PERSEO:
PErsonal Radiation Shielding for intErplanetary missiOns

Executive Summary

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1. MOTIVATION

The PERSEO project (PErsonal Radiation Shielding for intErplaetary missiOns) aimed at studying a wearable innovative radiation protection system to mitigate the effects of Solar Particle Events (SPE) on astronauts. SPE can be considered as related mainly to deterministic effects of the cosmic radiation, with hazards to man arising for physical doses above 2 Gy, when symptoms of the hematopoietic syndrome appear.

In view of future space exploration missions, an increasing duration and level of complexity will be required for Extra Vehicular Activities (EVA), as in the case of the construction of a permanent outpost on the lunar surface: the occurrence of a SPE in such scenario might not leave enough time for the astronaut to reach a safe shelter, and existing suits do not offer sufficient protection to prevent radiation sickness. Even if the shelter can be reached quickly enough, damages and failure of fundamental components of the spacecraft, possibly due to the SPE themselves, might require a direct intervention of the astronauts.
Concerning Intra Vehicular Activities (IVA), an adaptable shielding level of the newly conceived suit could make it comfortable enough to be worn on board most of the time while carrying on ordinary activities.

2. METHODOLOGY

GEANT4/GRAS calculations are performed to obtain information on dose delivery by solar protons, with an energy distribution calculated according to the ESP model.
Traditional and innovative materials are first reviewed using a simplified 1D slab geometry, and then different combinations of best performing materials in terms of shielding are used for 3D calculation of dose reduction to the organs of the GRAS mathematical phantom wearing different suit models.

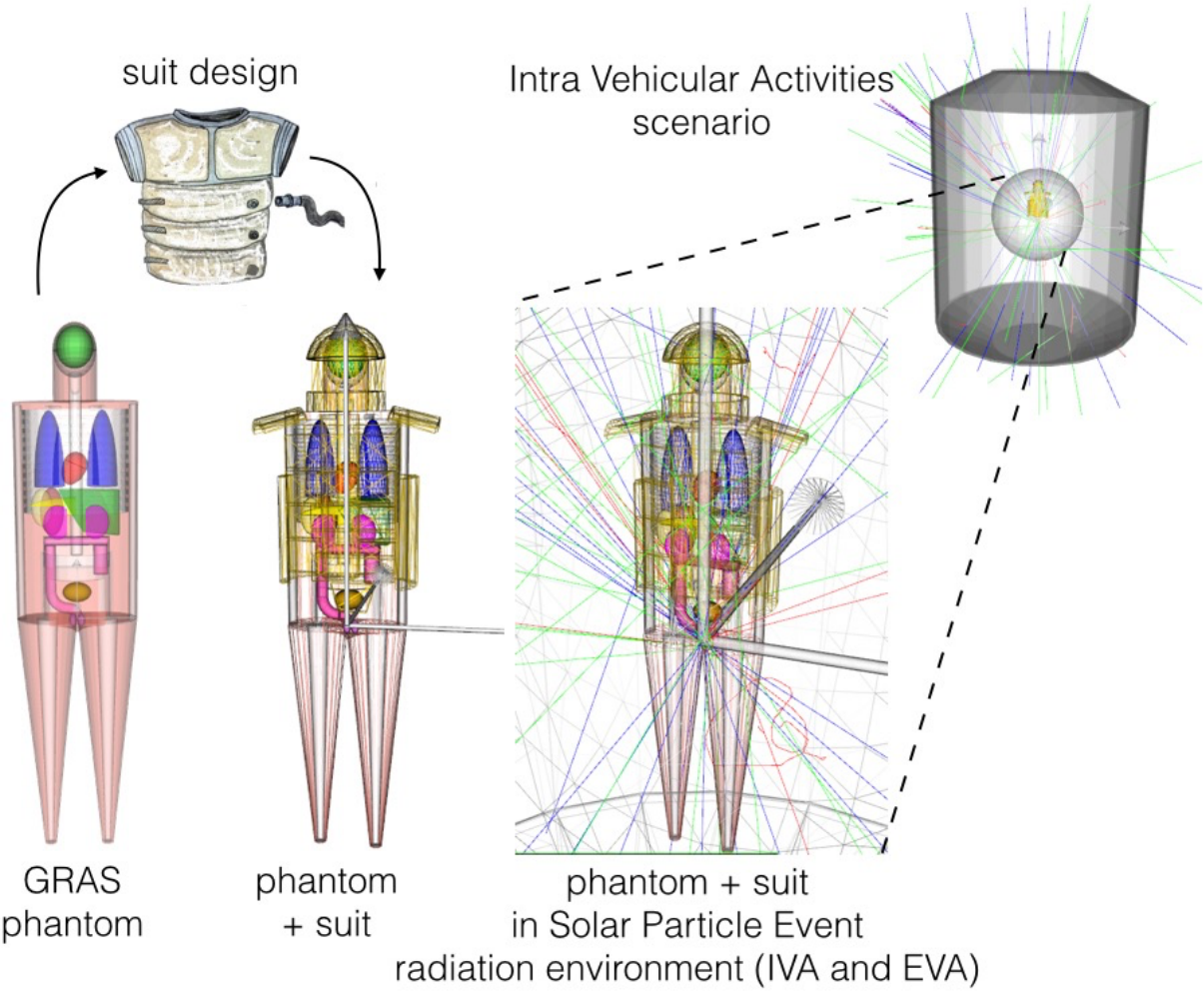
3. PROPOSED STRATEGY

For meeting the requirements of shielding both in EVA and IVA situations, a **selective** and **adaptable shielding strategy** is required, focusing on the most radiosensitive areas. The strategy proposed in the conclusions of this work is indeed based on selective shielding and the suit design is embedding inflatable elements made of a multilayer of high density material in the external region (arranged in bars, plaques, fibers, etc.) and a flexible material in the region close to the human body, as water or organic compounds from spacecraft waste. These are the most readily available materials on a spacecraft and they could be easily used to fill the inflatable suit and then reintroduced in the module hydraulic system. The dose and dose equivalent reduction to the Blood Forming Organ (BFO) is taken as indicator of the shielding performance of the suit.

4. RESULTS

Results on dose and dose equivalent reduction to BFO (and all organs of the mathematical phantoms) are given for different suit models both in EVA and IVA scenarios. The best results of a 38% dose reduction has been obtained for the Suit1-B-PLUS model during IVA.
Dose reductions have been converted in time gain, e.g. the increase of time delay between the occurrence of a SPE and the appearance of symptoms of radiation sickness: for the best performing suit the gain is ranging from about 60% in the IVA to more than 200% in the EVA scenario, even if additional elements of a realistic suit were not included in the modeling in this latter case.
The reduction of the Excess Relative Risk of leukemia induction due to SPE exposure was found to be a constant factor of approximately 1.7 over an exposure of up to 24 hours when wearing the suit.

5. ILLUSTRATION OF THE WORK



6. CONCLUSIONS AND PERSPECTIVES

Results of the PERSEO project proves the feasibility of a selective shielding strategy against SPE based on a wearable suit with inflatable elements.
Results presented in this feasibility study have the potential to pave the way for the realization of a space suit prototype to be tested in terms of wearability and radiation shielding.

The future implementation of this project would require the following actions:
- executive design of the space suit taking into account space compatibility of materials and wearability;
- shielding properties of newly proposed suits should be compared to the performance of existing suits, taking also into account suit elements as oxygen supply and propulsion systems in case of EVA;
- the proposed shielding strategy could be adapted to an existing space suit model;
- the realization of a space suit prototype and test of radiation shielding properties with on-ground measurements;
- ground/space (on the ISS) tests in terms of wearability;
- new design phase and prototype on the base of the results of wearability tests.

Potential non space applications of the strategy investigated in this project include the development of technologies for wearable protection systems for emergency situations due to different risk agents (nuclear, chemical, etc.):
- material studies in terms of:
    - protection properties;
    - workability for the realization of a suit/suit element;
    - compatibility with the environment, durability and resistance;
- wearability in terms of comfort and rapidity of wearing.

7. DISSEMINATION OF RESULTS

Results of the PERSEO project have been already presented at the **International Academy of Astronautics' 20th Humans in Space Symposium (HIS), June 29 - July 3 2015, Prague, Czech Republic**.
The title of the oral contribution was:

"The PERSEO project ("PErsonal Radiation Shielding for intErplanetary missiOns"): status and perspectives."
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Manuscripts for publication on peer-reviewed journals are currently under preparation.