RADIATION PROTECTION FOR HUMAN SPACEFLIGHT

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Space is a special workplace not only because of microgravity and the dependency on life support systems, but also owing to a constant considerable exposure to a natural radiation source, the cosmic radiation. Galactic cosmic rays (GCR) and solar cosmic radiation (SCR) are the primary sources of the radiation field in space. Whereas the GCR component comprises all particles from protons to heavy ions with energies up to 10^{11} GeV, the SCR component ejected in Solar Energetic Particle events (SPE) consists mostly of protons, with a small percentage of heavy ions with energies up to several GeV. In low Earth orbit, the exposure to GCR is ~ 100-250 x higher compared to sea level. This factor rises to ~ 770 x for travel in the interplanetary space according to recent measurements on a journey to Mars. On a six month mission to the International Space Station (ISS), astronauts accumulate radiation doses exceeding the terrestrial occupational annual limit of 20 mSv by far. Astronauts experience a chronic whole body exposure with single energetic particles (electrons, protons, α-particles and heavy ions) of GCR. Contrary to other workplaces, the exposure on ISS or in future, on exploratory missions, continues after end of the working hours. The main concerns resulting from this exposure are increased risks of cancer, cataract, neurodegenerative effects and infertility. The effective dose as a pre-requisite for the radiation risk assessment was determined from organ doses measured within a human antrophomorphic phantom (MATROSKHA) which was exposed four times on the ISS. The ratio of organ to skin dose determined in these experiments allows estimation of the effective dose based on personal dosimeters of the astronauts. In interplanetary missions, in addition to the chronic, in average low dose GCR exposure at low dose rate, an acute whole body exposure to a high radiation dose at a high dose rate can occur during a SPE with the risk of acute radiation sickness. While shielding (e.g. in a radiation shelter) is effective against SPE protons and high dose exposures can be prevented by alerts based on active dose monitoring and sun activity data from satellites, the chronic GCR exposure cannot be shielded completely during space travel. Currently, radiation protection for astronauts is based on risk management including reduction of exposure (limiting mission duration, shielding of sleeping quarters) and risk surveillance by radiation monitoring (area monitoring, personal dosimeters, SPE alert). Age, gender, genetic predispositions and health and immune status are factors determining individual sensitivity and might be considered for crew selection for interplanetary missions. Ameliorative actions, including prophylactic treatment in order to lower the risk for chronic diseases, are under research and can be summarized as general recommendations for a healthy lifestyle. The treatment of acute radiation sickness encompasses e.g. administration of colony stimulating factors and symptomatic medication (antibiotics, anti-emetics, anti-diarrheic, anti-inflammatory drugs). Risk assessment for space radiation exposure is incomplete and many uncertainties concerning the biological effects of GCR remain. This is also reflected by the different exposure limits space agencies have set for their astronauts. To improve space radiation protection, active space radiation dosimeters, space weather prediction methods, and efficient shielding have to be developed and radiation measurements, including depth dose distribution in the human body, e.g. on the way to Moon and on the Moon surface are required. Mitigation of the effects of heavy ions is one of the most important challenges to be solved for the exploration of the solar system. The biological effects have to be further characterized and risk models should be updated accordingly.

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