

Accepted Manuscript

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PII: S2214-5524(17)30032-9
DOI: [10.1016/j.lssr.2017.08.003](https://doi.org/10.1016/j.lssr.2017.08.003)
Reference: LSSR 146



To appear in: *Life Sciences in Space Research*

Received date: 29 March 2017
Revised date: 7 August 2017
Accepted date: 8 August 2017

Please cite this article as: M. Vuolo , G. Baiocco , S. Barbieri , L. Bocchini , M. Giraudo ,
T. Gheysens , C. Lobascio , A. Ottolenghi , Exploring innovative radiation shielding approaches in
space: a material and design study for a wearable radiation protection spacesuit, *Life Sciences in
Space Research* (2017), doi: [10.1016/j.lssr.2017.08.003](https://doi.org/10.1016/j.lssr.2017.08.003)

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Exploring innovative radiation shielding approaches in space: a material and design study for a wearable radiation protection spacesuit

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Abstract

We present a design study for a wearable radiation-shielding spacesuit, designed to protect astronauts' most radiosensitive organs. The suit could be used in an emergency, to perform necessary interventions outside a radiation shelter in the space habitat in case of a Solar Proton Event (SPE). A wearable shielding system of the kind we propose has the potential to prevent the onset of acute radiation effects in this scenario. In this work, selection of materials for the spacesuit elements is performed based on the results of dedicated GRAS/Geant4 1-dimensional Monte Carlo simulations, and after a trade-off analysis between shielding performance and availability of resources in the space habitat. Water is the first choice material, but also organic compounds compatible with a human space habitat are considered (such as fatty acids, gels and liquid organic wastes). Different designs and material combinations are proposed for the spacesuits. To quantify shielding performance we use GRAS/Geant4 simulations of an anthropomorphic phantom in an average SPE environment, with and without the spacesuit, and we compare results for the dose to Blood Forming Organs (BFO) in Gy-Eq, *i.e.* physical absorbed dose multiplied by the proton Relative Biological Effectiveness (RBE) for non-cancer effects. In case of SPE occurrence for Intra-Vehicular Activities (IVA) outside a radiation shelter, dose reductions to BFO in the range of 44 to 57% are demonstrated to be achievable with the spacesuit designs made only of water elements, or of multi-layer protection elements (with a thin layer of a high density material covering the water filled volume). Suit elements have a thickness in the range 2 to 6 cm and the total mass for the garment sums up to 35 - 43 kg depending on model and material combination. Dose reduction is converted into time gain, *i.e.* the increase of time interval between the occurrence of a SPE and the moment the dose limit to the BFO for acute effects is reached. Wearing a radiation shielding spacesuit of the kind we propose, the astronaut could have up to more than the double the time (*e.g.* almost 6 instead of 2.5 hours) to perform necessary interventions outside a radiation shelter during a SPE, his/her exposure remaining within dose limits. An indicative mass saving thanks to the shielding provided by the suits is also derived, calculating the amount of mass needed in addition to the 1.5 cm thick Al module considered for the IVA scenario to provide the same additional shielding given by the spacesuit. For an average 50% dose reduction to BFO this is equal to about 2.5 tons of Al. Overall, our results offer a proof-of-principle validation of a complementary personal shielding strategy in emergency situations in case of a SPE event. Such results pave the way for the design and realization of a prototype of a water-filled garment to be tested on board the International Space Station for wearability. A successful outcome will possibly lead to the further refining of the design of radiation protection spacesuits and their possible adoption in future long duration manned missions in deep space.

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