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Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Mikhail Dobynde

PhD Program: Engineering systems

Title of Thesis: Radiation Shielding of Astronauts during Interplanetary Flights

Supervisor: Prof. Rupert Gerzer

Date of Thesis Defense: 17 February 2020

Name of the Reviewer: Henni Ouerdane

I confirm the absence of any conflict of interest	**Signature:**  **Date: 27-01-2020**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

Reviewer's Report

Reviewers report should contain the following items:

- **Brief evaluation of the thesis quality and overall structure of the dissertation**

The doctoral thesis *Radiation shielding of astronauts during interplanetary flights*, submitted by Mr. Mikhail Dobynde, focuses on the development of models and their numerical simulations to address a timely and highly complex problem: the protection of astronauts during interplanetary flights. The thesis is structured over 5 chapters, including the introduction and the conclusion that summarizes the main findings, followed by the list of references used throughout the manuscript. The doctoral thesis is quite compact and has a logical structure for the development of its content which lies at the crossroads of several disciplines: radiation-matter interaction, biophysics, and space to name these broadly. Mr. Dobynde managed to introduce the basic concepts of his interdisciplinary research, his methodology and his results efficiently. The thesis shows also that he took great care to produce meaningful numerical results, which he competently discusses.

- **Relevance of the topic of dissertation work to its actual content**

Interplanetary flights entail many difficult challenges, ranging from spacecraft technology to astronauts and equipment safety. Manned spaceflights in particular have always been a highly important objective in the space industry since its inception, and still are highly topical given the projects to send humans on our neighbor Mars, not only for scientific purposes but also they constitute a foundational milestone to colonize and exploit resources available in our close space environment. In this regard, the safety of astronauts is of obvious importance. Interplanetary flights imply long stays in a low-gravity environment and continuous exposure to space radiations (solar and galactic). The impacts on a human body are many: loss of muscle mass and bone resistance, weakening of the immune system, decrease of motor skills, loss of balance, increased risks of cancer, etc. The mitigation of the dangers caused by radiations in space is the principal motivation of the doctoral work presented by Mr. Mikhail Dobynde. For that purpose he identified the different sources of radiations: galactic cosmic rays, solar energetic particles, and low-Earth orbit magnetically trapped protons and trapped electrons (Van Allen radiation belts), and analyzed the effects of each type of radiation source in terms of radiation dose to suggest solutions for optimal conditions for space flights. The research questions that form the basis of the doctoral work are all meaningful: i/ determination of the optimal combination of launch dates and spacecraft shielding to allow the longest possible mission duration before reaching the radiation dose limit of astronauts; ii/ calculation of the relative contributions of the different species to the net radiation dose and their dependence on spacecraft shielding; iii/ quantitative comparison of the radiation environment within a spacecraft, flying inside and outside of the Earth magnetosphere; iv/ calculation of depth-dose curves for urgent dose assessment and its validation; v/ definition of the limitations of the depth-dose method in terms of particle energy and shielding thickness.

- **Relevance of the methods used in the dissertation**

The accurate and complete modeling of radiation-matter interaction involving a complex organism such as the human body is a highly difficult endeavor for essentially two basic reasons: i/ the nature of the radiation, since the interaction mechanisms and amount of energy deposited depend upon it; the variety of biological tissues and their organization in an organism, which also govern the amount of energy deposited in the different parts of the body and the subsequent biochemical reactions. In his doctoral work, Mr. Dobynde assumed simplified geometries: spherical and planar. These geometries are standard in the field of research and are based on simple assumptions. The spherical geometry simplifies the analyses for cases when the model system constituted of shielding layer filled inside with water (phantom) is submitted to isotropic radiations (galactic cosmic rays and solar energetic particles), while the planar (or slab) geometry assumes irradiation from a single point source. To complement the basic models, a cylinder geometry that simulates the actual Matroshka physical model (for a human torso) under irradiation under long-duration space missions. Radiation matter interactions entail complex and ultrafast processes: electronic excitations, ionization cascades, etc. characterized by different energy-dependent interaction cross sections, which feed Monte-Carlo transport simulation codes. For his doctoral work, Mr. Dobynde used one state-of-the-art simulation toolkit: the GEANT4 software initially developed at CERN, to simulate and study the transport of particles through material media, using Monte Carlo methods. GEANT4 finds application in space physics for electronic equipment under irradiation, dosimetry, shielding optimization, radiation hazards, to name a few. Therefore, the methodology developed in the doctoral work of Mr. Dobynde is based on reasonable basic assumptions and the use of models and tools that correspond to the international standards in the community.

- **Scientific significance of the results obtained and their compliance with the international level and current state of the art**

The work and results presented in the doctoral thesis of Mr. Mikhail Dobynde provide quantitative answers to the research questions that constitute the basis of the thesis; these certainly are on par with the current state of the art in the field as shown by his publication record. Presentations at 5 different international meetings confirm the interest of the space community for this research work.

- **Relevance of the obtained results to applications** (if applicable)

While the results of the simulations will be of interest to the community and are aimed to find concrete and applicable solutions to one of the major problems of manned space missions and interplanetary flights in particular, these may not translate directly as solutions in the space industry. However, the results obtained in the present thesis can give directions to develop cost-effective strategies for the safety of astronauts during long-duration space missions.

- **Quality of publications**

Mr. Mikhail Dobynde is first author of 2 out of 3 published journal articles related to his doctoral work now recorded in the Scopus database; and also of first author of 2 articles currently under review. The journals: *Life Science in Space Research, Space Weather, Scientific Reports* (acceptance pending for this latter) are reputable journals in Mr. Dobynde's research field. Further, Mr. Dobynde has given 5 presentations at international meetings in Russia and in the USA. Mr. Dobynde's record thus clearly shows that his doctoral work has reached international standards.

Summary of issues to be addressed before/during the thesis defense

The numerical data obtained with GEANT4 had to be processed to be productively analyzed. The actual processing is mentioned in the thesis manuscript but there is a lack of detail. It is expected that Mr. Dobynde provides more detail on the data processing.

Given the complexity of the physical radiation-matter interaction problem and the amount of experimental data now available, would a machine learning approach be of added value to compute and simulate radiation doses considering different sources, more realistic geometries, and solar activity?

Provisional Recommendation
☒ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*
☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*
☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*