

SPRINGER BRIEFS IN SPACE DEVELOPMENT

Erik Seedhouse

Space Radiation and Astronaut Safety



 Springer

SpringerBriefs in Space Development

Series Editor

Joseph N. Pelton Jr., Arlington, USA

More information about this series at <http://www.springer.com/series/10058>

Erik Seedhouse

Space Radiation and Astronaut Safety



Erik Seedhouse
Applied Aviation Sciences
Embry-Riddle Aeronautical University
Daytona Beach, FL, USA

ISSN 2191-8171 ISSN 2191-818X (electronic)
SpringerBriefs in Space Development
ISBN 978-3-319-74614-2 ISBN 978-3-319-74615-9 (eBook)
<https://doi.org/10.1007/978-3-319-74615-9>

Library of Congress Control Number: 2018933376

© Springer International Publishing AG, part of Springer Nature 2018

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This Springer imprint is published by the registered company Springer International Publishing AG part of Springer Nature.

The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland



This Springer book is published in collaboration with the International Space University. At its central campus in Strasbourg, France, and at various locations around the world, the ISU provides graduate-level training to the future leaders of the global space community. The university offers a two-month Space Studies Program, a five-week Southern Hemisphere Program, a one-year Executive MBA and a one-year Master's program related to space science, space engineering, systems engineering, space policy and law, business and management, and space and society.

These programs give international graduate students and young space professionals the opportunity to learn while solving complex problems in an intercultural environment. Since its founding in 1987, the International Space University has graduated more than 3000 students from 100 countries, creating an international network of professionals and leaders. ISU faculty and lecturers from around the world have published hundreds of books and articles on space exploration, applications, science, and development.

Contents

1	Radiation: A Primer	1
	Galactic Cosmic Rays	3
	Solar Particle Events	5
	Radiation Doses on Board the International Space Station	7
	Improving Crew Health	9
	Intravehicular Radiation	10
	Purpose of This Brief	11
	Structure of This Brief	12
	References	13
2	Biomedical Consequences of Exposure to Space Radiation	15
	Central Nervous System Effects	16
	Behavioral Studies of CNS Risks	18
	Altered Neurogenesis	19
	Oxidative Damage	20
	Alzheimer’s Disease	20
	Radiation-Induced Bone Loss	21
	References	26
3	Setting Acceptable Risk Levels for Astronauts	29
	Permissible Exposure Limits	31
	The ALARA and AHARS Principles	34
	References	34
4	Space Radiation Analysis Group	37
	SRAG Console	38
	SRAG Interfaces	40
	Radiological Support	41
	Radiation Instruments	41
	Space Radiation Health Officer	43

Radiation Risk.	44
Protecting Crews During Solar Particle Events	46
Protecting Deep Space Crews.	46
References.	46
5 Radiation Dosimetry and Detection	49
Operations.	49
Exposure Limits	50
Passive Dosimetry.	50
Active Dosimetry	51
European Crew Personal Active Dosimeter	54
PADLES	55
ISS Detectors	56
Matroshka	58
References.	59
6 Shielding.	63
Water as a Radiation Shield	65
Magnetic Shielding	68
Electrical Shielding.	69
Linear Energy Transfer and Relative Biological Effectiveness	70
Utility and Applications of LET	72
Polyethylene as a Shielding Material	72
Hydrogenated Boron Nitride Nanotubes	73
AstroRad Radiation Shield	74
References.	75
7 Acute Radiation Sickness	77
Signs and Symptoms.	77
Genetic Damage	80
Management	82
Stages of Acute Radiation Syndrome	83
Dealing with ARS in Deep Space.	85
References.	86
8 Treating Acute Radiation Syndrome.	87
Treating Hematopoietic Syndrome	90
Treating Gastrointestinal Syndrome	92
Treating Neurovascular Syndrome	92
General Treatment.	93
Chief Medical Officer's Response to Radiologic Incident	93
The Reality of Treating ARS on a Spacecraft.	94
References.	94

9	Pharmacological Countermeasures	95
	Radiation Injury and Repair	95
	Candidate Radioprotectors	97
	Dietary Antioxidant Supplementation	99
	Nicotinamide Mononucleotide	100
	Granulocyte Colony Stimulating Factor	101
	Perspectives	101
	References	102
10	Genetic Profiling and Manipulation	105
	The <i>Gattaca</i> Option	108
	Extremophiles	109
	Omics	110
	Aggregation of Essential Inputs	112
	References	112
	Appendix A	115
	Appendix B	117
	Appendix C	119
	Index	121

About the Author



Erik Seedhouse is a highly published author. After completing his first degree, he joined the Second Battalion of the Parachute Regiment. During his time in the “Para’s,” Erik spent six months in Belize, where he was trained in the art of jungle warfare. Later, he spent several months learning the intricacies of desert warfare in Cyprus. He made 30+ jumps from a C130 aircraft, performed more than 200 helicopter abseils, and fired more light anti-tank weapons than he cares to remember!

Upon returning to academia, the author embarked upon a master's degree which he supported by winning prize money in 100-km running races. After placing third in the World 100-km Championships in 1992, Erik turned to ultra-distance triathlon, winning the World Endurance Triathlon Championships in 1995 and 1996. For good measure he won the World Double Ironman Championships in 1995 and the infamous Decatriathlon, an event requiring competitors to swim 38 km, cycle 1800 km, and run 422 km. Non-stop!

In 1996, Erik pursued his PhD at the German Space Agency's Institute for Space Medicine. While studying he found time to win Ultraman Hawai'i and the European Ultraman Championships as well as completing Race Across America. Due to his success as the world's leading ultra-distance triathlete Erik was featured in dozens of magazine and television interviews. In 1997 *GQ* magazine named him the "Fittest Man in the World."

Erik's PhD in space medicine and background in space life sciences provided him with a keen insight into and understanding of the medical problems faced by long duration astronauts. In 1999 Erik took a research job at Simon Fraser University. In 2005 the author worked as an astronaut training consultant for Bigelow Aerospace. Between 2008 and 2013 he served as director of Canada's manned centrifuge and hypobaric operations. In 2009 he was one of the final 30 candidates in the Canadian Space Agency's Astronaut Recruitment Campaign. Erik has a dream job as an assistant professor at Embry-Riddle Aeronautical University in Daytona Beach, Florida. In his spare time he works as an astronaut instructor for Project PoSSUM, occasional film consultant to Hollywood, a professional speaker, triathlon coach, and author. This is his 27th book. When not enjoying the sun and rocket launches on Florida's Space Coast with his fiancée, Alice, he divides his time between his second home in Sandefjord and Mauna Lani on the Big Island of Hawai'i.

Abbreviations

AHARS	As high as reasonably acceptable
ALARA	As low as reasonably achievable
ARS	Acute radiation syndrome
AST	Attentional set-shifting task
BEO	Beyond earth orbit
BFO	Blood forming organ
BMD	Bone mineral density
CME	Coronal mass ejection
CMO	Crew medical officer
CNS	Central nervous system
CPDS	Charged particle detector
ESA	European Space Agency
EVA	Extravehicular activity
EV-CPDS	Extravehicular charged particle directional spectrometer
GCR	Galactic cosmic radiation
GOES	Geostationary operational environmental satellite
Gy	Gray
HSC	Hematopoietic stem cells
ICRP	International Council on Radiation Protection
ISS	International Space Station
ITS	Interplanetary transport system
IV-CPDS	Intravehicular charged particle directional spectrometer
JSC	Johnson Space Center
LEO	Low earth orbit
LET	Linear energy transfer
LOC	Loss of crew
LOM	Loss of mission
LPA	Lysophosphatidic acid
LSAH	Longitudinal survey of astronaut health
MORD	Medical operations requirements document
MPCV	Multi-purpose crew vehicle

MSL	Mars Science Laboratory
NAD	Nicotinamide adenine dinucleotide
NAS	National Academy of Sciences
NCR	National Cancer Institute
NCRP	National Council on Radiation Protection
NHP	Non-human primate
NMN	Nicotinamide mononucleotide
NOAA	National Oceanic Atmospheric Administration
PEL	Permissible exposure limits
PSD	Positron sensitive detector
RAD	Radiation assessment detector
RAM	Radiation area monitor
RBE	Relative biological effectiveness
REID	Risk of exposure-induced death
SAA	South Atlantic anomaly
SEC	Space Environment Center
SPE	Solar particle event
SRAG	Space radiation assessment group
SRHO	Space radiation health officer
TBI	Total body irradiation
TEPC	Tissue equivalent proportional counter
TLD	Thermoluminescent detector
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

Chapter 1

Radiation: A Primer



One of the most challenging parts for the human journey to Mars is the risk of radiation exposure and the inflight and long-term health consequences of the exposure. This ionizing radiation travels through living tissues, depositing energy that causes structural damage to DNA and alters many cellular processes.

—NASA Space Radiation Element Scientist Lisa Simonsen, Ph.D.

Galactic cosmic ray exposure can devastate a cell's nucleus and cause mutations that can result in cancers. We learned the damaged cells send signals to the surrounding, unaffected cells and likely modify the tissues' microenvironments. Those signals seem to inspire the healthy cells to mutate, thereby causing additional tumors or cancers.

—Dr. Francis Cucinotta, University of Nevada, Las Vegas

Exposure to these particles can lead to a range of potential central nervous system complications that can occur during and persist long after actual space travel—such as various performance decrements, memory deficits, anxiety, depression, and impaired decision-making. Many of these adverse consequences to cognition may continue and progress throughout life.

—Dr. Charles Limoli, radiation oncology professor at the University of California, Irvine

As long as there have been astronauts there has been talk of a manned mission to Mars. Hardly a week goes by without an announcement of another humans-to-Mars initiative. Over the years the public has been introduced to Inspiration Mars, Mars One, and SpaceX's Interplanetary Transport System. Most such announcements garner plenty of press before dying a slow and natural death, but each mission shares one common denominator: they are either oblivious to (such as in the case of Mars One) or choose to ignore (Mars One again) the dangers of space radiation (Figs. 1.1 and 1.2). So let's take a look at what radiation sources are out there. We'll begin with galactic cosmic rays (GCR)