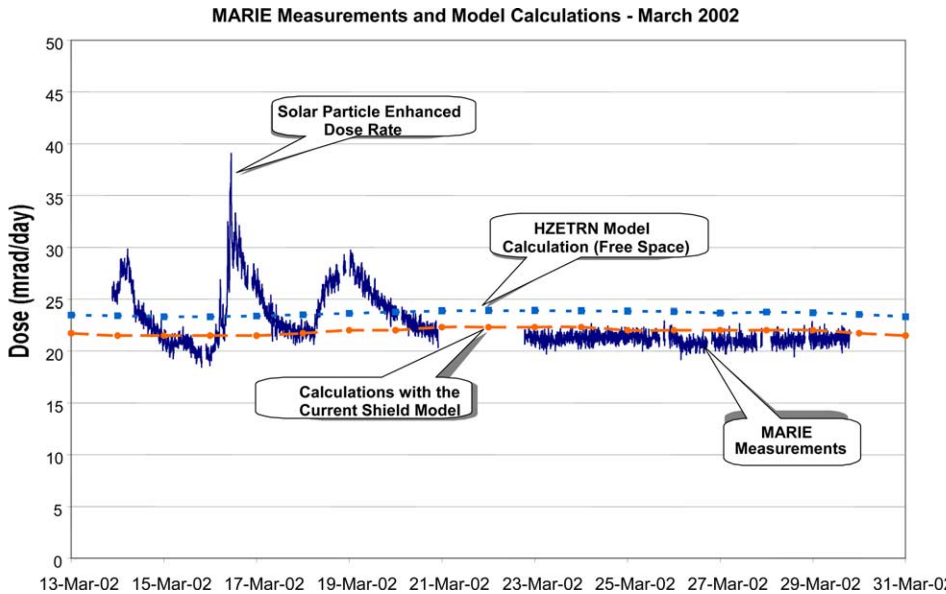


Fig. 7. MARIE measurements compared with model calculations for March 2002.

Shielding distributions for several of the individual detector locations are shown in Fig. 3 for the stand-alone MARIE shielding model. A realistic shielding distribution of the entire spacecraft at the MARIE location is shown in Fig. 4. Shielding distributions in a 3-D "look angle" format for the MARIE instrument's forward side, i.e., the FOV side and the backward side are shown in Figs. 5 and 6, respectively. As expected, Fig. 6 shows a more heavily shielded direction.

## 4. Conclusions

Dose rates have been calculated for GCR free-space environment (without any shielding) and with the MARIE instrument (with the spacecraft shielding) independently since the MARIE mapping phase began on March 13, 2002. The HZETRN (Wilson et al., 1991) model calculated free-space dose rate and the instrument measurements are within 10%. While the model calculated free-space dose rate is higher for most days that represent "quiet time" GCR dose rate, the instrument measured dose rate is lower. As anticipated, the augmentation of the MARIE (see Fig. 7) shield model into the GCR model calculations provides a much better agreement with the measured data. Fig. 7 also shows MARIE dose rate increases due to the solar proton events (SPE) of March 2002. These data represent the "first ever" SPE observations in Mars orbit. The "steady state" MARIE measurements (flat portion) represent the GCR background dose rate, which was ~22 mrad/day. This indicates the shield model data presented here is reliable and useful for further data analyses including the particle spectral distribution calculations.

The spacecraft shield model presented here represents more than 90% of the bulk mass of the spacecraft. Mass models of the major spacecraft components were represented as spherical geometric volumes. At present, work is in progress to develop a spacecraft-shielding model to achieve more than 95% of the actual spacecraft weight and one that will incorporate the exact geometrical volumes for all spacecraft components.

## Acknowledgements

The authors thank the other MARIE Science Team members for their support: Messrs. F. Riman, R. Dunn and J. Flanders, Lockheed-Martin, Houston, TX, Dr. Tim Cleghorn and P. Delaune, NASA JSC, Houston, TX and Dr. Larry Pinsky, Mr. Kerry Lee and Vic Andersen, University of Houston, Houston, TX.

## References

Badhwar, G.D., O'Neill, P.M. GCR model and its applications. Adv. Space Res. 17 (2), 7–17, 1996.

Wilson, J.W., Chun, S.Y., Badavi, F.F., et al. HZETRN: A Heavy Ion/Nucleon Transport Code for Space Radiations. NASA TP-3146, NASA Langley Research Center, Hampton, VA, 1991.

Zeitlin, C., Cleghorn, T., Cucinotta, F., et al. Overview of the Martian radiation environment experiment (MARIE). Adv. Space Res. 2003 (this issue), doi:10.1016/S0273-1177(03)00514-3.