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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:** Ondrej Ploc

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| I confirm the absence of any conflict of interest.<br><br>(Alternatively, Reviewer can formulate a possible conflict) | **Signature:**<br>  <br>**Date: 19-01-2020** |

*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 relevance of the topic of dissertation work to its actual content
- The relevance of the methods used in the dissertation
- The scientific significance of the results obtained and their compliance with the international level and current state of the art
- The relevance of the obtained results to applications (if applicable)
- The quality of publications

The summary of issues to be addressed before/during the thesis defense

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

The presented thesis is nicely written in usual scientific structure. It is based on already published papers in impacted journals which supports the good scientific quality of the thesis. Author showed his ability to fulfill the difficult tasks and also clearly explained how the tasks were met. My only comments (further detailed in the Summary of issues to addressed before the defense) to the structure and quality are following:

  - Little bit unusual is the formulation of goals in the abstract. I prefer to see the goals after the introduction with literature review because only with the knowledge on state-of-the-art it became clear what is missing in the given subject and what is needed to be done.
  - The high quality of the thesis is a little bit attacked by quite big number of misprints, wrong spelling, grammar and other errors in the text. There is still time to correct them and improve this slight defect on the beauty of an otherwise very nice and valuable thesis.

- The relevance of the topic of dissertation work to its actual content

The topic of the presented work is about the radiation shielding of astronauts during the interplanetary missions. The content of the presented thesis focuses on missions to Mars which is indeed relevant to the title, however, a sentence or a paragraph which would explain the expected difference between the flight to Mars and general interplanetary missions is missing.

- The relevance of the methods used in the dissertation

The selected method using the GEANT4 Monte-Carlo code is certainly appropriate calculation tool for simulation of radiation environment in space. The selection of simplified geometry of a sphere for both - the spacecraft hull and the human body - is sufficiently explained. What is missing is clear explanation on what GCR model was used and why.

- The scientific significance of the results obtained and their compliance with the international level and current state of the art

According to the ESA roadmap for future research, the radiation risk in space is essential for future human explorations of the Solar System. Evaluation of the radiation risk in space is therefore one of the main tasks for the preparation of the Deep Space Gateway (DSG, newly by NASA also titled as Lunar Gateway) – a crewed platform in deep space from which human exploration of the Solar System can set forth – which should be assembled and operated in the vicinity of the Moon during the 2020s.

The main health effects of an exposure to cosmic radiation to be addressed in exploration are cancer risk and central nervous system (CNS) effects; increasing attention is given to cardiovascular risk. NASA radiation Health Program now concentrates after detailed studies of mitigation of cancer effects on CNS risk for explorative missions with the view towards future long-term missions on the Moon and finally to Mars. Shielding against exposure due to galactic cosmic radiation (GCR) is quite ineffective due to the high particle energies, however, optimal shielding thickness presented in this work is also valuable.

Human mission performance requires to avoid high exposures due to Solar Energetic Particle (SEP) events from which the Solar Proton Events (SPE) are of major concern. Adequate measures needs to be provided which starts with the design of the DSG, but since the risk to astronauts within a complex structure is very sensitive to specifics of geometry and model setup in ways that indicate that application of these results directly into vehicle design may not be appropriate and therefore not advisable. For the reduction of radiation risk intelligent arrangement of the interior of spacecraft is a realistic consideration, for which improved modelling is certainly needed.

The topic of the presented thesis is therefore actual and scientifically significant.

- The relevance of the obtained results to applications (if applicable)

The scientific results (like the optimal time for flight to Mars, optimal shielding thickness, relative contributions of the different species to the radiation dose, and especially quantitative comparison of the radiation within a spacecraft flying inside and outside of the Earth magnetosphere) can be used for the preliminary design concept of the DSG spacecraft hull but also, using the information on calculated

fluxes of GCR inside and outside the Earth magnetosphere, for design of the space radiation reference DSG instrument.

- The quality of publications

Candidate has three publications already published and two are under review. All of them are in impacted, peer-reviewed journals. He is a first author of two of already published publications, both of them are in Life Science in Space Research (IF=2.066 ). The third one is in Space Weather (IF= 3.69). The number of scientific papers and their quality is sufficient for candidate to be admitted for thesis defense.

The summary of issues to be addressed **before** the thesis defense:

- To your abstract, add please a sentence or a paragraph explaining why you focus on calculations of radiation shielding to Mars only while the title is about the interplanetary missions in general. It would increase the relevance of the topic of dissertation work to its actual content.
- Neutrons have no charge, it is true, but the quality factor is not 1 as you stated in the thesis (section 1.2, page 8). Correct it and explain why. (See e.g. Veinot, K. G., & Hertel, N. E. (2005). Effective quality factors for neutrons based on the revised ICRP/ICRU recommendations. Radiation protection dosimetry, 115(1-4), 536-541.)
- Misprints, grammar errors, wrong spelling, and other editorial comments:
  - Abstract:
    - First sentence: wrong: "…as **a** one **on** the main…" correct: "…as one of the main…"
    - Fourth line: use "trapped radiation (TR)" instead of "radiation trapped (TR)"
    - In the paragraph describing the second main outcome, second line: use "Circulatory System (CS)" instead of "Circulatory System (CS**s**)" in your text
    - In the paragraph describing the second main outcome, second line: up **to** 90% ("to" is missing in your text)
    - In the paragraph describing the third main outcome, last line: use more common and correct "the net CS dose on the LEO is **halved**" instead of "the net CS dose on the LEO is **half less**"
    - In the paragraph describing the last main outcome
  - List of Symbols: "*r*" as a spherical shielding radius or outer radius appears two times in the list. Please select only one explanation of "*r*".
  - Abbreviations:
    - Abbreviation should be explained in their first appearance in the text of the thesis (independently on abstract) + they can be explained again in the extra list. This is not met in all cases (e.g. LEO on page 1, GOES on page 4, TR on page 6, etc.)
    - the abbreviation list is not full. Explanation of TR, TP, TE, CREME, SOHO, GOES, BFO (maybe more) is missing.
  - GCR is usually abbreviation for Galactic cosmic rays – including the "s" for plural of rays. In the presented thesis, sometimes is used "GCR" and sometimes "GCRs". I recommend to unify it via using "GCR" everywhere (including abstract, List of abbreviations, and the rest of thesis) and relating to "Galactic cosmic rays".
  - The title of Section 1.1 appears again as the first sentence of the Section. Please delete the sentence "Radiation environment in space." and keep the section title only.
  - Section 1.1.1, the second sentence of the last paragraph (page 3): use "…the sunspot or Wolf number…" instead of "…the sun-spo**r**t or Wo**o**lf number"

- Section 1.1.1, the third sentence from the end (page 3): Citation is missing and "(formula??)" is used instead of wrong "(formula??)" is used instead. Please correct it.
- Symbol for steradian is "sr" not "Sr" (Symbol "Sr" is used for Strontium). Please correct it in all of Figures 1.2 a) and b), 1.3 a) and b), 1.4 a) and b).
- The title of Section 1.1.4 appears again as the first sentence of the Section. Please delete the sentence "Trapped radiation." and keep the section title only.
- Chapter 1.2, third line: please use "… in units of **g**ray (symbol: Gy)." instead of wrong "… in units of **G**ray Gy." Indeed, the name of the units starts with lowercase (gray) but name of the scientist starts with uppercase (Gray). It should also be explained why the "Gy" is in the sentence, I recommend to use brackets as "(symbol: Gy)".
- Chapter 1.2, 19th line: please use "… in units of **sie**vert (symbol: Sv)." instead of wrong "… in units of **Si**vert Sv."
- Table 1.1, page 8:
  - Q=1 for LET<**10** and not for LET<**1** please correct it
  - The second range of LET must include the edge values, i.e. 10**≤**LET**≤**100
  - Usually, the variable LET is in the first column and the functionally dependent Q(LET) is in the second column. Please switch the columns.
- Please use correct "annual" instead of wrong "anual" in figures 4.1, 4.4 a),b), 4.5, 4.6.
- Section 1.4.3, first line: use "probability" instead of "prob-ability"
- Chapter 2, page 17, first line: comment in brackets "(ref to irradiation facilities)" is not clear to me.
- In Chapter 4, the first level subsections (4.1, 4.2, etc.) start with a new page while the first level subsections in chapters 1, 2, and 3 start at the same page as the previous subsection. Please unify it.
- Section 4.1, first sentence: specify which figure shows the time dependences of GCR doses (Figure 4.1).
- Be sure that values are at the same line with their units (it is not the case e.g. on page 36, last sentence).
- Chapter 4, page 45: missing Figure number and "refcompC" is there instead. Please correct it.
- Chapter 4, page 47: missing Figure number and "refcompC" is there instead. Please correct it.
- Chapter 4, page 66: missing Figure number and "{refleolab3)" is there instead. Please correct it.
- Page 42: add a reference instead of "[some reference needed?]"

My questions to be addressed **during** the thesis defense:

- Special attention in the thesis is paid to neutrons. What is the biological effect of neutrons and why is it much bigger than the biological effect of photons?
- What GCR models were used in your calculations and why?
- What are the sources of uncertainties related to your calculations and estimates of their values?
- Could be your codes provided for further use of broader public as e.g. an open-source license?

Summing up, I am convinced that the author Mikhail Dobynde of the presented Ph.D. thesis demonstrated his ability to conduct individual research work and bring valuable results. All main goals defined for this work were fulfilled. For this reason, I recommend that after corrections recommended in this report he will be admitted to the formal thesis defense and delivered the scientific title Ph.D.

| **Provisional Recommendation** |
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| ☐ *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* |