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HARMFUL IONIZING RADIATION IN SPACE AND THE USAGE OF BORON NITRIDE NANOTUBES FOR ASTRONAUTS' RADIATION PROTECTION

Abstract. This research aims to endorse the concept of usage of boron nitride nanotubes (BNNTs) in astronauts' protection from harmful ionizing space radiation. To highlight the importance of provided work, types of radiation and their dangers on human's organism were examined. Furthermore, it was studied that BNNTs have numerous highly required properties for the material to be used in space conditions. Thus, BNNTs were suggested as useful and essential material for the purpose of making a layered spacesuit to shield astronauts from radiation.

Key words: boron nitride nanotubes, nanomaterial, radiation protection, ionizing space radiation, radiosensitivity.

With the increasing interest of society towards space exploration, new space missions are being conducted by government organizations such as NASA, ESA, and private companies like SpaceX and Blue Origin. In the nearest future, it is being planned to launch several crewed missions outside of the low Earth orbit.

As we know, there are a lot of risks and dangers for human life in the outer space conditions. Although engineers have already found practical solutions for many issues that astronauts may face, the problem of radiation protection remains unsolved. However, it is being currently studied by specialists in both biomedical engineering and space medicine fields.

The radiation astronauts may deal with can be split onto following main types: galactic cosmic rays, particles trapped by the Earth's magnetic field, and solar energetic particles. Secondary particles may injure surface tissues such as eyes and skin as well as cause the degenerative tissue defects such as cataracts, circulatory and digestive diseases. Energetic particles radiated during solar flares affect deep tissues such as bones and the cardiovascular system. Thus, skin melanoma and loss of bone mass may occur. Moreover, there is a big chance of facing other types of cancerous diseases, sterility, and neurological disorders.

For the past few years, the use of nanomaterials has increased significantly. Meanwhile, a nanomaterial called Boron Nitride Nanotube (BNNT) has drawn the attention of many scientists and engineers due to its complex properties and various functions.

BNNTs are a type of one-dimensional nanostructure and are known as tubular structural analogs of carbon nanotubes (CNTs). Overall, in BNNT carbon atoms are replaced entirely by boron and nitrogen atoms, arranged in a hexagonal lattice.

As for their properties, Young's modulus and yield strength are higher in CNTs, yet thermal conductivity and oxidation resistance (up to 900 °C) are similar. However, BNNTs are more thermomechanically stable, they are an excellent insulator with a bandgap between 5.5 and 5.9 eV, and have high hydrophobicity, heat and electrical insulation, resistance to oxidation and flame, and hydrogen storage capacity.

The most important part is that BNNTs' molecular structure is attractive for hydrogenation as they are compounded of isotope 10B that has a high level of neutron absorption cross-section (3835 barn). Hence, hydrogenated BNNT is an excellent neutron shielding nanomaterial and has a great ability to protect astronauts from ionizing radiation.

It is known that hydrogen is capable of fragmenting heavy ions, stopping protons, and slowing down neutrons. BNNTs, enriched with hydrogen (H-BNNT), are going to be used in spacesuits created for astronauts' extravehicular activity. Among nanomaterials manufacturing companies there is American Boronite Corporation that has developed a method for producing a large amount of high qualified BNNTs. Hence, currently there is an opportunity for testing BNNTs as a radiation shielding component for advanced spacesuits.

Moreover, the layers of BNNTs are going to be inputted among other types of layers in spacesuits. As for that, another benefit of BNNTs nanostructures is that the whole fabric made up of them is light and will not make the suit bulkier and more uncomfortable for wearing and working in. Thus, comfort of astronaut will be maintained untouchable and on the highest level.

It is also important to mention that large studies on the risk of ionizing radiation have shown that different organs show a different risk of stochastic effects. Stochastic effects of ionizing radiation are chance events, with the probability of the effect increasing with dose, but the severity of the effect is independent of the dose received. Stochastic effects are assumed to have no threshold.

Specific risk coefficients of irradiation have been determined for various organs. The tissue weighting factor (W_T) is a relative measure of the risk of stochastic effects that might result from irradiation of that specific tissue.

Table 1

Tissue weighting factors according to ICRP 103 (ICRP 2007)

Tissues	Tissue weighting factors, W_T
Bone surface, brain, salivary glands, skin	0.01
Bladder, liver, esophagus, thyroid	0.04
Testes, ovaries	0.08
Red bone marrow, breast, colon, lungs, stomach, adrenals, extrathoracic airways, gallbladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus, uterus, cervix	0.12

Due to the different radiosensitivity of organs and tissues, some areas of the body require extra protection. For example, organs with the highest weighting factor that are located in the torso part of the body such as breast, stomach, and others may be covered by the wide piece of cloth made of several thick BNNTs layers. Organs of the hematopoietic system like thymus gland and lymph nodes of the neck should be protected by shrink-wrapping spacesuits with the high collar and probably balaclava for better radiation protection of neck and head, all made of BNNTs.

As a conclusion, BNNTs have a whole set of fascinating and essential properties required for a space suit to be worn during every astronaut's extravehicular activity: the material is strong, thermally stable, chemically passive, conducts heat excellently, and of course, catches neutrons. Accordingly, we can think of its application in space exploration missions to protect health and the life of astronauts from harmful ionizing radiation.

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