The All Terrain Bio nano Gear for Space Radiation Detection System

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Abstract. This paper discusses about the relevance of detecting space radiations which are very harmful and pose numerous health issues for astronauts. There are many ways to detect radiations, but we present a non-invasive way of detecting them in real-time while an astronaut is in the mission. All Terrain Bio-nano (ATB) gear system is one such concept where we propose to detect various levels of space radiations depending on their intensity and warn the astronaut of probable biological damage. A basic framework for radiation detection system which utilizes bio-nano machines is discussed. This radiation detection system is termed as “radiation-responsive molecular assembly” (RMA) for the detection of space radiations. Our objective is to create a device which could detect space radiations by creating an environment equivalent to human cells within its structure and bio-chemically sensing the effects induced therein. For creating such an environment and further bio-chemically sensing space radiations bio-nano systems could be potentially used. These bio-nano systems could interact with radiations and signal based on the intensity of the radiations their relative biological effectiveness. Based on the energy and kind of radiation encountered, a matrix of signals has to be created which corresponds to a particular biological effect. The key advantage of such a design is its ability to interact with the radiation at a molecular scale; characterize its intensity based on energy deposition and relate it to the relative biological effectiveness based on the correspondence established through molecular structures and bond strengths of the bio-nano system.

Keywords: Radiation Detection system, Astronaut Health, Bio Nano Robots, Molecular Assembly, Space Radiation.
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INTRODUCTION

To ensure enhanced health management capability for astronauts on future space missions, a multifunction system is needed to perform environment monitoring and serve as early warning and protection system against chemicals, radiations, temperature and pressure for the astronauts. This system will be like an adaptive shield protecting astronauts from possible health hazards. This device will form a complementary layer beneath the current or any other future space suits. The proposed All Terrain Bio nano (ATB) gear is one such concept that has the above-mentioned capabilities and functionalities. It will not only be lightweight but also be flexible for enabling the astronauts to wear it all the time. The ATB gear is like an extra layer of shield on the human body, which will have the capability of sensing dangerous and harmful environments (such as radiations or chemicals) long before they could significantly harm the human.

For any human space mission, space radiation is one of the most important concerns. There are numerous health risks that can be caused from the radiations based on the various degrees of exposures. The exact effects and how they propagate are not exactly known, though the intensity of these effects could be related to the type and amount of radiation exposure (SRAG, 2005). A human body can react to radiation exposure differently, but usually the short term and recoverable effects are nausea, and the long term and significant effects are damage to the central nervous system or even death. The other long term effects are the development of cataracts and chances of development of cancer in any part of the body (SRAG, 2005; UCAR, 2000). Hence due to existence of all these possible threats, there is an increasing need to determine and understand: radiation exposure range which is safe for humans; signaling mechanism to caution astronauts when the radiations become dangerous; ways to autonomously detect as well as prevent certain levels of radiations encountered by astronauts. There are many experimental studies which link the exposure to space radiations to the long term biological damage, such as cancer (Miller, 2005). Detecting this range of exposure which could have a potential to cause long term damage in humans is one of the key objectives of ATB concept. This paper illustrates and describes the ATB gear concept in great details.
HEALTH HAZARDS FROM SPACE RADIATIONS

The preliminary objective of the “All Terrain Bio-nano suit, ATB” is to detect the long term biological damages caused by the space radiations. Our concept is to create a device which could interact with the space radiations and can simulate certain similar conditions as would be induced in human cells. The focus is on utilizing bio-nano components (peptide, DNA based) to interact with these radiations and signal back information regarding the intensity of the radiation and classify based on their effects. These bio-nano components have to be designed for the whole range of radiation effects. Based on the energy and kind of radiations encountered, a matrix of signals has to be created which would correspond to the biological effects. The hypothesis (Figure 1) used for conceptualizing this device is described as following:

- Let $H[i]$ symbolically represents an effect ‘i’ caused by radiations in human cells.
- Let $G[i]$ symbolically represents the energy of the radiation which causes this effect ‘i’.
- Let the space radiation be represented by, its amplitude $I$, its magnetic field $B$ and its electric field $E$.

The ability to encapsulate the biological like conditions and reactions with bio-nano components render them with a great potential for this application. In our initial design, we would be focusing on a particular space radiation effect, i.e., radiations, which are capable of inducing long term effects in human cells. While we can never ascertain the exact limit where this occurs, but with experiments in laboratory, we can statistically ascertain a particular limit in terms of energy and kind of radiations where such conditions might occur. Figure 2, represents our initial objective.

![Figure 1](https://via.placeholder.com/150)

**FIGURE 1.** The Energy of the Space Radiation Responsible for Causing a Particular Biological Effect $H[i]$ in Human Cell is Compared to the Energy Required to Cause a Particular Bio-nano Robot Effect $A[j]$.

![Figure 2](https://via.placeholder.com/150)


ALL TERRAIN BIO-NANO (ATB) GEARS CONCEPT

This section details the preliminary concept of ATB gears. This concept represents a “non-invasive & approximate long term risk level radiation detection system”. ATB gears would be made of various micro membranes and surface
sheets forming a radiation detection layer. Each of these membranes and sheets would contain bio-nano components capable of the required sensing and signaling capabilities inside space radiation interaction centers.

### Space Radiation Interaction Centers

An ATB gear layer is made up of radiation responsive molecular assemblies which are integrated within micro membranes and surface sheets. Space radiation interaction centers are the modular structures comprising of basic machinery for detecting space radiations and hence will contain the molecular assemblies and all the related constituents for radiation detection and signaling. The building blocks of these molecular assemblies will be bio-nano based components. The basic function of these bio nano components is to demonstrate equivalence between the invasive and non invasive radiation effects as described in the hypothesis in the previous section. The challenge here is to define a precise reaction chemistry that can attain this equivalence. Further, these bio nano components are to be designed by utilizing particular proteins or peptides and their assembly in combination with nano-polymers or other nano materials such that the space radiations can interact and their detection and signaling sequences could be initiated in a methodological way. Achieving such a design would require the following steps:

**a) Design of a reaction chemistry.** There are various possibilities here; these reaction chemistries have to follow the sequence or consequence of the reactions that occurs inside a human cell, such as, generation of toxic oxides and their reaction with DNA and collision of high energy fields with the other bio-molecules. Bio nano based components would be required to emulate such reactions or their products and further signal such instances to macro scale devices. This design must have various stages. One stage has to detect the initial range of radiations and signal, the other stage has to survive the radiations and further detect more harsh levels of radiations, which are in the range of long term risks inducing levels in humans. For these stages similar design architectures could be used, but the levels of radiation resistance of these components and assemblies could vary to a certain degree.

**b) The design of reaction centers.** The main radiation interacting molecular architecture has to be designed before designing the reaction chemistries. A modular design approach is utilized where autonomous reaction centers are created (represented by spheres in Figure 3), which would be the centers of space radiation interaction initiations. These centers contain the molecular assemblies.

(c) **Possible characteristics of the reaction chemistries.** Space radiations interacting with a molecular assembly would trigger a reaction, such as breaking of a bond, change in molecular conformations or initiating another reaction. The precise chemistry based on energy could be hard to achieve, but certain range could be defined based on probability of occurrence of certain bio chemical events. The first level of interaction of molecular assembly and its components with the radiation would require certain specific radiation resistant molecules. These interactions are designed to take place inside the above mentioned centers for reaction initiations.

These modular reaction centers are central to the design of ATB space radiation detection system. The next section describes these reaction centers in more details. These detection layers would be spread all along the space suit and astronaut’s body (Figure 4). Many bacteria and photosynthetic plants orient their light sensitive proteins in a manner that are most homologous to (statistically closer to) its subsequent reactants. Here a similar design strategy is employed to maximize the effects. This sphere represents the modular design strategy, where all the radiation related reactants and their signaling pathways are enclosed in the homologous manner. Figure 5, shows the concept of reaction centers.
INSIDE REACTION CENTERS

In this section we detail the structure responsible for detecting space radiations within reaction centers as represented by the spheres. This radiation detection system would be termed as “radiation-responsive molecular assembly” (RMA). There are numerous challenges for materials exposed to space radiations. The following summarizes some of the main molecular level effects which are true for any material entity:

**FIGURE 4.** The Overall System Design of the ATB Radiation Detection Layer – This Shows the Arrangement of the ATB Radiation Detection Layer Along the Whole Space Suit.

a) **Damage to the molecular geometry:** This implies that the incoming radiations damage the molecular geometry of the material structure. There is a direct correspondence between the 3D structure of a bio-molecule and its functionality. Damage to the structure can totally or partially curb the functionality.

**FIGURE 5.** Probabilistic Molecular Arrangement – Creation of Intensified Reaction Centers.

b) **Destruction of the bonds between various atoms:** Damage to the molecular structure implies that destruction of the molecular bonds takes place. This potentially means knocking off electrons from their bonding orbital and creation of ions. These ionized atoms could themselves further attack other neutral species to generate further ionized species and hence totally destroy the molecular geometry. The free electrons have a potential to further collide with other atoms and thereby start a cascaded reaction in the material.

c) **Formation of harmful radicals:** These radicals have potent destructive power towards breaking or realigning bonds not suitable for the material's molecular identity, thereby rendering the material of no use.

This list of effects is not extensive and only the beginning towards the understanding of various effects induced in materials due to space radiations. The challenges compound when we talk about these effects in a biological system.
(astronauts for instance). Based on the energy of the incoming space radiations, various effects could be caused. Typically, atoms and molecules exist in a balanced state, i.e., number of electrons are same as number of protons. These orbiting electrons form bonds with other atoms and a molecule is formed (though the exact process is far more complex). The incoming radiations are in the form of high energy particles, which could be charged. Once these incoming particles interact with the atoms and molecules various effects come into picture. Each atom in the molecular system is subjected to the flux of incoming particles with very high energies and these effects and interactions are further cascaded. A simplistic view of the mentioned cascading effect is shown in figure 6. Shown are three atomic systems (namely a, b and c in the figure 6) that interact with an incident radiation α. Due to these interactions ionization takes place and creates other effects, such as, emissions of other particles (beta or gamma) and production of various ionized species including charged atoms, free electron and other harmful radicals. Here, the Stage-1 is made up of the outer most layer of the material or molecular system under study. The incident flux on this layer is highest and so is the total energy of the incoming particles. As the cascading of ionization and other radiation effects takes place, some energy is absorbed and the subsequent stages (or layers) experience lesser and lesser effects. But the important thing to note here is that, in case of biological materials even the energies in the range of keV (kilo eV) are enough to create effects or cause damage.

FIGURE 6. Schematics Showing the Cascading Mechanism Induced in a Molecular System Subjected to Ionizing Radiations.

Computational Algorithm for Evaluating These Effects

As a first assumption in quantifying these effects, we need to select the most observable situation when a molecular system is subjected to ionizing radiations. Typically, Monte Carlo simulations (Cucinotta, 2003) are performed which involves selecting a particular probability distribution of the particles and their energies, tracking them through various layers and calculating their effects in terms of the pre defined parameters. We are most interested in calculating:
a) the net energy transfer or deposition (Cucinotta, 2003) through a certain layer
b) keeping track of the excited electrons
c) generating the sequence of ionized particles with energy capable of carrying forward the cascaded effects
d) generation of other particles

This computational paradigm is indicative of the potential effects and the energy deposition in the molecular system. It is this deposited energy (and its gradients) which would give us pointers on how we signal this scenario and proceed towards space radiation detection sequence.

**RADIATION RESPONSIVE MOLECULAR ASSEMBLY (RMA) CONCEPT**

Before introducing and exploring the concept of “radiation responsive molecular assembly”, we will try to establish its design philosophy. The key advantage of such a design is its ability to interact with the radiation at the molecular scale; characterize its intensity based on energy deposition and relate it to the relative biological effectiveness based on the correspondence established through molecular structure and bond strength. Another feature of such a design is its integration with the current materials at the molecular scale and its widespread presence throughout the material structure. Some of the main design parameters are:

i) Selection of molecular structures with *simple and regularized geometries* for comparative ordering of cascading effects. More heterogeneous the molecular structures are more complex the cascading effects could be, hence simpler molecular structures are desired.

ii) *Consistent usage of molecular entities*. This implies that the number of different molecular entities to be utilized in the design should be minimized. This is again related to the cascading simplifications. Utilizing similar molecular structure would imply we have known values for various material properties such as ionization potentials of the electrons and their interactions with other molecular entities.

iii) *Energy absorbing molecular bridges*. Another parameter is the design of molecular bridges or homogenous structures which can absorb a high energy electron or react with it to produce a stable chemical species. This indicates presence of a solvent like material which is capable of de-accelerating or reducing the energy of free electrons or other ionized species.

iv) *Layered modules*. Layered modules would interact with various energy levels (and specifically the acute effects inducing ionizing radiations). Because here we are dealing with the issue of radiation detection and not absorption or prevention, we have to decrease the amount of incident radiations entering various layers. Hence we need an inter-layer medium which can potentially absorb certain magnitude of incident particles, while keeping the energies of the ones hitting not much altered. This is an approximation step, but is required so as to increase the life and usability of the molecular assembly.

v) *Signaling pathways*. Because we are interested in the characterization of various energy levels, we require a distinct pathway for various energy ranges so that when such a range is achieved, biological effectiveness information (in the form of electron flow or photo responsive reactions) could be transmitted.

**Information Flow in the Molecular Assembly Concept**

The key goal of this molecular design is to deduce information on the energy levels of the incident radiations, chemically relate it to biological effectiveness, and signal it through various pathways. Therefore, the net result of the integrated radiation responsive molecular assembly is to generate range of pre defined signals which could be correlated to the induced macro scale biological effects, such as, skin rashes, nausea etc. The information flow and the correspondence between the targeted stages are shown in figure 7.

The process initiates with the energy characterization which basically implies evaluating how much energy deposition per unit time and per unit mass is being caused by the radiation. This information has to be evaluated structurally, through specific bond cleavages and structural modifications. Hence through this crucial step we have to determine the biological effectiveness of that particular energy range. This structurally evaluated effectiveness has to be corresponded with a signaling pathway, which is further related (or pre defined in this case) to the assumed
induced acute effects. And hence a full loop is established between the ionizing radiations and the biological effect. Here, the described information flow loop has to be achieved in every energy range of the ionizing radiations.

**FIGURE 7.** Information Flow in the Radiation Responsive Molecular Assembly.

**PROPOSED DESIGN**

Keeping in mind the above mentioned design parameters and the information flow targets, a multiple layered design for the radiation responsive molecular assembly is proposed. For this design we require following sub-modules (Figure 8 details some of the key design aspects of the radiation responsive molecular assemblies.):

**FIGURE 8.** The Layered Concept of Radiation Responsive Molecular Assembly.

*a) Structural sub-module:* This module is responsible for integrating the molecular assemblies within the probabilistic reaction centers. These structural elements could be made by nano – polymers which are ‘reasonably’ resistant to radiations. As these are passive elements they don’t require an interaction capability with the ionizing
radiations. The only other feature they require is to be able to transmit a coherent signal through the probabilistic reaction centers so that a unified signal is generated.

b) Detection sub-module: This is the energy range sensitive sub-module and is responsible for interacting with the radiation within the layer. Through this sub-module primary cascading effect originates and hence should be homogeneous as described in design parameters.

c) Relative effectiveness sub-module: This sub-module interacts with the first few generation of cascading effects and evaluates its relative effectiveness through its unique molecular structures and ordered layers of molecular bonds. The geometry of the structures and the strength of these bonds would potentially identify harmful effects of radiations and hence, would connect with the signaling sub-module to trigger a chemical pathway.

d) Signaling sub-module: As described above, these will be integrated with the relative effectiveness sub-module and would amplify the initial triggers and generate them into signals, such as, emission of light, flow of electrons, change of color or variations in the conformations. These pre determined range of signals would potentially correspond with a particular biological affect (acute or long term).

Each of these sub-modules is part of the individual layers which forms the core of the probabilistic reaction centers within the ATB gear radiation detection system. Hence in each layer (which is based on the energy ranges) the whole information flow loop is covered and in the end we obtain a complex mixture of reactions and signaling pathways. Therefore, it is possible that more than one kind of biological effect is detected by an individual population of the probabilistic reaction centers.

CONCLUSION

A space radiation detection system is very crucial for human missions to space. Relating the space radiation effects to the relative biological effectiveness through reaction centers is the main design objective for the ATB gears. Hence, a multi-layered design for the radiation responsive molecular assembly is proposed. For this design we require various sub-modules having structural, detection & signaling functions. Each of these sub-modules is part of the individual layers which forms the core of the probabilistic reaction centers within the radiation detecting layer of the ATB. Once this framework is established we have to design the bio nano components which could behave in the desired manner. Relating energy ranges of the space radiations through structural and chemical entities is a key challenge for this research. Studying biological elements from radiation resistant micro organisms is the first step towards designing such components. Further is required to prove the validity of the proposed concept. Though many challenges exist but we believe integrating radiation responsive molecular assemblies with the space materials could be a way forward in designing a potent space radiation detection system for astronauts.

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