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ARCHITECTURAL AND PSYCHOLOGICAL ASPECTS IN OPTIMIZED RADIATION SHIELDING DESIGN FOR SPACE APPLICATIONS

Prof. Olga Bannova
University of Houston, United States, obannova@central.uh.edu

Dr. Ayako Ono
Japan Mars Society, Japan, a.ono@med.tohoku.ac.jp

Mr. Kent Nebergall
Day Five, LLC, United States, knebergall@gmail.com

Dr. Irene Lia Schlacht
Politecnico di Milano / Technische Universitaet Berlin, Germany, irene. schlacht@mail.polimi.it

NewSpace bears all the hallmarks of past revolutions in technology. Since we have other examples of exponential growth of specific technologies, we should maximize the economic and engineering potential of this movement by expanding the envelopes for long term crewed habitats in deep space. We should also take an approach that minimizes waste in both design and fabrication as these bases expand. This paper provides a systematic approach to habitats optimized for volume, radiation protection, crew psychology, reusability, affordability, crowd-sourced subsystem design, and expansion. These habitats and systems are designed to be as "future proof" as possible to allow rapid and safe technological advancement within the structures. One of major "showstoppers" of human space exploration is cosmic and solar events radiation. It is a serious problem that may cause cancer and other types of tissue damage and equipment malfunction. It has to be addressed in space vehicles design especially for long-term space exploration missions and future Moon or Mars surface settlements. This paper discusses a unique layered system incorporated into a habitat structure, which may help to reduce the radiation hazard to the crew and interior equipment and systems. The paper also argues that a successful mitigation of radiation impact on human health should be based on a multidisciplinary methodology that also includes psychophysiological approach to the problem. Multiple techniques and practices to minimize psychological stress that may suppress immune system and reduce resistance to cancer, are presented and compared. Conclusions are drawn upon results of those comparisons and a multidisciplinary design concept is proposed to be applied both in long-duration human space exploration missions and in radioactive environment on Earth.

I. INTRODUCTION

Planning and building future long-term space missions will challenge both: technology and humans. Scenarios for planetary exploration missions include short expeditions to the Moon and long-term manned missions to Mars (ISECG Global Exploration Roadmap, NASA; NASA/SP–2009-566-ADD2 Human Exploration of Mars Design Reference Architecture 5.0; and ESA Roadmaps for Technologies for Exploration). A human mission to Mars will include a long travel time each direction and stay on the planet's surface between 3 months and 2 years [(1)]. Table 1 shows relevant mission aspects that have to be addressed beforehand in the planning and design phase.

Among the psychological challenges, which can be foreseen for future long-term missions, are the following [1]:

- Lack of sensory stimulus
- Total isolation and autonomy
- Time factor and fatigue
- Group roles and leadership

Table 1 illustrates, that conditions on long-term space missions to Mars will differ significantly from conditions experienced during long time missions in Low Earth Orbit (e.g. Mir and ISS missions). The degree of crew isolation, monotony and autonomy will be extremely high.

Aspects \ Missions	Orbital missions	Polar Regions Winter-over	Lunar missions	Mars missions
Duration (months)	4-6	9-12	6	16-36
Distance to Earth (km)	300-400	n/a	350K-400K	60M-400M
Crew size	3-6	4-100	4≤	6≤
Degree of isolation and social monotony	Low to high	Medium	High	Very high
Crew autonomy level	Low	High	Medium	Very high
Emergency evacuation	Yes	No	Limited	No
Availability of mission support:				
Outside monitoring	Yes	Yes	Yes	Very limited
Two-way communications	Yes	Yes	Yes	Very constrained
Email up/down link	Yes	Yes	Yes	Yes
Internet access	Yes	Yes	Yes	No
Entertainment	Yes	Yes	Yes	Yes
Re-supply	Yes	No	Very limited	No
Visitors	Yes	No	No	No
Earth visibility	Yes	Yes	Yes	No

Table 1: Comparison between Polar, human Low Earth Orbital missions and future deep space exploration missions.

Both isolation and external environment in Polar Regions and other isolated environments affect one's consciousness and psychosomatic health [2, 3].

These psychological challenges also affect crew's physical health and resistance to detrimental influence of space travel including cosmic and SPE radiation.

There are various earlier studies that proved the metastatic spread of carcinomas by subverting antitumor immune responses [4]. These studies suggest inhibitors may potentially prevent the outgrowth of micro metastases in cancer patients [4]. Not only inhibitors in a form of medication but also activities such as laughter may inhibit outgrowth of micro metastases [5, 6]. Laughter is well known as Alternative Medicine, Laughter Therapy, and it is effective to improve resilience and quality of life (QOL) as well [7].

This paper outlines few space habitat design considerations that will be critical for planning successful long-term exploration missions in space and on surface of other than Earth planets.

II. MULTIDISCIPLINARY METHODOLOGY: APPLYING LAYERS

Designing a shelter to protect the crew in extremely dangerous environment of space requires thorough attention to every detail and aspect of that environment and every challenge it presents. The only way to tackle such complexity is to approach the mission design from different perspectives to cover the main 3 aspects: the needs related to human, environment and mission[8]. This means involving from the beginning of the project not only different specializations of engineering, but also humanities and science [9, 10]. Such approach is useful in designing structures buildings and structures on Earth and it is critical in spacecraft design.

With the layer methodology we start with fundamental physics and mathematics behind cosmic rays and solar flares and risks they present. Then, we attack identified problems by applying layers of technology and engineering. However, the structure must be safe and comfortable and satisfy bodies and minds of the crew. Every layer, from shelter's location in space to moods and habits of the crew, may ultimately make or break the mission of explorers.

That approach optimizes a design process where interior physical space, structure and overall environment enhance crew's survivability during an extended spaceflight by:

- Providing physical and psychological means for crew's immune system stability;
- Affording environment that offers tools for necessary adjustments and adapts to diverse tasks and situations;

- Applying advanced materials with minimal secondary radiation production;
- Incorporating advanced technologies for radiation and micrometeoroid protection;
- Stimulating improvement of personal mental stability and rationale;
- Offering structural adaptability to incorporate all of those possibilities.

III. LAYERED INTERIOR HABITAT SYSTEM

The Layer methodology may be applied to shelter design in different scales: from an overall habitat module structure and layout to an individual device that is designed according to personal preferences and habits. It is important to understand that those scales can be mixed and/or used separately, as well as in combination with other design techniques (Figure 1).

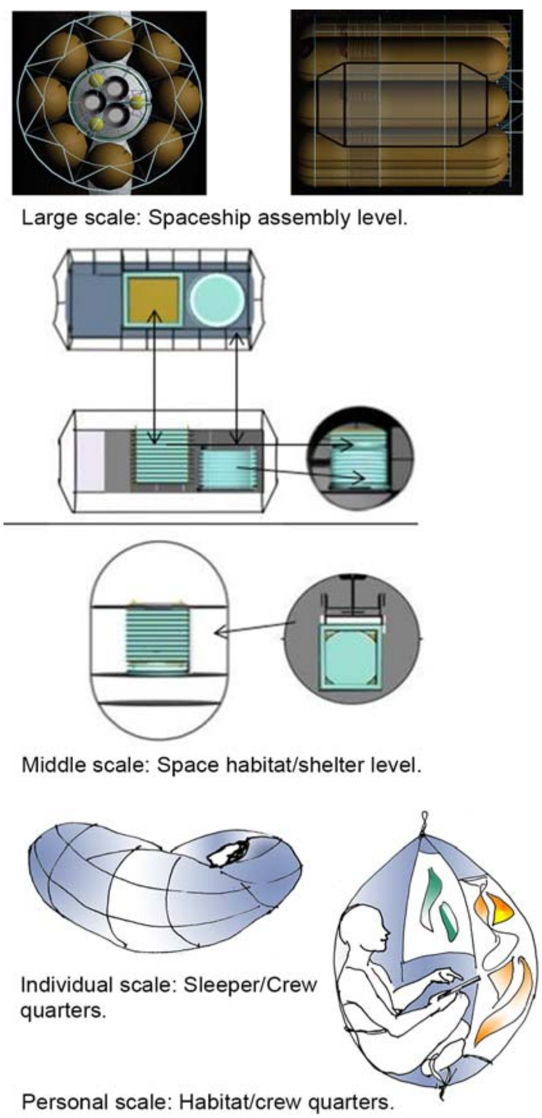

Fig. 1: Levels' scales.

A "shelter" can be a crew compartment for sleeping with a sleeping bag that minimizes radiation to increase crew's safety and comfort (Figure 2). A treadmill with Vibration Isolation System (TVIS) or a Cycle Ergometer with Vibration Isolation and Stabilization System (CEVIS), an advanced Resistive Exercise Device (aRED) – are assumed to be also located in a habitat module.

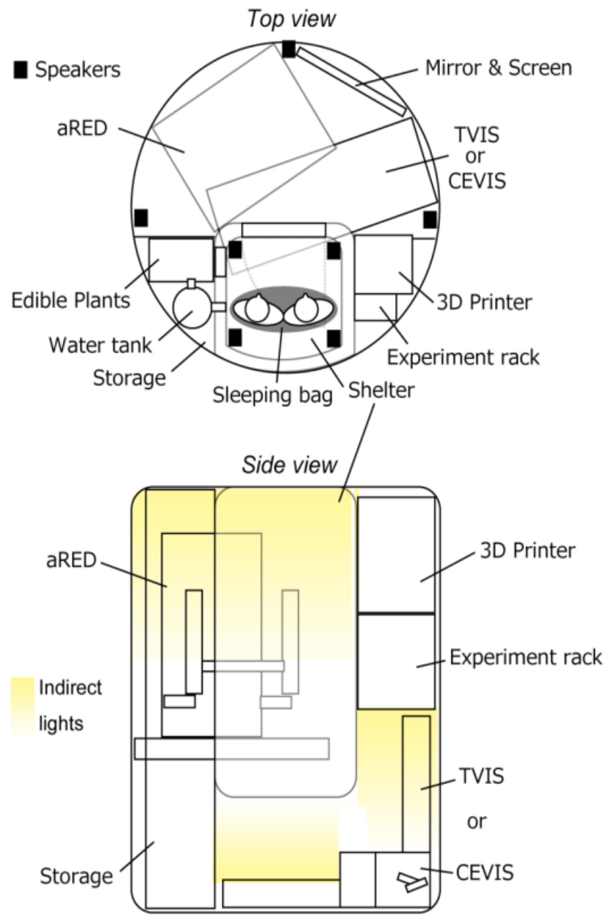

Fig. 2: Interior design of the habitat module.
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Designs for sleeping and radiation protection are very much related because these functions require design solutions that may share similar devices, can be located in the same areas, have to provide the crew with necessary means to perform essential activities, and both functions also pose significant mass and volume penalties [11].

A sleeping bag for two people may also be an option due to positive effect of physical contact helping to reduce stress and anxiety. To support that option the shelter can be also equipped with devices to provide a necessary level of privacy by deployable screens, lightweight partitions and other compact means.

Strategically colored habitat interiors provide the crew with spatial distinctions while dynamic interactive lights incorporated in the interior environment imitate different time of the day and enhance regulation of a circadian rhythm (Figure 3).

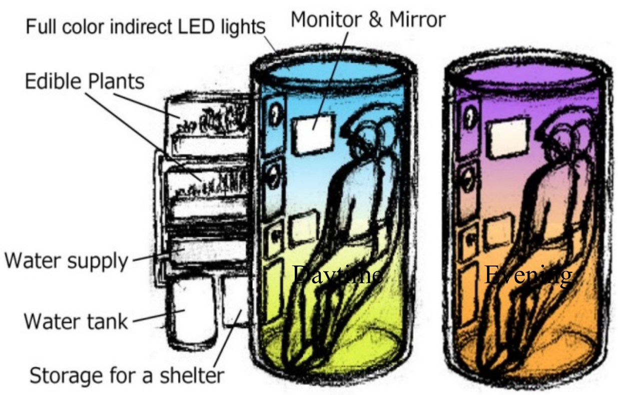

Fig. 3: Inside the shelter. Copyright: Ayako Ono and the Mars Society.

Indirect lights and mirrors may be placed complimenting each other, and multi-channel speakers attached in both shelter and habitat stimulate enjoyment of offered visual and soundscape. The habitat will be equipped with an iPad and a video projector to watch movies, to paint, to compose music and to write lyrics. In addition, the crew may collaborate with colleagues and friends on Earth and write a poem or perform any other form of art together. Such collaboration would provide additional psychological support.

V. ECONOMICAL AND TECHNOLOGICAL CONSIDERATIONS

With aviation, the field went from bare minimums (Wright Flyer) to near-term revenue (air mail), power competition (air racers, fighters), volume competition (transports, bombers), and commercialization (airlines, overnight shipping). The original space age continued and mirrored this, but the exponential technical growth curve suddenly became asymptotic around 1970. Once we reached the limits of chemical propulsion, the embryonic field of microchips and software became the low-hanging fruit of technology investment. It was easier double the transistors in a satellite than to double the size of the satellite. With NewSpace, we are circling back to the same challenges. Advances in computer technology and industrial capacity have made the multi-billion dollar governmental milestones of the 1960's accessible to NewSpace companies at a tenth that cost.

A proper technology revolution must lower the cost of innovation in order to keep the investment, and therefore the innovation, flowing. You cannot drive an upward spiral of innovation without a downward spiral of cost, so that the investment remains the same but continues paying dividends. It also opens the field to new companies and inventors, which further drives the innovation cycle and expands the niches where markets can be found.

A proper technology engine for New-Space, therefore, must be affordable, modular, and have near-term revenue potential. We saw this with Falcon I and are now seeing it with other companies. Once established at minimums and able to generate revenue (air mail era, in aviation), we can move onto competition, market specialization, and further lowering of costs. If this continues into crewed vehicles, commercial-enabled space stations, deep space missions (Inspiration Mars and other projects that may come along as a result), and eventually tiny lunar bases.

Opening the frontier also makes common the challenges of cosmic ray shielding, closed loop life support, and approximately eighteen other challenges identified to human missions extending beyond Earth Orbit and beyond 500 days. Direct approaches to these challenges using affordable modular solutions, as well as a direct R&D effort in quantifying both problems and solutions, should be a key goal of human flight beyond LEO.

Modularity is a feasible approach to design and planning efforts in exploration developments on Earth, in near-Earth and deep space, and can be applied equally in all scales of such developments. For example, scalable modular launching capabilities afford adjustable and inter-exchangeable planning components for a wide range of missions and include time and budget benefits during pre-launching planning process and implementing cutting-edge technologies at all, including late, stages of development.

This paper discusses affordability of modular and layer design approach that is demonstrated through application of disciplinary-inclusive methodology in design of radiation protective measures within a space habitat module.

VI. CONCLUSIONS AND FURTHER APPLICATIONS

This paper presented a new methodology of interior habitat design and its possible applications. Conclusions are drawn upon results of those considerations and a multidisciplinary design concept is proposed to be applied both in long-duration human space exploration missions and in radioactive environment on Earth.

Further studies will require more detailed evaluation of current and advanced technologies. Design research will include investigations of possible modular configurations and feasibility study of their scalability. The proposed shelter design as well as design methodology discussed in this paper, may be key factors to advance space technology spin-offs for Earth applications. One example of such applications are polar missions referred in the Table 1. Conversely, proposed radiation shielding may be also effective in radioactive environments on Earth such as nuclear power plants and natural radioactive locations [12].

VI.I Radiation Shielding in Space: Architectural and Psychological Aspects for Terrestrial Applications.

Cosmic radiation is a serious problem that may cause cancer and other types of tissue damage. That may be reduced by a layered system specially designed to be incorporated into the habitat structure. However, since psychological stress may suppress immune system and reduce resistance to cancer, in addition to the habitat's physical radiation shielding, a psychophysiological systems and techniques will be required to increase crew's chances to resist hazardous conditions of spaceflight.

This multidisciplinary approach is a key concept not only for long-duration human space exploration missions but also in man-made and natural radioactive environments on Earth (Figure 4). All those systems have to be lightweight, multipurpose, and cost effective while supporting safety and psychological stability of the crew in extremely dangerous environment. Effectiveness of design concepts depends and can be evaluated by simplicity of deployment process, and maintenance, as well as system's ability to reconfigure or adjust to new conditions.

Fig. 4: Exohab 1 on the Moon and in radioactive environment on Earth. Source: ©3Develop & Irene Schlacht.

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