MODELS FOR THE RADIATION ENVIRONMENT OF PLANET MARS AND OF ITS MOON PHOBOS.

G. De Angelis[1], Ts.P. Dachev[2], J.V. Semkova[2], S. Maltchev[2], B. Tomov[2], Yu. Matviichuk[2], R. Koleva[2], V. Benghin[3], I. Chernykh[3], V. Shurshakov[3], V. Petrov[3]
[1]Istituto Superiore di Sanità, Rome, I-00161, Italy (Mail Code CNESPS, Istituto Superiore di Sanità, Viale Regina Elena 299, Rome, I-00161, Italy, giovanni.deangelis@iss.it), [2]Solar-Terrestrial Influences Institute, Bulgarian Academy of Sci. (STIL-BAS), Sofia, Bulgaria, STIL-BAS tdachev@bas.bg; jsemkova@stil.bas.bg, [3]Institute of Biomedical Problems, Russian Academy of Sci. (IMBP-RAS), Moscow, Russian Federation, benghin@pike.net.ru

Introduction: The radiation protection is one of the two NASA highest concerns priorities [1]. In view of manned missions targeted to Mars [2], for which radiation exposure is one of the greatest challenges [3], it is fundamental to determine particle fluxes and doses at any time and at any location and elevation on and around Mars [4]. With this goal in mind, models of radiation environment induced by Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE) on Mars and Phobos have been developed [5]. The work is described [6] as incoming cosmic ray [7-9] and solar events [5-6] primary particles rescaled for Mars conditions then transported through the atmosphere down to the surface, with topography and backscattering taken into account, then through the subsurface layers, with volatile content and backscattering taken into account, eventually again through the atmosphere, and interacting with some targets described as material layers. Models have been developed for the surface of the satellites Phobos, as well as for the cruise phase. These results for Mars and Phobos Radiation Environment have been obtained in the framework of the LIULIN-PHOBOS investigation that will be onboard the PHOBOS-GRUNT mission by the Russian Space Agency RKA. The LIULIN-PHOBOS investigation is described in another LPSC 2009 paper by Ts. Dachev.

Physical Environments: The Mars atmosphere structure has been modeled in a time-dependent way [10-11], the atmospheric chemical and isotopic composition over results from Viking Landers [12-13]. The surface topography has been reconstructed with a model based on Mars Orbiter Laser Altimeter (MOLA) data at various scales [14]. Mars regolith has been modeled based on orbiter and lander spacecraft data from which an average composition has been derived [4-6]. The subsurface volatile inventory (e.g. CO_2 ice, H_2O ice), both in regolith and in the seasonal and perennial polar caps, has been modeled vs. location and time [15-16]. Models for both incoming GCR and SPE particles are those used in previous analyses as well as in NASA radiation analysis engineering applications, rescaled at Mars conditions [4-6]. Preliminary models have been developed for the surface of the Martian satellites Phobos. Models first developed for the Earth Moon [6,17-20] have been first adapted to the Phobos physical environment [21-23] then Mars-rescaled time-dependent primary particles fluxes [4-9] have been transported through the Phobos environment. The lunar surface and subsurface has been modeled as regolith and bedrock, with structure and composition taken from the results of landers as well as from groundbased radiophysical measurements (see discussion in [17-20]). After modifications, these lunar-like atmosphereless body surface models are used to develop models for the surfaces of Martian satellites Phobos [6].

Results - Mars: Particle transport computations were performed with a deterministic (HZETRN) code [24] adapted for planetary surfaces geometry and human body dose evaluations [4]. Fluxes and spectra for most kinds of particles, namely protons, neutrons, alpha particles, heavy ions, pions, muons etc., have been obtained. Neutrons show a much higher energy tail than for any atmosphereless bodies [4] (see Fig.1). Results have been obtained for different surface compositions: only at the latitudes closer to the equator the soil is mostly silicatic regolith, whereas for northern or southern locations a suitable mix, with variable ice concentration with time, of ices of water and carbon dioxide needs to be used [4-6]. Results have been calculated for different locations and atmospheric proper-

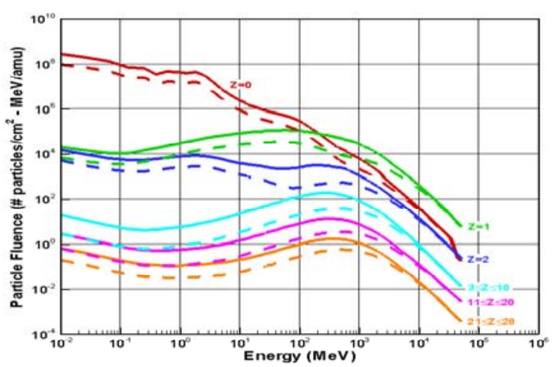

Fig. 1. GCR particle environment during the 1977 solar minimum (full lines) and the 1990 solar maximum (dashed lines) on the Martian surface (results on regolithic soil at the equator).

ties models [4-6]. The results obtained with these models differ from those from other models obtained with a simplified model of the Martian atmosphere (single composition, single thickness, no time dependence) and with a regolith-only (no-volatiles) surface model [25]. Other results, computed with the GEANT-

4 Monte Carlo transport code [26-28], also these showing doses lower than those from this work, have had mostly astrobiological applications.

Results – Cruise Phase: A tool for radiation shielding analysis developed for manned deep space missions [29] has been used. The tool allows obtaining radiation dose and dose rates for different interplanetary mission scenarios, composed of at least one out of three main segments, namely the launch and the interplanetary cruise phase, the planetary approach /departure and orbit insertion/escape phase, and the planetary surface phase. For each individual phase the respective radiation environment is taken into account, along with its variations with time. Only Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE) are considered during the interplanetary cruise phase, trapped radiation belts, where present, are also considered in the planetary approach phase, and the planetary environments (atmospheres, where present, and surfaces) effects are taken into account in the third phase. Some examples of analysis results for space missions are given in [30].

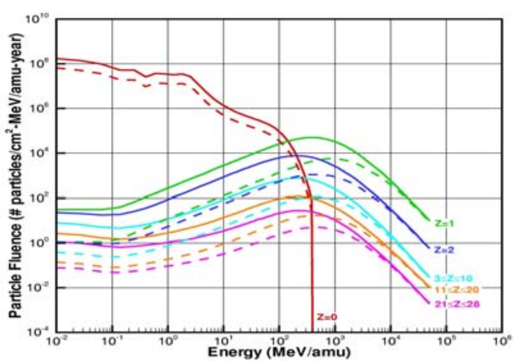

Fig. 2. GCR particle environment during the 1977 solar minimum (full lines) and the 1990 solar maximum (dashed lines)on the surface of the Martian satellite Phobos.

Results - Phobos: Particle transport computations were performed with a deterministic (HZETRN) code [24] adapted for planetary surfaces geometry and human body dose evaluations [4]. Fluxes and spectra for most kinds of particles, namely protons, neutrons, alpha particles, heavy ions, pions, muons etc., have been obtained for various lunar soil and rock compositions as well as for various Phobos surface locations (i.e. inside craters, different orientations with regards to mars, etc.), as well as for orbital scenarios, for surface (i.e. landers, habitats and rover) and subsurface scenarios (see Fig.2). This is the first model of the Phobos radiation environment, to be tested with the LIULIN-PHOBOS experiment.

Conclusions: Models for the radiation environment for Mars missions have been developed. The work have been extended to the Phobos surface as well as to the cruise phase. These radiation environmental models will be tested with the data from the LIULIN-PHOBOS experiment in the near future.

Acknowledgements: The authors are indebted with M. Caldora, C. Tesei, K.Y. Fan, S.H. Husch, B.D. Johns, W.A. Mickley, and G.D. Qualls for they invaluable help. This work has been performed under the ASI Grant I/033/06/0 and the NASA Research Grant NCC-1-404. This work is dedicated to the dear memory of Diana Bondanini.

References: [1] O'Keefe, S. (2002) http://www.spaceflightnow.com/news/n0203/27okeefe [2] Cucinotta F.A. et al. (2001) *Radiat. Res.*, 156, 682-688. [3] Hoffman S. J. and Kaplan D. L. (1997) NASA SP-6107. [4] De Angelis G. et al. (2004) *Adv. Space Res.*, 34, 1328-1332. [5] De Angelis G. et al. (2006) *Radiat.Meas..*, 41, 1097-1102. [6] De Angelis G. et al. (2007) *Nucl.Phys. B*, 166, 184-202. [7] Badhwar G. D. et al. (1994) *Radiat. Res.*, 138, 201-208. [8] Badhwar G. D. and O'Neill P. M. (1996) *Adv. Space Res.*, 17, 7-17. [9] Wilson J. W. et al. (1999) NASA TP-209369. [10] Justus C. G. and D. L. Johnson (2001) NASA TM-2001-210961. [11] Justus C. G. et al. (1996) NASA TM-108513. [12] Owen T. K. et al. (1977) *JGR*, 82, 4635-4639. [13] Levine J. S. (1985) *The Photochemistry of Atmospheres*, Academic Press, New York. [14] Smith D. E. et al. (1999) *Science*, 284, 1495-1503. [15] Christensen P. R. and Zurek R. K. (1984) *JGR*, 89, 4587-4596. [16] James P. B. et al. (1987) *Icarus*, 71, 298-305, 1987. [17] De Angelis G. et al. (2002) *J. Radiat. Res.*, 43, 41-45. [18] De Angelis G. et al. (2002) *Proc.Lunar Plan. Sci. Conf. XXXIII*, pp. 1417-1418. [19] De Angelis G. et al. (2007) *Nucl.Phys. B*, 166, 169-183. [20] De Angelis G. et al. (2005) *SAE-2005-01-2831*, pp. 1-11. [21] Kuzmin R.O et al. (2003) *Sol. Syst. Res.*, 37, 266-281. [22] Simonelli D.P et al. (1993) *Icarus*, 103, 49-61. [23] Simonelli D.P et al. (1998) *Icarus*, 131, 52-77. [24] Wilson J. W. et al. (1995) NASA TP-3495. [25] Saganti P. B. et al. (2004) *Space Scie. Rev.*, 110, 143-156. [26] Dartnell L. et al. (2007) *Biogeosciences*, 4, 545-558. [27] Dartnell L. et al. (2007) *Geophys. Res.Letters*, 34, L02207. [28] Morthekai P. et al. (2007) *Nucl. Instr. Meth. A*, 580, 667-670. [29] De Angelis G. et al. (2003) *Proc. Space Technol. Appl. Int. Forum 'STAIF-2003'*, pp. 972-983. [30] De Angelis G. et al. (2004) *Adv. Space Res.*, 34, 1395-1403.