Topical:

Space and Radiation Research Crisis in the Life Sciences

Where are the experts to ensure health and well-being in future space travel?

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Where are the experts to ensure health and well-being in future space travel?

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In a nutshell: Radiation and space life sciences provide the pool of experts associated with human spaceflight; but our community is in crisis. Within the next decade, many established faculty and leadership will retire. At the same time, we lack programs and infrastructure to train and retain a replacement generation. This loss is a critical risk for successful human space travel. As leaders in the field, we outline this crisis, identify priorities, and propose strategies. Support for our community is critical to ensure the U.S. retains its leadership role in the new Human Space Race.

1. The Second Space Race is a Public Health Concern

In 2021, three private companies sent passengers to space: Blue Origin and Virgin Galactic flew suborbital and SpaceX achieved orbital flight trajectories. With low-cost and green alternatives (high-altitude balloons) underway, space travel is expected to be accessible to a segment of the public over the next decade. Some private entrepreneurs are even pushing for prolonged expeditions to the Moon and Mars. Commercial and government enterprises will begin to establish space-based assets that will require crew to live and work in space for extended periods of time. During space flight, passengers are exposed to high energy particle radiation combined with physiological effects from altered gravity, increased CO_2 levels, limited nutrition, isolation and confinement, and sleep disruption. In addition, extended distances from Earth and limited available mass and volume can limit options for medical intervention. Examination of long-term health risks and countermeasure development–especially concerning exposure to space radiation–are an active field of scientific research and not an established medical discipline. This lack of health knowledge has the potential to become a major public health concern at the dawn of prolonged human presence in space for exploratory, commercial, and military reasons.

The radiation biology, chemistry, physics, epidemiology, and space life science communities provide the experts addressing the scientific questions to ensure spaceflight risks are well characterized and mitigation strategies are developed so that crew members and space agencies can make evidence-informed decisions. However, our joint radiation sciences community is in crisis: within the next decade, many of the currently involved faculty will no longer teach or perform research and development (R&D) due to attrition (e.g., age and retirement). At the same time, these disciplines lack formal education pipelines, resulting in growing deficits in the numbers of young experts needed to resolve critical knowledge gaps. A similar crisis in other radiation professions was identified by the National Council on Radiation Protection and Measurements (NCRP) last decade and started the ongoing initiative "Where are the Radiation Professionals (WARP)?" [1–3]. The upcoming NCRP report will evaluate the current status of the field and identify priorities for averting the crisis [4].

2. High Priority Scientific Questions for Human Spaceflight

Radiation exposure as both an individual risk challenge and in combination with other known spaceflight hazards (e.g., altered gravity, isolation, stress) has been identified as a mission critical concern for extended spaceflight missions. At the physical level, the ability to apply an understanding of space radiation is essential to the maintenance of NASA equipment and infrastructure such as satellites and the International Space Station (ISS). Biologically, low-to-moderate doses of charged particle radiation (characteristic of galactic cosmic rays, trapped radiation, or solar particle events) have been shown to contribute to pathologies that impact cognition and behavior, the cardiovascular system and cancer development in animal and cellular models [5–9]. However, the risks to humans from the highly complex space radiation environment remains undefined [10]. Furthermore, the development of potential radiation countermeasure strategies–including nutritional supplementation, prophylactic pharmaceuticals, specialized suits, and improved health surveillance–will require close collaborations among physical and biological radiation researchers. Many of the discoveries made to date have occurred just within the past 10 to 15 years, and thus continuity of expertise in these cross-disciplinary fields is essential for effective risk characterization and mitigation.

Due to the low transition rate from post-graduate to tenure positions (**see section 3**), we lack a sufficient junior cadre of scientific experts capable of addressing the current and future critical radiation research questions that will ensure astronaut and civilian health. We have charted a roadmap of key knowledge gaps and ask for strategic support (**see section 4**) to resolve the remaining high priority subjects:

- Mechanistic understanding and potential risk of the complex effects of space radiation in human tissues on the subjects of carcinogenesis, immune system effects, and cardiovascular disease in conjunction with spaceflight
- Development of robust risk models based on direct observations of populations exposed to relevant types and amounts of radiation to lessen the errors in risk projections based on populations exposed to different types and amounts of radiation
- Personalized risk estimates and biomarkers of individual sensitivity accounting for sex- and age-specific mechanisms and risks
- Characterizing combination effects with altered gravity and other space environment hazards, e.g. disrupted circadian rhythm
- Determine excess risk by population studies and epidemiology approaches
- Effects of space radiation as part of the space environment on cognitive function and decision making
    - The lack of effective models to predict neurocognitive dysfunction following low dose and low dose rate exposure
    - Defining the critical targets in the CNS that can account for functional deficits in neurotransmission and cognition, that to date appear not to be dependent on overt cell death or radiation quality and particle type
- Effects of combined altered gravity and radiation exposure on bone density; readjusting to Earth gravity after long-term space flights
- Countermeasures: effective radiation protectors and mitigators preventing or decreasing long-term health effects from space radiation
- Effects of radiation on medication stability

3. Radiation and Space Life Science Experts: A Problem of Training and Retention

Our community has a strong history of facilitating research, training, and outreach to date. However, a loss of existing researchers and declining numbers of new researchers in the coming decade is an existential threat to future R&D. Therefore, it is necessary to facilitate critical training of experts to ensure continued high level R&D before astronauts and civilians suffer from under-investigated space-induced diseases. Aggravating the problem of a retirement wave of senior faculty, our pipeline faces additional obstacles due to the complexity and multidisciplinary nature of radiation research and the space life sciences.

Training: Radiation and space research combines various disciplines. For instance, particle physics describes the high-energy space radiation environment and biology explains how molecular radiation damage leads to malignancies and other late effects over time. Generalist experts are needed who specialize in one area, but also have a solid understanding of the others. Space-focused programs are scarce and emerging experts usually acquire competences through cross-disciplinary training opportunities outside their regular programs. (The *NASA Space Radiation Summer School* at Brookhaven National Laboratory was an example of how our community provided successful training in the past). Additionally, many training programs which once existed to train graduate students and post-doctoral research fellows have completely disappeared. At best, this lack of a dedicated training infrastructure results in longer training periods for young scientists to acquire necessary expertise, and at worst, reduces cross-disciplinary knowledge and technical competences in our field–thus limiting our scientific output for public benefit.

Retention: Space life science is a small multidisciplinary field that commonly competes for funding with larger disciplines. Grant reviewers in open-call panels usually lack essential cross-disciplinary competences and, in turn, undervalue the merits of radiation and space biology, chemistry, physics, and epidemiology proposals. For instance, investigating carcinogenesis from space radiation exposure requires knowledge of radiation physics, radiation biology, molecular and cancer biology, and microgravity. Insufficient background in one area leads to misconceptions of research methodology, experimental constraints, and scientific impact which manifests as negative bias. As a consequence, funding for faculty positions and research projects is disproportionately low, particularly for junior scientists, which in turn decreases the transition rate from trainee to tenure despite competitive careers and scientific merit. In addition, the majority of radiation biologists are generally part of radiation oncology departments, where the strong clinical focus often leads to a lack of appreciation for how space research can be translated into the broader field of medicine.

4. Strategies for Retooling the Radiation Research and Space Life Science Training Pipeline

Strategic capability support is a core requirement for training and retaining the next generation of radiation biology, chemistry, physics, epidemiology and space life experts. Examples of successful career development platforms are the Scholars-in-Training and Early Career Investigator programs of the Radiation Research Society (RRS). These programs include targeted travel grants, organized meetings for career development and enhanced participation in symposia (as both chairs and speakers). Similar programs throughout our field can improve retention. Key mechanisms for developing sustained and competitive careers in our field are:

- Support for **Scholars-in-Training** (Ph.D. students, medical residents, Postdoctoral fellows etc.)
    - Training stipends and academic exchange programs
    - Travel grants for participation in conferences or workshops
    - Training programs at universities that have scientists with the appropriate capabilities similar to the NIH's F32 or R25 mechanisms
    - Research grant awards or fellowships for PhD students and Postdocs conducting space-related research
- (Re-)establishment of cross-disciplinary training programs through financial support, e.g., effort compensation for PIs or their team members establishing and maintaining programs or networking platforms
- Financial support to facilitate access for Scholars-in-Training and Early Career Investigators to **research facilities** and **training programs**, such as
    - Space Life Science Training through the NASA Space Biology Program
    - NASA Ames Research Center
    - NASA John H. Glenn Research Center
    - Beam time at the NASA Space Radiation Laboratory (NSRL)
- **Agency investment** in research efforts for Early Career Investigators as they transition to tenured faculty
- Incentives to departments or institutions that actively support career development for **Early Career Investigators** (non-tenured faculty such as Instructor level or Assistant Professor), e.g. through
    - Support for research efforts and career funding awards for space-related research
    - Dedicated salary support in conjunction with grant awards to fulfill the requirement of independent researcher (principal investigator)
    - Training grants for cross-disciplinary research (salary and research expenses)
- Dedicated grant awards or institutional funding support for international **recruitment of emerging experts** to the U.S.
- **Deconstructing barriers** to NIH funding for international researchers working on space-related topics at U.S. institutions
- Financial and infrastructure support for institutions who **establish or maintain international research collaborations** in the radiation and space life sectors

Funding dissemination and management on the federal level can be facilitated through NASA via established channels (Space Biology Program, The Translational Research Institute for Space Health, NASA´s Human Research Program, etc.), but the private sector and space industry should be informed about the eminent crisis and encouraged to engage in financial support. Therefore, it is essential to advocate for research related to space life sciences through public outreach programs to increase private sector engagement, pipeline entry and public support of federal expenses. This could include expanding upon existing outreach efforts (i.e. NASA, The Planetary Society, etc.), in featured articles or advertisements in popular published media, or in private and institutional social media outputs such as Facebook or Twitter. Moreover, short video productions featured on YouTube and related media can highlight current work and its impact not only on space research advances but public health and safety.

5. The Payoff at Home and Beyond

Future benefits of investing in the radiation research and space life science sector include future long-duration space exploration, public health, national security, interplanetary expansion, access to resources on an unprecedented scale, and ensure the survival of our species in case of cataclysmic events. If the general public considers space an unnecessary financial obligation in the face of more pressing socioeconomic concerns instead of an opportunity for technological advancements at all levels of science, partisan political pressure could halt our space endeavors and render the U.S. uncompetitive on the space market for many decades to come. Public support is a formable force in building and maintaining the success of a program and the space research enterprise is no exception.

Indeed, the payoff from a strong and sustainable radiation biology, chemistry, physics, epidemiology, and space life science community is expected to be tremendous and far-reaching:

- Space is an extreme environment where researchers can elucidate fundamental biological mechanisms otherwise masked by Earth-based conditions
- Accurate prediction of space radiation health effects is a critical safety component for realization of long duration missions and settlements (Mars design reference missions, commercial space stations, Moon bases, Mars bases)
- Novel radiation protectors and mitigators can be made available for
    - Radiation workers
    - Radiation therapy patients
    - The space tourism sector
    - The public receiving environmental (low dose) radiation exposure
- Advances in space health monitoring can be translated to the public health sector
- Development of treatment strategies against radiotherapy side-effects experienced in tissues and organs exposed to low doses
- Protection of clinical radiation workers and radiation workers in the nuclear energy sector through improved shielding design and health monitoring
- Protection against nuclear terrorism through effective and cost-efficient radiation mitigators

In summary, investments in training and retaining the future generation of radiation biologists, chemists, physicists, epidemiologists, and space life science researchers are essential to explore space and protect professional and recreational astronauts in the upcoming space age. We cannot afford to lose the collective capabilities of our current professionals in the field when we lack adequate new talent to fill the inevitable void. Moreover, the R&D performed by trained and retained space life science experts has enormous potential to provide technologies that can improve everyday life on Earth. While initial allocations may appear large, similar spending on innovation have proven that the payoff from space research is immense and worth the investment [11,12].

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