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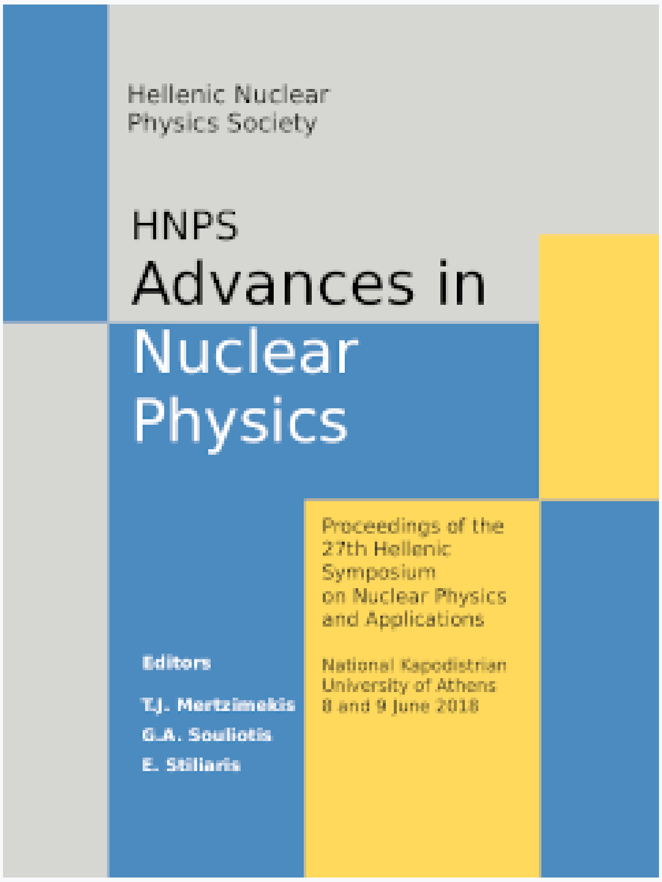

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Radiation exposure of aircrews due to Space Radiation

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Abstract: Space radiation mainly consists of trapped particles inside the Earth's magnetosphere, galactic and solar cosmic rays. Cosmic rays propagating in the interplanetary medium, reach the top of the Earth's atmosphere and collide with the molecules of the atmospheric layers creating showers of secondary particles that can be recorded by ground-based neutron monitors or muon detectors. Due to these cascades, the radiation environment in various atmospheric altitudes is entirely different than the one experienced on the Earth's surface. Space radiation is ionizing (trapped particles, galactic and solar cosmic rays) as well as non-ionizing (ultra-violet radiation). It is known that ionizing radiation is very dangerous for all biological systems, causing a variety of acute and chronic effects. The determination of the occupational exposure of aircrews to space radiation is of great importance. DYnamic Atmospheric Shower Tracking Interactive Model Application (DYASTIMA), as well as its extension DYASTIMA-R, is a standalone application, based on the toolkit Geant4, that simulates the propagation of cosmic radiation into the atmosphere. DYASTIMA provides all the necessary information about the study of the cascade in different atmospheric altitudes, while DYASTIMA-R, as a dosimetry application, calculates radiobiological quantities, such as dose rate and equivalent dose rate for the determination of the exposure, based on the output provided by DYASTIMA. These quantities are calculated for solar minimum and solar maximum conditions. DYASTIMA can be accessed through the portals of the European Space Agency (ESA) (http://swe.ssa.esa.int/spaceradiation) and the Athens Neutron Monitor Station (A.Ne.Mo.S) (http://cosray.phys.uoa.gr/index.php/dyastima).

Keywords Space Weather, cosmic radiation, dosimetry, aviation

INTRODUCTION

Radiation exposure in space is totally different than the one experienced on the surface of Earth. Ionizing space radiation refers to galactic and solar cosmic rays, while non-ionizing radiation refers to ultra-violet spectrum. As known, ionizing radiation can be extremely dangerous to biological systems, causing mutations and carcinogenesis. More specifically, the acute effects are mostly related to high intensity solar phenomena, while the chronic effects are due to the long term exposure to galactic cosmic rays. Typical examples are several types of cancers, melanoma, vision impairment, cataract [1,2], as well as some cardiovascular diseases [3]. For these reasons, several models and software applications for monitoring cosmic ray intensity and radiation dose received by aircrews and space crews are developed, such as SPENVIS [4], CRÈME [5-7], AVIDOS [8], etc.

Cosmic ray intensity on the top of the atmosphere is modulated by the solar activity, the Earth's atmosphere and magnetosphere, and the atmospheric altitude. As primary cosmic rays

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reach the top of the atmosphere, they collide with the atmospheric molecules and cascades of secondary particles are produced. These cascades are responsible for the dose accumulated to aviators on various atmospheric layers. Each particle type contribute to the total equivalent dose in a different way, based on the radiation quality factor [1,2].

In this work, a simulation software for the study of the atmospheric showers as well as their effects on human health, is presented. DYASTIMA and DYASTIMA-R are implemented by the Athens Cosmic Ray Group. The software is available at the Athens Neutron Monitor Station (A.Ne.Mo.S.) portal (http://cosray.phys.uoa.gr/index.php/dyastima) and at the ESA SSA SWE Space Radiation Expert Service Center portal as a new federated product (http://swe.ssa.esa.int/web/guest/dyastima-federated).

EXPERIMENTAL DETAILS

DYnamic Atmospheric Shower Tracking Interactive Model Application (DYASTIMA) [9] is a stand-alone application based on the Geant4 simulation toolkit [10-12] for the study of the atmospheric showers. More specifically, a Monte Carlo simulation of the cascades in the atmosphere of a planet is performed, allowing the thorough study of the cascades' properties. The primary cosmic ray spectrum at the top of the atmosphere, the structure of the atmosphere, the geomagnetic field, the physical interactions that take place between the cosmic ray particles and the molecules of the atmosphere, the space weather conditions, and the time and location of the simulation are the required input parameters and are provided by the user via a graphical user interface. The execution of the simulation provides all the necessary information about the cascade, such as the energy, the number and the energy deposit of the particles at different atmospheric layers (Fig. 1, left panel).

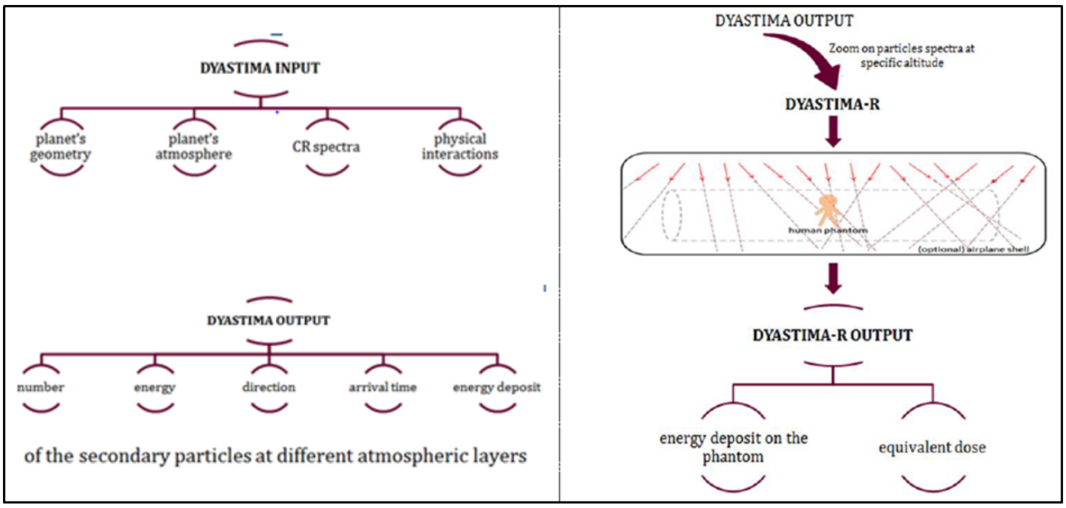

Fig. 1. Block diagram of the software DYASTIMA/DYASTIMA-R

DYASTIMA-R [13], an extension of DYASTIMA, allows radiation dosimetry calculations (dose, equivalent dose) by performing a second simulation on a human phantom for various flight scenarios, based on the output provided by DYASTIMA. The calculations are performed for different particle types and energies, different atmospheric altitudes, geographic coordinates, cut-off rigidity thresholds and phases of solar activity, such as the 11-years solar cycle, Forbush decreases and ground level enhancements, due to their hazardous effects on technological and biological systems. The geometry and shielding materials of the aircraft will also be taken under consideration (Fig. 1, right panel).

RESULTS AND DISCUSSION

Several runs of DYASTIMA and DYASTIMA-R have been performed in order to study the cascades inside the Earth's atmosphere for solar maximum and solar minimum conditions. The primary cosmic ray spectrum is calculated with the CRÈME96 tool [5-7], while the description of the atmosphere is provided by the International Standard Atmosphere model [14]. For the calculations of the radiobiological quantities a cylindrical phantom (1.75 m height, 0.12 m radius) consisting of water is used.

The dose rate and equivalent dose rate are given in Fig. 2. As expected, dose and equivalent dose rates are higher during the solar minimum conditions due to the anticorrelation of the cosmic ray intensity and the solar activity (sunspot number). Dose rates also declines when the magnetic rigidity threshold Rc (GV) increases. Therefore, the radiation accumulated during polar and high latitude flights (0-3 GV) is far greater than flights occurring close to the equatorial line (15 GV).

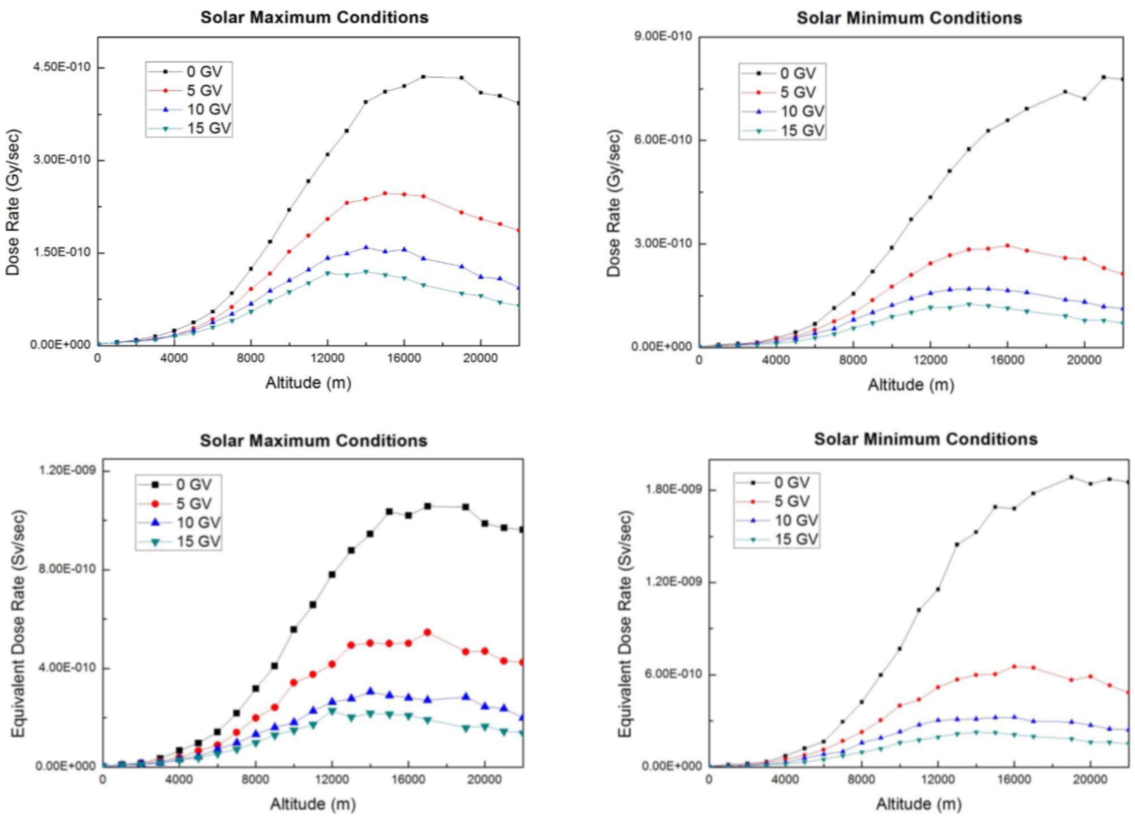

Fig. 2. Calculation of the dose rate (upper panel) and equivalent dose rate (lower panel) during solar maximum and solar minimum conditions with DYASTIMA-R

CONCLUSIONS

The study of the atmospheric showers is crucial for the determination and calculation of several radiobiological quantities. Therefore, the results provided by DYASTIMA may be useful for air-craft crews (such as pilots and flight attendants), passengers (especially for frequent travellers, pregnant women and children), airlines, tour operators, air-craft manufacturers, legislators and Civil Aviation.

DYASTIMA has already been used successfully for the study of the cascades at the Venusian atmosphere [15]. The next steps of this work include the launch of DYASTIMA and DYASTIMA-R inside the Martian atmosphere, in order to study the possible radiation accumulation for future space missions.

ACKNOWLEDGEMENTS

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