SPRINGER BRIEFS IN SPACE LIFE SCIENCES

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Radiation in Space: Relevance and Risk for Human Missions

DLR

Springer

SpringerBriefs in Space Life Sciences

The extraordinary conditions of space, especially microgravity, are utilized for research in various disciplines of space life sciences. This research that should unravel – above all – the role of gravity for the origin, evolution, and future of life as well as for the development and orientation of organisms up to humans, has only become possible with the advent of (human) spaceflight some 50 years ago. Today, the focus in space life sciences is 1) on the acquisition of knowledge that leads to answers to fundamental scientific questions in gravitational and astrobiology, human physiology and operational medicine as well as 2) on generating applications based upon the results of space experiments and new developments e.g. in non-invasive medical diagnostics for the benefit of humans on Earth. The idea behind this series is to reach not only space experts, but also and above all scientists from various biological, biotechnological and medical fields, who can make use of the results found in space for their own research. SpringerBriefs in Space Life Sciences addresses professors, students and undergraduates in biology, biotechnology and human physiology, medical doctors, and laymen interested in space research. The Series is initiated and supervised by Dr. Günter Ruyters and Dr. Markus Braun from the German Aerospace Center (DLR). Since the German Space Life Sciences Program celebrated its 40th anniversary in 2012, it seemed an appropriate time to start summarizing – with the help of scientific experts from the various areas - the achievements of the program from the point of view of the German Aerospace Center (DLR) especially in its role as German Space Administration that defines and implements the space activities on behalf of the German government.

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ISSN 2196-5560 ISSN 2196-5579 (electronic)
SpringerBriefs in Space Life Sciences
ISBN 978-3-030-46743-2 ISBN 978-3-030-46744-9 (eBook)
https://doi.org/10.1007/978-3-030-46744-9

This Springer imprint is published by the registered company Springer Nature Switzerland AG.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

Up to now, the ten books published in our series "Springer Briefs in Space Life Sciences" all have mainly focused on the effects of altered gravity conditions, especially microgravity, on living systems—from cells and microorganisms, plants and animals up to humans. However, also other environmental conditions are changed in space, above all the radiation field.

In fact, solar and galactic cosmic radiation are considered the main health hazard for human exploration and colonization of the solar system. Radiation risk is characterized by a high uncertainty and lack of simple countermeasures. Most of the uncertainty on space radiation risk is associated with the poor knowledge of biological effects of solar and cosmic rays. This creates the need for investigations into biological effects of space radiation, in order to allow more accurate risk assessments, which in turn could lead to more accurate planning of countermeasures. Moreover, results from numerous radiation measurements indicate that not only the radiation levels are increased in space, but also the nature of the radiation field changes, especially with regard to the presence of high energy heavy ions.

The different radiation fields exert various negative consequences on humans, such as DNA damage, carcinogenesis, central nervous system effects, degeneration of tissues, and other health effects. In addition, these risks from radiation exposure may be influenced by other spaceflight factors like microgravity and environmental contaminants; interaction of radiation and microgravity especially on the cellular level has been frequently demonstrated. From this it is clear that a mission—for instance—to Mars will not be feasible unless improved shielding or other effective (biological) countermeasures have been developed, and it is also obvious that our series "Springer Briefs in Space Life Sciences" is not complete without dealing with this important topic.

The authors of this book *Radiation in Space: Relevance and Risk for Human Missions* cover all these important aspects: After a general introduction to the topic, they describe in detail the physics of radiation in space. This includes the description of the different radiation sources present in low Earth orbit and beyond, methods and devices to measure the radiation (the so-called dosimetry) as well as possibilities to model space radiation on Earth and learn about its effects.

Chapter 3 deals with the biological aspect of space radiation, i.e., with the effects of radiation on the various tissues of organisms up to humans. Acute, chronic, and late radiation effects are described, such as those on the central nervous and the cardiovascular systems. These aspects are, of course, also of relevance for people on Earth, radiation therapy being of high importance for patients with cancer treatment.

The same holds true for Chap. 4, in which the authors describe the risk assessment. It becomes obvious that—in spite of radiation measurements in space having been performed for decades—uncertainties still exist leading to discussions on the acceptability of risk. The similarity to the treatment of patients is evident.

Consequently, Chap. 5 covers the development of countermeasures. A wide range of possibilities is described here, ranging from operational planning, shielding, nutritional and pharmaceutical countermeasures up to crew selection.

Finally, the book closes with asking the question: Are we ready for launch? Do we know enough about the risk and about the effectivity of countermeasures? Can we take the responsibility to send humans to Mars knowing about the radiation risk? The answers to these questions certainly are also dependent on the position of the scientists or the reader of this book towards human spaceflight in general and towards exploratory missions in detail. However, history shows that mankind has always pushed its frontiers and moved forward to new horizons. So, in our mind, the question is not, if humans will go to Mars and other distant destinations, but only who and when!

Bonn, Germany
March 2020

Günter Ruyters
Markus Braun

Preface to the Series

The extraordinary conditions in space, especially microgravity, are utilized today not only for research in the physical and materials sciences—they especially provide a unique tool for research in various areas of the life sciences. The major goal of this research is to uncover the role of gravity with regard to the origin, evolution, and future of life, and to the development and orientation of organisms from single cells and protists up to humans. This research only became possible with the advent of manned spaceflight some 50 years ago. With the first experiment having been conducted onboard Apollo 16, the German Space Life Sciences Program celebrated its 40th anniversary in 2012—a fitting occasion for Springer and the DLR (German Aerospace Center) to take stock of the space life sciences achievements made so far.

The DLR is the Federal Republic of Germany's National Aeronautics and Space Research Center. Its extensive research and development activities in aeronautics, space, energy, transport, and security are integrated into national and international cooperative ventures. In addition to its own research, as Germany's space agency the DLR has been charged by the federal government with the task of planning and implementing the German space program. Within the current space program, approved by the German government in November 2010, the overall goal for the life sciences section is to gain scientific knowledge and to reveal new application potentials by means of research under space conditions, especially by utilizing the microgravity environment of the International Space Station (ISS).

With regard to the program's implementation, the DLR Space Administration provides the infrastructure and flight opportunities required, contracts the German space industry for the development of innovative research facilities, and provides the necessary research funding for the scientific teams at universities and other research institutes. While so-called small flight opportunities like the drop tower in Bremen, sounding rockets, and parabolic airplane flights are made available within the national program, research on the ISS is implemented in the framework of Germany's participation in the ESA Microgravity Program or through bilateral cooperations with other space agencies. Free flyers such as BION or FOTON satellites are used in cooperation with Russia. The recently started utilization of Chinese spacecrafts like Shenzhou has further expanded Germany's spectrum of flight opportunities, and discussions about future cooperation on the planned Chinese Space Station are currently underway.

From the very beginning in the 1970s, Germany has been the driving force for human spaceflight as well as for related research in the life and physical sciences in Europe. It was Germany that initiated the development of Spacelab as the European contribution to the American Space Shuttle System, complemented by setting up a sound national program. And today Germany continues to be the major European contributor to the ESA programs for the ISS and its scientific utilization.

For our series, we have approached leading scientists first and foremost in Germany, but also—since science and research are international and cooperative endeavors—in other countries to provide us with their views and their summaries of the accomplishments in the various fields of space life sciences research. By presenting the current SpringerBriefs on muscle and bone physiology we start the series with an area that is currently attracting much attention—due in no small part to health problems such as muscle atrophy and osteoporosis in our modern aging society. Overall, it is interesting to note that the psycho-physiological changes that astronauts experience during their spaceflights closely resemble those of aging people on Earth but progress at a much faster rate. Circulatory and vestibular disorders set in immediately, muscles and bones degenerate within weeks or months, and even the immune system is impaired. Thus, the aging process as well as certain diseases can be studied at an accelerated pace, yielding valuable insights for the benefit of people on Earth as well. Luckily for the astronauts: these problems slowly disappear after their return to Earth, so that their recovery processes can also be investigated, yielding additional valuable information.

Booklets on nutrition and metabolism, on the immune system, on vestibular and neuroscience, on the cardiovascular and respiratory system, and on psychophysiological human performance will follow. This separation of human physiology and space medicine into the various research areas follows a classical division. It will certainly become evident, however, that space medicine research pursues a highly integrative approach, offering an example that should also be followed in terrestrial research. The series will eventually be rounded out by booklets on gravitational and radiation biology.

We are convinced that this series, starting with its first booklet on muscle and bone physiology in space, will find interested readers and will contribute to the goal of convincing the general public that research in space, especially in the life sciences, has been and will continue to be of concrete benefit to people on Earth.

DLR Space Administration in Bonn-Oberkassel (DLR)

The International Space Station (ISS); photo taken by an astronaut from the space shuttle Discovery, March 7, 2011 (NASA)

Extravehicular activity (EVA) of the German ESA astronaut Hans Schlegel working on the European Columbus lab of ISS, February 13, 2008 (NASA)

Bonn, Germany
July 2014

Günter Ruyters
Markus Braun

Acknowledgements

Own research described in this book has been made possible by scientific cooperation and by funding by the German Aerospace Center (DLR) grant FuE-Projekt "ISS LIFE" (program RF-FuW, "Teilprogramm 475"; funding of university partners by the DLR Space Agency), by funding of the Helmholtz Association, the European Union, and the National Institute of Radiation Science (NIRS). Doctoral students involved in this research participated in the Helmholtz Space Life Sciences Research School (SpaceLife), German Aerospace Center (DLR; Cologne, Germany), which was funded by the Helmholtz Association (Helmholtz Gemeinschaft) during a period of 6 years (grant VH-KO-300) and received additional funds from the DLR, including the Aerospace Executive Board and the Institute of Aerospace Medicine. The accelerator experiments at the "Grand Accélérateur National d'Ions Lourds" (GANIL), in Caen, France, and the "GSI Helmholtzzentrum für Schwerionenforschung" were supported in part by the European Union (EURONS, ENSAR) and by the European Space Agency (ESA) in the program "Investigations Into the Biological Effects of Radiation" (IBER), respectively. The travel costs to the Heavy Ion Medical Accelerator in Chiba (HIMAC), Japan, were supported in part by the International Open Laboratory of the National Institute of Radiation Science (NIRS) and National Institutes for Quantum and Radiological Science and Technology (QST), Anagawa, Inageku, in Chiba, Japan. We thank Isabelle Testard, Amine Cassimi, Hermann Rothard, Yannick Saintigny, Florent Durantel, and all the physicists of CIMAP (Caen, France) involved in dosimetry and the beam operator team at GANIL for providing us valuable advice and many help given during numerous night shifts at the French Heavy Ion Accelerator GANIL. Michael Scholz, Chiara La Tessa, Ulrich Weber, Insa Schröder, and the beam operators are acknowledged for their valuable help during beam times GSI. The authors would like to thank Teruaki Konishi, Satoshi Kodaira, and Hisashi Kitamura from NIRS and QST, Anagawa, Inageku, in Chiba, Japan, for the support during HIMAC beamtimes. We thank all astronauts and cosmonauts who provided their support for the performance of experiments on board the ISS as well as colleagues from CADMOS, Toulouse, France; DLR-MUSC, Cologne, and OHB Bremen, Germany as well as all colleagues from the "ESA European Space Agency." Last but not least the authors would like to thank Dr. Gerda Horneck and Dr. Günther Reitz, the former heads of the Radiation Biology Department at the DLR Institute of Aerospace Medicine, for their scientific advice and continuous support of our work.

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