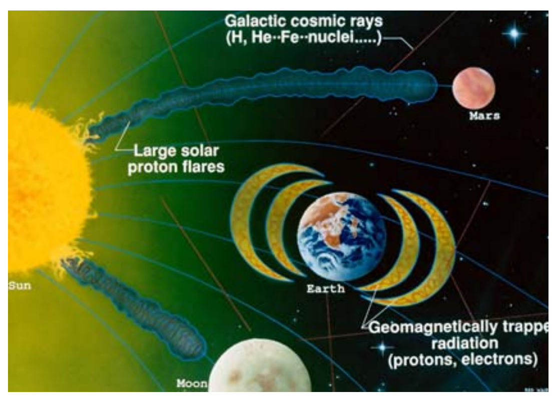
Fifty-Seventh
Annual Meeting Program

Radiation & Flight: A Down-to-Earth Look at Risks



April 19–20, 2021

Virtual

Monday, April 19, 10:00 am – 5:00 pm EDT

Tuesday, April 20, 10:00 am – 3:15 pm EDT

Cover:
Left: Buzz Aldrin walks on the Moon, where the ambient radiation is about 500 times more intense than on Earth, and where there is no atmosphere or magnetic field to protect against solar events. https://history.nasa.gov/ap11ann/kippsphotos/apollo.html

Top right: US Air Force pilots preparing to ascend to high-altitude, where they spend hundreds of hours per year receiving radiation at dose rates 10 to 100 times higher than that at sea level. https://www.airforcetimes.com

Bottom right: Artist's depiction of the radiation environment on Earth, the Moon, and Mars, with cosmic rays entering from outside the heliosphere, protons emanating from the Sun, and, near Earth, trapped radiation in the Van Allen belts. https://www.nasa.gov/audience/foreducators/stem-on-station/learning_launchers_radiation

NCRP Mission:

To support radiation protection by providing independent scientific analysis, information and recommendations that represent the consensus of leading scientists.

@NCRP2021

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NCRP Resource Development Committee is launching a series of efforts to increase the financial stability of NCRP. One effort is to request Council members and friends who shop online at Amazon to make a simple (no cost) modification. Simply register at AmazonSmile (https://smile.amazon.com/), and the AmazonSmile Foundation will donate 0.5 % of the purchase price to NCRP at no charge to you! It's easy!

Follow the directions and be sure to select the National Council on Radiation Protection and Measurements (from the pull down list or searchable request) as the 501(c)(3) public charitable organization to receive the Amazon contribution for each purchase. Donations are anonymous. However, we would like to recognize your support and if you notify NCRP (Laura.Atwell@ncrponline.org) we will add your name to the NCRP list of AmazonSmile contributors.

Introduction

Radiation & Flight: A Down-to-Earth Look at Risks

Fifty-Seventh Annual Meeting of the National Council on Radiation Protection and Measurements (NCRP)

How many people have imagined themselves as a fighter pilot, traveling through the upper atmosphere at Mach 5? And the prospect of space travel is an idea that has fascinated mankind for centuries. However, as these aspirational goals have become a reality, there has been a parallel expansion in our understanding of the complex stressors associated with these endeavors that can have a detrimental effect on our ground-evolved bodies. As a result, we are increasingly aware of a broad range of potential risks from exposure to cosmic radiation and other factors associated with aeronautical travel and that are now seen as issues for the involved professions.

Because of the inclusion of cosmic radiation as one of the acknowledged stressors in flight, and our limited understanding of the consequences of exposure, the National Council on Radiation Protection and Measurements (NCRP) has been intimately involved in furthering our understanding of the risks from flight, at high altitude and beyond, for many decades. With respect to space exploration, in 1989, Report No. 98, *Guidance on Radiation Received in Space Activities*, was released as an update of the 1970 recommendations made by the National Academy of Sciences. This document was itself updated in 2000 with the release of Report No. 132, *Radiation Protection Guidance for Activities in Low-Earth Orbit*, which focused on the excess cancer risks and other radiation effects from exposure, and introduced the possibility of differential risks dependent on age and sex. This report was followed quickly by Report No. 137 (2001), *Fluence-Based and Microdosimetric Event-Based Methods for Radiation Protection in Space*, which compared methodologic approaches that might be used to determine radiation risks from a long-term space mission, and Report No. 142 (2002), which provided an *Operational Radiation Safety Program for Astronauts in Low-Earth Orbit: A Basic Framework*.

Following the commitment of the Bush Presidency to the Space Exploration Program and in response to a request from the National Aeronautics and Space Administration (NASA), Report No. 153 was developed and released in 2006, *Information Needed to Make Radiation Protection Recommendations for Space Missions Beyond Low-Earth Orbit*; it described the data required, prior to future missions, that would enable the development of an adequate personnel radiation protection program. More recently, and reflecting our greater biological understanding of the mechanisms underlying radiation risk, Report No. 167, released in 2010, looked at the *Potential Impact of Individual Genetic Susceptibility and Previous Radiation Exposure on Radiation Risk for Astronauts*, and a recent report, Report No. 183, completed a two-phase effort concerning the impact of space radiation on the central nervous system (*Radiation Exposure in Space and the Potential for Central Nervous System Effects: Phase II*).

Commentary No. 12 (1995) explored radiation protection considerations associated with high-altitude flight at an altitude of ≥65,000 feet (~20,000 m). It addressed a number of relevant considerations, such as dose rates at different altitudes and from solar flares, as well as the biological effects of ionizing radiation at these altitudes. Estimates of the associated radiation risks for flight crews, passengers, frequent travelers, and conventional travelers were made. The Commentary concluded with comments on aspects of radiation protection philosophy and the measurements that needed to be addressed to operate commercial aircraft at these altitudes.

Despite the large volume of publications, there are still great uncertainties and gaps in our understanding of the risks from flight. Thus, NCRP is dedicating its Annual Meeting to this important topic. The Program has been divided into a number of topical sessions that will examine and discuss some of the important questions and issues facing our aeronautical professions.

The Seventeenth Annual Warren K. Sinclair Keynote Lecture will be delivered by Dr. Serena Auñón-Chancellor. Dr. Auñón-Chancellor is an American astronaut, physician, and engineer who recently flew on Expedition 56/57 (June to December 2018) to the International Space Station. She exemplifies the target audience for this year's subject matter and will set the tone of the meeting by bringing her personal perspective on the risks of high altitude flight, particularly in space, and how these are currently perceived by those personnel who may be most affected.

Following the Keynote, the first session will provide an overview of the amalgam of stressors experienced by aircrews and astronauts that may contribute to the risks from flight, providing a perspective on the complexity of the flight environment. The second session will take a critical look at the cancer risk seen in both aircrews and astronauts, and the following two sessions will be dedicated to a number of the noncancer risks that have been identified. The final session will assess the markers and potential countermeasures that may be available to predict and alleviate flight-associated effects.

Complementing this program, the Forty-Fourth Lauriston S. Taylor Lecture will be delivered by Dr. Robert Ullrich, Vice-Chair and Chief of Research for the Radiation Effects Research Foundation in Hiroshima, Japan, and former Director of the NASA Specialized Center for Research on Carcinogenesis. He is a pioneer in the field of radiation carcinogenesis and will provide an overview of the experimental work carried out in this field and its role in our understanding of the radiation risks associated with space flight.

The Fourth Thomas S. Tenforde Lecture will be delivered by Dr. Paul Locke, Professor at Johns Hopkins Bloomberg School of Public Health, whose research and practice targets the intersection of environmental health sciences, policy and law in the areas of radiation policy and law. Importantly, he will address the ethics of applying scientifically developed risk assessments to aeronautical professionals.

Program Committee Co-Chairs, Drs. Jacqueline P. Williams and Cary Zeitlin, will wrap up the meeting with reflections on some of the meeting's highlights. NCRP President, Dr. Kathryn D. Held, will conclude the meeting by presenting a brief overview of recent NCRP activities and a vision for the future direction of NCRP.

Questions from attendees at the virtual meeting can be submitted at any time using the Chat feature in the virtual meeting platform. Session chairs and speakers will address as many questions as time permits.

Established in April 2019, the inaugurational John D. Boice, Jr., Young Investigator Awardee, Dr. Deepesh Poudel, Los Alamos National Laboratory, was announced at the 2020 NCRP Annual Business Meeting and will be recognized at this meeting. This Award is given to recognize an early career professional engaged in some aspect of science pertaining to radiation protection and measurements.

NCRP gratefully acknowledges recordings provided by:

- the Joint Armed Forces Honor Guard from the Military District of Washington D.C. who will open our Annual Meeting; and
- Kimberly Jordan of the U.S. Nuclear Regulatory Commission who will sing our National Anthem.

Monday, April 19, 2021

Opening Session

10:00 am **Presentation of the Colors**
Joint Armed Forces Honor Guard from the Military District of Washington, DC

Singing of the National Anthem
Kimberly Jordan
U.S. Nuclear Regulatory Commission

10:05 am **NCRP Welcome**
Kathryn D. Held
President, NCRP

10:20 am **Introduction**
Jacqueline P. Williams
University of Rochester Medical Center
Cary J. Zeitlin
NASA Johnson Space Center
Program Co-Chairs

Seventeenth Annual Warren K. Sinclair Keynote Address

10:30 am **Introduction of the Speaker**
Kathryn D. Held

Perception of Radiation Risk from the Astronaut Office
Serena M. Auñón-Chancellor
NASA Johnson Space Center

Flight Environments & Combined Stressors

Mark Shavers & Cary J. Zeitlin, *Session Co-Chairs*

11:00 am **NASA Space Radiation Laboratory Galactic Cosmic Ray Simulator**
Lisa C. Simonsen
NASA Langley Research Center

11:20 am **Characterization & Prediction of the Aircraft Ionizing Radiation Environment**
Christopher J. Mertens
NASA Langley Research Center

11:40 am **Flight Doses & Associated Health Implications at Civil, Commercial & Military Altitudes**
Kyle Copeland
U.S. Air Force School of Aerospace Medicine/Occupational and Environmental Health Analytical Services Division

12:00 pm **It's Not Just Radiation: Other Environmental Factors Affecting Space Flight Health Risks**
Marianne B. Sowa
NASA Ames Research Center

12:20 pm **Q&A**

12:35 pm **Lunch**

Cancer Risks

Michael D. Story & Michael M. Weil,
Session Co-Chairs

1:20 pm **Cancer Risk Assessment for Astronauts Participating in Deep-Space Missions**
Tony Slaba
NASA Langley Research Center

1:40 pm **Space Radiation Cancer Biology: Individualizing Risk**
Michael M. Weil
Colorado State University

2:00 pm **Radiation Dose & Risks to Flight Crews: The European Perspective**
Werner Rühm
German Research Center for Environmental Health, Munich

2:20 pm **Cancer in U.S. Pilots & Flight Attendants: NIOSH Aircrew Studies**
Lynne Pinkerton
Maximus | Attain
National Institute for Occupational Safety & Health

2:40 pm **Q&A**

2:55 pm **Break**

Noncancer Risks (1)

Janice L. Huff & Jacqueline P. Williams,
Session Co-Chairs

3:05 pm **Radiation in the Context of Human System Risks in Exploration Spaceflight**
Erik L. Antonsen
NASA Johnson Space Center

3:25 pm **Long-Term Effects of Space Radiation on Cognition**
Antiño R. Allen
University of Arkansas for Medical Sciences

3:45 pm **Cosmic Radiation & Human Health: Evidence from Aircrews & Astronauts**
Robert J. Reynolds
Mortality Research & Consulting, Inc.

4:05 pm **Effects of the Space Flight Environment on Bone Health**
Jeffrey Willey
Wake Forest School of Medicine

4:25 pm **Q&A**

Forty-Fourth Lauriston S. Taylor Lecture on Radiation Protection & Measurements

4:35 pm **Introduction of the Lecturer**
Michael M. Weil

Taking Up Space: The Path to Understanding Radiation Risks
Robert L. Ullrich
Radiation Effects Research Foundation

Tuesday, April 20, 2021

Noncancer Risks (2)

Zarana Patel & Gayle E. Woloschak,
Session Co-Chairs

10:00 am **Fight-or-Flight: Immune Status & Radiation Resilience**
Dörthe Schaue
University of California - Los Angeles

10:20 am **Reproductive Hazards in Flight Crew: Radiation & Beyond**
Candice Johnson
National Institute for Occupational Safety & Health, Centers for Disease Control & Prevention

10:40 am **Cardiovascular Effects of Low-Dose Ionizing Radiation**
Marjan Boerma
University of Arkansas for Medical Sciences

11:00 am **Sleep, Circadian Rhythms, and Workload in Spaceflight**
Ajitkumar Mulavara
Alexandra Whitmire
NASA Johnson Space Center

11:20 am **Q&A**

Fourth Thomas S. Tenforde Topical Lecture

11:30 am **Introduction of the Lecturer**
Donald A. Cool

Collision or Cooperation? The Law, Ethics & Science of Personalized Risk Assessments for Space & Air Travel
Paul A. Locke
Johns Hopkins Bloomberg School of Public Health

12:00 pm **Lunch**

Biomarkers & Countermeasures

Polly Y. Chang & Evagelia C. Laiakis, *Session Co-Chairs*

1:00 pm **Hibernation & Radioprotection: Reduced Tissue Damage in Rats Under Synthetic Torpor**
Walter Tinganelli
GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt

1:20 pm **Strategy for Maturing Active Radiation Shielding Concepts**
Dan Fry
NASA Johnson Space Center

1:40 pm **Using DNA Damage to Investigate the Individual Variability of Human & Mouse Sensitivity to Ionizing Radiation**
Sylvain Costes
NASA Ames Research Center

2:00 pm **Mitigating Space Radiation Health Risks: Challenges and Opportunities**
Janice L. Huff
NASA Langley Research Center

2:20 pm **Q&A for All Speakers**

Conclusions

2:50 pm **Flying High - Program Wrap-Up**
Jacqueline P. Williams & Cary J. Zeitlin
Program Committee Co-Chairs

3:00 pm **NCRP Vision for the Future & PAC Activities**
Kathryn D. Held
President, NCRP

3:15 pm **Adjourn**

@NCRP2021

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Opening Session

10:00 am

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Singing of the National Anthem
Kimberly Jordan
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Kathryn D. Held, *President*
National Council on Radiation Protection and Measurements

10:20 am

Introduction
Jacqueline P. Williams
University of Rochester Medical Center

Cary J. Zeitlin
NASA Johnson Space Center

Program Co-Chairs

Seventeenth Annual Warren K. Sinclair Keynote Address

10:30 am

Introduction of the Speaker
Kathryn D. Held

Perception of Radiation Risk from the Astronaut Office
Serena M. Auñón-Chancellor
NASA Johnson Space Center

Radiation remains one of the top human health risks as the National Aeronautics and Space Administration (NASA) prepares for longer stays in low-Earth orbit and as we return to the Moon and press towards Mars. Astronauts who have flown on short- or long-duration missions (or both) understand that their daily working and living environment is a continuous, never-ending occupational exposure. Training is received preflight as to the type of background radiation expected, off nominal events that may occur, and any operational procedures required. What is less well understood by astronauts, as well as the scientific community, are those long-term impacts space radiation may have on the human system. The objective of this talk will be to express the perception of radiation from the astronaut, including questions, uncertainties, and even fears. Several astronauts, both active and retired, were engaged in individual discussions regarding the subject of space radiation. The goal was to drive out the top concerns astronauts had about the space radiation environment and present them in a very human manner. Not surprisingly, the top concerns encompassed the following: cancer risk, differing radiation standards between men and women, conservatism of NASA's operational radiation standard compared to other space agencies, current radiation research strategies, continued occupational screening after retiring from the corps, and fertility. In general, astronauts understand that radiation research currently being performed to answer these questions is difficult based on multiple limitations we have with our ground-based approach. They also understand that multiple agencies; individual boards; and a host of determined physicists, radiobiologists, physicians, scientists, epidemiologists and engineers continue to persevere, further the science, and provide a coherent, logical and safe approach for both women and men to continue to explore the solar system.

Flight Environments & Combined Stressors

Mark Shavers & Cary J. Zeitlin, *Session Co-Chairs*

11:00 am

NASA Space Radiation Laboratory Galactic Cosmic Ray Simulator

Lisa C. Simonsen
NASA Langley Research Center

With exciting new National Aeronautics and Space Administration (NASA) plans for a sustainable return to the Moon, astronauts will once again leave Earth's protective magnetosphere only to endure higher levels of radiation from galactic cosmic rays (GCR) and the possibility of a large solar particle event (SPE). Gateway, lunar landers, and surface habitats will be designed to protect crew against SPEs with vehicle optimization, storm shelter concepts, and/or active dosimetry; however, the ever-penetrating GCR will continue to pose the most significant health risks especially as lunar missions increase in duration and as NASA sets its aspirations on Mars. The primary risks of concern include carcinogenesis, central nervous system effects resulting in potential in-mission cognitive or behavioral impairment and/or late neurological disorders, degenerative tissue effects including cataracts, circulatory and heart disease, as well as, potential immune system decrements impacting multiple aspects of crew health. Characterization and mitigation of these risks requires a significant reduction in the large biological uncertainties of chronic (low-dose rate) heavy ion exposures and the validation of countermeasures in a relevant space environment. NASA has developed the “GCR Simulator” at Brookhaven National Laboratory to generate a spectrum of ion beams that approximates the primary and secondary GCR field experienced at human organ locations within a deep-space vehicle. The majority of the dose is delivered from protons (~65 to 75 %) and helium ions (~10 to 20 %) with heavier ions ($Z \geq 3$) contributing the remainder. The GCR Simulator exposes state-of-the art cellular and animal model systems to 33 sequential beams including four proton energies plus degrader, four helium energies plus degrader, and the five heavy ions of carbon, oxygen, silicon, titanium, and iron. A polyethylene degrader is used with the 100 MeV n^{-1} hydrogen and helium beams to provide a nearly continuous distribution of low-energy particles. A 500 mGy exposure, delivering doses from each of the 33 beams, requires 75 to 90 min. To more closely simulate the low dose rates found in space, sequential field exposures can be divided into daily fractions over two to six weeks, with individual beam fractions as low as 0.1 to 0.2 mGy. In the large beam configuration (60 × 60 cm^2), 54 special housing cages can accommodate two to three mice each for a 70 to 75 min duration or ~15 individually housed rats. Emerging research results from our 2018 runs utilizing mixed heavy ion fields and protracted space exposures are forthcoming and will deepen our understanding of the numerous health risks faced by astronauts. This talk discusses NASA's innovative technology solution for a ground-based GCR simulator at the NASA Space Radiation Laboratory to enable future exploration missions.

11:20 am

Characterization & Prediction of the Aircraft Ionizing Radiation Environment

Christopher J. Mertens
NASA Langley Research Center

Energetic particle radiation from cosmic rays continuously bombards Earth's atmosphere. Cosmic radiation has sufficient energy to penetrate deep within the atmosphere and increase the risk of adverse health effects to crew and passengers on aircraft. There are two sources of cosmic radiation: (1) the ubiquitous galactic cosmic rays (GCR), with origins outside of the solar system, and (2) transient solar energetic particles (SEP) (or solar cosmic rays), which are associated with eruptions on the Sun's surface lasting hours to days. Commercial aircrew are among the highest occupationally exposed workers in the terrestrial environment. During SEP events, annual GCR exposure levels can be received or exceeded during a single high-latitude flight. Thus, there is a need in the aerospace industry to provide reliable dose estimates to quantify the cumulative health risks from GCR exposure to commercial aviation and commercial spaceflight fliers, and to have reliable, real-time SEP radiation exposure predictions to make actionable grounding/re-routing flight decisions prior to and during an event. This presentation reviews the National Aeronautics and Space Administration's work in modeling and measuring the aviation radiation environment. The range of expected GCR and SEP exposure levels are presented along with the atmospheric and space weather influences that affect both long- and short-term variability of aviation radiation exposure. The challenges to predicting and measuring the atmospheric ionizing radiation environment are identified, as well the ongoing efforts to overcome these obstacles. The possibility of SEP aviation radiation forecasting is also discussed.

11:40 am

Flight Doses & Associated Health Implications at Civil, Commercial & Military Altitudes

Kyle Copeland
U.S. Air Force School of Aerospace Medicine/Occupational and Environmental Health Analytical Services Division

Ionizing radiation exposure is an unavoidable source of health risks in all aviation. There are significant differences in civil, commercial and military flights. While galactic cosmic radiation is always present, much more transient inflight sources of ionizing radiation include solar cosmic radiations, radioactive cargo (medical and research isotopes), radioactive substances released into the atmosphere (reactor accident, weapon test, etc.), lightning, and terrestrial gamma-ray flashes. These sources, the doses to aircrew and to passengers that could result from them, and possible resulting health effects and risks, are described and discussed.

12:00 pm

It's Not Just Radiation: Other Environmental Factors Affecting Space Flight Health Risks

Marianne B. Sowa
NASA Ames Research Center

With the ultimate goal of sending humans to Mars, the National Aeronautics and Space Administration's Artemis Program begins the next era of exploration by returning crew to the South Pole of the Moon by 2024. However, spaceflight in both low-Earth orbit (LEO) and beyond exposes crew to a combination of environmental stressors, such as, highly variable gravitational forces, ionizing radiation, elevated ambient CO_2 levels, confinement of living quarters, and social isolation. These conditions have health-related implications for astronauts and present challenges for human spaceflight and associated bioscience research. Data gathered from humans and animals in LEO have demonstrated impacts of spaceflight on musculoskeletal, neurovestibular, and cardiovascular systems, as well as altered immune responses. On a molecular level, exposure to the combined stressors of spaceflight may transiently or chronically activate stress responses that may impact crew health or performance. The reality of space travel is that these multiple environmental stressors are inseparable, and we must consider combined exposures when making decisions regarding protection of crew. This presentation will provide a brief overview of the spaceflight environment, followed by a discussion of the gaps in current knowledge of the health consequences associated with long-duration exploration missions. The emphasis will be on the molecular mechanisms and pathways that may influence biological responses from exposure to the space environment in relevant mammalian and non-mammalian model systems. How these data may be used for the development of new predictive risk models for combined exposures will also be speculated upon.

12:20 pm **Q&A**

12:35 pm **Lunch**

Cancer Risks

Michael D. Story & Michael M. Weil, *Session Co-Chairs*

1:20 pm

Cancer Risk Assessment for Astronauts Participating in Deep-Space Missions

Tony Slaba
NASA Langley Research Center

Missions are currently being planned for astronauts to travel beyond low-Earth orbit into deep space with possible destinations targeted for the Moon or Mars. The radiation environment on such missions includes episodic solar-particle events (SPE) comprising moderate energy protons (<500 MeV) and omnipresent galactic cosmic rays (GCR) comprising a mixture of particle types with broad energy distributions reaching hundreds of gigaelectron volts. These environments interact with vehicle shielding, tissue, planetary atmospheres (if present), and planetary surfaces resulting in a spectrum of secondary particles that further complicates astronaut exposure and the corresponding biological risks. In this talk, the National Aeronautics and Space Administration (NASA) models used to project lifetime cancer risk associated with these exposures are discussed in the context of a lunar mission currently being formulated for 2024. This includes descriptions of the ambient radiation environments, physical interactions, particle transport, and cancer risk model. Of particular interest are the uncertainties associated with radiation quality (increased effectiveness of ion radiation compared to gamma rays) and dose rate (differences due to chronic and acute irradiation), which remain the dominant sources of uncertainty in risk projections. The current NASA risk model utilizes specific submodels (*e.g.*, a single model for dose-rate effects) that contain subjectively assigned uncertainties, in some cases. New ensemble-based risk projection methods have been developed that consider multiple submodels (*e.g.*, multiple models for dose-rate effects) and provide a more complete picture of the risk landscape than the current NASA risk model by itself. These ensemble methods will be described, and results for the planned mission will be presented and discussed.

1:40 pm

Space Radiation Cancer Biology: Individualizing Risk

Michael M. Weil
Colorado State University

On currently envisioned missions in deep space, astronauts will be exposed to levels of ionizing radiation that will increase their risks of developing fatal cancer. Because there are negligible data for human exposures to deep-space radiation, these risks must be modeled in order to set permissible exposure limits. The current National Aeronautics and Space Administration Space Cancer Risk model is based predominantly on epidemiological data, takes into account an astronaut's age at exposure and sex, and assumes the astronaut is a nonsmoker. Radiation quality effect is a major source of uncertainty in the model since most human exposures have been to low linear energy transfer (LET) radiation, whereas space radiation also includes high-LET high atomic number, high energy (HZE) ions. Radiation quality effects have been studied in animal experiments using mice and rats irradiated with accelerator generated HZE ions, singularly or in combinations simulating galactic cosmic radiation. These experiments have mostly been done with inbred rodent strains, or stocks with limited genetic heterogeneity.

A curious finding emerging from animal studies is just how strain dependent the HZE ion carcinogenesis results are. The predominant tumor histotype induced by HZE ion exposure is determined by the strain or stock irradiated. This is strong evidence of genetic susceptibility to HZE ion carcinogenicity, which has been further bolstered by the identification of some of the loci controlling susceptibilities. There is further evidence that genetic susceptibility to radiogenic cancers extends beyond rodents to humans, and not just those with certain rare, readily identifiable heritable syndromes.

Given the estimated level of fatal cancer risk from protracted deep space radiation exposures, some type of mitigation will be needed. This might take the form of an as yet unknown biological, pharmacological or nutritional countermeasure, or post-flight tumor surveillance with the goal of detecting cancers at an earlier, more treatable stage. The existence of individual differences in susceptibility to radiogenic cancers can provide opportunities for risk reduction by pointing towards potential countermeasures and allowing us to make informed choices on when it makes sense to use them.

2:00 pm

Radiation Dose & Risk to Flight Crews: The European Perspective

Werner Rühm
German Research Center for Environmental Health, Munich

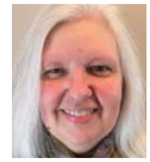
Following recommendations by the International Commission on Radiological Protection (ICRP), the European Commission issued a Directive that required European Union member states to monitor aircrew. Consequently, in Germany aircrew has been monitored since 2003. With a mean annual effective dose of ~2 mSv aircrew is amongst the occupations with the highest annual effective dose, and — in terms of collective annual effective dose — represents the most important radiation-exposed profession in Germany. Because this situation is similar in other countries, a number of studies on the health status of aircrew have been initiated. For example, results of a pooled study on the mortality from cancer and other diseases among aircrew from nine European countries and the United States were published a few years ago. Furthermore, the third follow-up of the health status of German aircrew was just completed.

Because the field of secondary cosmic radiation in the atmosphere is rather complex, air crew is typically monitored by means of “virtual dosimeters,” *i.e.*, by computer codes that take into account the dose rates from all relevant cosmic-ray particles at any point in the atmosphere. For a given flight route the total effective dose is then calculated. In a recent study the European Radiation Dosimetry Group analyzed aircrew doses for selected flight routes and found reasonable agreement among 11 codes used internationally for aircrew dosimetry. Calculation of doses from solar-particle events is still difficult, however, and requires further scientific studies.

This presentation will give a short overview on results of European studies on health risks and radiation doses from secondary cosmic radiation.

2:20 pm

Cancer in U.S. Pilots & Flight Attendants: NIOSH Aircrew Studies



Lynne Pinkerton
Maximus | Attain
National Institute for Occupational Safety & Health

Commercial aviation aircrew may have an increased risk of cancer and other outcomes from occupational exposure to galactic cosmic radiation and circadian rhythm disruption. U.S. aircrew have the highest estimated average annual effective dose of any radiation-exposed occupation. Disruption of circadian rhythms may occur due to frequent travel across time zones and irregular working hours. To evaluate the associations of these exposures with the risk of cancer and other outcomes, the National Institute for Occupational Safety and Health (NIOSH) conducted retrospective cohort mortality studies of 5,964 cockpit crew and 11,311 flight attendants employed by Pan American Airways, a large U.S.-based international airline that operated from the late 1920s to December 1991. Researchers further evaluated breast and other cancer incidence in a subset of 6,095 flight attendants who completed a questionnaire on cancer risk factors and cancer diagnoses. Cancer diagnoses among this subset of flight attendants were also identified from linkages with state cancer registries. These studies included reconstruction of individual domicile-era-based dose estimates due to cosmic ionizing radiation exposure and use of two NIOSH-developed metrics for circadian rhythm disruption: number of time zones crossed and time spent traveling in the standard sleep interval. This presentation describes the exposure assessment and epidemiological methods used in these studies and the results of the analyses.

2:40 pm **Q&A**

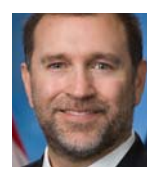
2:55 pm **Break**

Noncancer Risks (1)

Janice L. Huff & Jacqueline P. Williams, *Session Co-Chairs*

3:05 pm

Radiation in the Context of Human System Risks in Exploration Spaceflight



Erik L. Antonsen
NASA Johnson Space Center

Historically, radiation has been one of the most concerning hazards to humans in space. NCRP has enabled an understanding of both the risks posed by radiation and the knowledge gaps that remain to help guide research. Radiation risk contributes to the broader risks experienced at the mission enterprise level. Risk in lunar and other exploration missions is driven by multiple factors that must be weighed for likelihood, consequence and contribution to total mission and long term health risk. The increased distance from Earth increases the logistical challenges associated with medical and pharmaceutical countermeasures, time to definitive care, and maintenance of human performance. The relative contributions that radiation exposure brings to these larger operational challenges have yet to be quantified. Research suggests that longer durations in isolation and confinement may interact with radiation exposure to impact in-mission behavioral and cognitive function. Similarly, radiation exposure may result in some change to the long-term cardiovascular disease risk for astronauts. Appropriately assessing these contributions to the overall risk posture is critical to guiding future research and occupational health at the National Aeronautics and Space Administration (NASA).

The Human System Risk Board (HSRB) at NASA Johnson Space Center is responsible for the continuous risk management of 30 human system risks derived from the key human hazards in spaceflight. HSRB ensures that standardized clinical and data approaches are applied across all the human system risks to enable two key outcomes: (1) an apples-to-apples comparison of relative risk contributions to the crews both in-mission as well as post-career; and (2) systematic and repeatable risk-informed trade space analyses of impacts to human crews facing new operational environments. Because of the operational nature of the NASA mission, the board articulates risk in terms of contribution to operational or clinical outcomes. This talk describes the risk management approach and constraints for the set of human system risks, prioritization principles for assessing risk posture impact to missions, and updates in risk definitions intended to enable improved cross-disciplinary research opportunities that are better matched to the operational goals that NASA is undertaking in the next decade.

3:25 pm

Long-Term Effects of Space Radiation on Cognition

Antiño R. Allen, Frederico Kiffer, Jing Wang, Vijayalakshmi Sridharan, & Marjan Boerma
University of Arkansas for Medical Sciences

Astronauts in missions beyond Earth's protective magnetosphere, such as to the moon and Mars, will be exposed to the harmful radiation environment in deep space. The central nervous system is a major area of concern for astronauts who will be exposed to the deep-space radiation environment, as charged-particle radiation has been shown to elicit changes to the dendritic arbor within the hippocampus of rodents, and related cognitive-behavioral deficits. Changes in behavior have been paralleled with molecular, and electrophysiological alterations across several brain regions, with much attention placed on the hippocampus due to its centrality in the National Aeronautics and Space Administration's central nervous system risk modeling. High-LET exposure >1 Gy leads to short and long-term deficits in hippocampal-dependent spatial learning. Even lower doses of high-LET particles, 0.01 to 1 Gy, can lead to persistent deficits in hippocampal dependent spatial learning in ground-based murine simulations. Our current work explores the effects of charged particle radiation on the morphology of neurons throughout the murine hippocampus, a structure which is paramount to many cognitive processes including memory formation, consolidation, retrieval, and mood regulation in mice and humans. Our data indicate that ^{1}H and ^{16}O exposures at realistic dosages may pose significant risks to astronaut health, supporting the body of evidence preceding these studies.

3:45 pm

Cosmic Radiation & Human Health: Evidence from Aircrews & Astronauts

Robert J. Reynolds
Mortality Research & Consulting, Inc.

The best available terrestrial evidence suggests that cosmic radiation should be deleterious to human health, but relatively few people have been exposed to doses of cosmic radiation large enough to induce the predicted effects. Furthermore, because it consists mainly of highly energetic particles, cosmic radiation is difficult to simulate on Earth, making even animal studies scarce.

Aircrew and astronauts are two occupational groups exposed to levels of cosmic radiation higher than that experienced at ground level. Pilots and other crew fly at altitudes sufficient to increase their doses of galactic cosmic radiation (GCR), and log enough flight hours at these altitudes to make increased risk of cancer incidence and mortality plausible. Astronauts are exposed to both charged particle radiation from the Sun as well as GCR, and, with the length of increments aboard the International Space Station, likewise accrue relatively lengthy exposures to these types of radiation. Here we review the available epidemiological evidence regarding exposure to cosmic radiation and long-term human health.

Over more than 50 y of study with tens of thousands of individuals, aircrew have consistently shown evidence of the healthy worker effect (HWE), with most cancer incidence below that of the general population. However, aviators have also been repeatedly shown to be at increased risk of melanoma and other skin cancers. Meta-analyses estimate the standardized incidence ratio and standardized mortality ratio to both be approximately 2.0. However, it is unclear whether this is due to exposure to cosmic radiation, other occupational exposures, or – as has been suggested in the literature – nonoccupational lifestyle factors.

Astronauts have been repeatedly studied for evidence of radiation-induced illness, including incidence of cardiovascular disease (CVD) and mortality from CVD and cancers. U.S. astronauts too have demonstrated the HWE, as they are at ~25 % of the mortality risk from CVD and 60 % of the mortality risk of the general population from cancers. Soviet and Russian cosmonauts have been at ~30 % the risk of the Russian general population of death by CVD, and at 60 % the risk of death by cancers. No astronauts from international partner agencies or any Chinese astronauts have yet died, though this lack of death thus far only represents a significant reduction in risk for European Space Agency astronauts.

Studies that have examined cosmic radiation dose and these outcomes among U.S. astronauts have failed to detect a relationship, and the lack of interference in survival from these two causes rules out the presence of a common cause of CVD and cancer mortality among these cohorts. However, statistical power is quite low for these analyses, so results should be interpreted with care.

The evidence to date shows that the people with the most exposure to cosmic radiation – aircrew and astronauts – seem not to have suffered deleterious effects from their radiation doses. However, as space exploration moves to sustained missions to the moon and eventually on to Mars, doses will increase significantly, necessitating ongoing basic research and long-term astronaut health surveillance.

4:05 pm

Effects of the Space Flight Environment on Bone Health

Jeffrey Willey
Wake Forest School of Medicine

Astronauts face multiple hazards to skeletal health during spaceflight, including microgravity and low-dose radiation. Microgravity is known to be disadvantageous to skeletal tissues. Severe bone atrophy occurs in humans and rodents with reduced loading, both in orbit and from ground-based analogues (*e.g.*, bed-rest and rodent hind limb unloading). While countermeasures such as exercise with bisphosphonates are effective in orbit, recent studies show prolonged negative effects on bone density and strength even with readaptation on Earth to 1 g. This is concerning given the fractional gravitational loads astronauts will experience after lengthy transits to destinations such as Mars. While bone has historically been considered radiation-resistant and late responding, more recent studies identify bone architecture to be radiation-sensitive and acute responding both clinically and from spaceflight-relevant doses. Bone damage occurs after low-dose exposure (*e.g.*, 20 cGy), both from charged particles and photons. In rodents, the etiology of skeletal damage appears biphasic, with initial bone loss followed by late growth of poor quality bone with impaired mechanical and material properties. Combining reduced weight-bearing with low-dose radiation in rodents has identified unique pathways leading to bone damage from both challenges independently, and interacting responses across tissues (*e.g.*, vasculature and bone) that exacerbate the response. While exercise and bisphosphonate countermeasures mitigate bone loss due to microgravity, the combination of reduced weight-bearing with low-dose radiation could prolong damage to bone. Bone fractures and skeletal failure represent mission-critical events, thus understanding the role of low-dose radiation in a reduced weight-bearing environment is essential for successful missions.

4:25 pm

Q&A

Forty-Fourth Lauriston S. Taylor Lecture on Radiation Protection and Measurements

4:35 pm

Introduction of the Lecturer

Michael M. Weil

Taking Up Space: The Path to Understanding Radiation Risks

Robert L. Ullrich

The understanding of long-term risks associated with radiation exposure during spaceflight remains a challenge. This presentation will focus primarily on what we can learn from overall studies of radiation-induced cancer. Much of the current estimates of risks are derived from the long-term studies of the atomic-bomb survivors in Hiroshima and Nagasaki. These studies have provided information on dose responses for a number of tumor types, the influence of age and sex on risks, and potential modifying factors. While these represent the most comprehensive studies of radiation risks for human exposures, these data are for acute exposures to primarily low linear energy transfer (LET) radiations.

With these human studies serving as a starting point, estimates of risks at low doses and dose rates as well as risks for both low- and high-LET radiations must be made. Animal studies, in particular, can provide some of the best information related both to such risks and the mechanisms involved.

Tuesday, April 20

Noncancer Risks (2)

Zarana Patel & Gayle E. Woloschak, *Session Co-Chairs*

10:00 am

Fight-or-Flight: Immune Status & Radiation Resilience

Dörthe Schaue
University of California - Los Angeles

Irradiation disturbs tissue homeostasis and activates evolutionary conserved immune pathways. Some tissues and individuals are better than others at adapting to these new conditions, raising the question as to what drives radiation resilience and how does a complex, interconnected system of different cell types coordinate the response. In the immune system, this is reflected in part in "plasticity," allowing cells, myeloid cells in particular, to mold their phenotype along a broad spectrum. The general assumption is that the initial damage through damage-associated molecular patterns, including internal cytosolic DNA, alert the immune system driving inflammatory loops that can be self-sustaining in nature, and feed back to the bone marrow to preferentially drive myelopoiesis. The dose requirement for this tends to be relatively high and triggers anti-oxidant, anti-inflammatory counter-responses that collectively dictate the net effect, with regeneration, angiogenesis, fibrosis, and possible carcinogenesis as endpoints. In contrast, low-dose radiation may trigger only certain aspects of this program, but even seemingly minor immune network modifications can have important, if variable, outcomes depending on how they are propagated within each tissue context, and may ultimately promote frailty of the body as a whole. Factors that determine radiobiological resilience include internal anti-oxidant levels and metabolic status, with many possible external influences, including microenvironmental growth factors. There may be several resilience thresholds with different outcomes, depending on dose, dose rate, radiation quality, and other factors such as change in gravitational force, and other stressors that together affect the coordinated response of the interconnected subsystems, which in turn are guided by genetic and epigenetic wiring within the immune and tissue systems. The corollary is that low-dose radiation immune effects will not be linear or necessarily predictable from higher doses.

10:20 am

Reproductive Hazards in Flight Crew: Radiation & Beyond

Candice Johnson
National Institute for Occupational Safety & Health, Centers for Disease Control & Prevention

Commercial flight crew are occupationally exposed to cosmic ionizing radiation, a reproductive hazard. NCRP recommends limiting the monthly equivalent dose to the fetus to 0.5 mSv, with a maximum of 5 mSv over the duration of the pregnancy.

Although most flight crew do not exceed the recommended dose limits, these limits could be exceeded when flying through solar particle events.

Cosmic ionizing radiation is not the only reproductive hazard of concern to flight crew. Circadian disruption (jet lag), heavy lifting, prolonged standing, and long working hours are common among flight crew and are associated with reproductive effects such as menstrual cycle disturbances, lower fertility, miscarriage, and preterm birth.

To disentangle the roles of cosmic ionizing radiation exposure and nonradiation occupational exposures on reproductive health, the National Institute for Occupational Safety and Health, Federal Aviation Administration, and the U.S. Department of Defense collaborated on an epidemiologic study of female flight attendants. This presentation will discuss lessons learned from this and other studies regarding exposure assessment and reproductive health outcome measurement, choice of comparison populations, separating the effects of correlated occupational exposures, and future directions for studying flight crew reproductive health.

10:40 am

Cardiovascular Effects of Low-Dose Ionizing Radiation

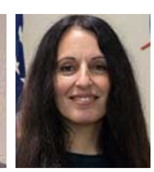
Marjan Boerma
University of Arkansas for Medical Sciences

Most of what we know about cardiovascular toxicity from ionizing radiation stems from observations in cancer patients who receive high doses of radiation to the heart or vasculature during cancer therapy. However, increased rates of cardiovascular disease are also seen in human populations after exposure to doses of ionizing radiation several fold lower than in radiation therapy. For instance, studies have shown an increased risk of heart and circulatory disease in Japanese atomic-bomb survivors, nuclear facility emergency workers, uranium miners, radiation workers, and after exposure to low doses of ionizing radiation due to medical treatment. The analysis of these human populations is complicated by several confounding factors such as life-style factors that affect risk of cardiovascular disease. Therefore, studies in animal models have been designed to complement these results by addressing the cardiovascular risk of low-dose radiation and identifying potential mechanisms by which radiation may cause or accelerate cardiovascular disease. More recently, facilities have been built to expose small experimental animals to ionizing radiation at chronic low-dose rates that last for weeks to months. While results from studies in animal models vary, there is some evidence for a role of endothelial dysfunction and inflammation in cardiovascular disease from external exposure to low doses of ionizing radiation.

11:00 am

Sleep, Circadian Rhythms, & Workload in Spaceflight

Ajitkumar Mulavara
Alexandra Whitmire
NASA Johnson Space Center



Humans traveling to Mars will face unprecedented exposure to unique stressors, including deep-space radiation; additionally, crew will concurrently endure other hazards, such as altered gravity and prolonged isolation and confinement. Studies from spaceflight have demonstrated that historically, circadian rhythms in spaceflight are misaligned, and sleep is often reduced. While environmental, scheduling and operational demands may drive many of these changes, the anticipation of high-stress events has been shown to alter sleep, with sleep fragmentation serving as an indicator of chronic stress. Recent efforts have identified the need to characterize additive and/or potentially synergistic effects of radiation, altered gravity, and isolation and confinement, on the central nervous system, behavioral health, and performance-given these hazards will be experienced simultaneously by exploration mission astronauts. This presentation will highlight spaceflight and analog research assessing sleep, circadian rhythms, and workload relevant for spaceflight exploration missions, as we consider the potential impacts of radiation in conditions of altered gravity and prolonged isolation and confinement.

11:20 am **Q&A**

Fourth Thomas S. Tenforde Topical Lecture

11:30 am **Introduction of the Lecturer**

Donald A. Cool

Collision or Cooperation? The Law, Ethics & Science of Personalized Risk Assessments for Space & Air Travel

Paul A. Locke

Johns Hopkins Bloomberg School of Public Health

Space travel and exploration captivate our nation and the world. To date, fewer than 600 people have traveled in space, almost all in low-Earth orbit (LEO). However, that number is poised to increase exponentially in the coming decades, and missions are likely to be longer and go farther away from Earth. The U.S. Congress has set the nation on an ambitious course to accelerate its leadership in space activities, and has established a goal for a series of beyond LEO missions, including a Mars mission in the 2030s. It has also called for increasing the participation of the private sector in space. Commercial companies are active in developing business models centered around space, and the prospect of space tourism is getting closer and closer to reality.

These future plans for expansion of space travel create challenges for public health protection. The space environment is harsh, and human physiology, which evolved in a terrestrial setting, experiences significant stress in space just in trying to maintain homeostasis. In addition, exposure to space radiation creates a series of unique risks that are not easily studied, and difficult to manage. For example, while research is underway to better understand the biological impacts of high-charge and high-energy particles associated with galactic cosmic rays, much remains to be learned. The necessities of space exploration also limit the feasibility of effective shielding against such radiation, given today's technologies.

NCRP has been actively studying, and offering recommendations regarding, efforts to protect humans in space for the past 30 y. Partnering with the National Aeronautics and Space Administration (NASA), it produced a series of reports and commentaries laying out the risks and uncertainties associated with space radiation exposure, recommending research to better understand these risks, providing advice about standard-setting, and establishing a series of ethical principles to help guide decisions. NASA has used NCRP's advice in setting its career limit exposure to radiation for astronauts at an amount that will not result in more than a 3 % probability of fatal cancer (risk of exposure induced death) at the upper 95 % confidence interval. Because the risk for most radiation induced cancers decreases with age and is greater in females than males, the effect of this guidance is less cumulative flight time for younger and female astronauts. NASA's current risk model accounts for sex, age at exposure, and prior tobacco use.

As science develops and a greater understanding about individual radiosensitivity emerges, it is more and more likely that personalized cancer risk assessments designed for astronauts can be deployed for decision making. These personalized risk assessments could include information from assays that measure radiosensitivity and incorporate family history of cancer, lifestyle choices and other relevant exposures and preconditions. These assessments could be very useful tools in providing guidance to astronauts about their risks, and helping to comply with the radiation protection standards that NASA uses. Once the science develops more completely, information from pre- and post-mission testing could also be modeled so that each astronaut has an accurate picture of their unique future risk.

Some astronauts are civilian employees of the federal government, and as such are subject to federal laws governing the workplace. These laws include, but are not limited to, statutes prohibiting discrimination based on protected characteristics; statutes requiring NASA, as an employer, to provide workplace protections; and laws that prohibit the use of genetic information in making employment decisions. In addition, the statutes that establish the space program contain provisions that cover medical monitoring, human health research and liability for accidents.

This presentation will integrate the current laws and regulations that are applicable to astronauts as employees, and the state of knowledge about space radiation risks, to examine their impact on the potential use of personalized risk assessments. In addition, the presentation will assess how the ethical framework suggested by NCRP — founded on the principles of autonomy, beneficence, nonmaleficence and justice, and organized around a shared decision-making model — could be influenced by the expected changes in the federal and commercial space missions that the future will bring.

12:00 pm **Lunch**

Biomarkers & Countermeasures

Polly Y. Chang & Evagelia C. Laiakis, *Session Co-Chairs*

1:00 pm

Hibernation & Radioprotection: Reduced Tissue Damage in Rats Under Synthetic Torpor

Walter Tinganelli
GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt

The concept of hibernation in spaceflight was early introduced in the history of the human exploration of the solar system as a potential solution to the problems (food, psychology, aging, etc.) of very long-term missions. Early studies funded by the National Aeronautics and Space Administration also showed that mammals exposed during hibernation (such as squirrels) acquired resistance to x rays compared to the exposure in normal metabolic condition. However, humans do not go into hibernation and therefore the topic was considered as science fiction and abandoned in scientific research.

Recently, a phenotype resembling hibernation (synthetic torpor) was induced in nonhibernating animals (such as rats) by inhibiting the neurons within the region of the Raphe Pallidus, a key brainstem region in the control of body temperature and energy expenditure in mammals. While the induction of synthetic torpor in humans has yet to be proven viable, such state was suggested as an effective way to transport animals in space both for experiments and for support of a human colony.

We have demonstrated that, similarly to natural hibernation, animals in synthetic torpor are less sensitive to radiation damage. The radioresistance seems to be associated to a downregulation of the DNA damage response pathway. The increased radioresistance is promising as countermeasure in space travel, and for possible applications in medicine. Current experiments to clarify the mechanism of the increased radioresistance and to test the effect of protons and heavy ions will be discussed.

1:20 pm

Strategy for Maturing Active Radiation Shielding Concepts

Dan Fry
NASA Johnson Space Center

Active shielding strategies for protecting astronauts on exploration missions has long been a dream that proved evasive. Study after study since the early 1970s has shown that solutions are both mass and power prohibitive. This talk will give an overview of current National Aeronautics and Space Administration (NASA) work aimed at making advancements in the area of active shielding. The basic project premise is that we may have a better chance at success if we:

- remove the constraint of having to reduce the exposure to zero, and instead focus on how to increase the number of “safe” days in space according to the current NASA risk posture;
- subdivide the proton and heavy ion energy spectrum to identify a starting point in energy that may yield a non-negligible reduction in ion flux at power levels achievable with current technology, and;

- develop methods to use scaling to build, test and mature small-scale shielding structures on the ground as a pathway to identifying technology development investment strategies.

A top-level overview of these strategies will be presented during this talk.

1:40 pm

Using DNA Damage to Investigate the Individual Variability of Human & Mouse Sensitivity to Ionizing Radiation

Sylvain Costes
NASA Ames Research Center

High linear energy transfer (LET) ionizing radiation has been considered as a major occupational health hazard for astronauts for decades, but risk assessment remains elusive due to limited epidemiological data. Identifying genetic factors modulating the individual radiation response may be the most effective strategy to provide individualized risk management for long-duration high-radiation missions. We have started tackling the challenge of predicting individual risks by identifying human genetic loci associated with various radiation sensitivity phenotypes in primary blood mononuclear cells (PBMCs) from a relatively large healthy human cohort. To date, we have performed the isolation of PBMCs from 768 subjects of the same ethnicity, and irradiated PBMCs from all 768 subjects with one and three particles/100 μm^2 of 600 MeV n^{-1} ^{56}Fe, 350 MeV n^{-1} ^{40}Ar and 350 MeV n^{-1} ^{28}Si ions. The phenotypes of interest were: number of radiation-induced foci (or RIFs), CellROX oxidative stress responses and cell death, at 4 and 24 h following irradiation. Image acquisition is still being conducted. To this date, we have observed a significant inter-individual variability at 0 Gy between the 576 studied subjects, with a mean fold difference between the 10 % lowest and highest responders of 5.6 for the number of RIFs/cell, 7.9 in mean CellRox intensity, and 9.3 in percentage of dead cells. In order to better assess genetic factors influencing DNA repair, we used a metric previously introduced by our group to sort out radiation sensitivity phenotypes in mice: *i.e.*, the ratio of the first slope (between zero and one particle/100 μm^2) and the second slope (between one and three particles/100 μm^2) of RIFs/cell. Preliminary data on 192 individuals showed a distribution of “low-dose responders” (ratio > 1) to “high-dose responders” (ratio < 1) at 4 h of 12, 55, and 52 % respectively for ^{56}Fe, ^{40}Ar, and ^{28}Si. The average value for the first and the second slopes was very similar for the two lowest LET, with respectively 0.10 (–0.26; 0.58) and 0.09 (–0.45; 0.41) for ^{40}Ar, 0.07 (–0.27; 0.38) and 0.08 (–0.19; 0.42) for ^{28}Si, indicating a linear dose response across both fluence. On the other hand, ^{56}Fe showed clear saturation for the highest dose with a slope of –0.09 (–0.86; 1.51) against 0.68 [over the range (–2.21; 2.20)] for the low-dose range, which probably reflects many PBMC are beyond repair at the high dose and cells do not survive to be quantified for DNA damage. Note that other significances were found for additional factors — such as BMI and age — whereas none were found for sex. Human genome wide-association study will be performed on all phenotypes upon completion of measurements to *uncover the genes linked with individual levels of sensitivity to ionizing radiation*. Similar data on DNA repair using 53BP1 will also be presented from primary skin cells derived from 15 strains of mice (three males and three females per strain for a total of 76 primary lines) and genetic association to radiation sensitivity discussed.

2:00 pm

Mitigating Space Radiation Health Risks: Challenges and Opportunities

Janice L. Huff
NASA Langley Research Center

Galactic cosmic rays consist of high-energy protons, helium nuclei and high atomic number (Z) and energy (HZE) ions and pose a health concern for pilots and flight crews flying at high altitudes and latitudes on Earth, as well as for astronauts embarking on missions beyond low-Earth orbit. Exposure to these particles increases the risks of developing cancer, cardiovascular diseases, central nervous system disorders, and immune decrements. Operational parameters (location, mission duration, solar cycle, vehicle design) are the primary determinants of crew radiation exposure, and the National Aeronautics and Space Administration (NASA) uses integrated design tools and risk models to optimize these parameters in order to minimize radiation exposure. NASA is also considering medical countermeasures (MCMs) to reduce radiation-associated health risks.

MCMs for use in space-based applications can be developed from a variety of sources, including: population-based chemoprevention trials against targeted diseases; drug development efforts focused on treating acute effects from accidental radiation exposures; drug development or repurposing efforts to mitigate side effects of radiotherapy; and mechanistic studies of unique damage caused by HZE particle radiation. However, proper evaluation and successful establishment of the clinical efficacy of an agent is a significant and difficult challenge. This large pool of candidates requires a cost-effective method to identify, down select, and confirm suitable agents. One approach is to focus on drugs developed for other applications, or repurposed, which may be advantageous because long-term safety in humans is already established. This will involve development of an effective testing pipeline with high capacity *in vitro* and *in vivo* screening solutions incorporating intermediate endpoints that reliably predict effectiveness against human disease. Studies using realistic space radiation exposure scenarios will also need to be included in the evaluation process.

Overall, the choice of appropriate human disease models, endpoints and assays are key considerations for successful identification of MCM candidates and effective translation of results to human applications. This presentation will review these key considerations for identifying MCM for use in space radiation risk reduction and will survey the many challenges as well as potential opportunities associated with this endeavor.

2:20 pm **Q&A for All Speakers**

Conclusions

2:50 pm

Flying High - Program Wrap-Up

Jacqueline P. Williams & Cary J. Zeitlin
Program Committee Co-Chairs

3:00 pm

NCRP Vision for the Future and Program Area Committee Activities
Kathryn D. Held
President, NCRP

3:15 pm

Adjourn

Program Committee

Co-Chairs

Jacqueline P. Williams
University of Rochester School of Medicine & Dentistry

Cary J. Zeitlin
National Aeronautics & Space Administration

Members

Jeri Anderson
National Institute for Occupational Safety & Health, Centers for Disease Control & Prevention

Janice L. Huff
National Aeronautics & Space Administration

Evagelia C. Laiakis
Georgetown University

M. Kerry O'Banion
University of Rochester Medical Center

Zarana Patel
Kellogg, Brown and Root

Mark Shavers
National Aeronautics and Space Administration

Michael D. Story
University of Texas Southwestern Medical Center

Michael M. Weil
Colorado State University

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@NCRP2021

Annual Warren K. Sinclair Keynote Address

Dr. Auñón-Chancellor was selected by the National Aeronautics and Space Administration (NASA) in 2009. Board certified in Internal and Aerospace Medicine, she recently served as Flight Engineer on the International Space Station (ISS) for Expeditions 56 and 57. During her time on orbit, the crews contributed to hundreds of experiments in biology, biotechnology, physical science, and Earth science aboard the ISS. Investigations were led into new cancer treatment methods and algae growth in space. The crew also installed a new Life Sciences Glovebox, a sealed work area for life science and technology investigations that can accommodate two astronauts. During Dr. Auñón-Chancellor's first flight, she logged in 197 d in space. She currently covers medical issues and on-orbit support in the Astronaut Office.

Dr. Auñón-Chancellor received a BS in Electrical Engineering from George Washington University, Washington, D.C., in 1997 and an MD from the University of Texas - Health Science Center at Houston in 2001. She completed a 3 y residency in internal medicine at the University of Texas Medical Branch (UTMB) in Galveston, Texas, in 2004, and then completed an additional year as Chief Resident in the Internal Medicine Department in 2005. She also completed an aerospace medicine residency at UTMB as well as an MPH in 2007.

Dr. Ullrich is Vice Chairman and Chief of Research at the Radiation Effects Research Foundation. After obtaining his PhD at the University of Rochester, he joined Oak Ridge National Laboratory in 1974 and served as Director of the Radiation Carcinogenesis Unit until 1989 when he became Vice Chair and Director of the Biology Division in the Department of Radiation Oncology at the University of Texas Medical Branch. In 2001, he joined Colorado State University as Professor and Director of the Radiological Health Science and Cancer Research Program. In 2008 he moved back to the University of Texas Medical Branch where he served as the John Sealy Distinguished Chair in Cancer Biology, Professor and Director of the Sealy Center for Cancer Biology and most recently Director of the Cancer Center. His research over many years has focused on risks and mechanisms of radiation-induced cancer. Initially this work was on the dose-response relationships at low doses and dose rates for radiation-induced cancer in mice. Subsequently, his laboratory developed cell and molecular approaches to study mechanisms in the development of mammary cancer after radiation exposure. His most recent work has been funded by the National Aeronautics and Space Administration (NASA) to establish a Specialized Center of Research in Radiation Carcinogenesis with a focus of studying cancer risks and mechanisms of cancer development following exposure to the unique forms of radiation encountered during space travel.

Dr. Ullrich was first elected as a Council member in 1988 and became a Distinguished Emeritus member in 2006. During his tenure he served on the NCRP Board of Directors from 1996 to 2001 and the Nominating Committee from1993 to 1996 and again in 2002 serving as Chair from 1997 to 1999. He was a member of Scientific Committee (SC) 1-3 which produced Report No. 121, *Principles and Application of Collective Dose in Radiation Protection* (1995) and SC 40 that wrote Report No. 64, *Influence of Dose and its Distribution in Time on Dose-Response Relationships for Low-LET Radiations* (1980) and Report No. 104, *The Relative Biological Effectiveness of Radiations of Different Quality* (1990).

He has served on a number of scientific advisory groups both in the United States as well as internationally. In the United States, Dr. Ullrich served on committees for the National Cancer Institute, the U.S. Department of Energy, NASA, NCRP, and the National Academies/National Research Council. Internationally he served on advisory committees including the International Commission on Radiological Protection, the European Commission, and the International Agency for Cancer Research. He is a member of several scientific societies including the American Association for Cancer Research and the Radiation Research Society (RRS). Most recently the RRS awarded him their highest honor, the Failla Medal, for significant contributions in the radiological sciences.

Thomas S. Tenforde Topical Lecture

Dr. Locke, a public health scientist and attorney, is an Associate Professor at the Johns Hopkins University Bloomberg School of Public Health in the Department of Environmental Health and Engineering. He holds an MPH from Yale University School of Medicine, a DrPH from the Johns Hopkins University Bloomberg School of Public Health, and a JD degree from Vanderbilt University School of Law. He is admitted to practice law in New York and Washington, D.C., and is also a member of the Bar of the United States Supreme Court.

Dr. Locke's research and public health practice examine how laws, regulations and policies utilize science and data in standard setting and decision making. His work spans the fields of radiation risk assessment and communication, low-dose radiation policies, radon risk reduction, safe disposal of high-level radioactive waste, uranium mining, and challenges of protecting against harmful radiation exposures in space. Dr. Locke co-directs the School's Doctor of Public Health concentration in Environmental Health and co-directs a certificate program in Humane Sciences and Toxicology Policy.

Dr. Locke was first elected to the Council in 2004 and was a member of the Board of Directors of NCRP from 2008 to 2014. He was Program Committee chair of the NCRP's 2010 Annual Meeting entitled "Communication of Radiation Benefits and Risks in Decision Making." In addition, Dr. Locke was a member of NCRP's Nominating Committee (2012 to 2016) and Scientific Committee 87-5, which produced Report No. 146, *Approaches to Risk Management in Remediation of Radioactively Contaminated Sites*. In 2013 he initiated the formation of, and served as the founding Vice-President for, NCRP's Program Area Committee (PAC) 7, which addresses radiation education, risk communication, and outreach.

Dr. Locke was a member of the National Academy of Sciences (NAS) Nuclear and Radiation Studies Board from 2003 to 2009. He has served on eleven National Academy committees, including the NAS committees that provided an assessment of lessons learned from the Fukushima nuclear accident for improving the safety and security of nuclear plants in the United States. He chaired the NAS committee that examined the scientific, technical, environmental, human health and safety, and regulatory aspects of uranium mining and processing in Virginia.

John D. Boice, Jr., Young Investigator Award

Established in April 2019 by a generous donation by President Emeritus / Director of Science John D. Boice, Jr., the Young Investigator Award is given to recognize an early career professional engaged in some aspect of science pertaining to radiation protection and measurements. Dr. Deepesh Poudel, an Internal Dosimetrist at Los Alamos National Laboratory (LANL), has been selected as the inaugural recipient which includes a travel grant to attend the annual meeting of the NCRP where he will be recognized for his accomplishments.

Dr. Poudel obtained his MS in Physics and PhD in Nuclear Science and Engineering from Idaho State University (ISU). His research interests include internal dosimetry and biokinetic modeling, radiation protection and applied health physics, radiation instrumentation and counting statistics, and environmental health physics. He has authored or co-authored 25 peer-reviewed papers and several dozen conference abstracts and papers.

In addition to being the first recipient of the J.D. Boice Jr. Young Investigator Award, Dr. Poudel has received Postdoctoral Distinguished Performance Award from LANL in 2017, Outstanding Student Award from ISU in 2016, and several scholarships and fellowships in the field of Health Physics. He has been certified by the American Board of Health Physics since 2018.

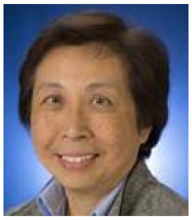
Biographies

Antiño R. Allen (Speaker): Dr. Allen graduated from Jackson State University with a BS in Biology. He completed an MA degree in Animal Behavior and a PhD degree in Evolution and Neuroscience at Indiana University Bloomington. He wrote and defended his PhD dissertation while serving as Company Commander in the Army Infantry. Upon release from active duty in 2010, he accepted a postdoctoral position in Department of Neurological Surgery, University of California - San Francisco with John R. Fike PhD. In 2013, he accepted a position at the University of Arkansas for Medical Sciences where he is currently an Associate Professor with Tenure. The primary objective of the Allen Laboratory is to understand the neurobiological cascade of events following exposure to particulate irradiation, x rays, and/or traumatic brain injury, with the goal of identifying mechanisms underlying cognitive impairment.

Jeri Anderson (Program Committee): A health physicist at the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC) in Cincinnati, Ohio, a position she has held since 2004. She is primarily responsible for performing retrospective radiation exposure assessment in support of epidemiological studies of workers occupationally exposed to radiation and radioactive materials. She also provides technical support to workplaces with radiological concerns and to CDC and other federal, state and local agencies during radiological/nuclear emergency response and preparation activities. Previously, Dr. Anderson was employed as a senior internal dosimetrist and consulting health physicist with a private radiological consulting firm outside Buffalo, New York. She received her BS in Physics, MS in Health Physics, and PhD in Nuclear Engineering from the Georgia Institute of Technology.

Erik L. Antonsen (Speaker): Is the Assistant Professor of Emergency Medicine with a co-appointment as an Assistant Professor of Space Medicine at the Center for Space Medicine, both at Baylor College of Medicine in Houston Texas. From 2015 to 2018 he served as the Element Scientist for Exploration Medical Capabilities in the National Aeronautics and Space Administration's (NASA) Human Research Program. From 2018 to 2021 he served as the Assistant Director for Risk Management for the Human Health and Performance Directorate at NASA Johnson Space Center where he was responsible for chairing the Human System Risk Board and working with human spaceflight programs to prioritize research and operational investments that protect human health and performance in space. His current research interests include causal diagramming and probabilistic approaches to human spaceflight risk management. He received his BS (1997), MS (2001), and PhD (2004) in Aerospace Engineering from the University of Illinois at Urbana-Champaign (UIUC) and later his MD (2009) from the University of Illinois at Chicago. He is Board Certified in Emergency Medicine and practices at Ben Taub General Hospital in Houston, Texas.

Marjan Boerma (Speaker): Received her PhD in radiation biology from Leiden University, the Netherlands in 2004 and followed this with a postdoctoral fellowship in the Department of Surgery at the University of Arkansas for Medical Sciences (UAMS). She is currently an associate professor and the director of the Division of Radiation Health within the College of Pharmacy at UAMS. She also directs the Ultrasound Imaging Core and the Experimental Radiation Core at UAMS. Her research expertise is in animal models of normal tissue injury from ionizing radiation, specifically in the cardiovascular system. Her laboratory uses animal models that address whole-body radiation exposure due to radiological accidents, cardiac side effects of radiation therapy, and cardiovascular effects of low- and high-linear energy transfer radiation to mimic exposures during deep-space travel. She has co-authored more than 100 peer-reviewed articles in this area, and her research funding has been provided by the National Cancer Institute, the National Institute of Allergy and Infectious Diseases, the National Aeronautics and Space Administration, the American Cancer Society, and other federal and private funding sources.



Polly Y. Chang (Session Co-Chair): Scientific Director of the Non-clinical Development Program in SRI International's Biosciences Division. Dr. Chang received her BA in mammalian physiology, MA in bioradiology, and PhD in radiation biology/biophysics from the University of California, Berkeley. She is the principal investigator (PI) on a number of National Institute of Health, National Aeronautics and Space Administration, Biomedical Advanced Research and Development Authority (BARDA), and commercially-sponsored projects, using both *in vitro* and *in vivo* model systems to understand mechanisms of radiation injury and efficacy of medical countermeasures. As PI for the National Institute of Allergy and Infectious Diseases-supported medical countermeasure product development program, she and her team conducted a battery of studies that contributed to the Food and Drug Administration's approval of Romiplostim for hematopoietic syndrome under the Animal Rule. During her tenure at SRI, Dr. Chang has led multiple nonclinical product development programs for vaccines, biologics, metal decorporation agents, and small molecules that have resulted in over 10 approved investigational new drug applications. In collaboration with a team of SRI investigators, she is working on a BARDA-funded biodosimetry project to develop a hand-held field-deployable device for early detection of radiation exposure and triage. She has served on NCRP Scientific Committees for Report No. 181 on the evaluation of the biological effectiveness of low energy photons and electrons in inducing cancers in humans and Report No. 183 on radiation exposure in space and the potential for central nervous system effects.

Donald A. Cool (Speaker): Received his Doctorate degree in Radiation Biology from the University of Rochester School of Medicine and Dentistry. He is currently the Technical Executive for Radiation Safety at the Electric Power Research Institute (EPRI), providing advice on EPRI's Low Dose Radiation research and various aspects of the EPRI Radiation Safety Program. Before joining EPRI, Dr. Cool served with the U.S. Nuclear Regulatory Commission (NRC) for more than 32 y in a number of positions, including as Senior Advisor for Radiation Safety and International Liaison and several roles as a Senior Executive. At NRC, he was responsible for coordinating the wide range of national and international activities related to radiation protection, safety, and security of byproduct materials; decommissioning and waste management; radiation protection policy; and international radiation protection recommendations and standards. Dr. Cool is a Council Member of the National Council on Radiation Protection and Measurements (NCRP), was Co-Chair of NCRP Council Committee 1, is a member of the Main Commission of the International Commission on Radiological Protection (ICRP), Chairman of ICRP Committee 4 on Application of the Commission's Recommendations, and is a Fellow of the Health Physics Society.

Kyle Copeland (Speaker): For almost 23 y Dr. Copeland has worked for the U.S. Federal Aviation Administration's (FAA) Office of Aerospace Medicine as a researcher at the Civil Aerospace Medical Institute in Oklahoma City, investigating ionizing radiation in aerospace environments. He currently serves as Team Coordinator of the Numerical Sciences Research Team in the Life Sciences branch of the Protection and Survival Laboratory. Dr. Copeland earned his BS degree from the University of Wisconsin-Oshkosh, his MS degree from the Department of Physics of the University of Oklahoma, and his PhD from the Department of Chemistry of the Royal Military College of Canada. Dr. Copeland is the primary author or co-author of over 40 articles and scientific reports. He has helped develop and maintain all FAA's inflight radiation related software since 1996, including the CARI software for calculating doses of galactic cosmic radiation during air travel and the Solar Radiation Alert System. He is the primary software developer of CARI-7 and CARI-7A, which are the latest variants of the program, as well as all versions of the Solar Radiation Alert System. His scientific interests include modeling of cosmic radiation environments, radiation dosimetry, and aerospace physiology.

Sylvain Costes (Speaker): Space Biosciences Research Branch Chief, principal investigator and director of the Radiation Biophysics Laboratory at the National Aeronautics and Space Administration (NASA), Ames Research Center and Project Manager for the Space Omics database GeneLab. Dr. Costes has spent his career leading multidisciplinary research in both academic and government scientific institutions. He is managing the systems biology scientific research effort for the GeneLab Project, developing new biodosimetry/biomarker and advanced human three-dimensional tissue capabilities for space mission in the Radiation Biophysics Laboratory and overseeing the scientific efforts of the Space Biosciences Branch.

Dr. Costes obtained his PhD in the Nuclear Engineering Department at the University of California, Berkeley, where he studied radiation biology. He then joined the mathematics department as a postdoctoral fellow where he developed mathematical formalisms predicting gene deletions observed after exposure to ionizing radiation. Dr. Costes served as a staff scientist at the Image Analysis and Confocal Laboratory of the National Cancer Institute in Frederick, Maryland, where he expanded his research to include high-throughput imaging, live-cell imaging, and biochemical models describing the interaction and movement of fluorescent proteins. He joined Lawrence Berkeley National Laboratory (LBNL) in 2004 where he has led the computer modeling effort for a NASA Specialized Center of Research looking at the risk of Space Radiation on the human breast. This work was in collaboration with the New York University Medical School, University of California, San Francisco, and Colorado State University. During his time at LBNL, he also supervised a bioinformatics lab for multi-dimensional microscope image analysis, agent-based modeling, and genomic analysis. He also co-founded a startup in 2012, Exogen Biotechnology Inc., a spin-off of the Berkeley Lab, dedicated to measure DNA damage in individuals and predicting cancer risk using DNA repair phenotypes.

Dan J. Fry (Speaker): Has been a member of the National Aeronautics and Space Administration (NASA) Johnson Space Center (JSC) Space Radiation Analysis Group since 2008. Prior to this he was a staff scientist at the Jet Propulsion Laboratory (JPL). He has lead efforts in hardware development and space weather forecasting and was the International Space Station Radiation System Manager from 2011 until 2017. He is currently a technical discipline lead in the radiation group and principal investigator on the Advanced Exploration Systems Radworks Active Shielding Project. He was one of the lead scientists on the development of the Hybrid Electronic Radiation Assessor, utilizing pixel detectors, for the Orion vehicle. Dr. Fry completed his undergraduate at Texas A&M University in Physics through a Welch fellowship and his PhD in Physics at Kansas State University, specializing in experimental physics of highly charged ions and computational methods in soft condensed matter. He completed a post-doctoral appointment as a National Research Council Fellow at the National Institute of Standards and Technology before becoming a staff scientist at JPL. Dr. Fry is a recipient of the NASA Exceptional Achievement Medal and the NASA JSC Innovation Award. In addition to his work at NASA, Dr. Fry serves as an adjunct in the department of physics at the University of Houston Clear Lake, teaching undergraduate and graduate physics courses.

Kathryn D. Held (President, Speaker): Became President of the NCRP in January 2019. She held the position of Executive Director and Chief Science Officer from 2016 to 2018. She was first elected to the Council in 2006 and served on the NCRP Board of Directors from 2008 to 2014. She was Vice President from 2011 to 2016 of Program Area Committee 1 on Basic Criteria, Epidemiology, Radiobiology, and Risk. She also served as Chair of the Program Committee for the 2011 Annual Meeting on “Scientific and Policy Challenges of Particle Radiations in Medical Therapy and Space Missions.” Dr. Held was a member of Scientific Committee (SC) 1-22 on Radiation Protection for Astronauts in Short-Term Missions and Phase I of SC 1-24 on Radiation Exposures in Space and the Potential of Central Nervous System Effects and an advisor to several NCRP committees. Dr. Held is an Associate Radiation Biologist in the Department of Radiation Oncology, Massachusetts General Hospital and Associate Professor of Radiation Oncology (Radiation Biology) at Harvard Medical School.

Dr. Held earned her PhD in biology from the University of Texas, Austin. She has served on review panels for numerous federal agencies including the National Institutes of Health, the National Aeronautics and Space Administration (NASA), and the U.S. Army Medical Research and Material Command programs and other organizations such as the Radiological Society of North America. She is on the Editorial Boards of *Radiation Research* and the *International Journal of Radiation Biology*, and has served on committees for the National Academy of Science/National Research Council, NASA, the American Society of Radiation Oncology, and the American Board of Radiology. Dr. Held is a Past President of the Radiation Research Society.

Janice L. Huff (Program Committee, Session Co-Chair, Speaker): Is a scientist with the Space Radiation Group at the National Aeronautics and Space Administration (NASA) Langley Research Center in Hampton, Virginia where her work focuses on space radiation risk modeling, medical countermeasure approaches and technologies supporting radiation protection for human space exploration missions. Previously she served as the Deputy Element Scientist for the NASA Space Radiation Element in the Human Research Program at the Johnson Space Center. In this role she was responsible for strategic planning and scientific management of the space radiation research portfolio, which focuses on characterizing and mitigating the major radiation health risks for the astronaut corps. She has been involved in a variety of NASA funded research projects centered on elucidating the role of heavy ion exposure in cancer development and genomic instability, and other projects aimed at development of technologies supporting manned space missions. Before joining NASA, Dr. Huff was a scientist at Bioforce Nanosciences, Inc., a bio-nanotechnology company specializing in development of ultraminiaturized biodiagnostic tools and was a research assistant professor at the University of Nevada, Las Vegas, where she studied integrin-mediated cancer cell migration and metastasis. She received a BS in Microbiology and a BA in Psychology from the University of Rochester and earned a PhD in Microbiology from the University of Virginia studying molecular biology, oncogenes and signal transduction in the laboratory of J. Thomas Parsons. Dr. Huff was elected to the National Council on Radiation Protection and Measurements (NCRP) in 2017, was a member of Scientific Committee (SC) 1-24P2: Radiation Exposures in Space and the Potential of Central Nervous System Effects, and currently serves on SC 1-27: Evaluation of Sex-Specific Differences in Lung Cancer Radiation Risks and Recommendations for Use in Transfer and Projection Models. She was a member of the Program Committee for the 2019 and 2021 NCRP Annual Meetings.

Candice Johnson (Speaker): Dr. Johnson is Assistant Professor at Duke University in the Division of Occupational and Environmental Medicine, Department of Family Medicine and Community Health. Her research focuses on the effects of occupational exposures and workplace policies on the health of women, transgender people, and families. She also researches methods to adapt existing epidemiologic study designs to account for sources of bias specific to studies of these populations. Dr. Johnson previously worked as an epidemiologist at the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC), where she led epidemiologic studies of flight crew and women's health. Dr. Johnson earned her PhD in Epidemiology from Emory University and completed a postdoctoral fellowship at CDC/NIOSH.

Evagelia C. Laiakis (Program Committee, Session Co-Chair): Received her PhD degree in Human Genetics from the University of Maryland at Baltimore, studying radiation induced genomic instability and the contribution of proinflammatory processes under the guidance of Dr. Bill Morgan. She subsequently completed her postdoctoral fellowship with Dr. Albert J. Fornace, Jr. at Georgetown University, in the field of radiation biodosimetry through metabolomics. She is currently an Associate Professor in the Department of Oncology at the Lombardi Comprehensive Cancer Center and the Department of Biochemistry and Molecular and Cellular Biology. She is an elected Council Member to NCRP and has been serving as a member of Program Area Committee 1 of NCRP since 2016. She is also a current Councilor-at-Large of the Radiation Research Society and a dedicated mentor to students and postdocs in various societies and the Sallie

Rosen Kaplan Fellowship Program. Dr. Laiakis' lab aims to expand the field of radiation metabolomics and lipidomics through mass spectrometry with untargeted and targeted approaches. Her research focus includes understanding metabolic responses to scenarios involving a wide range of doses (low dose to acute radiation syndrome associated doses), dose rates, normal tissue responses, and radiation quality effects (photons, neutrons, HZE particles), utilizing biofluids and tissues from rodents to humans. Her work has also expanded to space radiation effects, in combination with stressors such as microgravity, with emphasis on immune and muscle related changes. Finally, she is an Associate Editor for the *International Journal of Radiation Biology* and the *Radiation Research* journal and the 2019 recipient of the Jack Fowler award from the Radiation Research Society.

Christopher J. Mertens (Speaker): Dr. Mertens is a senior research physicist at the National Aeronautics and Space Administration (NASA) Langley Research Center. His areas of expertise include atmospheric and space ionizing radiation transport and dosimetry, and space environment modeling. He is the primary developer and Principal Investigator (PI) of the Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) model, and the PI of the recent NASA Radiation Dosimetry Experiment (RaD-X) flight campaign. His current research activities include developing an active dosimeter-based methodology of estimating real-time astronaut organ doses in deep-space during solar energetic particle events, extending the applicability of the NAIRAS model to the low-Earth orbit environment and producing output data products to characterize single-event effects in spacecraft microelectronic systems, and developing methods for improving the nowcasting and forecasting of space and atmospheric radiation exposure during solar energetic particle events.

Ajitkumar Mulavara (Speaker): Is the CBS Portfolio Scientist for Kellogg, Brown and Root (KBR), currently serving as the lead scientist for the CBS portfolio responsible for characterizing and mitigating risk associated with the interaction of the spaceflight hazards associated with space radiation, behavioral medicine, and altered gravity, for the Human Research Program within the Human Health and Performance Directorate at National Aeronautics and Space Administration Johnson Space Center, through the Human Health and Performance Contract. Dr. Mulavara is a Neuroscientist with a background by training in Neuroscience and Biomedical Engineering. He is interested in the health effects of spaceflight on human performance (*e.g.*, adaptations of the central nervous system), as well as how to support human health and performance by mitigating the deleterious effects of adaptations in spaceflight.

M. Kerry O'Banion (Program Committee): Is a Professor of Neuroscience and Neurology and member of the Del Monte Neuroscience Institute at the University of Rochester School of Medicine and Dentistry in Rochester, New York. His research focuses on neuroinflammation and glial cell biology, emphasizing cellular interactions in neurodegenerative disorders, including Alzheimer's disease, as well as in central nervous system radiation exposure, and how these contribute to pathology and cognitive deficits in preclinical models. His laboratory has participated in ground-based radiation research studies for the National Aeronautics and Space Administration since 2004, and he was a member of NCRP Scientific Committee 1-24P2 on Radiation Exposures in Space and the Potential for Central Nervous System Effects (Phase II).

Zarana Patel (Program Committee, Session Co-Chair): Is a Senior Scientist at Kellogg, Brown and Root and serves as Discipline Lead for the Risk of Cardiovascular Disease from Radiation within the National Aeronautics and Space Administration (NASA) Human Research Program. She earned her PhD in Bioengineering from Rice University and then joined the Space Radiation Element at NASA Johnson Space Center. She has performed NASA-funded radiation research and education outreach for over 10 y. This has included investigations to elucidate the role of radiation exposure (both gamma and space radiation heavy-ion exposures) in the development and progression of epithelial cancers for cancer risk assessment models, as well as effects on endothelial dysfunction, inflammation, and senescence for radiation-induced cardiovascular disease.

Biographies

Lynne Pinkerton (Speaker): An epidemiologist at Maximus | Attain as a contractor to the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention. Before joining Attain in 2019, she was a medical officer in the U.S. Public Health Service at NIOSH in Cincinnati, Ohio for over 25 y. At NIOSH, she has conducted epidemiologic studies of cancer and other health outcomes among workers, including studies of cancer among aircrew. She received her MD from the University of Kansas School of Medicine and her MPH from the University of Washington School of Public Health.

Robert J. Reynolds (Speaker): Consulting Research Scientist for Mortality Research & Consulting, Inc., currently serving as the Visiting Data Scientist for the Human Health and Performance Directorate at the National Aeronautics and Space Administration (NASA) Johnson Space Center, through the Translational Research Institute for Space Health at the Baylor College of Medicine.

Dr. Reynolds is a Health Data Scientist with a background in epidemiology and biostatistics. He is interested in the long-term health effects of spaceflight, as well as how advanced analytics and machine learning can be employed to support human health and performance in spaceflight. He has published extensively on the mortality of space explorers, including U.S. astronauts, Soviet and Russian cosmonauts, and other international astronauts.

Werner Rühm (Speaker): Leads the Medical and Environmental Dosimetry Group at the Helmholtz Center Munich Institute of Radiation Medicine, Germany. In addition he is professor at the Medical Faculty of the University of Munich.

Dr. Rühm has been a member of Committee 1 (C1) of the International Commission on Radiological Protection (ICRP) since 2005. He served as C1 Secretary from 2012 to 2016, and has continued as C1 Chair since 2016. He was a member of ICRP Task Group (TG) 83 (Protection of Aircraft Crew Against Cosmic Radiation Exposure), and is currently chairing ICRP TG91 on Dose and Dose-Rate Effectiveness Factor. Since 2005 he has served as Editor-in-Chief of the *Radiation and Environmental Biophysics Journal*. From 2014 to 2020 he was Chair of the European Radiation Dosimetry Group (EURADOS), and of ICRP TG115 on Risk and Dose Assessment for Radiological Protection of Astronauts, and in 2020 he was elected Chair of the German Radiation Protection Commission. In 2020 Werner Rühm was elected by the German Federal Parliament and the Federal Council of Germany as a member of the National Civil Society Board. He has published on various topics including quantification of neutron exposure of atomic-bomb survivors, cosmic-ray exposure of air crew, the role of neutrons in risk assessment of atomic-bomb survivors, risks from low-dose-rate exposures, behavior of radionuclides in the environment, internal exposures from incorporated radionuclides, and radiation measurement techniques.

Dörthe Schaue (Speaker): Dr. Schaue's interests for almost two decades have been in the effects of ionizing radiation on the immune system, tumor immunity, and on normal tissues protection. Originally trained at premier radiation research institutions in the United Kingdom and Germany, including the Gray Laboratory in London and the Paterson Institute in Manchester, she developed an interest in the immunological aspects of radiation exposures. She was able to build on this knowledge as a postdoctoral fellow and now as an Associate Professor in the Department of Radiation Oncology at University of California-Los Angeles as evidenced in her publications, invitations to present at scientific meetings, and success with funding. As part of a U.S. Department of Defense multi-team award that studied TGFβ blockade in the context of radiation therapy in advanced breast cancer patients she was in charge of the immune monitoring. Her current research efforts focus on understanding the complex interaction at the irradiated immune-tumor-host interface. Her interests in radiation-induced immune imbalances and the role of chronic inflammation, fibrosis and tissue remodeling in late effects of radiation damage, and life shortening grew through her involvement in extensive radiation mitigation studies.

Biographies

Mark Shavers (Program Committee, Session Co-Chair): Is a Senior Scientist on the National Aeronautics and Space Administration (NASA) KBRwyle Human Health and Performance Contract and supports the NASA Radiation Health Officer in the Space Radiation Analysis Group (SRAG) at the Johnson Space Center (JSC) in Houston, Texas. He leads the SRAG development and implementation team for cancer risk analysis and is a member of a medical operations radiation health working group and a radiation discipline systems maturation team for the partner agencies of the International Space Station. Over the past two decades, his responsibilities in the Space Medicine Group, Habitability and Human Factors, and Biomedical Research Groups at JSC include the assessment and protection of astronauts from ionizing and nonionizing radiations, various aspects of protection for human spaceflight, including evaluating radiation shielding effectiveness, and other aspects of the cancer risk analysis of the exposures of astronauts to various sources of ionizing and nonionizing radiations. Earlier work includes transport modeling of accelerated proton (Loma Linda University Medical Center) and heavy ion (Lawrence Berkeley National Laboratory) beam interacting in thick absorbers, quantitative modeling of the biological effectiveness of cosmic ions at space-like energies. His education includes degrees in environmental engineering sciences, radiological sciences, and nuclear engineering.

Lisa C. Simonsen (Speaker): Currently, as the National Aeronautics and Space Administration's (NASA) senior scientist for Space Radiation Systems Integration, Lisa Simonsen provides scientific and technical assessments to guide Agency strategic technology planning and investment strategies for radiation protection systems. In addition, Dr. Simonsen provides NASA senior technical leadership to maintain the NASA Space Radiation Laboratory (at the U.S. Department of Energy's Brookhaven National Laboratory) as world-class facility to meet NASA objectives and U.S. national interests to mitigate risk and optimize engineering designs. From 2013 to 2019, Dr. Simonsen was the Space Radiation Element Scientist assigned to the Human Research Program. She was responsible for establishing the strategic direction and providing scientific leadership of a robust research portfolio to mitigate operationally relevant, radiogenic health risks. She was responsible for maintaining an integrated research plan and coordinating scientific content across disciplines with other Elements, the Translational Research Institute for Space Health, domestic and international partners, and other NASA organizations. She is recognized as a radiation subject matter expert for the Agency and has provided strong scientific leadership in addressing key challenges associated with establishing permissible exposure limits, validating physical and biological countermeasures, and developing the modeling tools required to design shielding for spacecraft to optimally protect astronauts on future Lunar Mars exploration missions. Dr. Simonsen received her PhD in Nuclear Engineering with a focus on Radiation Health Physics and her MS in Chemical Engineering from the University of Virginia, Charlottesville. She received her BS in Chemical Engineering from Clarkson University, Potsdam, New York.

Tony Slaba (Speaker): Is a research physicist at the National Aeronautics and Space Administration (NASA) Langley Research Center working in the areas of space radiation physics, particle transport, experimental radiobiology, and risk assessment. His work has focused mainly on developing improved space radiation environment and transport models used in engineering design, shield optimization, and operational applications at NASA. He is the primary developer for NASA's space radiation transport code, HZETRN. Recent efforts have also centered on developing experimental procedures for simulating the space radiation environment at ground-based accelerator facilities for radiobiology experiments (galactic cosmic-ray simulation). Dr. Slaba received his PhD in computational and applied mathematics from Old Dominion University in 2007 and has authored or contributed to over 50 peer reviewed journal articles since 2010. He received the Committee on Space Research outstanding paper award for young scientists in 2010, a NASA Silver Snoopy Award in 2012, a NASA group achievement medal in 2012, 2013, and 2019, and a NASA early career achievement medal in 2016.

Biographies

Marianne B. Sowa (Speaker): Dr. Sowa is the Chief of the Space Biosciences Division at the National Aeronautics and Space Administration Ames Research Center (ARC) where she leads a team of approximately 50 civil servant scientists and engineers as they perform biological research and technology development that addresses the challenges posed to life by the extreme environments of spaceflight. Dr. Sowa also serves as the Acting Senior Project Scientist for the Space Biology Project at ARC. Dr. Sowa has more than 25 y of experience leading research in academic and government scientific institutions. Her research uses systems biology approaches to study both the targeted and nontargeted effects of exposures to ionizing radiation, as well as the combined effects of altered gravity and radiation. Her work makes wide use of three-dimensional culture models that more realistically replicate the cellular environment *in situ*. Dr. Sowa has combined computational methods with experiments to more fully understand the fundamental mechanisms of response to low doses of ionizing radiation. More recently she has looked at alternate platforms to study spaceflight exposures, such as high-altitude balloons and combined exposure facilities. She is a member of the GeneLab Analysis Working Group and a research Principal Investigator in the Bone and Signaling Laboratory (ARC).

Michael D. Story (Program Committee, Session Co-Chair): Is a professor at the University of Texas Southwestern (UTSW) Medical Center, Dallas. Dr. Story earned his PhD from Colorado State University. He holds the David A. Pistenmaa, M.D., Ph.D. Distinguished Chair in Radiation Oncology, serves as Vice Chair of the Department of Radiation Oncology, Chief of the Division of Molecular Radiation Biology, and Director of the Pre-Clinical Radiation Core Facility. Dr. Story also serves on the editorial board of the journals *Mutagenesis* and *The International Journal of Particle Therapy*. He has served on a number of review panels for the National Cancer Institute (NCI), the National Aeronautics and Space Administration (NASA), and other entities. Dr. Story also serves on the Board of Directors of NCRP, is a member of the Executive Committee of the Particle Therapy Cooperative Group and is a past council member of the Radiation Research Society.

Dr. Story was a faculty member for the NASA Space Radiation Summer School, directs the radiobiology course for the UTSW radiation oncology and nuclear medicine residency programs, directs the radiobiology program for the medical physics graduate program, and lectures in radiation oncology/biology for the Graduate School of Biological Sciences at UTSW. Dr. Story's research is focused on four areas associated with radiation exposure including: the identification of genomic or epigenomic factors that predict or are prognostic for hepatocellular carcinoma or lung cancer risk after heavy ion exposures; the combinatorial application of radiation with other biologic- or chemo-agents that act as radioprotectors or radiation enhancers; as well as the application of low-frequency electromagnetic fields (Tumor Treating Fields) to alter the response of tumors to radiation, chemotherapy and biologic agents; and lastly, he heads the development of research programs in charged particle radiotherapy at UTSW. Dr. Story's research is funded by NCI, NASA, the Cancer Prevention and Research Institute of Texas, and industry.

Walter Tinganelli (Speaker): Biotechnologist with more than 10 y of international research experience. Since January 2019, Dr. Tinganelli is the Clinical Radiobiology Group Leader at the GSI, Germany. He received his MS in Biotechnology at the University of Naples Federico II and his PhD in Radiobiology at the Technical University of Darmstadt in Germany. After his PhD, he worked 2 y as the International Open Laboratory Group Director at the National Institute of Radiological Sciences in Japan. Back in Europe, he worked as Principal Investigator of the Clinical Radiobiology Group at the Helmholtz Research Center for Heavy Ion (GSI) in Darmstadt, Germany and from November 2015 to December 2018, as Project Manager and Principal Investigator at the National Institute of Nuclear Physics, part of the National Institute of Nuclear Physics in Trento, Italy.

Michael M. Weil (Program Committee, Session Co-Chair, Speaker): Professor in the Department of Environmental and Radiological Health Sciences at Colorado State University (CSU). His research, which takes advantage of murine models of radiation carcinogenesis and leukemogenesis, is focused on understanding how radiation exposure can lead to cancer and why some individuals may be more susceptible than others. At CSU, Dr. Weil teaches a graduate level course in Cancer Genetics and lectures in courses on Cancer Biology, Environmental Carcinogenesis, Principles of Radiation Biology, and the Pathobiology of Laboratory Animals. Dr, Weil earned his PhD in Microbiology from the University of Texas (UT) at Austin and was trained in cancer genetics and radiation biology in the Department of Biochemistry and Molecular Biology and the Department of Experimental Radiotherapy at the UT M.D. Anderson Cancer Center. Dr. Weil is a former council member of the Radiation Research Society and has served on National Institutes of Health, U.S. Department of Defense, and National Aeronautics and Space Administration (NASA) grant review panels and on the Scientific Advisory Committee for Radiation Research at the Brookhaven National Laboratory. He is currently the Director of the NASA Specialized Center of Research on Carcinogenesis.

Alexandra Whitmire (Speaker): Serves as the Deputy Element Scientist for the National Aeronautics and Space Administration Human Research Program Human Factors and Behavioral Performance (HFBP) Element. In this role, she helps define the research strategy needed to address human health risks for a future mission to Mars, particularly in the areas of behavioral medicine, team and psychosocial adaptation, sleep and circadian rhythms, and human factors. Alongside with others in HFBP, Dr. Whitmire serves as part of the leadership team for the CBS portfolio, responsible for characterizing and mitigating risk associated with the interaction of spaceflight hazards, including space radiation, isolation and confinement, and altered gravity.

Jeffrey Willey (Speaker): An Associate Professor of Radiation Oncology at Wake Forest School of Medicine. Dr. Willey received his PhD in Bioengineering at Clemson University in 2008. He completed a National Space Biomedical Research Institute postdoctoral fellowship that focused on the cause, progression and prevention of the radiation-induced bone loss that is observed both from spaceflight conditions (*e.g.*, low-dose radiation and/or microgravity) and cancer therapy. His second postdoctoral fellowship in the Translational Radiation Oncology Program at Wake Forest School of Medicine focused on prevention of joint damage and arthropathy in cancer survivors. His current National Institutes of Health- and National Aeronautics and Space Administration (NASA)-funded research program focuses on preventing musculoskeletal toxicity from radiation therapy and during spaceflight. Dr. Willey has extensive experience performing both NASA-funded research and educational outreach, including serving as a Principal Investigator for the Rodent Research-9 Science Mission to the International Space Station on a SpaceX Falcon 9 rocket in 2017, and a primary science team member for two space-shuttle missions investigating bone and muscle loss prevention during time in orbit.

Jacqueline P. Williams (Co-Chair Program Committee, Session Co-Chair, Speaker): Completed her undergraduate degrees at the University of Nottingham, followed by her post-doctoral training in radiation biology at St. Bartholomew's Hospital, University of London. Shortly after completing her studies, she joined the faculty at the University of Rochester, New York, in the department of Radiation Oncology, and recently in the department of Environmental Medicine. Since that time, Dr. Williams has accrued more than 25 y of experience in radiation biology and related fields and has been involved in a wide range of research areas, including clinically-related oncologic studies and clinical trials, tumor blood flow studies, long-term carcinogenic studies, and pharmacological and toxicological projects.

Over her 40 y career, Dr. Williams' research interests mostly have been focused on investigation of normal tissue radiobiological effects, whether consequent to high-dose clinical treatments/accidental exposures or the low doses associated with space travel, imaging, etc. Her dual expertise in the radiation sciences and pharmacology have supported her overall goal of developing protection, mitigation or treatment strategies against off-target radiation-induced diseases. Dr. Williams has served on many national and international committees, including as President of the Radiation Research Society and Research Chair on the Board of the American Society for Radiation Oncology.

Biographies

Gayle E. Woloschak (Session Co-Chair): Is a Professor of Radiation Oncology and Radiology at Northwestern University Feinberg School of Medicine in Chicago. She and her group have been involved in studies of molecular consequences of radiation exposure, late tissue effects associated with radiation, and the use of radiation-inducible nanomaterials for cancer imaging and therapy. Dr. Woloschak also teaches radiation biology to radiation oncology and radiology residents, cardiology trainees, and graduate students and manages the Advanced Grant Writing Workshop for the Radiological Society of North America (RSNA). She earned her PhD in medical sciences from the University of Toledo (Ohio) and did post-doctoral studies in molecular biology at the Mayo Clinic. She has served on review panels for various federal agencies including the National Institutes of Health, the National Aeronautics and Space Administration, the U.S. Department of Energy, RSNA, the U.S. Army Medical Research and Material Command, and others. She is currently an associate editor for *Radiation Research*, the *International Journal of Radiation Biology*, *PLOS One*, and *Nanomedicine*. She is Vice President of NCRP Program Area Committee 1, has served on organizational committees for several NCRP meetings, and has been involved in committees for several NCRP reports. She also served as President of the Radiation Research Society.

Cary J. Zeitlin (Co-Chair Program Committee, Session Co-Chair, Speaker): Is a Senior Research Scientist with Leidos Corporation, working for the National Aeronautics and Space Administration (NASA) Johnson Space Center Space Radiation Analysis Group to assess exposures and risks to astronauts in current and future mission scenarios. He began his career in particle physics in the early 1980s, scanning nuclear emulsion that had been exposed to a beam of high-energy iron ions at the Lawrence Berkeley Laboratory (LBL) Bevalac. As this is one of the most tedious jobs imaginable, greener pastures soon beckoned, leading him to join the TPC/Two-Gamma Collaboration at the Stanford Linear Accelerator Center. After receiving his PhD in experimental high-energy physics and spending another 3 y at the Stanford Linear Accelerator Center as a post-doc studying the decays of the Z boson, Dr. Zeitlin returned to LBL and to nuclear physics in 1991 to work on a long-term project measuring the fragmentation cross sections most pertinent to NASA's space radiation transport codes. This experience led to his taking over as Principal Investigator of the Martian Radiation Environment Experiment (MARIE) aboard the Mars Odyssey orbiter following the untimely passing of Dr. Gautam Badhwar. This led subsequently to his role as Co-Investigator with the Radiation Assessment Detector (RAD) project starting in 2008, as the instrument was being prepared for integration into the Curiosity Rover. After the successful transit and spectacular landing of Curiosity on Mars in 2012, RAD has been operating almost without interruption on the surface, sending back the first detailed radiation environment measurements from another planet. A second RAD was built for the International Space Station and began flight operations in early 2016. Dr. Zeitlin has received two Outstanding Performance awards from LBL and has received three awards from NASA for his work on the MARIE, RAD, and CRaTER projects. He was elected to the NCRP in 2014.

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