The Space Habitat Guidebook: Chapter Space Radiation Effects

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The exposure to the space radiation environment remains a major limiting factor for human long-duration space missions and permanent presence in space habitats due to its high biological effectiveness and the difficulties to effectively shield the radiation. The next decade in human spaceflight will be characterized by a continuous presence of human beings in Low Earth Orbit (LEO), by their return to the Moon and by longer stays in a Moon orbit on the Lunar Orbital Platform - Gateway (LOP-G). These endeavors are also performed to prepare for a human Mars mission. Also, plans for permanent presence of humans on the Moon are assuming shape.

To support and enable these missions, ongoing improvement of radiation dosimetry for accurate and continuous monitoring and the development of shielding approaches including personal shielding equipment are necessary. In a cooperative project, a personal protection vest will be tested during the first Orion mission using female phantoms. This will be the first determination of depth dose distribution beyond LEO. The organ doses which are essential for space radiation risk assessment will be derived from the dose distribution in the phantoms. For protection from high-dose exposure during solar flares, a warning system and a suitable radiation shelter are required.

In the last decades, the cancer risk induced by exposure to galactic cosmic rays was in the focus of attention. Numerous animal experiments and mechanistic studies were performed to derive the relative biological effectiveness of heavy ions to induce cancer and to elucidate the mechanisms and patterns specific to heavy ions. E.g., heavy ions activate the Nuclear Factor κB (NF-κB) pathway which is involved in inflammatory responses with very high efficiency [1-3]. Radiation quality factors and dose-rate modifying factors based on these results were integrated into a model to estimate space radiation cancer risk (NASA Space Cancer Risk (NSCR) model) [4].

Now, target organs for degenerative effects induced by galactic cosmic rays, especially the brain, the cardiovascular system and the eye lens, are in the focus of the radiobiological research. A suspected cognitive decline by chronic exposure to galactic cosmic rays has achieved some celebrity as “Space Brain”. The roles of neurons, glia cells including astrocytes, oligodendrocytes and microglia remain to be elucidated – even sex-specific differences in the involvement of microglia have to be considered [5]. Experiments with accelerated heavy ions will help to elucidate the mechanisms of the degenerative effects of space radiation and will set the foundation to develop countermeasures. Here, besides the combination of beams to simulate better the radiation field in space, low dose rate experiments are of high interest.

Besides the chronic space radiation exposure, astronauts experience a quite unique combination of possibly health-deteriorating environmental factors such as microgravity, noise, smell, disturbed circadian rhythm, increased carbon dioxide concentrations and decreased sleep quality. The interaction of radiation exposure with these space environmental factors such as microgravity or changes in the atmospheric conditions might influence the cells’ capability to cope with radiation damage. Also, the fluid shift towards the head might modulate radiation effects on the brain and eye. Recently, it was observed that the body temperature of astronauts on ISS is increased. In this context, it has to be considered that in some cancer therapy regimens, hyperthermia is combined with radiotherapy in order to augment the tumor cell killing effect.

Finally, it has to be considered that humans are not only composed of their body cells that can be affected by heavy ion hits, but they also carry a microbiome inside and at the surface that quickly colonizes the surroundings, also spacecraft. The knowledge on how the human-microbiome and microbiome-environment interactions change under chronic space radiation exposure is very scarce.

In conclusion, health risks by space radiation exposure have to be taken into account for an integrated design concept of space habitats, spacesuits and spacecraft. Despite some promising results on dietary measures (berries, dried plums) modulating the deteriorating effects of space radiation, a “magic pill” that can erase all radiation damage will most probably not be available.

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